

**Science and Mathematics Education Centre**

**A Study of Teaching and Learning About  
the Paradoxical Concept of Physical and Chemical Change**

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**This thesis is presented for the Degree of  
Doctor of Philosophy  
of  
Curtin University of Technology**

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## DECLARATION

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This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made.

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## ABSTRACT

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Science is sometimes seen as contained in a little box on its own, separate from the rest of the world. The questions underpinning this thesis set in train thoughts about investigating the chosen topic, the teaching and learning of physical and chemical change, using a very wide range of methodologies. The perspective is of someone involved in the teaching of the physical sciences for more than 40 years. The topic still remains contentious in teaching chemistry.

The thesis sets out the evidence for and against the teaching of physical and chemical change and tracks the historical origins of the concept, its changing definitions and the research relating to the concept of physical and chemical change. A number of historically based textbook case studies are presented, some of which the author considers to be pioneering. The study ends with consideration of the public understanding of science, wondering whether the concept of physical and chemical change can be helpful in this respect.

The conclusions reached are not in themselves remarkable, expressing a belief, that overall the concept of physical and chemical change is of benefit to the chemical community and perhaps to the wider public.

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One chapter involved a questionnaire and some 80 people gave freely of their time to complete a rather long and complicated form. My thanks to all respondents from more than 20 different countries. Amongst these 80 people, four agreed to be interviewed for nearly two hours each and I would like to thank Dr David Knight (Durham University), Dr Alex Johnstone (Glasgow University), Dr Glen Chittleborough (University of South Australia) and Dr Robert Bucat (University of Western Australia). Also to thank Mr Tom Kenney of the United States who went to considerable trouble to send me a tape-recording of his views.

I suppose every thesis relies on the opinions of scholars over the ages. Being historical in nature this thesis depends on the views, opinions and research of academics, scholars and teachers of many different countries and times. I have wanted to make this as international as possible as I have lived and worked in many different countries.

Finally I hope that the thesis adds to our knowledge of the teaching and learning of physical and chemical change and that each of my readers may learn something from reading this study.

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# CHAPTER 1

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## MY PERSONAL EXPERIENCE OF PHYSICAL AND CHEMICAL CHANGE

*Research Question 1: What is my personal experience of the teaching and learning of physical and chemical change?*

### 1.0 Rationale for the study

The nature of matter is something of fundamental interest to all chemists. How to teach the first steps of any major concept is always a matter of vital interest to all teachers. As a chemistry teacher, this topic of physical and chemical change had been central in my thoughts for some time, before I started the research. In Section 1.2, I try to reflect on this experience and explain this choice of topic in greater detail.

I believe the study to be necessary as there does not appear to be any other comprehensive and holistic study on physical and chemical change. This study has an overall structure which contains the main historical, social, pedagogical and educational arguments for and against the teaching of physical and chemical change. These aspects will now be comprehensively explored. Scientific discovery will be viewed not only as science content, but through the lives of scientists, textbook writers and teachers who made the discoveries.

### 1.1 An overview of the thesis and its research problems

My experience as a learner, my experience as a teacher and my experience as a researcher all confirmed that some students found difficulty with the topic of physical and chemical change, which many teachers often consider straightforward. I thus determined to investigate 'physical and chemical change' from as wide a variety of perspectives as was possible.

One of the research problems that should be brought into the open at as early a stage as possible is definitional. The phrase 'physical and chemical change' is now

very familiar to all science teachers and it is partially this familiarity that is the problem. In other words physical and chemical change exists as a phrase in many curricula and has existed for a long time in the same form, so the phrase now represents a set of materials to be taught rather than a concept to be thought about. As will be indicated in the next section on personal history, the phrase is a part of my knowledge of chemistry whether I have been teaching or learning. The phrase 'physical and chemical change' is almost embodied in the fabric of chemistry, so that many chemists (teachers or learners), blinded by familiarity, do not think what the phrase means. There is one very straightforward answer: physical change means change relating to physics; chemical change means change relating to chemistry. Thus on each occasion that we use the phrase we are classifying the event as being either in the realm of physics or in the realm of chemistry. Other definitions of physical and chemical change can be much less straightforward and this issue of definition will recur throughout the thesis.

However, the definitions of all the science content areas are comparatively loose: it is not possible to define physics so as to exclude all chemistry nor is it possible to define chemistry so as to exclude all physics. For example, many phenomena, such as charging batteries and the gas laws are commonly included in both chemistry and physics syllabi. Thus if precision of definition is not possible for chemistry and physics, then it is not possible to be precise about the meaning of the words chemical and physical. Indeed it is this unrealistic expectation of a degree of precision of definition that is at least partly responsible for strikingly different views expressed by different educators that are discussed in the fifth and ninth chapters. In the sixth chapter some researchers considering children's ideas about physical and chemical change do not clarify what scientists mean by physical and chemical change, but assume some undefined traditional view. Such assumptions make it far from clear where the alternative conceptions lie.

There is a long history of dispute about physical and chemical change and this will be frequently referred to in different contexts throughout the thesis, but at this stage I will set the historical scene for this study in very broad and sweeping general terms. In a sense, modern science was set on its path in the early seventeenth century with Galileo starting to break the hold of Aristotelian science. Subject areas were not fixed. Sometimes research in certain topics was banned; for example, in

Britain it was not lawful to experiment in alchemy. During the nineteenth century, there were many scientific subject areas, natural philosophy, physics, mechanics, alchemy, chemistry, astronomy, astrology, geology, geography, physiography, phrenology, meteorology, sciography, vulcanology and the life sciences of natural history, biology, botany, and zoology. The numbers of scientific disciplines expanded rapidly: some of these sciences have expanded and prospered, whereas others have been discredited or subsumed in other areas.

In the late seventeenth century, many discoveries were made in the science of physics (natural philosophy), whilst fewer discoveries were made in chemistry, perhaps because alchemical ideas are incompatible with an understanding of chemical change. There were those who experimented mainly in what we would now call physics such as Newton and Hooke, though Newton also experimented in alchemy. This may be part of the explanation with Newton's secretive behaviour. Robert Boyle experimented mainly in chemistry, though he is remembered mostly for the gas law (in physics) that bears his name and he too experimented in alchemy even though it was against the law.

Throughout the history of science, it is observed that some areas of study advance quickly for a time and then stay unchanged for long periods. It is noticeable that in many periods of rapid change (paradigm shifts) one content area is aided by particular expertise of a scientist from another discipline. I will mention some examples of this, particularly in the areas of chemistry and physics. White (1998) considers that Newton's study of alchemy helped him in formulating the laws of gravitational attraction, claiming that:

From alchemy, Newton continued to find new stimulus, further nudges towards an all-embracing concept of gravity. (White, 1998, p. 208)

In the 18th century, Lavoisier used the balance to great effect establishing the basic laws of chemistry (Palmer, 1995a) and overthrowing the phlogiston theory. Lavoisier has been described as a physicist who changed the field of chemistry.

In this way chemical science would approach the model of the experimental physicists that Lavoisier clearly admired and with whose advocates he

frequently collaborated. This last point has led some historians to question whether Lavoisier was a chemist at all and whether the chemical revolution was instead the result of a brief and useful invasion of chemistry by French physicists. (Brock, 1992, p. 166)

In the middle of the nineteenth century, Loschmidt, an Austrian industrial chemist, combined ideas from the disciplines of philosophy, physics and chemistry to calculate the number of particles in a litre of a gas (Palmer, 1995b). This number is the Loschmidt number which is related to what is generally known today as the Avogadro number.

In the late nineteenth century, Robert Bunsen, a chemist, persuaded his university at Heidelberg to employ Kirchoff, a physicist (Palmer, 1999). The co-operation between them led to the development of spectrometry and 'a new impetus in chemistry, in physics and in astronomy' (Pearson & Ihde, 1951, p. 269).

The examples above illustrate ways in which scientists studying different areas of the sciences can use their knowledge of these areas to make discoveries that enrich science as a whole. Not all scientists integrate knowledge in this way. Some scientists may engage themselves in defining boundaries between different areas of science. These scientists expand their chosen area of science, working within its boundaries and strengthening these boundaries where they can. This is merely a different process for increasing scientific knowledge and may in fact be the more common activity for most scientists. In the case of physics and chemistry, one instance of defining the boundary is the example of physical and chemical change.

At this point, the way that subject matter should be taught (pedagogy) enters into the discussion. Why should physical and chemical change be taught to students? Or should the concept of physical and chemical change be consigned to the dustbin of history? There is the theory that teachers should integrate subjects as far as possible and in an atmosphere where advocacy of integration is considered progressive (Brown, 1977; Clish, 1977), arguments against integration carry little weight. Although there are those who argue against integration of the individual sciences into a single subject called science (Chapman, 1976), these are probably minority views. This is particularly the case in Australia where up to Year 10 science is

taught as a single subject in all states and territories. In such an educational climate, it is difficult to argue for the concept of physical and chemical change, which is a concept that helps to strengthen the basis of subject differentiation. In matters of pedagogy, the opinion of experienced teachers is of great importance, which is why Chapter 9 includes the results of a survey which asked experienced teachers for their views about the concept of physical and chemical change.

Another way of approaching the teaching of the concept of physical and chemical change is to examine chemistry and physics textbooks over time with regard to their usage of physical and chemical change. To this end I have lately become very interested in chemistry and physics textbooks and have built a collection of such books. It is noticeable that they may contain many permutations and combinations of the various sciences and topics within the sciences. These were often published early in the nineteenth century but by the end of the century there was far greater consistency of title. In comparison the chemistry textbook of the late twentieth/early twenty-first century is a very standardised model. I have used the study of chemistry and physics textbooks as a main part of my analysis for this research.

## **1.2 A deconstruction of the thesis title**

A decimal system is used in this study to indicate the chapter (prior to the decimal point), a general theme within the chapter (the first decimal place) and related themes (the second decimal place). Tables and figures use a similar system.

The title of the thesis 'A study of teaching and learning about the paradoxical concept of physical and chemical change' is deconstructed to clarify the meaning.

The thesis sets out to be a study in the sense provided by the dictionary of devoting time to the pursuit of knowledge (Turner, 1987, p. 1124). There is a further non-defined implication that the study will be fair and even-handed in its treatment of data gathered. Fairness is in some sense problematic as the term 'physical and chemical change' is generally considered a chemical expression and my own experience has been greater in chemistry than in physics.

Both teaching and learning are considered in the thesis. Teaching is considered in terms of some of the history of development of a science pedagogy in both the USA and in Britain and also in the analysis of the texts used. Learning is considered in the analysis of research on physical and chemical change and also in the analysis of students' answers to experiments about physical and chemical change in laboratory manuals.

One problem is the phrase concept of physical and chemical change. I am not sure that it is possible to consider two different ideas together as a single entity and refer to that dual entity as a concept. I have previously tried to find a single accurate meaning for what a concept is and find it to be a favourite expression of educationalists which is used differently by different authors (Palmer, 1992b). Whatever the philosophical niceties of this, it is common in English to have two words expressing dissimilar ideas that are often found together: these are called contrasting pairs or sometimes I refer to the ideas being in opposition to each other. The discipline of chemistry makes frequent use of such contrasting pairs for example, metals and non-metals: elements and compounds: electrons and protons. This may be a pedagogic device as well as a physical reality. I note that the use of contrasting pairs as a pedagogic tool is widespread, perhaps because of the symmetry of the human body (on the one hand/on the other hand): it is certainly true of ancient documents which were often primarily written as pedagogic tools – for example *St Luke's Gospel* is replete with contrasting pairs such as the actions of the Sadducees and the Pharisees.

I have sought advice from Room's *Dictionary of contrasting pairs*, which does not include physical and chemical change though it does include the other contrasting pair in the thesis title which is teaching and learning as teach/learn. In the introduction Room (1988) discusses several issues, which are important in this study. For example, he believes that there are various reasons for which term of a contrasting pair comes first 'the goodies come first' (p. xii). He also states that 'some contrasting pairs remain firmly in a particular order because they either rhyme or alliterate' (p. xii). It is noticeable that physical and chemical change has a rhythm whereas 'chemical and physical change' does not. Can such apparently trivial reasons far removed from science have anything to do with the permanence of the expression physical and chemical change?

A further part of the title involves 'paradox'. Further discussion of paradox may be found in Chapter 5 (Section 5.4). Paradox is defined variously but generally with a definition, for example 'a seemingly contradictory or absurd statement that expresses a possible truth' (Scott Crocheron, 1999; www reference).

There are claimed to be four types of paradox which are:

1. The paradox of surprise, that is it is intuitively unexpected, but logically secure.
2. The paradox of usage, a standard logical procedure of deriving a contradiction.
3. The paradox of double negation and the confusions of duality.
4. The paradox of definition, whereby we refuse to give up incompatible definitions. (Antonowitz, 1999; www)

Many of the paradoxes, for example the Barber Paradox, the Learning Paradox and the Liar Paradox (Scott Crocheron, 1999) seem to have as a root cause some element of vagueness which can be exploited to create the paradox. A concept can appear to be paradoxical due to our lack of understanding or the inadequacies of language and some of these paradoxes may be resolved in time with improvements in human knowledge, but many will remain as paradoxes.

Thus in the case of the concept of physical and chemical change, we have a concept of processes that are not uniquely defined and the paradoxical elements of this thesis are brought out by emphasising these contradictions. There are certainly elements of paradox and these will be mentioned where relevant, but it should be remembered that much of the teaching and learning of physical and chemical change is non-paradoxical.

### **1.3 Personal history**

I am starting the thesis at the same point that I currently ask student teachers to start, namely to reflect on their own experiences of science. After this reflection on the part that science, and in particular, chemistry has played in my life, I indicate the overall structure of the thesis.



### 1.3.1 *Personal Comment*

It is said that writing a doctoral thesis is a voyage of discovery and this is proving to be the case. However, for someone starting the project at the tail end of a career, it is necessary to point out that the start of the voyage is not the date of acceptance of the doctoral proposal, it is somewhere back in the past, where I must seek my own interest in chemistry and hence in chemical change. I have read a number of autobiographical extracts, essays and books of the famous, scientists and non-scientists and others, whose accounts show early interest in chemistry. It is a part of this thesis to point out that there is a fascination with chemical change in many of these accounts. However, it is important to state early on in the thesis that my fascination with chemical change does not imply that explanation of chemical change has to be in terms of the concept of physical and chemical change.

### 1.3.2 *Autobiographical: Early years*

Looking back to the age of about seven, I can recollect collecting together some clippings from the privet hedge and putting them in a tin with water to ferment. I was intensely proud of the rather smelly result and still have a photograph of myself with the tin can containing the concoction at my feet. This would have been my first conscious experience of a chemical change that I had caused.

### 1.3.3 *Secondary school*

At secondary school, when offered a choice of subject, I chose science, not from any natural predilection, but because I feared or disliked those teaching other possible subject choices more than those teaching science. One of the two chemistry teachers was a very small man, a competent teacher, who was still interested in chemical research. I don't remember his exact field of research, but I do remember students being afraid of him and on one occasion he pulled and twisted some unfortunate student's ear until he drew blood. The other chemistry teacher was an amiable man, from whom I copied reams of notes from the blackboard, but I now realise that most of this material would already have been outdated by the 1930s whilst I was learning it in the 1950s. I do recollect the organic section of the G.C.E. 'A' level examination, where I clearly recall understanding during the examination for the

first time what carbon having a valency of four actually meant. During the examination I worked out and answered the questions on organic chemistry from first principles. Surprisingly I did very well in this examination. It was physics and mathematics where I failed.

#### *1.3.4 Repeating 'A' Level*

I spent a year at the local technical college, now Bournemouth University, repeating my 'A' levels, and also doing some evening classes at first year degree level out of interest. It is curious to note that my 'A' level results then, with a different examination board, were reversed, just passing chemistry and passing mathematics very well. To this day I do not understand this result, as I had improved my chemical knowledge considerably over that year, which was a year, where for the first time in my life, I had actually worked as hard as I was able.

#### *1.3.5 University*

At university chemistry was my favourite subject, and I have only selected a few brief vignettes that come to mind. I spilt my solution during volumetric analysis. A deep laconic Scots voice inquired "Are you carrying out basement titrations again today, Mr Palmer?"

I recollect the student next to me going up in flames as he was trying to crystallise an organic substance in an open evaporating dish using a volatile organic solvent (not a wise procedure). He spilled the material over his laboratory coat and it ignited. We quickly got his coat off and he was a bit pale, but otherwise none the worse for his adventure. One can certainly reflect over time on the power of chemical change.

The final examinations in inorganic chemistry had to contain a question on the nitrogen compounds of mercury that were a research interest of our lecturer. Joy! Yes! They were there! I had passed the course, but although I learnt something of these compounds at that time, I have never heard of them since, but retain a covert affection for these otherwise unremembered substances. When we came to calculate the percentage pass, less than half those who had started the course finished on

schedule and I always feel that a number of capable students were lost to science through unreasonably high failure rates. I believe that this is something we should guard against, when considering the results of our students.

### 1.3.6 *Teacher training*

I continued at the same university (Exeter) to take the one year teacher training course (Post Graduate Certificate of Education). Of relevance to this project is the special study I did on Michael Faraday and his influence on education. I retain a great regard for his genius and for both his scientific and personal integrity: this admiration will certainly become apparent at other places in this thesis.

I do not think I can make any claims for excellence or inspiration in the course as a whole, but it was a relaxing, and useful year where I gained a great deal of breadth in my education. Teaching practice was the only part of the course, where I felt that I learned anything about schools and children. Lectures appeared largely irrelevant to the improvement of teaching skills. I was fortunate to go to Falmouth Grammar School, where there was an extremely competent Head of Chemistry (Mr Lee). He was an elderly man, who himself taught chemistry throughout the school, sharing the teaching with one assistant. In the junior school, in Forms 1 and 2, there were three lessons of chemistry per week, with one double period per week always in the laboratory and always practically based. His whole five year course was written up as notes, lesson by lesson. During the term that I was there I copied these notes out word for word and used them as a basis for my subsequent chemistry teaching, until the advent of Nuffield, nearly a decade later. Looking back at events and with the opportunity for further reading that I have had, I can see that this was "pure Armstrong" indicating the enormous influence that Henry Armstrong had on English science education for the first thirty years of this century (Argles, 1964, p. 63).

The topics of Mr Lee's notes were not surprising—crystallisation, pure substances, separation of mixtures, water, combustion, physical and chemical change, preparation of hydrogen, preparation of oxygen, etc. However, the notes were always written, so that one went from the known to the unknown, using the results of earlier experiments as a basis for later experiments. In the preparation of

hydrogen, for example, one did not look only at the product hydrogen, one had carried out sufficient earlier experiments to indicate that the other product was zinc sulfate. I personally did not see Nuffield as such a great revolution as I had, for the previous 10 years in Britain and Nigeria, used practical work as the basis for the majority of my science teaching. I think that I have to thank Mr Lee for this approach rather than my university tutors.

### *1.3.7 My first years of teaching*

I taught at a grammar school in Sandwich, Kent for my first two years. They were a learning experience where I taught Forms 1 to 5 with mixed success. My first surprise was the very great difficulty some children have in being able to balance and interpret chemical equations, which remain today the essential language of chemistry. This lesson was more salutary than it sounds, because as I was teaching at a grammar school, I was teaching the top twenty percent (approximately) of the ability range and yet equations were not being understood.

I mention two practical demonstrations that went wrong over this period, as the causes of the accidents represent both chemical and physical change, yet both experiments remain centrally embedded in chemistry. In the first demonstration I was attempting to prepare hydrogen by passing steam over red-hot magnesium ribbon in a silica tube on a moderately large scale. The hydrogen produced is collected over water. I would never attempt this now, firstly because it is a dangerous experiment which is difficult to control, and secondly because it is possible to carry out the experiment on a micro scale, where the consequences of error are greatly reduced. Because of the dimensions of the experiment and the volume of water used it was difficult to adjust the supply of steam: the reaction of steam and magnesium is strongly exothermic once it gets going. When the hydrogen is produced suddenly, it does not always oblige by going immediately where it should, that is into the upturned gas jar filled with water that waits patiently upon the beehive shelf. Instead, the hydrogen seeks other exits and on this particular day it found them – around and through the stoppers that contain the delivery tubing to take steam in and hydrogen out. The flash-back from the hydrogen igniting caused an explosion that shattered the apparatus – both the students and I were very fortunate not to be hurt by flying glass. Hydrogen

combining with oxygen is a good example of a chemical reaction with plenty of energy released. I now certainly avoid having glass around when igniting hydrogen, and for preference may now show a video clip of this experiment.

In the second experiment where I had an accident, I was preparing nitrogen dioxide by heating lead(II) nitrate. In this experiment there is, one would think, little possibility of anything going amiss, as the nitrogen dioxide is collected in a freezing mixture and the oxygen is collected over water; neither gas is of itself explosive. On this occasion I was too greedy – I wanted plenty of nitrogen dioxide to experiment with. There are two other points to mention, on heating, lead(II) nitrate decrepitates, melts and decomposes into lead(II) oxide, nitrogen dioxide and oxygen. Like many lead salts, it combines with glass and makes it mechanically less strong. On this occasion, I think that the fact that there was a large amount of solid lead nitrate, meant that the solid was close to the only exit for the gases being produced. Some may have melted and the decrepitation then built up liquid lead nitrate near the mouth of the exit tube and this re-solidified, blocking the exit for the gas. Maybe the bung was extra strong or it too had been held firmly in place by resolidifying lead(II) nitrate, but gas was being produced with nowhere to go. I would probably have been disappointed with the lack of results and may have increased the heat at that stage. Presumably the lead oxide weakened the glass or perhaps this was a faulty test tube, but a moment later, the test tube shattered with an almighty bang (from the physical change of gases under pressure expanding), in no way inferior to the theoretically far more energetic chemical change of hydrogen combining with oxygen. Again, we were all deluged with broken glass and again fortunately no one was hurt.

In the first case the cause of the accident would generally be considered to be purely a chemical change, but in the second case the cause would have been a mixture of chemical and physical changes. Until there is further discussion about classifying changes, the type of change causing the accident has been left vague deliberately. Both types of change contributed to the result.

There was one other accident that I remember from the description of the students, which was purely chemical in nature and certainly remained more firmly in the minds of the students than either of the failed experiments previously described. As

there was a dearth of science teachers in that era, a history teacher was asked to teach general science. After preparing oxygen, he was testing its chemical properties. The book suggested burning phosphorus (symbol P) in oxygen, and this was what my colleague thought he was doing. Unfortunately he assumed that the symbol "P" stood for potassium, so he was actually heating potassium not phosphorus. He was most disappointed with the lack of action of very hot potassium in oxygen (I would have expected it to ignite but it did not oblige), so he decided to cool the deflagrating spoon down in a bowl of cold water. Needless to say, there was then an immediate chemical reaction as the potassium leapt out of the water and buried itself making a large hole in the wooden bench a couple of centimetres deep. The students felt that they had been well entertained for the day, but my colleague went back to history teaching as soon as he could. Chemical reactions can certainly be entertaining, which is I suspect part of the appeal of chemistry.

#### *1.3.8 Teaching chemistry in Nigeria*

I spent the next six years teaching chemistry (and physics) at an isolated secondary school in Nigeria, where I was able to plan, furnish and equip the school laboratory to my own design; this was a marvellous experience. For some years I also marked examination papers for the West African Examinations Council. On one of these marking forays, I learnt something extremely valuable, namely, that my own knowledge of chemistry, even of elementary chemistry, was far from infallible. In discussing the marking of students' scripts with the Chief Examiner, the point was made that both sulfur dioxide and carbon dioxide gave a precipitate with lime water. Thus the chemical test with lime water alone does not distinguish between the two gases. Only the physical test of smell in combination with the lime water test distinguishes them individually from other gases. I did not believe this as I did not think sulfur dioxide would form a precipitate with lime water. All the way on the 150 mile drive back from Lagos to Ile-Oluji, I was thinking how I would go to the laboratory and prove them wrong! Unfortunately the sulfur dioxide bubbled into lime water did give a white precipitate, so it was I who was proved wrong. I have learnt to be a little more tentative about what reactions will or will not occur. From my own teaching and from the Examinations Council work, I certainly observed the difficulty that so many students have with writing, balancing and

interpreting of chemical equations, particularly in second language situations. Chemistry is not easy for beginners.

### *1.3.9 Teaching in London*

On leaving Nigeria in the middle of the Biafran conflict, I taught in Mitcham, London for the next five years, with one year during that time spent at the University of East Anglia doing a Masters degree in chemical education under Professor Frank Halliwell, the driving force behind the Nuffield Chemistry scheme. Frank Halliwell remained a lifelong friend and visited myself and my family when I was teaching in Papua New Guinea (PNG). My thesis (Palmer, 1970) related mainly to understanding children's learning in relation to the Gagné hierarchy, though the science content was a three hour 'Super 8' mm film on chemical combination, by considering atomic structure. Even in the highly theoretical representations of atoms as circles, orbited by tiddlywinks representing electrons, I had not escaped from chemical change.

### *1.3.10 School inspection in Nigeria*

I left Mitcham and spent the next five years as a Federal Inspector of Education in Nigeria, where the problems were more administrative than academic (Palmer, 1979; 1990a), but I spent a lot of time observing teaching, mainly in science classes, but also in all curriculum subjects. One incident that I remember that relates to chemistry was at Federal Government Girls College, Kazaure, where the teacher was going to pour what he said was concentrated hydrochloric acid onto potassium permanganate to make chlorine gas. However even from the back of the class I could see him struggling with the weight of the Winchester bottle and I could see the viscous oiliness of the liquid. Knowing that the reaction between concentrated sulfuric acid (for that was what the liquid was) and potassium permanganate can be explosive I suggested that he desist from mixing the chemicals. This, of course, prevented a possibly violent chemical change. At the end of five years of school inspection, I went back to England to do a masters degree in Educational Administration at Oxford University.

### *1.3.11 Teacher training in Papua New Guinea*

As a result of the Oxford masters degree, and of the position with the University of Papua New Guinea (UPNG), where academic writing was encouraged (rather than discouraged as it had been in the Nigerian civil service), I wrote an increasing number of papers, both on science education and education generally. At Goroka Teachers' College I also was involved in teaching chemistry and in observing the student teachers on teaching practice. One of the earliest papers that I wrote in Papua New Guinea was on the understanding of chemistry by Papua New Guinean students (Palmer, 1983). Just before I left Papua New Guinea to start work in Australia I wrote a paper looking at teachers' knowledge of chemistry and analysed some questions from the Second International Science Survey that teachers and some of their older students had answered (see Section 6.6). I observed that Papua New Guinean teachers and students over quite a period of time were having difficulty in answering questions relating to chemical change (Palmer, 1986).

### *1.3.12 Teaching in Australian secondary schools in Victoria and at Northern Territory University*

I left Papua New Guinea to work in Australia, mainly due to the necessity for my children to receive an appropriate secondary education. I gained some experience of the Australian system as a science teacher in Victoria for two years after which I took up a position lecturing in science education at Northern Territory University. I wrote about some of my ideas concerning chemical and physical change soon after arriving (Palmer, 1989a; 1989b). I decided to make the teaching and learning of physical and chemical change my major study, as the difficulty that I think students have with this area has bothered me over a long period of time. I have previously reflected on my life in education (Palmer, 1993), but in a broader educational context. My ideas about chemical and physical change have changed considerably as can be ascertained by comparing the earlier papers (Palmer, 1989a; 1989b; 1992a) with a later paper (Palmer & Treagust, 1996) and indeed will have changed further during the writing of this thesis.

The writing of this thesis has provided the motivation for my current interest in the history of chemistry and has also inspired me to make collections of



science/chemistry textbooks and books relating to the history and philosophy of science/chemistry as well as biographies of well known scientists.

The chapters in the thesis will be arranged as follows to answer the research questions indicated.

#### **1.4 What are the research questions for this thesis on a chapter by chapter basis?**

The major research questions are listed below, but frequently additional questions are used to clarify the aims of the main questions:

##### *Research Question 1*

What is my personal experience of the teaching and learning of physical and chemical change?

##### *Research Question 2*

Does the concept of the physical and chemical change exist as a scientific explanation in the early history of chemistry?

##### *Research Question 3*

When does the concept of physical and chemical change take shape as a scientific explanation?

##### *Research Question 4*

What part do textbook writers, educationalists and teacher splay in the historical development of a concept of physical and chemical change?

##### *Research Question 5*

What is the debate about the distinction between physical and chemical change over the past 200 years and how has this debate changed with the increased understanding of chemical processes?

##### *Research Question 6*

What does science education research say about children's/student's learning of physical and chemical change?

### *Research Question 7*

7.1 Is there any discernible trend in the way that textbooks deal with physical and chemical change and has this altered over the last two hundred years?

7.2 Did textbook authors who wrote both chemistry and physics (natural philosophy) textbooks introduce the concept of physical and chemical change into their natural philosophy/physics texts more frequently than those authors who only wrote physics textbooks?

### *Research Question 8*

8.1 What can we learn about student misconceptions relating to the concept of physical and chemical change from student laboratory manuals (1890-1950)?

8.2 What can we learn from the history of the experiments using iron and sulfur to illustrate the differentiated concept of physical and chemical change?

### *Research Question 9*

Is there a divergence of views between scientists and science educators over the science of physical and chemical change?

### *Research Question 10*

Does the expression physical and chemical change have a future?

#### *1.4.1 Significance of research questions*

The research questions provide central themes to each chapter and thus act as a guide to the research as a whole, whilst they also provoke further research questions. Answering these further questions directs the sub-themes followed in each chapter.

#### *1.4.2 Overview of research methods used in the study*

The main methodologies used are explained in detail in each chapter. I will explain in broad terms the way in which I chose to investigate physical and chemical change.

At the very start of the project, I easily convinced myself of the case for choosing a small area of science education and investigating it thoroughly. The case has been argued convincingly by De Berg (1989) and Stewart, Finley and Yaroch (1982). The latter authors assert:

A new pattern of empirical research is needed—research on the conceptual content of science instruction (the concepts, laws and theories of science) and its intersection with the other common-places, especially the learner. One research focus that would be of particular value to teachers is the detailed study of student learning in narrowly delineated areas of science.

(Stewart et al., 1982, p. 428)

I think that was already the sort of thesis I was seeking. It was obvious even at an early stage in planning that I wanted to look 'across the current' so to speak, so that I might find something about physical and chemical change in relation to teaching methodology in one place, and elsewhere about the history of the concept. I would search for information about the assessment of physical and chemical change in third place and yet another search would be required to find data about associated linguistic problems. Thus undertaking the thesis would provide me with a broad learning experience, whilst investigating a topic that has not previously been holistically investigated. The scattered nature of the information likely to be provided, persuaded me to use the idea of biography or brief histories, where possible, as a means of making the information more cohesive and interesting for the reader.

Another aspect of this thesis is that I wished it to be international in scope; perhaps this is because I have lived and worked, teaching science in five different countries. This aspect is problematic in that it adds to the difficulty in drawing clear conclusions, but it also gives a greater likelihood of applicability to any conclusions that are drawn. In general, comparisons relate to the USA, the United Kingdom, and Australia and to a lesser extent to other countries.

I also kept seeing paradoxes between different aspects of the materials that I was using so the idea of paradox (see Section 1.2 and 5.6.6) is also used as a cohesive agent in the narrative.

### 1.4.3 *Triangulation*

Triangulation is the use of two or more methods of data collection in the study of some aspect of human behaviour (Cohen & Manion, 1992, p. 269). Many researchers have championed the idea of using multiple methods, dating from 1959 (Campbell & Fiske, 1959). Mathison (1988) and others have suggested the triangulation of these multiple methods. Guba and Lincoln (1999, p. 147) also believe that triangulation is one of several techniques that increase the credibility of research in naturalistic enquiry. Cohen and Manion (1992, pp. 269-286) state both the advantages and the limitations of the methodology. Briefly the advantages were that the use of triangulation reduced the likelihood of distortion of results that relied on only one method and should enable researchers to avoid ethnocentrism and methodological parochialism (p. 270). The main problems with triangulation are of the validity of the methods chosen (p. 278).

Burns (1990) gives a warning that I thought was particularly relevant to my own research, as I had a considerable knowledge of the topic prior to starting this research. He says: 'Triangulation prevents the investigator from accepting too readily the validity of initial impressions' (Burns, 1990, p. 248).

### 1.4.4 *Other research methods*

In this study, some quantitative analysis has been used in examining and recording data about a large number of textbooks, but the majority of research methods used are qualitative. The thesis starts with reflection as a means of establishing personal relevance. There are several historical studies, including tracking the development of a concept through successive editions of the *Encyclopaedia Britannica*. There are two case studies and the evaluation of the research of others. Questionnaire and interview methods were used. The reasons and explanations for the methods used will generally be found at the appropriate place in the thesis. However, because the thesis involves the history of science, some explanation of the historical research methods will be included at this point.

#### 1.4.5 *Historical research methods*

Borg and Gall (1989, p. 807) have adapted an earlier categorisation for the subject matter for historical educational research. It is interesting to note that none of the ten categories which they list precisely covers the objective of charting the changes of a concept in a curriculum over time. Best and Kahn (1989, pp. 71-72) provide 23 examples for educational historical study, one of which involves the analysis of textbooks.

Borg and Gall (1989, p. 810) suggest that there are generally four steps in historical educational research. These are:

- Define the problem.
- Search for sources of historical fact.
- Summarise and evaluate historical sources.
- Present the facts within an interpretive framework.

The advice provided by these steps has in general been followed, though the authors also refer to the comment by Edson (Edson quoted by Borg and Gall, 1989, p. 810) that 'There is no single definable method of historical inquiry'. This comment has left scope for some creativity.

Kaestle (1994, pp. 2605-2607) has four pieces of advice about assessing the validity of historical arguments. I note, in particular, the second of these admonitions concerning definitions, which Kaestle (1994, pp. 2606) divides into two parts. The first he calls 'vagueness': the second he calls 'presentism'. 'Presentism' is defined by Kaestle (1994) as:

the danger of investing key terms from the past with their present connotations, or, conversely applying to past developments present-day terms that did not exist or meant something else at the time. (p. 2606)

The terms affinity, attraction (of various sorts), cohesion, chemism and physical and chemical change are all related terms whose meaning shifts over time and in usage by different authors. Kaestle's solution is below as some considerable attention is focussed on etymology in this study.

Avoiding presentism thus means paying close attention to the etymology of key terms, and it is a methodological imperative in good history. (p. 2606)

Borg and Gall (1989) are also helpful in advising how to distinguish between primary and secondary sources in historical educational research. Most of the methodologies chosen examine the content of textbooks and this can be considered as a primary source of the textbook author's view of physical and chemical change at the time of publication of the text. The section analysing chemistry manuals written in by students mainly in the 1890-1940 period (Section 8.1), opens up a unique primary resource for tracing student thought. I believe this to be the first attempt to trace students' alternative conceptions historically. In chapter 2 where the origin of the concept of physical and chemical change as a scientific explanation is sought historically, the majority of the sources will be secondary, though some primary sources are used. Travers (1978, p. 393) simplifies this concern by stating that sources should be primary rather than secondary and this view is confirmed by Ary, Jacobs and Razavieh (1990, p. 454).

Travers (1978, pp. 390-393) gives some helpful advice on using case studies, which proved relevant to the case study on the history of the practical laboratory experiment on iron filings and sulfur.

## 1.5 Autobiography

There are very large numbers of autobiographical works written by physicists and chemists, some of which I utilise in later chapters, but few reflect on the differences between physical and chemical change in the light of the scientist's own research and experience. *Uncle Tungsten* is the autobiography of Oliver Sacks (Sacks, 2001) and it seems to explain some of the differences between physics and chemistry through the descriptions of the characters and interests of two of Oliver's uncles. In a simple view, one uncle (Abe) can be seen to represent physics and the other uncle (Dave) can be seen to represent chemistry. The analogy is not tight as both uncles have interests in physics and chemistry, yet in a sense this strengthens the analogy as part of the nature of physics and chemistry is that they cannot be separated by simple definition.

The autobiography is very moving in that it represents the life of an extremely intelligent and sensitive boy, turned in on itself by the cruelty (sadism) of the headmaster of a small private school to which Oliver was entrusted when he was very young. Oliver's defence was to become passionately interested and absorbed by chemistry to a greater extent, and also physics and biology to a lesser extent.

Very briefly Oliver's life as recorded in the autobiography is a virtual history of the major experiments and theories of chemistry, which he carried out in his home laboratory mainly during his early teens, supervised, befriended and encouraged by his uncles. When I reflect on what Sacks said that he understood as a teenager in terms of chemistry and its history and what complex and dangerous experiments he carried out, I am quite amazed as I myself feel that I am only coming to some of those understandings now.

#### **1.6 Limitations and scope of thesis**

The question of limitation of the thesis is perhaps the most difficult to resolve. The possible amount of information available is massive since in one sense it includes the whole of chemistry and the whole of physics combined with the pedagogy of these areas. I have progressed down the grand highways and also innumerable insignificant byways always seeking further explanations of the expression 'physical and chemical change'. There seems to be no way of defining in advance which routes will be the most successful. However the thesis has a structure which I consider contains the main historical, social, pedagogical and educational arguments for and against the teaching of physical and chemical change. I believe that tracing these arguments is interesting and useful. However it is unlikely to affect what happens in practice because it is comparatively easy to avoid using the concept of physical and chemical change in elementary science courses since it is one of a number of alternatives. Tradition, commercial interest or major pedagogical change are far more powerful factors and it is these factors that will determine whether the concept of physical and chemical change is used 20 years from now.

## 1.7 Summary

This chapter is a general introduction to the thesis indicating the overall aim, research methodologies and giving space for personal reflection. The chapter has raised the questions in my mind as to what the phrase 'the concept of physical and chemical change' means and as to whether it is a scientific concept. The second chapter continues widening my understanding of the meaning and derivation of the phrase 'physical and chemical change' and examines its history.



## CHAPTER 2

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### PHYSICAL AND CHEMICAL CHANGE AND THE EARLY HISTORY OF CHEMISTRY

*Research Question 2: Does the concept of the physical and chemical change exist as a scientific explanation in the early history of chemistry?*

#### **2.0 The big picture—the origin of physical and chemical change as a scientific explanation. Major ideas in the composition of matter**

This chapter will include a historical survey of the scientific discoveries, philosophical changes and pedagogical developments that have led to the traditional ways of teaching physical and chemical change in schools up to the present time. I see this as a continuous story and biographical elements of major contributors will be included where possible, in line with my view that scientific fact is enriched by including elements of human experience.

The concept of physical and chemical change relates strongly to the nature of matter. Figure 2.2 (Section 2.1.2) indicates the main stages of development in a history of discoveries relating to the nature of matter.

#### **2.1 Sources relating to the history of chemistry**

There is a richness and tremendous diversity in sources of all sorts on the history of chemistry. It is noteworthy that there are many fewer histories of physics than histories of chemistry. There are at least 20 easily available histories of chemistry in English with five or so being works of the last decade. Yet all of these manage to be interesting and exciting, telling parallel but different stories. These historical accounts will be referenced as required at different points in this thesis.

Amongst these, there are many general histories, covering the whole of chemical thought and invention listed in chronological order. Some are: (Thompson, 1830; Picton, 1889; Armitage, 1906; Meyer, 1906; Brown, 1913; Moore, 1918; Hilditch, 1922; Darrow, 1927; Jaffe, 1934; Irwin, 1959; Reichen, 1962; Ihde, 1964; Partington,

1965; Farber, 1969; Hartley, 1971; Asimov, 1973; Russell, 1985; McGowan, 1989; Mierzecki, 1990; Salzberg, 1991; Brock, 1992; Hudson, 1992; Cobb & Goldwhite, 1995; Bensavde-Vincent & Stengers, 1996; Partington, 1998; Brock, 2000; Greenberg, 2000).

There are many articles on different aspects of the history of chemistry. Additionally there are many books that are biographies of individual chemists such as Pasteur (Gieson, 1995), Davy (Knight, 1998) or Lavoisier (McKie, 1952).

There are biographical dictionaries giving brief biographies of large numbers of scientists such as Asimov (1975a), Abbott (1983a), Abbott (1983b), Alic (1990), Millar, Millar, Millar, and Millar (1990), Ogilvie (1991), Bailey (1994), Williams (1994), Jenkins-Jones (1997), Rayner-Canham and Rayner-Canham, (1998) and Hessenbruch, (2000). Frequently too there are little gems of information in shorter articles about the famous chemists, and also those of lesser stature whose false leads sometimes stimulated research or who discovered little themselves but inspired others through their teaching.

Finally there are books that cover particular periods such as eighteenth century chemistry (Holmes, 1989; Levere, 1993), or particular geographic areas (Dahrrampal, 1971; Knight & Kragh, 1998) or which concentrate on matter or particular elements in an historical context (Levere, 1971; Nye, 1993; Brooke, 1995; Krebs, 1998, Sass, 1998, Emsley, 2001; Levere, 2001).

The following histories of physics have been consulted in chronological order – Cajori (1899), Reichen (1964), Pedersen (1996), Bernal (1997), Purrington (1997), and Kragh (1999). Also these histories of science have been found useful: Buckley (1876), Routledge (1892); Williams (1904); Libby (1917); Sherwood Taylor (1949); Sarton (1952); Schwartz and Bishop (1959); Forbes and Dijksterhuis, (1963); Taton 1963; Sherwood Taylor (1964); Taton 1964; Taton 1965; Snyder (1969); Bernal (1969); Bronowski (1975); Bynum, Browne and Porter (1983); Ronan (1983); Ronan (1984); Gribben (1998); Crump (2001). The literature in this area is extensive and the above works are merely some of the many available.

Also there is now a huge variety of web-sites. In many ways these web-sites parallel the sorts of books that were described above. There are those that deal with the history of the individual sciences and those that deal with science generally. There is massive bibliographic information available with sites on the birthdays of scientists, major anniversaries of the births and deaths of famous scientists or of their inventions. One site of this type to which I have contributed information is <http://TodayInSci.com> (viewed 29 August 2002).

Generally the quality of information on sites and the search engines to access them have greatly improved in the last few years, but site addresses change so frequently that it is pointless recording a huge number of sites. Searching as needed rather than bookmarking lots of sites is probably now the best way to access information. The World Wide Web is an excellent source for information in the history of science, but the assurance of the accuracy of the information provided is less certain than with the printed medium because many websites have no systematic form of editing.

### 2.1.1 *The origin of the term chemistry*

Firstly I will look at the origins of the word chemistry. On consulting a number of texts, I came across the following theories, none of which can claim to be proven absolutely.

Theory 1. (Asimov, 1973, p. 8). Khemeia derives from the Egyptian's name for their own land *Kham*. Khemeia might therefore mean 'the Egyptian art'.

Theory 2. (Asimov, 1973, p. 8). Khemeia derives from the Greek *khumos*, meaning the juice of a plant, so that khemeia might mean 'the art of extracting juices'. Or the juice referred to may even have been molten metal, so that the word may mean the art of metallurgy.

Theory 3. (Mierzecki, 1990). There is a possibility that chemistry is associated with the Greek word *chymea* which referred to the art of smelting metals or with the word *chymos*, which meant 'juice' flowing from treated ores.

Theory 4. Borrows (1985) puts a nice modern touch to this when he says one of his sixth formers told him that the Chinese for chemistry literally means 'change study'.

The ideogram (Figure 2.1 ) is the Chinese symbol for chemistry.



**Figure 2.1** Chinese symbol for chemistry Borrows (1985)

Theory 5. (Farber, 1969). Zosimus, a Gnostic Christian from Panopolis in Upper Egypt living at about 300 AD; mentions *chemia* as a secret art which was derived from a legendary figure Chemes.

Theory 6. The word 'chemistry' is fairly generally agreed to have come from the word 'alchemy' through the medieval Latin *alchemia* but originally from the Arabic word *al-kimiya*. It is however unclear whether the word *Kim* (chem) came from Ancient Egypt, the Middle East or China (Butler & Reid, 1986).

Theory 7. (Mierzecki, 1990). A further theory is that the term chemistry stems from the Hebrew core *chm* meaning something hot.

Theory 8. (Finlay, 1880) The name chemistry has been variously derived from - *Kyamon*, an Arabic word signifying 'the substance, or constitution of anything'.

When there are a number of theories, as in this case, there can be no certainty as to which of them is correct. It is thus uncertain how the word chemistry originated, but for the purposes of this thesis I like the idea that chemistry really means 'change study', which makes the word change redundant in the phrase chemical change.

### 2.1.2 *The nature of chemistry*

The usual dictionary definition of chemistry is some such phrase as 'the study of matter and its transformations' or that it is concerned with 'the composition, properties and reactions of substances'. However chemistry is defined, the following quotation indicates that studying the development of chemistry as a whole or even of a single concept within it, will not be easy. The study of a single

concept will be difficult because its development is entwined with the development of other chemical concepts.

The story of chemistry is fascinating, full of paradoxes and oddities, false starts and misdirections. (Salzberg, 1991, p. xv)

The definition of chemistry as the study of matter and its transformations provides a basis for looking at the main ideas in the history of chemistry which describe the nature of matter. Figure 2.2 indicates some of these:

DATE	PERSON	IDEA	REFERENCE
600BC	Thales of Miletus	All matter made of water	(Mierzecki, 1990)
550BC	Anaximenes	All matter made of air	(Mierzecki, 1990)
450BC	Empedocles	Four primary matters	(Mierzecki, 1990)
400BC	Democritus	Atomism	(Mierzecki, 1990)
350BC	Aristotle	Four elements and associated properties	(Mierzecki, 1990)
200BC to 1600AD		Alchemy coexists with chemistry	
1200	Arabs/A Magnus	Matter consists of Mercury/Sulfur	(Mierzecki, 1990)
1500	Paracelsus	Iatrochemistry: matter made of salt, mercury and sulfur	(Taylor, nd)
1650	Boyle/Others	Rebirth of corpuscular view of matter	(Mierzecki, 1990)
1700	Stahl/Becher	Phlogiston (fiery principle)	(Taylor, nd)
1775	Lavoisier	Phlogiston theory overthrown	(Taylor, nd)
		Used idea of elements first used by Boyle	
1800	Dalton	Put forward his atomic theory	(Taylor, nd)
1904	JJ Thompson	Plum pudding atom	(Ihde, 1964, p. 500)
1915	Bohr/Rutherford	Nuclear atom, electrons in orbit	(Ihde, 1964, p. 502)

**Figure 2.2** Major ideas on the composition of matter

## 2.2 What is chemical change: An introduction

At its simplest the concept of physical and chemical change must involve the concept of matter. When subjected to some change in external conditions, matter can change in two different ways. These different sorts of change are referred to as physical and chemical change. Unfortunately, neither sort of change has a clear unambiguous definition, either historically or even currently. As one looks back in history, our current fuzzy image of physical and chemical change looks even fuzzier. In the history of chemistry literature that I have examined so far, I have not found any book or article that has attempted to follow the history of physical and chemical change. This pursuit is one of the aims of this thesis.

However, the history of the development of the concept of matter is replete with references, articles and books (Brooke, 1995; Multhauf, 1978; Toulmin & Goodfield, 1968). Within this literature, a fair amount can be gleaned about the changing concept of physical and chemical change. Subordinate to the concept of matter is the concept of particles, atoms and molecules, which also has an extensive literature, some of which relates to the concept of physical and chemical change.

When matter undergoes chemical change (combination or decomposition), chemists eventually explained this by developing ideas of affinity, valency and bonding, about which much has been written. The relevant literature concerns the scientific theories themselves and the history of the development of the scientific theories. For example, Russell (1971) has elucidated the history of the development of the theory of valency. That study is very relevant to the concept of physical and chemical change. There are a number of other concepts, such as the concept of elements (Knight, 1967; Za'rour, 1971), the concept of substance (Partington, 1948), the concept of compound (Siegfried & Dobbs, 1963) and the concept of whole number atomic weight (Brock, 1985), which have also yielded some valuable information.

### 2.2.1 *A history of physical and chemical change*

Chemical change is the change in the chemical composition of substances or as Asimov (1973) states:

Fundamental alteration in the nature and structure of a substance is a chemical change. (p. 1)

Human beings have found the changes in matter as it is transformed, such as those of colour, taste, texture and smell, of the greatest interest since the earliest times, but one must suppose that that interest was primarily in the uses of chemistry in those early times, since no theory supported the skilful uses to which chemistry was put.

I have included in this history of physical and chemical change some biographical information about many of the scientists mentioned. In some cases the biographies

of these scientists will be well known; in other cases their stories will be less well-known. Due to the large number of these scientists, the biographical information will generally be succinct.

The second element for inclusion was the idea of a central character to cement past and present together. In his history of cosmology, *The sleepwalkers*, Arthur Koestler (Koestler, 1969) casts the timid canon Copernicus as the last Aristotelian scientist, trying desperately to make his data fit 'a geocentric universe'. Copernicus realised that the data made more sense if the sun were at the centre of the universe. He wrote *The book of revolutions of the heavenly spheres*, which advocated a heliocentric system, but did not publish it until he knew he was dying. Kepler is portrayed as being at the "watershed" simultaneously in two roles: he is both a modern person, who has accepting a heliocentric theory and yet a person who also looks backward to medieval superstition. Koestler likens this to the Roman god, Janus, looking back to the old year and forward to the new year. In this short history I have expanded the section on Antoine Lavoisier to give him a central role in this history of chemistry because he destroyed the theories and practices that were holding back progress in chemistry. Lavoisier also should be credited with educational innovation in his advice to readers about his aims and his novel approaches to textbook writing.

Finally, in order to define this history of physical and chemical change, I developed a list of scientists, chemists, physicists, philosophers, scientific writers of notable textbooks and educationalists all of whom have in some way influenced the formation of the concept of physical and chemical change in order to guide the historical part of the thesis. In developing this list, one starting point was "Chemists" a list created by Zoran Zdravkovski and Kiro Stojanoski from the University of St. Cyril & Methodius in Skopje, Republic of Macedonia at <http://www.pmf.ukim.edu.mk/PMF/Chemistry/chemists/chemists.htm> (viewed 22 September 2000).

This site contained a list mentioning 354 chemists, listed chronologically. For my purposes the list was far too large and was drastically pruned, but was then expanded to fit my requirements. I wanted this history to start at an earlier date, to include physicists, more textbook writers and educationalists, so appropriate

modifications were made which has expanded the list. Additional assistance is provided by the biographical dictionaries most of which include chronological lists of scientists, for example Jenkins-Jones (1997, pp. 533-534). It must be stated that there is no perfect list and this is merely an attempt to write a slightly different history of chemistry and physics to those that are commonly seen.

### 2.2.2 *The first chemical changes used by humans*

The purpose of this section is to trace the concept chemical change back to earliest times, which is attempted by a number of chemical historians writing the history of chemistry (Asimov, 1973; Farber, 1969; Mierzecki, 1990; Reichen, 1962). Since the science of chemistry is largely the story of chemical change, there might seem a limited element of novelty in the task. However, the overall purpose is slightly more complex than this since the eventual aim is to see who first used the idea of chemical and physical change in opposition to one another (as contrasting pairs). A clear and definite result in this task is likely to prove elusive since the words used and the meanings attached to those words have changed with time. Also I will be relying largely on secondary sources, so that the ideas of other authors will also tend to cloud the view. Even authors of any one period were not always consistent in their own views, so as we look further and further back into history, it is less certain what ideas the chemists of those eras had.

Chemical change must have been used in fire, cooking and the use of particular plants as medicine way back into prehistory. Salzberg (1991, pp. 16-18) puts the manufacture and use of pigments in cave paintings at about 30,000 BC. Gallant (1958, pp. 17-32) writing a simplified history of chemistry for teenagers, traces ideas of chemical change back to the craftsmen-chemists of the Middle East to around 6000 BC or earlier. Levey (1959) gives us a more detailed picture of the chemistry that the Sumerians who carried on their trades in about 3500 BC actually practised. They were essentially a very practical people and they used the processes of filtration, distillation, sublimation and fermentation. They were familiar with making wine, tanning leather, using mordants in dyeing, making soap and perfume, making and glazing pottery, making gold silver and bronze objects. They were evidently able to carry out these processes successfully, which are in fact a variety of common physical and chemical changes, but had little in the way of



theory in their chemistry. The Sumerians thus dealt with physical and chemical changes but they did not classify them as such. Evidently these processes were seen in general as being part of the everyday fabric of life.

It is interesting to note that a number of authors stress the magical and supernatural elements of the chemistry practised in ancient times (Reichen, 1962; Salzberg, 1991) whereas other authors tend to emphasise the practical non-magical everyday chemistry used by artisans skilled in their trades (Levey, 1959).

### 2.3 Chemical change in Greek eyes

It was thousands of years later, in Greece, that attempts were made to find a theory to account for the changes that were observed when matter was transformed from one substance to another. Salzberg (1991) explains the Hellenic ideas of chemical science extremely clearly, asserting that the Greek thinkers, unlike the Sumerian chemists, were not artisans who could actually glaze pottery or make a sword from iron ore. These early theoretical attempts by the Greek philosophers held sway to a greater or lesser extent for the next 2000 years so will be addressed in some detail, as they form the basis of other theories of physical and chemical change, since that time.

The arguments about the details and implications of early theories of matter are still matters of debate in conferences (McMullin, 1965) or in books (Toulmin & Goodfield, 1968), so there is almost an inevitability about oversimplification in this discussion. The first recorded contributions to Greek science are from the coastal city of Miletus (in what is now Turkey) beginning with Thales in about 585 B.C., followed by Anaximander about 555 B.C., then Anaximenes in 535 B.C.

#### 2.3.1 *Thales, Anaximander, Anaximenes and Heraclitus*

Thales suggested that in the beginning there was only water. Little is known about him though a number of stories about him exist. He is said to have fallen down a well whilst gazing upwards at the stars and was rescued by a pretty maid-servant (Koestler, 1969, p. 28). Was this the first record of the stereotypical absent-minded scientist? It is said that it was not this misfortune, but rather the discovery of fossil

sea-shells on a walk in the hills from which he concluded that, as the shells must have been in the sea at one time in the past, then one element, water was the source of all matter (Budd, 2000, p. 48). Anaximander thought that the source was an unknown substance of variable properties that was indestructible. All matter starts from this substance and eventually returns to this state. Anaximenes suggested that originally there was only air (really meaning a gas) and liquids and solids were formed by condensation. The transition from gas to liquid and from liquid to solid is, of course, one aspect of physical change. Heraclitus, 540- 475 BC, a nobleman from Ephesus, (Stumpf, 1994, p. 13) changed the agenda from the question "How did things start?" to "How do things change?" Heraclitus considered that fire was the basic element in change.

### 2.3.2 *Empedocles*

The first philosopher to propose a resolution of the problem of change was Empedocles, who lived in Agrigentum in Sicily. He stated that everything was made up of four elements: earth, water, air and fire. He also said that the elements themselves were eternal and unchanging. Rather than starting a new philosophy, he ingeniously combined the ideas of earlier philosophers. He suggested that different substances were created by mixing these four elements in different proportions. He drew a clear distinction between compounds and their constituents (Lloyd, 1970, p. 40) and likened this distinction to the work of an artist who can make any colour by mixing the primary colours in appropriate proportions. Empedocles related opposite qualities with the elements—hot with fire and cold with water. He referred to forces of attraction between these elements as love and to forces of repulsion as hate (Stumpf, 1994, p. 22). These forces caused combination and separation, which were the apparent cause of changes in substances. This seems not unlike an eighteenth century view of chemical change already briefly described, though like all the previous theories, it is simply conjecture without any experimental basis. Empedocles is said to have ended his life by leaping into the crater of Mount Etna.

An alternative source of the four element theory is that it originated with the Persia prophet Zarathusta (Zoroaster 630-583BC) (Habashi, 2000, p. 110). However the prophet claimed that these were the four sacred elements, sacred in the sense that they were the substances essential for the survival of all living beings. Thus in a sense the idea championed by Empedocles, Aristotle and others over nearly 2000 years of air fire earth and water being believed to be the material (elements) of which all matter consisted, was a misconception. Zoroaster's original idea, which would be historically earlier than Aristotles', was a religious and an environmental one in that air, fire, earth and water should be venerated and kept free from contamination (Habashi, 2000, p. 115). It is difficult to find confirmation or otherwise of this but the idea of 'air, fire, earth and water' does seem common in a widely available document, *The Psalms of David* that may be approximately contemporary to Zoroaster/Aristotle or with some psalms being older than either. For example, Psalm 104, verses 4-6 reads:

Who makest the winds messengers, fire and flame thy ministers.  
Thou didst set the earth on its foundations, so that it should never be shaken.  
Thou didst cover it with the deep as with a garment; the waters stood above the mountains. (David, 1000 BC -approx, Psalm 104, verses 4-6)

Air, fire, earth and water are all mentioned in terms of their creation or service to God, and are seen by the psalmist as important aspects of the natural world but it is probably only speculation to go further than this.

### 2.3.3 *Leucippus and Democritus*

Leucippus and his follower Democritus conceived an atomic theory, which is in many ways similar to current ideas of the nature of matter. Their atoms were eternal, indestructible, and in constant motion (Stumpf, 1994, p. 26). Democritus suggested that the physical properties of the atoms were related to their shape. For example, he thought that things made of sharp, pointed atoms tasted acidic, while those of large round atoms tasted sweet. Democritus thought that the movement of atoms was natural and thus did not require explanation (Partington I, 1998, p. 45)

### 2.3.4 Plato and Aristotle

Plato added an extra layer of complexity to Aristotle's theory of elements by suggesting that each of these elements was one of the regular solids with a perfect form: fire with the tetrahedron, air with the octahedron, water with the icosahedron and earth with the cube. However, these conjectures were still without experimental evidence.

These were the earliest ideas of changes in matter. They were to some extent simplified by Aristotle and put in a more coherent form with plenty of examples. The so-called 'first textbook of chemistry' is Aristotle's fourth book *Meteorologica* (Sarton, 1966, p. 518) and it was written in about the fourth century BC. In it, Aristotle describes a number of changes that occur naturally ranging from melting (physical change) to putrefaction (chemical change). When considering what happened when two substances are mixed together Aristotle said that they either remained separate or separable,

. . . or they may be combined into something essentially new; their two forms may disappear or exist only in potentia, while a new form is created.

(Sarton, 1966, p. 518)

This sounds not dissimilar to the idea of creating a new substance in the modern idea of chemical change. However, the similarities are probably not as great as the words suggest because Aristotle's basic idea of matter (everything on earth) was that matter was made of varying proportions of the basic elements (air, fire, earth and water), each associated with two of the opposing qualities of hot and cold and wet and dry which are closest to the element in Figure 2.3. This classification is illustrated below by a simple diagram.

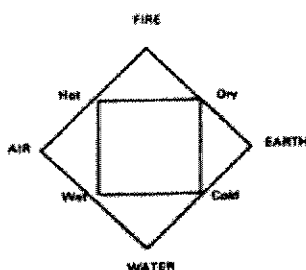


Figure 2.3 Aristotle's four elements and their properties (Lapp, 1963, p. 12)

It can be seen that Aristotle's idea was that all chemicals were made in varying proportions of the same four basic elements each of which was associated with different qualities. The terms *mixis* or *krasis* were used to denote chemical combination. A mechanical mixture was called *synthesis* (Bolzan, 1976, p. 136). Matter in the heavens was said to be made of an entirely different fifth substance called the quintessence. The problem from a modern point of view was that to Aristotle it was the qualities that were important, so that each element could change into any of the other three elements and its observed properties, including mass, could also change. As Salzberg (1991) says:

This theory implies that there is no such thing as internal composition or structure and also that substances react with each other in all proportions, so that we need not measure out proportions of starting materials. (p. 25)

Pedersen (1996, p. 140) considers that Aristotle's *Meteorologica* is the first known work on theoretical chemistry as it arranges and classifies physical and chemical properties and processes using the four element theory.

The outcome of this discussion is that, at best, there is only some very vague concept of physical and chemical change present in Greek science. The vagueness may be because Aristotles' theory of elements that had not arisen from the actual use of chemistry, because the craftsmen and artisans knew that recipes had to be followed quantitatively to obtain the best product. The theory is too academic to be useful, or perhaps the rider to this would be that no one who was experienced in using chemistry would have come up with a theory like this. Nonetheless, Aristotle's theories were to remain, with various minor alterations, the basis of chemical theory for the next two thousand years.

It is difficult to say why Aristotle's scientific theories remained so influential for so long but one reason might be that Aristotle's reasoning was so powerful over a whole range of issues that people were not anxious to contradict him on what seemed minor inconsistencies. However, more recent physicists and chemists are less kind. The Greek legacy to science in general and physics in particular is criticised, for example, by Cajori (1899, p. 14) who asks "What causes led keen minds thus to blunder", though Pedersen (1996, p. 32) praises Aristotle's rational

classification of the different sciences. It is this bipolar categorisation of properties that appears to be a Greek and perhaps universal way of teaching and remembering. The categories of 'physical' and 'chemical', being considered in this thesis, are just another example of this pedagogical methodology.

Greek science after Aristotle waned, at least in the sense of new theory being formulated, though there was criticism of, and some additions to, Aristotle's concepts by Theophrastus and later by Strato (Lloyd, 1973, pp. 8-17). Theophrastus may well have been the first to record chemical (mechanochemical) reactions in his book *The history of stones* (Takacs, 2000, pp. 12-15).

### 2.3.5 Epicurean and Stoic philosophies

Greek science diverged with the growth of Epicurean and Stoic philosophies. Both schools divided philosophy into ethics, physics and logic, with physics being the least important aspect of this philosophy (Lloyd, 1973, pp. 21-32). Simplifying considerably, it can be said that the Epicureans developed a materialist philosophy, with their idea of matter being atomist. The Stoics, by contrast, developed a deterministic philosophy and a continuous theory of matter. Both philosophies have been claimed to be influential in the development of science even as late as the nineteenth century. Lucretius (Titus Lucretius Carus) was a Roman poet, a follower of the Epicurean school, who left just one work, the *De rerum natura*, for posterity. This is a didactic poem in six books, and one book (Book II) is devoted to an elaborate discussion of the atoms, considering their movements, shapes, and combinations. Sensation and feeling are declared to be an accident of atomic combination, a result of the coming together of atoms of certain shapes in certain ways (Winspear, 1963). Lucretius supported atomism and the Epicurean philosophy. These two facts meant that in later generations, the Christian church which strongly disapproved of the Epicurean philosophy and treated anyone interested in atomism with suspicion or worse. The quotation below from a translation of *De rerum natura* seems to be a fair description of an atomic explanation of solids and liquids.

On which account, the elemental forms  
Must differ widely, as enabled thus  
To cause diverse sensations. And, again,

What seems to us the hardened and condensed  
Must be of atoms among themselves more hooked,  
Be held compacted deep within, as 'twere  
By branch-like atoms- of which sort the chief  
Are diamond stones, despisers of all blows,  
And stalwart flint and strength of solid iron,  
And brazen bars, which, budging hard in locks,  
Do grate and scream. But what are liquid, formed  
Of fluid body, they indeed must be  
Of elements more smooth and round- because  
Their globules severally will not cohere:

(Lucretius taken from <http://www.authorslibrary.net/b/natng10.htm>)  
(viewed 26 September 2000)

Furthermore Dickinson (1987) pointed out that passage from Lucretius (Book II), which he quotes, indicates that Lucretius was a precursor of Robert Brown (1773-1858), discoverer of 'Brownian Motion' in 1827, (see Section 3.5) which even today is used as evidence for the existence of atoms/molecules and the fact they are constantly in motion. Lucretius's poem says it all:

Observe what happens when sunbeams are admitted into a building and shed light on its shadowy places. You will see a multitude of tiny particles mingling in a multitude of ways of in the empty space within the light of the beam, as though contending in everlasting conflict, rushing into battle rank upon rank with never a moment's pause in a rapid sequence of unions and disunions...their dancing is an actual indication of underlying movements of matter that are hidden from our sight. There you will see many particles under the impact of invisible blows changing their course and driven back upon their tracks, this way and that, in all directions. You must understand that they all derive this restlessness from the atoms.

(Lucretius, Book II, taken from Dickinson, 1987, pp. 208-209)

### 2.3.6 *Alexandrian science*

Applied science flourished in the Greek and Roman empires after Alexander and particularly in the city of Alexandria where there was a world famous library (Hudson, 1992, p. 16). It was here that alchemy began as a formal discipline (Ihde, 1966, p.10) in about the year 100AD, perhaps due to the influence of Greek science and of Egyptian craftsman skilled in working gold. The major purpose of alchemy was the transmutation of base metals into gold. Thomas (1991, p. 11) divides alchemists into two groups: one group consisted of those who believed in the existence of the philosopher's stone (which was supposed to be able to cure disease, extend the human lifespan and to change base metals into gold) and sought to find it; the other group simply believed that they could change base metals into gold. Thomas (1991, p. 11) considers the first group to be honest, and the latter group to be swindlers and provides examples to illustrate his point.

These were also the ideas and inventions from outside that flowed into Alexandria from as far afield as India and China as trade increased as a result of Alexander's military conquests. Alexandria was a major port, and centre of international trade, so this mixture of ideas easily took root in this multicultural society. There is evidence of Chinese alchemy and that some ideas from Chinese alchemy found their way into Arabic alchemy (Hudson, 1992, p. 16). Pullman (1998, p. 77) also provides evidence of a Hindu atomism and indicates the possibility that it influenced Greek atomism.

Very little written material survives from the earlier period and Zosimus in the third to fourth century summarised what was then known in an encyclopedia made up of twenty-eight books (Asimov, 1975a, p. 43). Hypatia was one of the last great pagan philosophers. In 412 AD, she was killed by a crowd of monks in Alexandria and the knowledge represented by the Alexandrian museum and library dissipated on their closure in 415AD (Salzberg, 1991, p. 49).

## 2.4 **Chemical change in Arabic eyes**

Over the following centuries, the power of the Roman Empire decreased and that of the Arabic Empire increased so that by about 760 AD the Islamic world stretched



from Spain to Persia. It was largely in the Islamic world that Greek knowledge was retained and developed; it was here that alchemy gained a firm foothold.

#### 2.4.1 *Jabir ibn Hayyan*

The first and best known of Arabic alchemists was Geber, properly Jabir ibn Hayyan, the father of chemistry (Ali, 1999) who lived in the eighth century at the height of Arabic power. Portions of his alchemical works are available in English (Russell, 1678; Steele, 1988). Geber modified the Greek idea of four elements. He considered that the four elements could be combined into two solids, which were sulfur and mercury (Holmyard, 1957, pp. 74-75). Sulfur contained the quality of combustibility whereas mercury contained metallic character. All the alchemist had to do to make gold, was to alter the proportions of mercury and sulfur in other substances by means of material with mysterious or magical properties, often a called the philosopher's stone. This was the fruitless quest of alchemists for the next millennium.

Geber did make other chemical discoveries, but due to the custom of apprentices attributing their discoveries to their master (even after his death), it is difficult to be sure what discoveries were personally made by Geber. There was a second person using the same name 'Geber' (The Latin Geber) who also made similar discoveries (Pollard, 1988, p. 702) in the twelfth century. There also appears to have been another Geber (The false Geber) in the fourteenth century. Leicester (1971, pp. 65-66) comments that Jabir's theories of alchemy were much more precise and logical than the Greek alchemical ideas. He notes that the best Arab alchemists tended to classify substances in terms of their 'physical properties'.

#### 2.4.2 *Rhazes (Abu-bakr Al-razi)*

Rhazes (Razi) was another alchemist and he was born in what is now Iran. He accepted what Geber had said (Asimov, 1975a, pp. 46-7) regarding matter consisting of mercury and sulfur but included salt in addition. Holmyard (1929, p. 18) relates interesting story about Razi who had evidently been carrying out some chemical experiments and fell ill after inhaling the poisonous fumes. The doctor charged him a large sum of money, so he immediately took up medicine

deciding that this was the true art of *al-kimia* (gold making). Razi did make contributions to early chemistry by making the first useful classification in chemistry in which he divided chemical substances into three groups, namely animal, mineral and vegetable (Holmyard, 1929, p.20); he then further subdivided these groups making a practical and systematic classification.

Avicenna (Abu Ali ibn Sina) was a successful Iranian bureaucrat who was born near Bukhara on the borders of Iran and Uzbekistan. He lived in the tenth century. Avicenna's view of alchemy was very unusual for his time in that he did not think the transmutation of elements was possible (Asimov, 1975a, p. 51). He stated.

As to the claims of the alchemists, it must be clearly understood that it is not in their power to bring about transmutation.

(Quoted by Holmyard, 1929, p. 24)

#### 2.4.3 *Abu Al-Majiriti*

Kettani (1976) considered the experiment described below as similar to Lavoisier's experiment on conservation of mass carried out in about 1780. However this was performed by Abu Al-Majiriti, a Moorish astronomer and alchemist from the eleventh century Spain. Kettani (1976) sees this as evidence that Arabic scholars of the eleventh century were equal in skill and knowledge to the eighteenth century European scientists.

I took clean, shining mercury and I put it in an egg shaped utensil made of glass, and I introduced it into another vessel similar to kitchen utensils. I let it warm under such a low fire as I could put my hand on the outer surface of the instrument. The heating continued for forty days, and when I opened the instrument I found the mercury which weighed a quarter of a pound had been transformed into a red powder 'without any change in the overall weight' . . .

(Quoted in Kettani, 1976, p. 143)

Leicester (1971, p. 71) quotes the same passage seeing it as a high point in passage in Arab alchemy as Arab alchemists seek a quantitative element in their science yet lacked the instruments to achieve this in practice. He also sees this as the great

legacy of scientific knowledge developed by the Arabs and passed on to medieval Europe.

## 2.5 Chemical change and alchemy in the medieval period to 1500

The Arabs had expanded the scientific knowledge they had received from the Greek philosophers and alchemists considerably and had discovered new processes such as sublimation, new apparatus, such as the alembic, and new ideas such as all matter consisting of mercury and sulfur. It was not actual mercury and actual sulfur but the idealised principle behind these elements about which they were thinking. Sulfur eventually stood for the spirit of fire, the property of combustibility (Fabricus, 1994, p. 8) and it is interesting to note that these ideas were transformed in the seventeenth century into the phlogiston theory by Becher and Stahl. Another prevalent idea was that any imperfections in the processes being carried out would produce unwanted products instead of the much-desired gold. This was the alchemists' explanation for their failure.

### 2.5.1 *Albertus Magnus and Roger Bacon*

In Europe, Albertus Magnus was the Bishop of Regensburg in Germany. He conducted alchemical experiments, was critical of Aristotle's views on matter and was sometimes sceptical about the possibility of transmutation (Holmyard, 1957, p. 116). Roger Bacon was an English scholar with a huge range of scientific interests who was reputed, incorrectly, to have invented gun-powder (Hall, 1995, p.xxiii). Bacon wrote a three volume encyclopaedia of all the scientific knowledge of the time in 18 months for Pope Clement IV without the aid of other books (Wilson, 1929, pp.74-75) He was interested in alchemy and seems to have accepted the possibility of transmutation (Asimov, 1975a, p. 55). Arnold of Villanova was both a mystic and an alchemist who tried to change the mercury sulfur theory teaching that mercury alone was sufficient (Asimov, 1975a, p. 57). He is remembered for two alchemical works *The book called the treasure of treasures* and *the rosary of the philosophers* as well as a book on poisons (Lockermann, 1959, p. 39). He is also said to have discovered the poisonous effects of carbon monoxide.

### 2.5.2 *William of Ockham*

William of Ockham was an English scholar and philosopher whose great achievement for science was the Ockham's Razor Principle that suggests that the theory with the smallest number of assumptions is the most likely to be true. Some alchemical writing (Kelly, 1678) is attributed to Basil Valentine (Partington II, 1998, pp. 183-203), but it seems uncertain whether Valentine's works are those of a real person or in fact later forgeries. His views of the nature of matter seem similar to those of Paracelsus. There are large numbers of alchemical writings, for example by Petrus Bonus of Ferrara (Redgrove, 1969, pp.49-51), False Geber, Raymond Lully (Redgrove, 1969, pp. 47-48) and many others continuing well into the sixteenth century, yet the overall corpus of knowledge alters very little.

### 2.5.3 *Alchemy in literary works*

Alchemy received considerable attention in literary works. There are warnings about the dishonesty of alchemists in Langland's *Piers ploughman* (Brock, 2000, p.33) The chemical knowledge of the period is summed up by Chaucer (circa 1340-1400) in one of his *Canterbury Tales* (*The canon's yeoman's tale*). In this, he uses an alchemist as a major character in his story, so there is very definite evidence as to what substances and apparatus were known at the time.

I will you tell, as was me taught also,  
The foure spirits, and the bodies seven,  
By order, as oft I heard my lord them neven  
The first spirit Quicksilver called is;  
The second Orpiment; the third, y-wis,  
Sal-Armoniac, and the fourth Brimstone.  
The bodies sev'n eke, lo them here anon.  
Sol gold is, and Luna silver we threpe  
Mars iron, Mercury quicksilver we clepe  
Saturnus lead, and Jupiter is tin,  
And Venus copper, by my father's kin.

(By Geoffrey Chaucer taken from Project Gutenberg site)

ftp://metalab.unc.edu/pub/docs/books/gutenberg/etext00/cbtl10.txt)

(Accessed 29 September 2000).

Dante had earlier (1317) assigned all alchemists to the inferno (Brock, 2000, p.34). There is a good description of an alchemist's activities in the 'Easter Walk' in Goethe's *Faust* (quoted Lockermann, 1959, p. 45). There is also considerable fun made at the expense of alchemy in Ben Jonson's play, *The alchemist*, written in 1610 (Brock, 2000, p. 34). Brock (2000, pp. 34-36) provides an explanation of why alchemy became illegal (which may explain some of Newton's secretive behaviour (Section 2.6.8).

## 2.6 From alchemy to a concept of chemical change 1500 to 1750

Alchemy was probably at its zenith in the thirteenth and fourteenth centuries (Lockermann, 1959, p. 43). A little while after that, alchemy reached what Leicester (1971, p. 87) calls a 'dead end'. By that, he means that during the Renaissance with its emphasis on logical thought and reason, alchemy was unlikely to prosper. Nonetheless the apparent fascination with alchemy never entirely disappeared for some people. In a footnote (Leicester, 1971, p. 87), there is a reference to a 1951 article which indicates that activity in alchemy continues to the present day. Certainly there is a very active and informative web site at URL <http://www.levity.com/alchemy/home.html> (viewed 29 September 2000).

This contains more than 100 alchemical works online. It also advertises courses in alchemy, which indicates that even in the twenty-first century alchemy still holds appeal to some people.

There are many alchemical works, many of which are only available as fragments in short booklets, for example Lully (n.d.), Vaughan (n.d.), and Vaughan (1651), but a more complete and holistic view is provided by an encyclopaedia of science and art (Wecker & Read, 1660) of 1660. It claims to contain a discussion of the secrets of animals, jewels, meteors, life and death and a multitude of other topics. This encyclopaedia contains a mixture of alchemy, superstition, magic, recipes, most of which look as though they would not work and generally poor advice about health issues. Although all the topics are labelled secret, the instructions given are clear,

though following these could lead to some most unfortunate results. This work shows clearly the dangerous and unpleasant side of a belief in alchemy.

There was no sudden rejection of alchemy, but a gradual movement from it and as the interest and belief in alchemy disappeared, so a notion of the true nature of chemical change was established. For example, the alchemy web site (mentioned in this section) refers to many of those working in chemistry or alchemy up to 1730 as alchemists, and after that date no one is referred to as an alchemist. Meyer (1906) says:

We may safely say that scientific chemistry only really began with the fruitful endeavours to discover the real composition of substances.

(pp. 44-45)

#### 2.6.1 *Theophrastus Bombastus von Hohenheim (Paracelsus)*

Another major change in viewpoint was due to Theophrastus Bombastus von Hohenheim (Jacobi, 1979; Multhauf, 1961; Pachter, 1961; Paracelsus, n.d.). He was a difficult and eccentric personality, but he changed alchemy from only being concerned with the making of gold to allow it to include a concern for human health. He advocated a number of inorganic substances as cures for various diseases, though not entirely successfully, as some of his cures containing antimony and mercury compounds were toxic (Ihde, 1964, p. 21). Thus, Paracelsus is said to be the father of iatro-chemistry (i.e., responsible for the insertion of chemistry into medicine) (Dawbarn, 2001, p. 546), though some appear to reject this view (Kremers & Urdang, 1951, p. 54). Paracelsus accepted Aristotle's four element theory to which he added the three principles mercury, sulfur and salt.

#### 2.6.2 *The books of Georgius Agricola, Libavius and Giambattista Porta*

Georgius Agricola's book, *De re metallica*, was not published until the year after his death in 1555. It deals with mineralogy and was a masterpiece of its time filled with many woodcut illustrations of the mining industry of the period and even as a reprint (Agricola, 1566), it is a joy to view. Agricola accepted an Aristotelean theory of

matter and the work contains few new chemical ideas, though it records existing practice brilliantly.

There are the practical chemists such as Libavius (Muir, 1994, p. 319) who opposed the mysticism of Paracelsus. He wrote *Alchemia* in which the preparation of compounds such as hydrochloric acid and ammonium sulfate was explained. Porta (1658; also available online) gives lists of recipes but his work does not appear to contain any obvious theoretical links to chemical change, though the recipes provided consist mainly of chemical changes. Nonetheless the differentiation between alchemists and practising chemists cannot be carried too far as alchemists discovered some new chemicals, for example, arsenic was discovered by Albertus Magnus and ammonium carbonate was said to have been discovered by pseudo Raymond Lully (pseudo as some attributions may be spurious – Idhe, 1964, p. 16) (Caron & Hutin, 1961, pp. 86-87). A new process for the distillation of alcohol from fermented grains and fruits was discovered at this time by alchemists. Michael Puff von Schrick, a German physician, wrote the first book on distillation (1478) and readers were assured that brandy would even revive the dying (Boas, 1962, p. 160)

Also in the same period there are other writers, for example, Robert Fludd (Rodwell, 1871, xvii - xxiii) who wrote *Historia macrocosmi*, Arthur Dee who wrote *Fasiculus chemicus* (Abraham, 1994, p. 135) and Sendivogius (Szydlo, 1994; Partington II, 1965, pp. 426-429).

### 2.6.3 *Jan Baptista van Helmont*

Many people consider Van Helmont to be one of the first to have bridged the gulf between alchemy and chemistry. As a mystic, he believed in the philosopher's stone, but he was a careful observer and exact experimenter. Van Helmont invented the word "gas". Up to that time people thought air was an inert substance that played no part in chemical phenomena (Chalmers, 1949, pp. 100-101) and although they recognised different airs, they thought the difference was just due to dust or impurity. He was the first scientist to recognize the existence of gases distinct from atmospheric air. He proved that what he called 'spiritus sylvestre' or 'wild spirit' which was produced by burning charcoal was the same as that produced by fermenting grape juice. Both were actually carbon dioxide. Van Helmont is

probably chiefly remembered for his experiment with the willow tree, which at the start of his experiment weighed five pounds. At the end of five years the willow tree weighed one hundred and sixty nine pounds. Van Helmont believed that this showed that he had proved that all matter consisted of just water and air (Heinecke, 1995, p. 74) and not air, fire, earth and water as Aristotle had stated. This explanation was incorrect because the discovery of photosynthesis was a long way into the future, but the concept of a third state of matter of gas (or chaos) had been asserted. Many of Van Helmont's ideas were mistaken, but his experimental results acted as a starting point for Robert Boyle.

#### 2.6.4 Francis Bacon and René Descartes

Chemistry is an experimental science yet some of those who influenced the climate of educated opinion to make the experimental sciences academically respectable were not, in the main, scientists, but philosophers and communicators. In England, Francis Bacon made science respectable for English gentlemen. As Asimov (1975a, p. 90) points out, Bacon's own attempts at food preservation by stuffing a chicken with snow actually led to his death, through catching a chill from which he did not recover. Bacon favoured the exhaustive collection of facts as the basis for science (Pledge, 1966, p. 56) whereas Descartes first brought abstraction into science (Pledge, 1966, p. 57). In his great book, entitled in English, *Discourse on method*, Descartes advocated a mechanical philosophy, which influenced Newton and later Lavoisier.

It is interesting to note that it was Descartes who first enunciated a law of inertia rather than a law of the earlier theories of 'angelic impulsion of the planets' (Shipley, 1926, pp. 10-11): the law of inertia is now known as Newton's first law of motion. The mechanical philosophy proposed by Descartes included the concept of atoms whose shapes dictated their physical and chemical properties (Goodman & Russell, 1991, p. 181) but these assertions were entirely speculative (Partington II, 1998, p. 431).

Descartes went to school with Mersenne (Asimov, 1975a, p. 104). Mersenne (Dear, 1988) influenced science through his communications with scientists, by translating important scientific works, by defending scientific work within the church and by



attacking mysticism and superstition. Gassendi influenced the revival of atomism rejecting Aristotelianism but is sometimes classed as a propagandist rather than an original thinker (Jenkins-Jones, 1997, p. 190).

#### 2.6.5 *The books of Christopher Glaser, Johann Glauber and Nicholas Lemery*

Glaser, Glauber and Lemery all wrote chemistry textbooks early in the seventeenth century. Johann Glauber was the son of a barber and evidently taught himself chemistry. He was a firm believer in alchemy (Partington II, 1998, p. 348), perhaps due to curing himself from a serious illness by drinking water from a spring containing sodium sulfate known as Glauber's salt (Partington II, 1998, p. 341). However Glauber was also a very competent practical chemist. Golinski (1990, pp. 374-375) comments that Glauber (and Sendivogius) both use an 'open' style of writing as well as a 'dark' (secret) style. This latter style was the custom in alchemical writings. Expressed simply, those who wrote in an alchemical style desired to keep the chemical information secret. Glauber appears to be one of those writers who wrote at least partially openly, thus allowing others to repeat and improve on existing chemical knowledge. Glauber is of particular interest to this history as Read (1947, p. 97) claims that Glauber was the first to 'visualise dimly the idea of chemical affinity'.

Glaser (1677) was the author of *The complete chemist* which is a recipe-type book, yet it expresses quite clearly the author's knowledge and belief system including a definition of chemistry, subject matter and functions, the three active principles (mercury, sulfur and salt) and two passive principles (earth and phlegm) of which matter is composed. Glaser was born in Basel, Switzerland but little is known of his early life and he eventually settled in Paris (Hannaway, 1972, pp.417-418). He was a teacher of Nicholas Lemery, who later succeeded him and held a post at the Jardin du Roi. History has not been kind to Glaser perhaps due to Lemery's unfavourable opinion of him (Ferguson, 1906, pp. 320-321), or perhaps because he was involved in the poisoning case of the Marchioness de Brinvilliers, and was imprisoned and released due to lack of evidence against him. Lemery worked under Glaser for a short time but is said to have disliked his secretive attitude (Williams, 1994, pp. 302-303). Lemery wrote a textbook *Cours de Chymie*, which became really popular amongst students of medicine of the time. Golinski (1990, p. 376) says that it was

advertised as making the hidden mysteries of chemistry 'plain and open'. Fontenelle (1961, p. 154) has pointed out that in spite of all his protestations about openness, Lemery kept some of his most profitable recipes secret.

#### 2.6.6 *Jean Rey, Robert Hooke, Michael Sendivogius and John Mayow*

There were other experimenters who pioneered measuring and weighing. Amongst these was Jan Rey (Rosen, 1984, pp. 58-59) whose careful work showed that on heating tin in air there was an increase in weight, though there were experiments that produced the opposite result (Rey, 1630, p. 54). Hooke was for a time an assistant to Robert Boyle. Hooke's writings indicate that he realised that both air and nitre contained some common constituent that enabled carbon and sulfur to burn (Clark & Spiring, 1968, p. 504). Hooke was a friend of John Mayow, who died at an early age. Mayow discovered the similarity between combustion and breathing (Williams, 1994, p. 336) and also that burning was a combination of the burning material and a constituent of air (Clark & Spiring, 1968 p. 504). Sendivogius had come to similar conclusions to Mayow about combustion about 70 years earlier (Szydlo, 1996, p. 94).

#### 2.6.7 *Robert Boyle*

Robert Boyle was a natural philosopher and chemist born on January 25, 1627. He was the youngest son (one of 14 children) of the Earl of Cork, who was then amongst the wealthiest men in England (Pilkington, 1959, pp. 18-20). Boyle had a privileged start in life, received a conventional gentleman's education and was studious and introspective (Hunter, 2003). He and his tutor travelled widely on the continent, but during this time there was a rebellion in Ireland, where most of his father's estates were and a civil war in England. For a time it seemed that he was penniless with little hope of any of his fortune being recovered. Eventually through the help of his sister he had some of his estates returned to him. He went to his estate in Stalbridge where his reading provided him with a passionate interest in chemistry.

He set up a laboratory in Oxford where he hired an assistant, Robert Hooke, who was a talented experimenter and who helped him both intellectually and

practically. Boyle's earliest publication was on the physical properties of air, from which he derived his law that the volume of a given amount of a gas varies inversely with pressure. Boyle moved to London from Oxford. He was a founder and an influential fellow of the Royal Society. He was continuously active in scientific affairs, and wrote prolifically on science, philosophy, and theology. He had had a conversion when travelling as a young man and was deeply religious. Accounts of his early writings indicate his piety (Principe, 1994, p. 258).

His work in chemistry was aimed at establishing it as a rational theoretical science on the basis of a mechanistic theory of matter. In his chemical philosophy he was the first to define the term element. He was said also to have discovered hydrogen and indicators. 'Hermetick' philosophers of this period still held to Aristotle's view that matter consists of air, fire, earth and water, whilst chemists of the time, referred to by Boyle as 'vulgar spagyrist' believed, following Paracelsus, that matter consisted of salt, sulfur and mercury combined in different proportions. Boyle argued against both these views (as Carneades in the text) on the basis of the experiments he had performed. In *The Sceptical Chemist* (1661), Boyle opposed the theory proposed by Greek philosopher and scientist Aristotle that four elements—earth, air, fire, and water—compose all matter. Boyle suggested that tiny particles of primary matter combine in various ways to form what he called corpuscles, and that all observable phenomena resulted from the motion and structure of the corpuscles. Although many of Boyle's ideas (for example, that primary particles move freely in fluids and less freely in solids) were similar to those of Descartes, there were differences.

Descartes had not believed that a vacuum could exist, and thought that there was an all-pervading ether. In his experiments with his improved air pump (Conant, 1947, pp. 42-44; Conant, 1970, pp. 1-63), Boyle had obtained a partial vacuum, so did not accept Descartes' view. There were a wide range of theoretical views and a number of competing designs for air-pumps and the story (Shapin & Schaffer, 1985) of the changes in these and the interactions between Boyle, Hobbes, Hooke, von Guericke and other scientists is told in *Leviathan and the air-pump* making fascinating reading.

Perhaps most crucial was Boyle's *Physico-chymicall essay, containing an experiment with some considerations touching the differing parts and redintegration of salt-peter* (often referred to as his *Essay of nitre*), in which he experimentally demonstrated how the changes that could be brought about in saltpetre by chemical means could be explained entirely in terms of the size and motion of corpuscles, without the need for any of the explanations in terms of 'forms' and 'qualities' associated with scholastic science.

In *The sceptical chymist*, Boyle makes a clear break with the alchemists' tradition of secrecy as his books contain considerable experimental detail and he even includes unsuccessful experiments. Interestingly, in *The sceptical chymist* Boyle purposely played the role of devil's advocate in the alchemical debate and although he is seemingly antagonistic to alchemy, it provoked the opposite effect to what was intended. It helped to defend alchemy's worth as a sacred science.

On the other hand, Principe (1992, pp. 63-64) points out that Boyle was inconsistent in this, employing many characteristics of concealment throughout his career and never abandoning his beliefs in alchemy. For example, in 1676, he reported to the Royal Society on his attempts to change quicksilver into gold and thought that he was near to success in this endeavour. Summarising Boyle's philosophy, Kim (1991, p. 9), argues that Boyle attempted to give mechanical explanations for chemical operations, but these frequently were circular arguments and lacked credibility. So Boyle's attempts to raise the status of chemistry by linking it to a mechanical philosophy were unsuccessful in spite of his excellent intentions. As he said:

I shall think myself to have done no useless service to the common-wealth of learning, if I prove so fortunate to beget a good understanding betwixt the chymists and the mechanical philosophers.

(Robert Boyle, quoted Kim, 1991, p. 8)

Robert Boyle left too many contradictions in his opus (evidently two and a half million words) and was too inconsistent in his own practice but historically he was shown to be correct in many of his ideas so he has some claim to be called 'father of chemistry'.

### 2.6.8 *Isaac Newton*

Isaac Newton made immense contributions to our understanding of physical phenomena but his name is not usually associated with discoveries in chemistry. His life and works are available in considerable detail in a number of books and on the WWW. The two URLs given are link pages that provide details of some of the better and more accessible sites.

The Newton Institute for Mathematical Sciences- Newton Links page

<http://www.newton.cam.ac.uk/newton.htm> (Accessed 20 October 2000).

Optics Notes - Isaac Newton

At <http://qis.net/~bnichols/opticsnotes/isaac.htm> (Accessed 20 October 2000).

Newton was born on Christmas Day, 1642, the year in which Galileo died. He had an unhappy childhood (White, 1998). Newton entered Trinity College, Cambridge in 1661, where he studied the works of Boyle, Descartes, Gassendi, and Galileo. When an outbreak of the plague closed the university in 1665, Newton returned to Lincolnshire and used this time to good effect in scientific endeavour. Newton was promoted to Lucasian Professor of Mathematics at Cambridge in 1669, when he was only twenty-seven and was elected a Fellow of the Royal Society in the following year. Newton had lengthy and bitter public feuds with Huygens and Hooke. In 1678, Newton suffered a serious emotional breakdown, and in the following year his mother died. Newton withdrew from public academic work, cut off contact with others and engrossed himself in alchemical research.

Newton's alchemical writings, which were ignored until the 1930s (Christianson, 1984, pp. 203-236; Dobbs, 1984, pp. 126-233), indicate he worked for a time on the regulus of antimony to try to produce the true philosophical mercury. For example, an early biography of Newton (Summers, 1897) makes no mention of Newton's alchemical works, consisting of more than 1 million words (Christianson, 1984, p. 203). To a modern reader this material appears somewhat bizarre, but Newton evidently believed that he had achieved some success toward his goal of making gold. As was pointed out at the beginning of this study (Section 1.1), Newton's alchemical studies contained within them rigorous investigations into the hidden

forces of nature, that is, the forces of attraction and repulsion at the particulate level which eventually led to his gravitational theory at the celestial level. Newton's later insights in celestial mechanics can be traced in part to his alchemical interests. Newton remodelled the existing mechanical philosophy of Descartes and Boyle (Green, 1978) in ways that transformed the ways of thinking of future physicists, astronomers and chemists (Goehring, 1976). Newton's view of particles was that they were hard glassy atoms, not indefinite particles, without the hooks on them of Descartes. Newton stated

. . . it seems probable to me that God in the Beginning form'd Matter in solid, massy, hard impenetrable, moveable particles of such Sizes, and Figures, with such other Properties, and in such Proportion to Space as most conduced to the End for which he form'd them. . .

(Newton quoted Partington II, 1998, p. 475.)

At about this time, Joseph Boscovich (1711-1787) abandoned the idea of material corpuscles, replacing them with point-centres of alternating repulsive and attractive forces. This theory was revived over the years by various well known scientists including Michael Faraday (Partington II, 1998, p. 476.). The work of Daniel Bernoulli (1700-1782) shows the first quantitative inkling of how the pressure exerted by gases was related to molecular bombardment (Jenkins-Jones, 1997, pp. 46-47), though Partington II (1998, p. 477) indicates that similar ideas were known to Lomonosov (Kudryavtsev, 1954; Leicester, 1970).

Newton had a series of quarrels with Leibniz and later with Flamsteed which may have been instrumental in a further mental breakdown in 1693. He then retired from active scientific research. In 1696 he became Warden of the Royal Mint being promoted to Master three years later in which position he supervised England's coinage policies. In his earlier alchemical work he had tried to transmute base metals into gold but as Master of the Royal Mint he supervised the production of gold and other coins. In 1703 he was elected President of the Royal Society which was a position that he held until his death after a protracted illness in March 1727 (White, 1998, p. 360).

Hoskin (1961), who wrote a foreword to a reprinting of *Vegetable statics* (Hales, 1727), gives an account of Hales' life and also surveys the state of knowledge at the time. Hales took Holy Orders at Cambridge and appears to have had more interest in science than the care of parishioners at Teddington where he was Perpetual Curate (Hoskin, 1961, p.ix). His work on plants showed that some part of air enters the composition of plants. He was a good experimentalist who worked quantitatively and his techniques, such as the pneumatic trough, were used by others, including Priestley when he investigated gases. Hoskin's comments on the knowledge of mechanical philosophy at the time are particularly pertinent.

. . . and by the time the Royal Society was founded in 1660 the mechanical philosophy, the view that at least physical and chemical changes were to be explained simply in terms of matter in motion seemed so unexceptional, so natural that it was no longer regarded merely as one of several possible approaches to the natural world: no other view could be taken seriously. . .

(Hoskin, 1961, pp. v-vi)

This is an interesting view and seems to differ from other historians quoted as they refer to quite diverse views between different scientists of the period as to the reason for change in matter.

#### 2.6.9 *Hermann Boerhaave*

Hermann Boerhaave, 1668-1738, was a Dutch physician, chemist, humanist of devout religious belief (Gibbs, 1963, p. 27) and one of the towering intellects of his time. He accepted the unenviable task of holding three of the five chairs in the University of Leiden's Faculty of Medicine for 10 years. In fact, he stayed at the University of Leiden all his working life. He was a great teacher and his influence spread throughout Europe because of his textbooks. He was a friend of Samuel Johnson (Atkinson, 1942), the English essayist and lexicographer, who wrote a moving appreciation of Boerhaave's life on his death over four issues of *The Gentleman's Magazine* (January to April 1739). This appreciation can now be found at *Hermann Boerhaave by Samuel Johnson* (Accessed 25 October 2000) <http://www.samueljohnson.com/boerhaave.html>.

With regard to chemistry, Boerhaave is remembered mostly for his writing. A spurious edition of his chemical lecture notes by his students was published in 1724 as *Institutiones et Experimenta Chemiae* (Kerker, 1961, p.169) and this was followed by an English translation by Peter Shaw entitled *A new method of chemistry*. Boerhaave was greatly vexed by the unauthorised publication due to its many errors and he wrote *Elementa chemiae* (1732) which was translated into English by Timothy Dallowe and remained a standard chemistry textbook for decades (Goodman & Russell, 1991, p. 263).

Lindeboom (1968) provides an authoritative biography of Boerhaave including a chapter explaining the status of chemistry at the time and Boerhaave's contributions to the field. Boerhaave accepted the Chair of Chemistry in 1718 but chemistry at that time was little respected (Lindeboom, 1968, p. 324) because chemistry as a science had not yet developed as far as physics. Chemistry was not generally a university subject, but was essentially practised as a trade in the chemist's shop (pharmacy). Several sources claim that Boerhaave was the first to use the term affinity (Brown, 1913, p. 481), but whether this is the case or not he used the term and tried to clarify its meaning. As Armitage (1906) says

The modern connotation of the word "affinity" was first given it by Boerhaave. (p. 32)

His books show the reliance he placed on Newton's mechanical thought and his ideas of affinity are an instance of this, for example, with the combination of mercury and sulfur forming cinnabar. Boerhaave states that there:

is a power in both, whereby, when touching in many surfaces, they attract each other so strongly, as to require a great force, or a stronger attractive of either, before they will separate again; and this mutual attraction is the principal cause of the effect. (Boerhaave quoted Lindeboom, 1968, p. 330)

Boerhaave was also a great experimentalist producing a series of lecture demonstrations for his students (Lindeboom, 1968, pp. 331-340). In fact some of the chemistry is so interesting that it is still regarded as best practice (Diemente, 2000).



Most of these demonstrations involve fire (Love, 1975), the archetypal chemical reaction. Love (1974) explains Boerhaave's views thus:

In particular, Boerhaave treated one of the elements, fire, in a quite distinctive way. He argued that fire was at the same time an element of matter and an instrument of chemical change, and moreover it was an instrument of chemical change which itself remained unchanged in the natural and artificial changes it initiated. (p. 547)

In solutions (Love, 1974, p. 552) says that Boerhaave distinguishes between physical and chemical types of solution essentially by a reversibility test which is one of the criteria used by many students today.

It is possible that the origins of physical and chemical change being used as a contrasting pair can be credited to Boerhaave, because Read (1947) states that:

. . . Boerhaave distinguishes between chemical union and mechanical admixture (p. 145)

This may be the definite place in time where the concept of the opposition of physical and chemical change was created, though if it is the case it is not strongly established. Evidence of some aspects of a scientific concept of physical and chemical change may be present in Boerhaave's writing but the concept is not pressed as a teaching methodology. Overall there is evidence that Boerhaave got closer to an explanation of physical and chemical change than any of his contemporaries, yet his work remains largely unappreciated and forgotten (Novak, 1971).

## 2.7 William Cullen and Joseph Black

Cullen introduced chemistry courses at the University of Glasgow, hired Black as an assistant, then lectured in chemistry at Edinburgh University and eventually became Professor of Medicine there. He was a contemporary of Boerhaave and used Shaw's translation of Boerhaave's chemistry in his lectures (Partington III, 1998, p. 128). He also used affinity diagrams in his teaching. Black eventually took

over from him, becoming Professor of Chemistry at Edinburgh University. Black was always grateful to Cullen for what he had learned from him. Golinski (2001) says:

It was Cullen who initiated Scottish research on heat in relation to physical and chemical change. In doing so, he made use of an influential doctrine advanced by Boerhaave, who had taught his students at Leiden that the four ancient elements should be regarded, not as components of matter responsible for its properties, but as "instruments" of all kinds of physical and chemical change.

(Golinski, 2001, @ <http://www.unh.edu/history/golinski/paper5.htm>)

Golinski (2001) goes on to say :

The theory (Cullen's) had limited success in the realm of chemical change, but it enjoyed its most triumphant application in the discoveries of specific heat capacities and latent heats by Cullen's pupil Joseph Black (1728-99).

(Golinski, 2001, @ <http://www.unh.edu/history/golinski/paper5.htm>)

There is a sense in which the phrase 'physical and chemical change' is a more recent phrase being used to describe eighteenth century concepts which may not be identical to present day ideas, but it does indicate that some historians of science recognise that the essentials of the concept of physical and chemical change were present early in the eighteenth century.

The phlogiston theory successfully deals with combustion and calcination, but the heating of calcium carbonate in lime burning really contains inherent contradictions. A number of these contradictions were discovered by Joseph Black, particularly in his work on Magnesia alba, but Black, in spite of all these contradictions, remained a staunch 'phlogistonist'. Black's doctoral dissertation in 1754 was the first example of the use of weighing to help interpret chemical changes (Duncan, 1970, p. xv). Black was an excellent teacher and it is said that his style of lecturing was elegant yet simple (Brougham, 1961, p. 221).

## 2.8 Introducing the phlogiston theory

Whereas earlier theories of the nature of matter were summarised in Table 2.1, this section explains the phlogiston theory and its origins. The phlogiston theory (Brown & Dronsfield, 1991, pp. 43-45) was put forward by Becher in his extensive writings in the period 1650-1680. The theory was modified and publicised by Stahl and by the early eighteenth century was the theory accepted by most chemists as the explanation of combustion.

More recently, Bronowski (1975) reflected on the problem that chemists had in explaining the nature of fire by stating that:

Fire is the alchemists' element by which man is able to cut deeply into the structure of matter. (p. 142)

Chemists put forward the phlogiston theory to explain fire but this was unsuccessful as fire is not a real material. As Bronowski (1975) says:

Fire is a process of transformation and change, by which material elements are rejoined into new combinations. The nature of chemical processes was only understood when fire itself came to be understood as a process. (p. 142)

Fire is the archetypal chemical change and historically it was through the understanding of the nature of fire that an understanding of chemical change came about.

### 2.8.1 *Johann Joachim Becher, Georg Ernst Stahl and the phlogiston theory*

Becher, whilst still believing in Aristotle's four elements, considered that one of them, earth, exists in three forms—inert earth (salt), fatty earth (sulfur) and volatile earth (mercury). He was so convinced that transmutation was possible that he attempted (unsuccessfully) to turn the sands of the River Danube into gold. It was left to Stahl (1730, p. 4) to clarify Becher's theories. Stahl still thought that the chemical principles were salt, sulfur and mercury. Stahl, writing between 1697 and 1734, attributes combustibility to the peculiar substance 'phlogiston' which is like

fire and is held in bodies. Phlogiston was believed to be a real substance, which was transferred from one chemical to another. Stahl said that when a substance burnt, phlogiston was lost. Similarly in smelting (that is, making steel from iron ore or making copper from copper ore) the ore would be heated with charcoal. The charcoal, which was rich in phlogiston, would give its phlogiston to the ore and the ore would become a metal. In its simple form the theory gave a reasonable explanation of burning, but it became increasingly difficult to explain all its reactions and the changes in weight involved. However, the theory was similar to earlier theories and suited those of a conservative disposition well enough.

On the other hand the phlogiston theory was not universally accepted, for example, a natural philosophy book translated from a French work dated 1740 states:

First fire does not consist, as the moderns maintain, of rapid motion in all sorts of matter; but it is a real body different from others. Secondly it is a fluid. . . (Anon IV, 1740, p. 103)

The remainder of the chapter 'The theory of fire' shows considerable confusion between phenomena that today would be associated with heat (physical change) and fire (chemical change), so Francis Bacon's aphorism of a century earlier 'The cause of heat is motion' (McKenzie, 1973, p. 138) was far from accepted at this time and was not demonstrated experimentally until Count Rumford's work on boring canons in 1797 (Lyons, 1985, p. 14). It can be concluded that considerable elements of confusion remained between fire and heat and the cause of each at this time.

Goldsmith (1776, p. 214) asks the rhetorical question 'What is fire?' and answers it by stating that it is a question which 'has divided the greatest of men'. Goldsmith (1776, p. 214) set up the following dichotomy with Boerhaave, Homberg and Lemery considering that fire is 'a body actually existing, like air, water or any other fluid and diffused through all nature'. On the other hand, he sets up Bacon, Boyle and Newton as denying that fire is a body, Goldsmith (1776, p. 215) ' . . . but only arises from the attrition or rubbing of bodies one against the other.' Goldsmith concludes by commenting that most modern philosophers believe Boerhaave to be correct.

A French chemical dictionary of a similar period considers the phlogiston theory to be established science, dedicating some 20 pages to the topic. The author (Anon, 1766) begins by saying what chemists mean by the word phlogiston (phlogistique) which is 'the purest and simplest inflammable principal' (Anon, 1766, p. 199) and ends by claiming that phlogiston has become 'so important and so essential' for the understanding of chemistry since its discovery by Becher, Stahl, Geoffroy and the best modern chemists (Anon, 1766, p. 220). What is remarkable is that the author, in describing phlogiston, builds up a real enthusiasm for what is now considered both wrong in terms of its chemistry and intensely boring.

It was Lavoisier whose diligent and patient work destroyed the phlogiston theory, and by the end of the eighteenth century it was no longer a part of chemical thought (Brock, 1992; Butterfield, 1951; Dampier, 1945; Salzberg, 1991). The phlogiston hypothesis, though incorrect, was the first widespread generalisation that correlated a variety of chemical reactions and it thus encouraged research in chemistry (Stillman, 1960, p. 429).

### 2.8.2 *Georg Ernst Stahl*

Stahl (1730) also provides the earliest mention that I have found of the phrase 'physical and chemical' as a contrasting/opposing pair when he states:

4. Both these definitions are exact if we allow a purely rational resolution: but as this is not easily obtainable from the chemistry of these days and so can hardly be come at by Art; a difference at present prevails between the physical and chemical Principles for mix'd Bodies. (p. 4)

There is a well known quotation sometimes attributed to Becher (Asimov, 1975a, pp. 130-131) and sometimes to Stahl to the effect that chemists are as happy as 'Persian kings' to practice their profession amongst smoke, poisons and poverty. This sentiment has been one of those ideas that emphasise the practical, hands-on role of chemistry and differentiated the role of chemists from the role of natural philosophers (physicists). Here are the beginnings of the contrast between physics and chemistry!

Stahl was enthusiastic about his chemistry and was dismissive of physicist's attempts to capture it:

Mechanical Philosophy, (he remarked) though it vaunts itself as capable of explaining everything most clearly, has applied itself rather presumptuously to the consideration of chemico-physical matters. . . it scratches the shell and surface of things and leaves the kernel untouched.

(Stahl, quoted Knight, 1967, p. 139)

### 2.8.3 Peter Shaw

Peter Shaw, son of a teacher at Litchfield Grammar School (Ferguson, 1906, p.381), edited and translated many chemical works including works by Francis Bacon, Boyle, Stahl and Boerhaave as well as writing a number of his own books that included his lectures and his book called *Proposals for a course of chemical experiments* (Ferguson, 1906, p. 381). This indicates that thought was being given to the teaching of chemistry at this time.

### 2.8.4 Etienne Geoffroy

E. F. Geoffroy was a 'phlogistonist', like other chemists of his time but he was also an opponent of alchemy (Partington III, 1998, pp. 49-53) and he is best known for his table of affinity (Klein, 1995, pp. 79-100). A table of affinity records the degree of attraction one substance has for another with the aim of predicting chemical reactions. Thereafter many chemists published their own versions of these tables, but none succeeded in their aim of predicting all reactions.

### 2.8.5 Pierre Macquer and Guillaume Rouelle

P. J. Macquer was the author of a number of elementary chemistry textbooks, which effectively spread chemical knowledge (Meyer, 1906, p. 125), but he is probably best known for his chemical dictionary, *Dictionnaire chimique*, (1778). G. F. Rouelle was a demonstrator of chemistry from 1742 to 1768 at the Jardin de Roi, where Macquer was professor. Many French chemists including Lavoisier were amongst his pupils (Partington III, 1998, pp. 73-76). He taught the phlogiston theory which Lavoisier was later to disprove.

Meyer (1906, p. 125) has an interesting footnote about the brilliance of Rouelle's teaching. Evidently at that time in France lecturers taught in pairs (team teaching). Rouelle (a very competent practical chemist) was paired with Bourdelin who talked about the theory. Bourdelin was said to have tired his audience with his abstract reasoning, whilst Rouelle inspired his students with novel experiments and lively teaching during which he would get so excited that he would throw off his wig and formal jacket. On one occasion, his assistant did not arrive, so he continued his demonstration alone. He was heating a cauldron on a brazier. He pointed out to his audience that if he ceased to stir the cauldron an explosion would occur. He then forgot to stir the cauldron, which then exploded, throwing him in the air as predicted, but fortunately he was unhurt (Anon Hodgskin, 1824, pp. 10-12). This is an example of violent chemical change.

#### 2.8.6 *Understanding chemical change circa 1750*

In this period, there was a general acceptance of the atomic theory championed by Newton (Pullman, 1998, p. 136), a grudging acceptance that there was a third state of matter (gaseous) and that these gases could consist of different substances. For example, Venel (1723-1775) had just rediscovered that carbon dioxide could be dissolved in water and called this aerated (airated) water indicating that he did not distinguish between carbon dioxide and air (Partington III, 1998, pp. 78-79), though he quoted from Hales who had made that distinction. There was considerable uncertainty and confusion about many aspects of chemistry.

Kinetic theory had been outlined by Bernoulli. Aristotle's theory of elements was no longer accepted nor the various mercury, sulfur and salt theories, yet remained familiar ideas. The phlogiston theory would be the current theory of chemistry, but there would have been continuous interchange between chemists as to the implications of new discoveries for the phlogiston theory. Chemistry and alchemy were largely separated but chemistry was not completely distinguished from natural philosophy (physics). Chemistry was still not a gentleman's occupation in the same way natural philosophy was. It would have been these understandings of natural philosophy and chemistry that the young Lavoisier would have been taught as a student.

## CHAPTER 3

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### THE CONCEPT OF THE PHYSICAL AND CHEMICAL CHANGE TAKES SHAPE

*Research Question 3: When does the concept of physical and chemical change take shape as a scientific explanation?*

#### 3.0 Clarity in a concept of chemical change and related concepts

Chapter 2 produced some evidence that in the years prior to 1770 a concept of chemical change was slowly and falteringly being established or had been established though in vague and generalised terms. There was still argument about whether a vacuum was possible, about the nature of heat, about the existence of atoms and whether the shape of these atoms effected the physical and chemical properties of matter and about what an element was. All these arguments were uncertain; Chapter 3 shows the way to some resolution of these problems.

#### 3.1 Chemical change and Antoine Lavoisier

I am placing Antoine Lavoisier as a key figure in the understanding of chemical change because in my view he was responsible in his lifetime for more of the understanding of chemical change than all of those who had considered the problem before him. This is not to say that prior to Lavoisier there was no understanding of chemical change or that after his death there was a complete understanding of chemical change. The picture is rather as Koestler described the situation in cosmology (see Section 2.2.1) placing Copernicus and Kepler as the fulcrum on which Koestler tells the story of human understanding of the sun, stars and planets.

##### 3.1.1 *Antoine Lavoisier: A biography*

I will include a brief history of Antoine Lavoisier's life: the main features of his private life can be found in Figure 3.1; the main features of his scientific progress can be found in Figure 3.2. In reading about his life and works, the features that are



exposed are his arrogance, his vanity, his greed and yet his steadfastness of purpose. His writing gives a different impression, that of Lavoisier the educator. The next section examines this latter facet of Lavoisier's character prior to returning to his life story.

### 3.1.2 *Antoine Lavoisier: Author and educator*

Lavoisier wrote *Opuscules physique et chimique* in 1774. The first part of this book is mainly a history of experiments on gases carried out by other chemists whilst the second part is about experiments on gases that he had undertaken himself. It is interesting to note the title of the work is physical and chemical essays and thus shows early usage of the contrasting pair physical and chemical. He jointly wrote *Méthode de nomenclature chimique* with Guyton de Morveau, Berthollet and Foucroy after eight months intensive work. This was published in 1787. His most available major work, written in 1789, was *Elements of chemistry*.

I am using his preface in the 1806 (5th Edinburgh edition) rather than the modern Dover reprint (Lavoisier, 1990) to try to get closer to understanding of the message that Lavoisier was trying to send in writing this book. The preface explains the structure and philosophy of the book. Lavoisier expresses his admiration for the Abbé de Condillac and his book on logic. Lavoisier (1806) then expresses his own philosophy:

Every branch of physical science must consist of three things: the series of facts that are the objects of science; the ideas which represent these facts; and the words by which these ideas are expressed. (Lavoisier p. xiii)

This same information may also be found on line at URL <http://maple.lemoyne.edu/~giunta/lavpref.html>

It is interesting to note that Lavoisier sees beyond the facts and beyond the ideas to seeking the best way to express his thoughts and sees the language as a vital element in obtaining an understanding of chemistry. Lavoisier (1806), having emphasised the importance of language, now emphasises the importance of logical structure in writing textbooks. He considers that writers should write paying

attention to the difficulties that beginners may have with abstract concepts such as affinity and that these topics should be broached later in the student's career.

Thoroughly convinced of these truths, I have imposed upon myself, as a law, never to advance but from what is known to what is unknown; never to form any conclusion which is not an immediate consequence necessarily flowing from observation and experiment; and always to arrange the fact, and the conclusions which are drawn from them, in such an order as shall render it most easy for beginners in the study of chemistry thoroughly to understand them. (p. xiii)

The principles above remain excellent advice for any textbook writer, yet textbooks prior to Lavoisier did not follow those precepts, nor do most textbooks written after Lavoisier. Bensaude-Vincent (1990) compares the chemistry textbooks of Lavoisier, Fourcroy and Chaptal and indicates that only Lavoisier (1806) managed to write a truly revolutionary text.

Hence I have been obliged to depart from the usual order of courses of lectures and of treatises upon chemistry, which always assume the first principles of the science, as known, when the pupil or the reader should never be supposed to know them till they have been explained in subsequent lessons. In almost every instance, these begin by treating of the elements of matter, and by explaining the table of affinities, without considering, that, in so doing, they must bring the principal phenomena of chemistry into view at the very outset: They make use of terms which have not been defined, and suppose the science to be understood by the very persons they are only beginning to teach. (Lavoisier, 1806, p. xiii)

Bensaude-Vincent (1990, p. 449) provides evidence that Lavoisier was not satisfied with the changes that his *Elements of chemistry* had made; he wanted to go further and publish a common course containing physics and chemistry. It is true that many later texts carried large sections of physics prior to starting chemistry but it was only in the 1960s-1980s that texts that genuinely integrated physics and chemistry were published.

It ought likewise to be considered, that very little of chemistry can be learned in a first course, which is hardly sufficient to make the language of the science familiar to the ears, or the apparatus familiar to the eyes. It is almost impossible to become a chemist in less than three or four years of constant application. (Lavoisier, 1806, p. xiii)

Farber (1961, p. 285) gives an example to show the heavy load of memory work that must have been associated with chemistry before Lavoisier. It will be remembered that the Scottish chemist Joseph Black worked with *magnesia alba* (magnesium carbonate) but *magnesia nigra* was manganese oxide and *magnesia usta* evidently magnesium oxide: these illogical names would have been extremely confusing. All chemists should be extremely appreciative of Lavoisier's reforms of the language of chemistry. It is interesting to note that well after Lavoisier's death, William Henry (1774-1834) wrote in his textbook *An epitome of chemistry*:

Of all the introductory treatises on chemistry, that of Mr Lavoisier is certainly the one, from which a person entering for the first time on this study, will derive most pleasure and advantage. (Henry, 1801, p. 1)

### 3.1.3 Lavoisier's personal history

Figure 3.1 lists the main features of Lavoisier's life relating to his personal history. I will not repeat all of this material, but will try to enlarge the general picture of Antoine Lavoisier. The picture that emerges is of a man, who was a good and caring person in many respects, passionately interested in science, intensely ambitious and well aware of the way in which scientific reputations are constructed. He was born wealthy, married well and further increased the family fortunes by utilising these family connections. There is a sense in which this wealth and the envy which it provoked was his undoing, yet it also provided the initial educational experiences that he needed to become a successful scientist.

It will be noted that Lavoisier's wealth purchased influence and power. He was able to buy and use equipment made to his own design and built by the best craftsman. He could thus be more accurate than his less wealthy rivals. He also set up a journal of his own, *Annales de Chimie*, which used the nomenclature he had proposed. Those

who did not use the new names or wrote in favour of phlogiston did not get their papers published in his journal and it soon became the major journal of chemistry in France. His discoveries, his theories, and his writings were pursued so that he increased his control over the scientific media of the time. His views and those who agreed with him were published, whereas the viewpoints of those who disagreed with him were gradually excluded.

The officer who arrested Antoine Lavoisier during the French Revolution said, 'The Republic has no need of scientists'. A farcical trial followed this statement and soon afterwards Lavoisier was guillotined, on 8 May 1794 in his fifty-first year. In his comparatively short life he had changed the science of chemistry completely.

When considering the history of science in Lavoisier's time, it is natural for us to understand the science of the event being considered from a modern point of view, but it is a much more difficult and also a necessary task to know what the science of the time was in its full context. Only then can modern day observers enter the mind-set of people of this era, and see problems as they would have seen them.

#### 3.1.4 *Antoine Lavoisier's life story in tabular form*

Lavoisier's life story is told in tabular form, firstly in terms of his personal history (Figure 3.1) followed by a table indicating his scientific achievements (Figure 3.2).

Birth:	Born in Paris, France 26 August 1743.
Father:	Lawyer
Mother:	His mother died when he was 5 years old and he was brought up by a maiden aunt (Ihde, 1964).
Grandparents:	Grandfather was a lawyer.
School:	Attended College Mazarin, where his best subjects were under Abbé de la Caille, a professor of astronomy and physics (Ihde, 1964). He studied geology, astronomy botany, chemistry and mathematics with all his instructors being members of the Royal Academy of France (Salzberg, 1991).
University:	When he left college, he went on to prepare for law and received his Licentiate in 1764
Marriage:	He married Marie Anne Pierrette Paulze in 1771. He was 28 years old and she was 14 years old.
Social:	His father made a large inheritance over to him, when he was 23 years old. He used this to purchase a share in a private company (The Ferme Generale) that collected taxes on tobacco, salt and imported goods for the Government in return for a salary plus expenses plus interest on the original investment. In return the Ferme Generale paid the government a fixed sum each year. He thus became a 'fermier', a member of a group that were very unpopular, because the system was wide open to corruption, though Lavoisier was honest in his dealings. His wife was the daughter of another 'fermier' and the marriage cemented his position.
Interest in Science:	His interest in chemistry developed as a result of being taught by Rouelle at his apothecary's shop (Ihde, 1964).
Public Offices:	Director of the state gunpowder works (1776); member of the commission to establish uniform weights and measures (1790); Commissary of the Treasury (1791) (Dickey, 1990).
Family:	Antoine and Marie Anne had no children, but they were evidently a devoted couple (Hutchins, 1952).
Philanthropy:	He started a model farm to show the advantages of scientific agriculture and other community ventures such as banks, insurance societies and canals to help the poor.
Enemies:	In 1791 he was subjected to a vitriolic attack by Marat (Hutchins, 1952) perhaps because Marat, a revolutionary, who had fancied himself as a chemist, had failed to gain admission to the academy (Brock 1992)
Economy:	France was a monarchy when Lavoisier was young. Throughout the 1780s there was an agricultural depression, which lead to national bankruptcy and the French Revolution in 1789 (Meadows, 1987).

**Figure 3.1** Antoine Lavoisier: A life – basic facts

1763:	Graduated from College Mazarin. He started work as a scientist in collaboration with Guettard (his geology teacher) preparing a mineralogical atlas of France.
1764:	Lost interest in law, did a course in chemistry and tried to become a member of the French Academy of Science.
1764-8:	Carried out a number of experiments: (a) Experiments on the cause of thunder. (b) Experiments on the cause of the aurora borealis (Northern Lights). (c) Experiments on the chemical make-up of gypsum (Plaster of Paris). (Palmer, L. Y., 1998)
1768:	Elected an Associate Member of the French Academy of Science. (McGowan, 1989; McKie, 1952)
1768-70:	Carried out a series of experiments that caused a stir in that they indicated that the Aristotelian view that water on heating eventually turned to earth was incorrect. He used the balance as the major instrument for the proof.
1771:	Married Marie Anne Pierrette Paulze. She became his scientific assistant and secretary. She was a good linguist (translated papers for him from English etc) and artist (helped him with illustrations) (Ihde, 1964)
1772:	His father bought him a title, so that he was a member of the nobility (this proved to be a costly error).
1772:	Experiments with the great burning lens of Tschirnhausen to find out if diamond was combustible, which it is. (McKie, 1965, p. xix)
1772:	The crucial year for his investigations of the central problem of combustion. (Guerlac, 1961, p. xiii)
1773:	Wrote that he was determined to bring about a revolution in chemistry and physics. (Brock, 1992)
1772-5:	Worked on the reactions of various elements with air, for example phosphorus, sulfur, tin, lead and mercury.
1775:	Wrote a paper about his discoveries that showed that he no longer believed in the phlogiston theory.
1775:	Appointed <i>Regisseur des poudres</i> at the Arsenal, where he set up his laboratory. (Hutchins, 1952)
1777:	Revised the 1775 paper and presented it to the French Academy of Science.
1777:	Wrote <i>Sur la combustion en generale</i> . (Dickey, 1990).
1788:	Wrote <i>Considerations sur la nature des acides</i> . (Dickey, 1990)
1782-3:	Lavoisier and Laplace (the well-known mathematician) worked on the heat given out in chemical changes using the idea of the ice-calorimeter that they had designed. (McKie, 1965, p. xxiii)
1783:	Launched an attack on the phlogiston theory in his <i>Reflexions sur Phlogistique</i> . (Williams, 1976)
1785:	Proved water to contain hydrogen and oxygen only. (Brock, 1992, p. 117)
1787:	Wrote with Claude Berthollet and others a book called <i>Methode de nomenclature chimique</i> , which is a system of chemical nomenclature on which the modern system is based. (Dickey, 1990).
1789:	Wrote a textbook called <i>Traite elementaire de chemi</i> in a different style to earlier texts. (Dickey, 1990)
1789:	Worked on respiration with Armand Seguin (Meadows, 1987).
1794:	Guillotined on 8 May (Dickey, 1990) with his father-in-law at the 'Place de la Revolution' and their bodies were thrown into unnamed graves in the cemetery of 'La Madeleine'.
1805:	Lavoisier's memoirs published by his widow, Marie-Anne, who by then had married Count Rumford (Meadows, 1987).

**Figure 3.2** Antoine Lavoisier: A life – scientific achievements 1743-1775

### 3.1.5 Lavoisier's scientific contribution

Lavoisier's major discoveries are listed in Figure 3.2. He started his scientific work as a young man, writing a number of scientific papers on a variety of topics to try to gain the attention of the French Academy of Science. He also appeared at that stage to be searching for a place in science where he could make a major contribution. Some historians see his main motivation as the replacement of the phlogiston theory by oxygen theory in explaining combustion. However, others see his theory of acidity as being his driving force with the name, oxygen, which means acid-producer, being the clue to his purpose. It is certainly true that he believed (mistakenly) that all acids contained oxygen and it was Humphry Davy who later corrected this error by proving that hydrochloric acid contains no oxygen.

There are a number of features about his general method of working that helped Lavoisier achieve greatness. As stated earlier, he was helped by his wealth and the position of power and influence that money could buy. He was not modest about his achievements and had an eye to the future in ensuring that he was named as the discoverer, even when that was not strictly true. He wrote with Claude Berthollet and others a book called *Methode de nomenclature chimique*, which is a system of chemical nomenclature on which the modern system is based. It is his organisational genius that changed the old unsystematic names such as flowers of sulfur, sugar of lead, plaster of Paris to sulfur, lead acetate, and calcium sulfate. Within a comparatively short time most chemists used this nomenclature.

Lavoisier, sometimes on his own and sometimes in partnership between 1773 and 1792, worked on a variety of topics, for example, respiration, fermentation and plant and animal analysis (Holmes, 1987, p. 494). Eventually he became director of the Academy of Science in 1785 and treasurer in 1791 and certainly worked as a scientist for the 'Revolution' until the reign of terror. Apart from his brilliance as a chemist, he is praised as an economist (Poirier, 1996) and as an industrialist due to his work organising the manufacture of gunpowder and saltpetre (Wisniak, 2000a), which led to the founding of the Dupont Company.

### 3.1.6 *A summary of Lavoisier's achievements*

- Lavoisier showed that the "phlogiston " theory was no longer tenable.
- Lavoisier published a table of chemical elements in 1789. (Mellor, 1960)
- Lavoisier was the first to classify elements into metals and non-metals. (Mellor, 1960)
- The chemical equation appears to have originated with Antoine Lavoisier. (Kolb, 1978)
- Lavoisier did not prove the law of conservation of mass, but he regarded it as axiomatic. (Mierzecki, 1990)
- By 1790 most American scientists (Beer, 1976) and indeed scientists all over the world had been won over by Lavoisier's explanation of burning.
- Lavoisier claimed that he discovered that water was not an element but consisted of hydrogen and oxygen.

Although the revolution may have executed Lavoisier and suppressed the French Academy of Science, it certainly did mobilise and politicise science and scientists to the national cause. Lavoisier played a major role in a chemical revolution but was executed by a political one.

### 3.1.7 *Chemical change, cohesion and affinity 1750 - 1810*

Much of the long story of the long history of the explanation of combustion, oxidation and reduction has already been told noting the contributions of scientists over a thousand years to solving this problem, but oxygen itself needed to be prepared and its properties distinguished from any other gas.

### 3.1.8 *Nationalism in chemistry: Who discovered oxygen?*

Three scientists, Scheele, Priestley and Lavoisier, each have some claim to be the discoverer of oxygen. Firstly, it is necessary to know what is meant by discovery. Is discovery just producing a new substance or is discovery also understanding the correct theory behind the production of a new substance? Or is the most important



factor the date of publication of the discovery? Or are historians of chemistry unduly influenced by considerations of nationality? Perhaps the quotations below may help to provide answers to these questions.

My argument is, therefore, that Priestley on 1 August 1774 had found properties that distinguished oxygen from the only other gas it could be (nitrous oxide) and he had described these properties. Even if he misunderstood the results, this does not deprive him of the discovery of oxygen on that date. (Partington, 1965, p. 124)

. . . but he [Priestley] is best remembered as the discoverer of oxygen. For that Karl Wilhelm Scheele (1742 - 1786), from Sweden, deserves at least equal credit. He discovered oxygen independently a short time before Priestley, but Priestley published first. (Salzberg, 1991, p. 186)

A typical early twentieth century English textbook states with patriotic clarity and with no mention of Scheele or Lavoisier that 'Oxygen was discovered by Priestley in 1774'. (Taylor, 1900, p. 5)

A French historian sees things a little differently:

What shows better than anything else, the fundamental importance of Lavoisier's work, which even to this day German chemists, like Ostwald have insidiously tried to depreciate, what proves the novelty of his discoveries, was the violent, unanimous and continued opposition it met at the hands of all chemists, both French and foreign.... (Caullery, 1975, p. 50)

Thompson (1830) considers that Lavoisier was deliberately vague about the discovery of oxygen with the intention of expecting that posterity would believe that he was the discoverer of oxygen.

It is obviously the intention of the author of the paper [Lavoisier] to induce his readers to infer that he himself was the discoverer of oxygen gas.

(Thompson, 1830, p. 106)

An American textbook puts the story more fairly:

Perhaps the most important chemical reaction that Lavoisier performed was the decomposition of the red oxide of mercury to form metallic mercury and a gas which he named oxygen. The reaction had been carried out before—by Karl Wilhelm Scheele, a Swedish apothecary (1742-1786), and Joseph Priestley, a Unitarian minister, who later fled England and settled in America—but Lavoisier was the first to weigh all reactants and products. Lavoisier was also the first to interpret the reaction correctly. (Hill, 1984, p. 28)

### 3.2 Chemists of the late eighteenth century

Gibbs (1965, pp. 248-249) quotes Davy (chemist and poet) as rating Priestley, Black, Cavendish and Scheele (but not Lavoisier) as the four greatest chemical discoverers of the eighteenth century. The next four sections will show some of the reasons for Davy's view.

#### 3.2.1 *Carl Wilhelm Scheele*

Scheele was born in Straslund in Pomerania which was German-speaking even though it was a part of Sweden. An unattributed article in *The Pharmaceutical Journal* (Anon, 1893) gives this as the reason for all Scheele's papers being written in German, before being translated into Swedish.

Because the events described happened so long ago, there are numerous factual differences between sources about the minor details of his life. Even the exact date of his birth is uncertain. It is stated very emphatically to be 9th December by Anon (1893) in *The Pharmaceutical Journal* and to be 19th December by Boklund (1981). There are also different accounts of the type of school he attended, but most agree that he only had an elementary education.

In his youth Scheele was said to be shy, but hardworking. He was apprenticed to Martin Bauch in Goteborg, who was a pharmacist and Scheele stayed with him for eight years. He worked as an assistant in pharmacies in Malmo in 1865, in

Stockholm in 1868 and in Upsala in 1870. However in 1875 he set up on his own at Koping, purchasing a pharmacy from the widow of the pharmacist who had recently died there. These basic facts are agreed between sources, but where there are opinions expressed, quite major differences develop. One such opinion given by Lenard (1933) is that Scheele's ability as a scientist was due to his lack of formal schooling

A fortunate element in his development was the fact that his mind had been protected from a long period of compulsory education at school.

(Lenard, 1933, p. 137)

So much for the value of education! Scheele seems to have been a quiet, honest and hardworking man whose over-riding interest in life was his scientific research. Thorpe (1902) states that he had an excellent relationship with the other great contemporary Swedish chemist Torbern Bergman, though he was deeply upset that his first two scientific papers were rejected by Bergman. Partington (III, 1998, p. 209) quotes a relation of Bergman's who said that Scheele was Bergman's greatest discovery.

Partington (III 1998, p. 209) states that Scheele's death was due to gout and rheumatism, but Asimov, (1975b, p. 73) points out that 'his [Scheele's] habit of sniffing and sipping unknown chemicals drastically shortened his life'. Shortly before his death he unselfishly married the widow from whom he had purchased the pharmacy, so that she would inherit the business when he died.

Scheele had an amazingly productive scientific career and his discoveries were truly remarkable for their number and importance (Palmer, 1998a; 2000). Crell (1961) comments

. . . Scheele was great, extraordinarily great; until now nobody has exceeded him in the number of important discoveries. (p. 255)

Scheele discovered oxygen (Scheele, 1777) (see Section 3.1.8) and he also discovered chlorine, which he called 'dephlogisticated acid of salt'. He discovered a host of other substances. Cassenbaum and Kauffman (1976) examine the views of Bergman

and Scheele on the concept of elements, showing that Scheele had theoretical views, as well as being a brilliant experimentalist. The difficulty in understanding Scheele's work is the problem of explaining how he could make so many discoveries whilst espousing the phlogiston theory which was becoming untenable even whilst he was researching. Perhaps the conclusion must be that even incorrect theories can stimulate worthwhile research.

Scheele's place in the history of science remains secure, partly because of the number and importance of his discoveries and partly because a diverse selection of scientists and technologists recognise his pioneering efforts in their field. Such groups include pharmacists, organic chemists, analysts, photographers, and metallurgists.

### 3.2.2 *Joseph Priestley*

Priestley (Orange, 1974; Porter, 1975) was an amateur scientist who made an immense contribution to chemical discovery, but like Scheele his theoretical input was limited mainly due to his belief in the phlogiston theory. Priestley was born in 1733 near Leeds and brought up in the dissenting non-conformist tradition. His education was classical, but may have included more science than was common in his day. He became a Minister and then a tutor at Warrington Academy. He was encouraged by Benjamin Franklin to publish *A History of Electricity* (Williams, 1994, pp. 399-400) which was published in 1767. He entered the service of Lord Shelbourne as Librarian/Secretary and found time to engage in much scientific work (Uglow, 2002, pp. 229-2421). He returned to the dissenting ministry in Birmingham, was the object of mob violence when his house was burnt down, and he then emigrated to the United States, where he died in 1804.

Priestley was a man of wide interests who wrote on a range of issues (Priestley, 1775). He completed a small book giving his general educational views (Priestley, 1796) but it contains no direct opinions on science education. His letters give a picture of a man corresponding with the greatest scientists of his day (Priestley, 1806), trying to understand his own or other scientist's experiments where possible (for example to Henry Cavendish, p. 231) but vigorously defending his actions where he feels himself to have been unjustly criticised (for example, to Abbé Boscovich, p. 166).

Jefferson, President of the United States at that time, considered Priestley to be a great scientist, educationalist and religious writer.

### 3.2.3 *Lord Henry Cavendish*

Lord Henry Cavendish, a contemporary of Priestley, was extremely wealthy but reclusive by nature. He was a careful and extremely accurate experimenter and made useful discoveries in both chemistry and physics (Cavendish, 1784). He is credited with discovering that hydrogen and oxygen gas can be completely converted to their own weight of water (Partington III, 1998, p. 332). Asimov (1975b) has expressed the view that Cavendish's burning of a jet of hydrogen was the crucial experiment on which all 'Modern Chemistry' rests. Later Lavoisier repeated Cavendish's experiment without giving him credit for it and this caused a major dispute over priority (Partington III, 1998, pp. 436-453). Perhaps because of this dispute, Cavendish would have no part of Lavoisier's systematic nomenclature. Partington III (1998) quotes Cavendish as writing:

I have been reading LaV [Lavoisier's] preface. It has only served the more to convince me of the impropriety of systematic names in chemistry. (p. 336)

### 3.2.4 *Torbern Bergman*

Torbern Bergman was a Swedish chemist, physicist, mathematician and mineralogist. Asimov (1975a, p. 183) says that his greatest discovery was another Swedish chemist Willhem Scheele (also see Section 3.2.1). Bergman was a professor at the University of Uppsala, whose major interest in chemistry was his study of affinity (Bergman, 1775). He invented the term 'elective affinity', which was influential at the time, so much so that Goethe wrote a play entitled *Elective affinities* (Duncan, 1970, p. xxxvii). Goethe was a practicing scientist (Magnus, 1949) as well as a literary giant and had an interest in chemistry as is shown by his extensive library of chemistry books (Magnus, 1949, p. 205).

Bergman's thesis was called *A dissertation on elective attractions* and his collected works, *Essays, physical and chemical*, appeared in six volumes. The theory attempts to explain why one substance reacts with another substance but not with a third.

Bergman proposed the existence of affinities (attractions) between substances; these affinities vary in intensity. He prepared elaborate tables listing various affinities. These tables were very influential during Bergman's lifetime and for some time afterwards. Bergman was a skilful chemist who worked immensely hard at classifying chemical reactions in order of their reactivity, yet for reasons that are now understood the attempt was doomed to failure.

### 3.3 Some French chemists

In France, Lavoisier had many colleagues, particularly Louis Bernard Guyton de Morveau, Claude Louis Berthollet, and Antoine François de Fourcroy, who had made important chemical discoveries themselves and who had cooperated with Lavoisier on his chemical nomenclature and other projects.

#### 3.3.1 *Claude Louis Berthollet*

Berthollet was a good researcher, an indifferent lecturer and a man of principle. At the height of the revolutionary terror he was asked to analyse some wine which was alleged to have poisoned some soldiers. His analysis showed it was only diluted with water and contained some particulate matter that could be removed by filtration. However the vendors were on trial for their lives and Robespierre wanting a guilty verdict expected him to agree that the brandy had been poisoned. To prove his analysis was correct Berthollet filtered a glass of the brandy and drank it (Partington III, 1998, pp. 496-497).

Later Berthollet became a personal friend of Napoleon, and with a group of scientists accompanied Napoleon's expedition to Egypt in 1798-99 (Newbold, 1999). It was here that he observed an unusual chemical change. He noticed sodium carbonate crystallising out at the edge of a salt-water lake with a limestone bottom (Salzberg, 1991, pp. 209-210). This is precisely the reverse of what is usually observed. His further experiments with this reaction nearly provided him with evidence for the law of mass action, which was not discovered until later, but this was not the conclusion that Berthollet drew from the experiment. He argued that his observations could be explained by assuming that elements could combine in any proportions whatsoever. He spent much of the rest of his career contradicting Louis

Joseph Proust (1754-1826) (Williams, 1994, pp. 401-402), who had discovered the law of definite proportions. Several authors date the origin of the distinction between physical and chemical change to this controversy (Duhem, 2002, pp. 41-42; Pattison Muir, 1889, p. 3; Mauskopf, 1972, p. 170). A further explanation of the evidence for this apparent starting point for a concept of physical and chemical change will be provided later in the study. Proust was proved right when Dalton's law of multiple proportions was accepted, but further research has shown that not all compounds obey the law of definite proportions and those that do not obey it are still called Berthollides (see Section 5.5.1 and 8.2.3).

Berthollet's lectures started traditionally and included chemical attractions (simple, elective and complex) and anomalies relating to attractions (Partington III, 1998, p. 498). Learning about chemistry as explained in textbooks starts with the various forms of attraction called affinity. Berthollet published his research on affinity as *Recherches sur les lois de l'affinité* and in his *Essai de statique chimique* (Anon, 1824, p. 413). Even though Berthollet made a number of errors, Partington III (1998) says that he was:

One of the outstanding founders of physical chemistry; his broad sweep of view, his critical power, and his full realisation of the interplay of chemical and physical forces mark him as a master mind in this science. (pp. 499-500).

### 3.3.2 *Antoine François de Fourcroy*

Antoine François de Fourcroy was a pioneer in animal and plant chemistry. He left school as a very average student at the age of 15 and became a copy clerk. By chance he met an anatomist Vicq d'Azyr and studied medicine, where he was found to be a brilliant student (Smeaton, 1962, p. 1). He was professor from 1784 at the Jardin du Roi (later called the Jardin des Plantes) and held public offices during the Revolution. He became director-general of public instruction from 1801 and instituted reforms in the French system of higher education.

Fourcroy was a hard working researcher, lecturer and author. In his published works he was the first author to write a chemistry text that had no mention of phlogiston and amongst the first to write a text for ladies who used to attend

courses on literary and scientific subjects (Smeaton, 1962, p. 183). Fourcroy's popular textbooks helped to establish the chemical revolution (Siegfried, 1988, pp. 49-50) by emphasising definite composition and the 'pneumatic doctrine', rather than the metaphysical doctrines of the four elements. The pneumatic doctrine meant that gases were now understood to exist as different substances, each with its own physical and chemical properties.

### 3.3.3 *Louis Bernard Guyton de Morveau*

Louis Bernard Guyton de Morveau was trained as a lawyer and his interest in chemistry was sparked in an unusual way. He attended a lecture by Chardenon and criticised it; Chardenon told him to keep his comments to subjects with which he was familiar (Partington III, 1998, pp. 516-517). He then did some chemical experiments on his own and criticised Chardenon further, and on this occasion Chardenon complimented him. Guyton wrote and experimented on chemistry throughout his lifetime changing his views on phlogiston, but there is little of his work that has left a lasting legacy. Nonetheless, with regard to the language of chemistry, Guyton was a major mover behind the nomenclature project and in 1786 Lavoisier was 'captivated' by his ideas which were designed to 'snatch chemistry from obscurity and make it accessible to everybody' (Poirier, 1996, pp. 183-184).

## 3.4 Chemists of the late eighteenth/early nineteenth century

At the turn of the nineteenth century chemical change was much clearer than it had been. Combustion was understood as chemical combination with oxygen. However, Lavoisier had made mistakes over his oxygen theory of acids and his inclusion of the imponderables, heat, light and electricity and also of sodium hydroxide in his list of elements. Humphrey Davy was later able to correct some of these errors.

Dalton and Davy carried out their chemical research in Britain early in the nineteenth century. Their discoveries combined with the principles enunciated by Gay-Lussac and Avogadro, provide the beginner with basic knowledge for an understanding of the science involved in physical and chemical change. It is true that some historians of science believe that this basic understanding of chemistry was available in the early seventeenth century (Hoskin, 1961; Metzger, 1923 quoted



in Golinski, 2001) whereas others put the date of such an understanding at the end of the eighteenth century (Butterfield quoted in Golinski, 2001). The discussion is likely to be inconclusive unless the parameters are more sharply defined.

### 3.4.1 *John Dalton*

Dalton was the founder of modern chemical atomic theory, which differed from previous attempted atomic theories in that it had a quantitative basis. He was the son of a handloom weaver (Hopwood, 1961) and lived very simply all his life. He became a teacher at the village school at the age of twelve. He was a Quaker (a member of the Society of Friends) and went to teach in a 'Friends' School in Kendall when he was 15 (Hurd & Kipling, 1958b, p. 23). His career was helped by his own determination to improve himself and by his good fortune in being befriended by a variety of scholarly people. He tried public lecturing in natural philosophy, but this was not a great success as even when he became famous people did not find his lectures interesting. He was particularly interested in meteorology and published a book on this subject in 1793. It appears that it was this interest that led him to investigate gases and to develop his atomic theory. Different sources provide very different assessments of his atomic theory, which was his major achievement and the achievement most relevant to this thesis.

Thackray (1972), in his scholarly biography, provides details of Dalton's manuscripts, many of which were damaged during the second world war. Thackray (1972) outlines the development of Dalton's thought as Dalton struggled to earn enough money through teaching and providing private tuition to carry out sufficient experimental work to rebut the criticism that his early theories provoked. In 1796 he attended a series of 30 lectures by a Dr Garnett which enabled him to teach chemistry, natural philosophy and mathematics at New College, Manchester. His background in chemistry was meagre as were his resources for the subject. He only owned three chemistry textbooks (Lavoisier's, Chaptal's and Nicholson's) and about £6 worth of apparatus (Thackray, 1972, p. 66), but was soon engaged in research in chemistry. Publication of his ideas followed quickly.

By 1801, he had written an article about the pressures of mixed gases, now known as Dalton's law of partial pressures, which was challenged and he was then engaged

in continued argument with the top scientists of his time: his career progressed from this point onwards. The development of the atomic theory resulted from a further extension of this work. Fleming (1974, pp. 561-574) argues that Dalton knew of the faults of his theory stating that 'Dalton's model of combination was built upon a known falsified theory' (p. 574).

Dalton was awarded the King's medal in 1822 and a government pension in 1833 (Knickerbocker, 1962, p. 166). The literature cited so far is basically sympathetic to Dalton, but there is an alternative viewpoint expressed by Wisniak (2000b) in his biographical article about the Avogadro hypothesis. In order to bridge the gap between Gay-Lussac's Law on reacting volumes of gases and Dalton's atoms, Avogadro suggested an entity called molecules for gases, where these molecules would be made up of some simple number of atoms. Dalton opposed this idea very strongly, and this was unfortunate for the progress of chemistry. It took the restatement of the Avogadro hypothesis by Canizzaro 50 years later for the idea of molecules to be accepted.

The Dalton theory of atoms had been built on the idea of atoms being coated with a layer of caloric (heat). Theoretically, the concept of caloric had been made untenable by Count Rumford, formerly Benjamin Thompson, 10 years earlier, but both Dalton and Avogadro still accepted the caloric theory. Count Rumford had married Mme Lavoisier, some years after her husband's execution. Rumford with his well-known experiment on boring cannons with the continuous production of heat in 1798 wrote after criticism of his results by Berthollet:

Whence, then, came the caloric which the apparatus furnished in such abundance? I leave this question to be answered by those persons who believe in the actual existence of caloric.

(Thompson, 1798 quoted in Knickerbocker, 1962, p. 165)

Davy carried out an experiment rubbing blocks of ice together in vacuo and the ice melted, only allowing heat to have come as a result of the relative motion (Hart, 1924, p. 122). Knight (1998, p. 43) believes a better explanation might be poor insulation of the equipment. In 1807 Thomas Young attacked the caloric theory in his *Natural Philosophy* but nonetheless the caloric theory continued to be accepted for

another 50 years (Hart, 1924, p. 122). This can be seen by examining an 1854 chemical textbook which still includes caloric in its early chapters. Its author, Comstock (1854, p. 16), does mention Davy's experiment with rubbing blocks of ice together, but comments that 'it is difficult to reconcile the results of the experiment with the theory'. The idea of caloric can perhaps be seen as a re-emergence of phlogiston theory, which itself could be seen as a restatement of 'fire' as an element in Aristotle's four element theory. Old ideas are extremely difficult to destroy. Dalton was no doubt protecting his theory against further attack, but the consequence for chemistry was that even the formula for water could not be established. Dalton argued that its formula was HO whereas others proposed a formula of H<sub>2</sub>O.

### 3.4.2 *Humphry Davy*

Humphry Davy was another scientist who rose from humble beginnings. In fact his life story was a popular story for children (Mayhew, 1856) providing what would today be called a role model. There are a number of biographies (Hartley, 1976; Knight, 1998; Siegfried & Dott, 1980) of Davy and a plentiful supply of stories (often gossip) about him (see Golinski, 1999). He discovered nitrous oxide (dinitrogen monoxide) otherwise called laughing gas (Asimov, 1975a, p. 254), a number of new elements (sodium and potassium) using electrolysis (Metzger, 1991, pp. 98-99) and the miner's safety lamp (Hurd & Kipling, 1958b, p. 27). Davy also possessed literary abilities and is known as a poet as well as a chemist (Knight, 1998). Davy wrote a number of books and is probably best known for *Elements of agricultural chemistry*.

He also influenced the future of physics and chemistry by employing a young man called Michael Faraday as his assistant. He had also unknowingly made this recruitment possible by giving lectures of such great interest that he made chemistry comprehensible to a Mrs Marcet who then wrote a book on chemistry (Davy, 1814). The young Michael Faraday, when working as a bookbinder's apprentice, read this book and became fascinated by chemistry and sought employment related to chemistry. A further aspect of Davy's work that is of particular relevance to this thesis is his ongoing research on electricity and chemistry. His Bakerian lectures on *The relations between electrical and chemical changes* were published in three parts (Davy, 1827). The phrase chemical change recurs time and time again in each article,

it can be said that the term chemical change is firmly established at this time. Davy was convinced that chemical change and electrical energy were closely interrelated.

### 3.4.3 *Michael Faraday and chemical change in the nineteenth century*

Michael Faraday started life in an extremely poor family and through persistence and hard work made outstanding contributions to both physics and chemistry. He also made valuable contributions to the presentation of science for young people in his Christmas lectures and to the public understanding of science in general. There is a mass of biographical material about Faraday and in my 'education year' (1959) at Exeter University (see Section 1.3.6), Faraday was the scientist/educationalist that I chose to write about. There are a number of Faraday biographies (Gooding & James, 1989; Thomas, 1991; Tyndall, 1961; Williams, 1965) which provide details of different aspects of his life. The common feature of Faraday's biographers is that all speak very highly of him. Did Faraday play any part in the development of the concept of physical and chemical change? Faraday was opposed to complex theorising, had little mathematical understanding (Asimov, 1975a, p. 283) but had a talent for experimental evidence and of simplifying complex ideas. These latter virtues are amongst those required of science teachers. Faraday inaugurated the Christmas lectures for young people so that interest in science would grow and spread. The actual transcribed content of the 1827 Christmas Lectures of Michael Faraday can be found on the World Wide Web.

<http://www.woodrow.org/teachers/chemistry/institutes/faraday/lect1.html>

From these lectures, it can be seen what content Faraday thought important. The first section contains *Substances—solids, fluids, gases and chemical affinity*. The words physical and chemical change are absent, but the basic concept is undoubtedly there. In his first Christmas Lectures in 1827, Faraday presented 86 experiments or demonstrations. The first experiment illustrating the attraction of dissimilar particles was as indicated below:

#### Exp. 35: Phosphorus and iodine in air

Striking effects. Heat produced, the old substances disappear and new ones appear altogether different. It is also found that particular quantities are best. This is chemical attraction or affinity. Some of its effects are transient as the evolution of light and heat and electricity. (Faraday, 1827, www reference)

This example indicates that Faraday had the pedagogical flare to provide in his lectures a simple course in elementary science including what was later called physical and chemical change. We see the simplification of complex ideas combined with experimental interest, but his lectures were outside the school system.

Faraday's best known book (Faraday, 1861) among the extensive literature that he left (Faraday 1855; 1859) is probably *The chemical history of a candle: A course of lectures*; these were the six Royal Institution Christmas lectures delivered to children during the 1860/1861 Christmas holidays recorded from shorthand notes by Sir William Crookes. The full text of these lectures is online at URL:

<http://www.fordham.edu/halsall/mod/1860Faraday-candle.html>

In these lectures Faraday performed 22 experiments and they illustrate the chemical change of the candle on burning into carbon dioxide and water. He then looked at water in more detail and at the changes it undergoes from ice to water to steam, though he did not use the expression physical change to describe these changes. Many of the experiments that Faraday performed in these Christmas lectures are commonly used around the world today, and some are still used to illustrate physical and chemical change.

#### 3.4.4 Jöns Jacob Berzelius

The other major name in chemistry in the early nineteenth century was Berzelius (Nicholson, 1998, pp. 95-97) who became the most respected chemist of the period (Berzelius, 1934). Berzelius's father and mother died when he was young, so he was looked after by his step-father; he was an indifferent student at medical school, but excelled at physics (Asimov, 1975a, pp. 359-360) and later at chemistry. Berzelius accepted Dalton's atomic theory and also Lavoisier's modernised nomenclature. He

refined and extended chemical nomenclature and used letters rather than the odd alchemical symbols of Dalton to represent the elements. His analytical procedures were very thorough and so he was responsible for producing the most accurate list of atomic weights. To do this he used the newly discovered law of atomic heats of Dulong and Petit (Freund, 1904, pp. 261-263; Hughes, 1970, p. 490) and the law of isomorphism of Mitscherlich (Ihde, 1961, pp. 400-401). His contribution considerably enlarged the knowledge and representation of chemical change.

Understanding chemical change is perhaps incomplete even today, but I will leave the story at this point, briefly outlining some further areas of progress and those responsible for it before focussing on the development of pedagogical issues.

### **3.5 Brownian motion, vitalism, heats of reaction and periodicity**

Robert Brown (Abbott, 1983a, pp. 24-25) was a Scottish medical officer and a brilliant botanist who accompanied Flinders on his voyage around Australia and visited the coastline of what is now the Northern Territory (Mabberly, 2003). He also discovered what is now called Brownian motion (see Section 2.3.5) which is about the most direct evidence that exists with simple apparatus of continuous molecular motion. Brown had no explanation for the phenomenon, which had to wait to the twentieth century for explanations by Einstein and Perrin (Maiocchi, 1990, pp. 257-283).

The theory of vitalism was that matter from living things was quite separate from all other types of matter. Wöhler (Brooke, 1968) put an end to the theory of vitalism through his preparation of urea from inorganic material (ammonium cyanate) in 1828, though as will be seen later in the thesis many Victorian scientists accepted vitalism in one form or another long after Wöhler's experiment (Cohen & Cohen, 1996).

Considerable progress was made in the understanding of heat in the middle of the nineteenth century. Hess (Asimov, 1975a, p. 310) provided new information about the amounts of heat produced or absorbed during chemical reactions, making Hess the founder of thermochemistry. In physics, James Prescott Joule (Daintith, Mitchell, Toothill & Gjertsen, 1994a, p. 466) finally demolished the last remnants of the caloric

theory by determining the mechanical equivalent of heat using a variety of experimental procedures.

The periodic table relates the physical and chemical properties of elements to their position in the periodic table. The idea of the periodic table was put forward by Mendeléeef (Tilden, 1921, pp. 240-258), but related suggestions had been put forward by De Chancourtois (Asimov, 1962, pp. 88-90), Dobreiner (Kauffman, 1999), Newlands (Daintith, Mitchell, Toothill & Gjertsen, 1994b; Giunta, 1999) and Lothar Meyer (Howard, 1961, pp. 314-315).

### 3.5.1 *Thomas Andrews and changes of state*

Andrews was born in Belfast in 1813. He studied under Dumas in Paris (Williams, 1994, p. 13). Initially he worked as a medical practitioner, but kept up his chemical research. When his scientific reputation was established, he was appointed Professor of Chemistry at Queen's College, Belfast. His research was almost invariably centred on physico-chemical problems, especially heats of chemical combination, the allotropy of oxygen and the continuity of the liquid and gaseous states. He died in 1885. Andrew's work on gases, largely carbon dioxide under pressure gave evidence of an intermediate state of matter between liquid and gas.

Carbonic acid at 35.5, and under 1.08 atmospheres of pressure, stands nearly midway between the gas and the liquid; and we have no valid grounds for assigning it to the one form of matter any more than to the other.

(Andrews, Tait & Crum Brown, 1889, pp. 342-343)

However, at elementary levels students are still taught about three phases of matter. There is more still to be learnt about the 'so-called' three phases of matter and the discoveries of the 1880s about intermediate phases of matter are still not mentioned when considering physical change. More recently, for example, Hungarian physicists working on a computer simulation envisage a situation where after heating a solid to melt it, further heating will cause it to resolidify (Buchanan, 2000, pp. 28-31) which is very confusing.

### 3.6 Johann Joseph Loschmidt and the Loschmidt number

Loschmidt (Fleischhacker & Schonfeld, 1998; Palmer, 1995b) is of particular interest as he was the first person to calculate the number of particles in a given volume of any gas. Loschmidt found the number of particles in one millilitre of an ideal gas at STP to be  $2.687 \times 10^{19}$  particles. This is directly related to what is now called the Avogadro number. Loschmidt's value for this would have been  $4.4 \times 10^{23}$  particles/mole (Wisniak, 2000b), whereas today's value is about  $6.02 \times 10^{23}$  particles/mole. The attempt to quantify the number of molecules was another factor in clarifying a kinetic theory of matter.

Johann Joseph Loschmidt was born in Putschirn near Carlsbad, Austria (then Bohemia), on 15 March 1821 (Bohm, 1973, p. 507). His parents were poor peasants. He was the eldest of four children and had to help his parents in the fields. His exceptional mental abilities at primary school were recognised by the local pastor/teacher, who assisted his career as far as he could, ensuring that he went to high school (the Humanistic Gymnasium in Prague).

When he left school, he went to the German University in Prague reading philosophy and natural science. He was helped by Franz Exner, the professor of philosophy, who later obtained a post at the University of Vienna (Bohm, 1973, p. 507). Whilst working with Exner in philosophy, Exner commissioned Loschmidt to work on Herbart's attempts at a mathematical treatment of psychology, but little came of this at the time. It is of interest that Herbart's influence in the planning of lessons is with us today in that lessons are structured into an introduction, a middle portion and an ending and this was a part of Herbart's methodology. Perhaps this start is why Loschmidt was later considered a successful teacher. Loschmidt took up an interest in chemistry and in 1842 also moved to Vienna, where he worked in Schotter's laboratory at the Polytechnic. This gave him some insights into industrial chemistry.

Loschmidt started three different chemical manufacturing industries at different times, none of which were financially successful (Wiswesser, 1989, p. 17). He arrived back in Vienna sick and penniless and worked as a private tutor. In 1856 he passed



his examinations to become a teacher with very good grades and obtained a regular teaching appointment at the Vienna Realschule. Kohn (1945, pp. 381-384) knew an old man who had been a pupil in Loschmidt's class who said Loschmidt was a remarkable teacher:

...who had made a lasting impression on classes, both through his personality and his interesting, effective, pedagogic methods.

(Kohn, 1945, pp. 381-384)

When he was not teaching, he spent the remainder of his time on scientific research. In 1868 he was appointed professor of physical chemistry at the University of Vienna. It was only quite late in his career that he achieved any social prestige but he did make a number of friends amongst whom was the physicist Stefan. Through Stefan he became known to Boltzman, who gave his funeral oration. He rose very rapidly through the university to the position of university senator. Quite late in life he married his housekeeper (1887) and died in Vienna on July 8, 1895, after a long and painful illness.

### 3.6.1 *The Karlsruhe Congress, 1860*

Theories of chemical action/chemical composition in organic and inorganic chemistry were put forward by Williamson (Tilden, 1921, pp. 228-240), Frankland (Russell, 1985; 1996), Laurent and Gerhard (Brooke, 1975, pp. 405-430), Kekulé (Anschütz, 1961, pp. 697-702), Couper (Duff, 1987) and Dumas (Thorpe, 1902, pp. 318-363). In 1860, an international chemistry conference was arranged at Karlsruhe in Germany from 3-5 September (de Milt, 1948, p. 153), and it was attended by most leading chemists of the time.

The Karlsruhe Congress was important as it eventually resolved the difference of opinion between chemists over the chemical formulae of simple substances. The first session of the Congress debated the notions of molecule and atom with Cannizzaro and Kekulé as main speakers. Numerous historians of science (Brooke, 1981; Rocke, 1993; Wisniak, 2000b) have examined the facts relating to failure of chemists to adopt the Avogadro hypothesis in 1811 and to accept that the common gases existed as molecules with an atomicity of two. The conclusions are not simple

and even the facts are disputed. It should be remembered that when this problem is considered today, the right answer is known and the tendency is to brush away the evidence that is now known to be erroneous or anomalous. It was not so easy for the chemists at the time! However Cannizzaro convinced a majority of chemists of the truth. Lothar Meyer is recorded as saying that after reading Cannizzaro's paper 'scales fell from my eyes, doubts disappeared and a feeling of quiet certainty replaced them' (quoted Rocke, 1993, p. 93).

### 3.6.2 *Bunsen and spectrometry*

Bunsen (Palmer, 1999) was a prolific chemical innovator. Comparatively late in his career he collaborated with Kirchoff, a physicist, to invent the spectroscope. The spectroscope was then used to show that each element had its own unique spectrum; the device was soon used to discover two new elements which were caesium and rubidium. This is illustrative of this borderline between physics and chemistry, where co-operation between the sciences leads to progress for science as a whole.

Robert Wilhelm Bunsen was born in Gottingen on 31 March 1811. (Partington, IV 1998, p. 281). His father was a Professor of Modern Languages and librarian at the University of Gottingen (Williams, 1994, p. 83). He attended the gymnasium at Holzminden (Moore, 1918, p. 193) and entered the University of Gottingen in 1828, obtaining his doctorate two years later. He presented his thesis in Latin on the topic of hygrometers. (Moore, 1918, p. 193). He then travelled for two years visiting scientists in Paris, Berlin and Vienna (Millar, et al., 1990, p. 72) and travelled for large parts of the journey on foot (Lockermann, 1959, p. 175). He did not marry and died in Heidelberg on 16 August 8, 1899 (Partington IV, 1998, p. 281; Oesper, 1927, p. 431). Bunsen's life outside science appears scarcely to exist. He was simple and straightforward, hating duplicity, but with a keen sense of humour (Read, 1947, p. 250). One of his friends, Henry Roscoe, said of him:

As an investigator he was great, as a teacher he was greater, as a man and a friend he was greatest. (Partington IV, 1998, p. 282).

He was a successful teacher and a good experimentalist, though sometimes his demonstrations went wrong as when he put a bird's beak in hydrocyanic acid gas to demonstrate its poisonous properties and the bird flew away instead of dying (Partington IV, 1998, p. 283). After his own experience of losing an eye in an explosion with experiments on cacodyl (an organic compound of arsenic) and then nearly dying from the cacodyl radical's poisonous effects (Dronsfield, Brown, Morris & Parker, 1999, pp. 127-129), he refused to allow work on organic chemistry in his laboratories (Irwin, 1959, p. 80). Bunsen's name is known to generations of children due to his so-called invention—the Bunsen burner. Yet he did not invent this, but rather encouraged his technician, Peter Desaga to improve an existing design (Lockemann, 1956, pp. 20-22). He gradually obtained positions at more influential German universities and in each improved the laboratory facilities (Lockemann & Oesper, 1955, pp. 456-463; Scurlock, 1978, p. 581). Over the course of his lifetime Bunsen made an extraordinary number of scientific inventions and discoveries that included the Bunsen battery, an explanation of the workings of geysers, silicate analysis, the filter pump the Bunsen valve and the Bunsen ice-calorimeter. Bunsen also wrote a paper entitled chemical affinity (Bunsen, 1854, pp. 82-89) and it is interesting to note that as late as 1854 the nature of chemical affinity is still a matter of active research. Following from this in partnership with Roscoe he carried out photo-chemical investigations on hydrogen/chlorine mixtures from 1855 to 1862 which Oswald called 'Bunsen's experimental masterpiece' (Lockemann, 1959, p. 177). Thus his research included aspects of both physical and chemical change.

### **3.7 Chemical equilibrium, the law of mass action, and the chemistry of solutions**

Chemical equilibrium and rates of reaction became clearer with the law of mass action, which was independently discovered by a number of researchers (Williams, 1994, p. 216) in the middle of the nineteenth century but which is generally credited to Cato Maximillian Guldberg (Daintith et al., 1994a, p. 373) and Peter Waage (Williams, 1994, p. 506). Carrying on in this tradition, Vernon Harcourt (1867, pp. 460-493) looked at chemical changes and he relates his work to the earlier work of Berthollet and Bunsen and Roscoe. He considers that knowledge of chemical change will come only through considering reactions that are fairly slow. However it was

through studies such as these that knowledge of the nature of chemical change was slowly built up.

There was also the important work of the physical chemists Jacobus Henricus Van't Hoff (Fleck, 1995, pp. 1-7, Williams, 1994, p. 496), Svante Arrhenius (Arrhenius, 1913; 1966, pp. 45-58; Laidler, 1995, p. 210; Salzberg, 1991, pp. 255-256) and Wilhelm Ostwald (Salzberg, 1991, pp. 256-257) on the understanding of dilute solutions at the end of the nineteenth century. This produced the start of the sub-discipline of physical chemistry.

### 3.7.1 *Complexities of chemical change in the nineteenth century*

In the late nineteenth century and the early twentieth century the atom ceased to be an academic possibility (the chemist's atom) and became a physical reality. Brock (1992, pp. 166-171) explains the difference between the chemist's understanding of the physical atom and their understanding of the chemical atom. Most nineteenth century chemists were uncertain as to whether atoms existed or not. Because they believed that the existence of atoms could never be proven one way or the other, they might agree that the argument was interesting but they felt that it was not important in any practical sense. They could use assigned relative weights of atoms, whether they existed or not and found these tables of atomic weights invaluable for many practical purposes.

However particularly after the Karlsruhe Congress, chemists gradually came round to agreeing that atoms actually existed; there were some notable exceptions such as Ernst Mach and H. E. Armstrong. Physicists were already convinced of the existence of the atom as 'a hard massy particle' and at the end of the nineteenth century, it was found that it consisted of smaller particles. There was soon hard evidence of protons and electrons (Thomson, 1923; Pullman, 1998, pp. 257-261) and later of neutrons (Ihde, 1964, pp. 508-513). The views of Davy and Faraday were vindicated as they had believed that there was a relationship between chemical change and electrical phenomena.

### 3.7.2 *Atomic particles and chemical bonding*

The work on atomic particles led to the explanation of physical and chemical properties of elements in terms of their atomic structure, with the various types of bonding. A long way back in 1858 Couper had introduced the idea of chemical bonds (Hellemens & Bunch, 1988, p. 328). In 1916, G. N. Lewis (Calvin, 1979, pp. 61-68; Lewis, 1984, pp. 3-5; Servos, 1984, pp. 5-10) explained the concept of chemical bonding by his shared electron rule (Hellemens & Bunch, 1988, p. 328 and 330; Brock, 1992, pp. 465-483). Advance at this time was very rapid and it is difficult to associate the discovery of particular types of bonding with particular individuals and it is noticeable that most textbooks tend to avoid the issue by simply describing the type of bonding. Ihde (1964, pp. 536-541) identifies the main explanations of covalent chemical bonding with G. N. Lewis, Walther Kossel and Irving Langmuir. Nevil Sidgwick developed the idea of coordinate covalency during 1923 (Ihde, 1964, p. 540; Russell, 2002).

### 3.7.3 *Hydrogen bonding and crystallography*

Huggins, working as an ambitious undergraduate student under G. N. Lewis (Kohler, 1975, p. 437), conceived the idea of hydrogen bonding (Brock, 1992, pp. 482-483; Huggins, 1980). The concept of hydrogen bonding was later pursued by Linus Pauling (Davenport, 1996, pp. 21-28) and greatly extended as a vital type of bonding (Mason, 2000; Paradowski, 1995, pp. 368-379). William and Lawrence Bragg (Thomas & McCabe, 1990, pp. 156-159) with their work on X-ray diffraction on crystals gave an indication on crystal structure of common inorganic salts which helped towards a theory of electrovalency. It should be noted that William Bragg (1862-1942) did some of his early work at the University of Adelaide in Australia and Lawrence Bragg (1890-1971) was a student at the University of Adelaide (Williams, 1994, pp. 71-72). Research on X-ray crystallography was continued by Dorothy Crowfoot Hodgkin who eventually used the method to elucidate the structure of very complex substances such as insulin; as a young girl she remembered obtaining inspiration from the beauty of common crystals such as copper sulphate (Hunter, 1995, pp. 456-461).

How is this comparatively recent chemical history relevant to the concept of physical and chemical change? It is in answering this question that one of the elements of the paradox can be exposed. Chemical theory, as has been stated earlier, had a concept of physical and chemical change, though perhaps a shaky and unstated one, perhaps pre-dating Lavoisier. Certainly by the 1830s there are textbooks that use the phrase or paraphrase the expression. In the 1860s, the British textbook writer and academic William Odling uses the words, physical and chemical change, regularly in his textbooks. In 1870 the American textbook writer Cooley (see Section 4.4.4 and 7.4.2) uses the phrase, physical and chemical change, as the title of the first chapter of a beginner's book. The concept of physical and chemical change seems to be used as a means of simplifying the complex explanations of the various types of affinities and aggregation to the following simple option. Is a particular change a physical change or is it a chemical change? It is a straightforward teaching device and quite a successful one, which was taken up by most textbook writers and used mainly in schools and school textbooks to describe large-scale macroscopic changes. The expression tended not to be used amongst practising chemists involved in research. The story previously has told of the major advances in understanding of the various types of bonding and of the behaviour of chemicals in solution, but these almost always involve explanations of events in the micro-scale world, far too small to see. It took some time, perhaps 40 years for simplified explanations of the different types of bonding (covalent, electrovalent, co-ordination/dative bonding, hydrogen bonding and metallic bonding) to become a part of school curricula. However, when they became part of school curricula, the explanations of events such as going into solution or boiling or freezing provided further difficulties in using the concept of physical and chemical change, as will be illustrated in the next section.

### **3.8 The paradox of physical and chemical change**

By the 1960s the idea of two types of change, physical and chemical, had become very firmly established as moderately good explanations of macroscopic phenomena (even though, there were definitional problems, see Johnstone, 1982, pp. 337-339); they also fitted in well with the 'massy' atom concept used in kinetic theory. Effectively the new ideas of bonding on the micro-scale were included in syllabi on top of the earlier macro-scale concepts of physical and chemical change.

The problem is that defining events as physical or chemical change on the macro-scale definitions gives different results when compared with the results of micro-scale definitions. This is a paradox!

I will provide just one concrete example: heating cold water until it boils turning into steam. Boiling water (changing water into steam) is normally understood in the macro-scale world to be a physical change (because no new substance has been created). Water at room temperature has large numbers of hydrogen bonds between adjacent water molecules. On changing water to steam most of these bonds are broken. Breaking a chemical bond is, by definition, a chemical change. So, boiling water is a chemical change under this definition. Thus boiling water is simultaneously defined as both a physical change. This is a typical paradox arising from inadequate or conflicting definitions.

## CHAPTER 4

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### TEXTBOOK WRITERS, EDUCATIONALISTS AND TEACHERS AND THE DEVELOPMENT OF A CONCEPT OF PHYSICAL AND CHEMICAL CHANGE

*Research Question 4: What part do textbook writers, educationalists and teachers play in the historical development of a concept of physical and chemical change?*

#### 4.0 Education and teaching the sciences—general

In describing educational practice in Britain, Curtis (1967, p. 2) starts at 597 AD, the year when St Augustine landed in England. There is insufficient space to follow education's detailed history, but I will make a few generalisations to introduce the teaching of science in schools. Firstly education, even basic reading and writing, was confined to a small elite of society, usually the monks and the nobility. As time went by, particularly after the advent of the printing press, the proportion of the literate increased to include the merchant classes and formal schools were established. The grammar school at which I first taught, Sir Roger Manwood's School (see Section 1.3.7), was founded in the sixteenth century.

Also the amount of knowledge in almost every field increased, partly due to new discoveries, partly due the ability to record new knowledge in books and partly due to the vastly increased spread in the ownership of books, which allowed more students to gain knowledge through these printed materials. Some illustrations make these points clearly.

A French book from 1765 (Anon, 1765) illustrates what children aged between six and ten years of age needed to know about science. It is only a short book (an abridged science text of 78 pages). It consists of a few pages about time, the names of the months and the seasons and a few pages about geography and cosmology, but the majority of the book is about the names of the royal families of Europe, their armorial bearings and some mythology. The style is formal questions and answers as in a catechism and in small print without pictures. It is a long way from the current view as to what science might interest primary age children.



Another book of a similar period provides all the information that a young man would need as a guide for life. Baron Bielfeld (1770), a German university administrator, who was an extremely knowledgeable and cultured man, wrote such a guide in three volumes. Each of the sciences including chemistry gains a place in the work but it is only a very small proportion of the whole. In other words, science does not really play an important role in what it was considered that a young gentleman should know at that time. A similar but less ambitious book than Bielfeld's, called *The preceptor*, indicates what teachers ought to teach in that period. It is noticeable that the place of science in the whole course is limited with astronomy and natural history getting the lion's share of the space available for science. In the section on logic there are a few words about chemistry (Anon, 1754).

In the several experiments made by Chymists, Bodies undergo many Changes and put on successively a great Variety of different Shapes.

(Anon, 1754, Volume 2, Book 1 Chapter 2, p. 19)

This appears to be an isolated example rather than a systematic introduction to chemistry. Knox (1784), writing on liberal education, makes no mention of chemistry or indeed of any of the sciences, so it is safe to assume that very little teaching and learning of science was taking place in the latter part of the eighteenth century.

However, the amount of science known and its importance in society does increase rapidly from that time. During the nineteenth century, the number of primary schools increased rapidly and in Britain in 1870 Foster introduced legislation that gave children free primary education (Curtis, 1967, p. 282). But it took a further 25 years before primary education became compulsory. In general, science education in primary schools has been slow to develop. For example, in the USA, Smith (1842) makes no mention of science (natural philosophy) being amongst the topics needed for initial instruction though natural philosophy receives brief mention as necessary for the completion of college studies (Smith, 1842, p. 264). White (1886, p. 116) has a few paragraphs on the teaching of science in primary schools in which object lessons are strongly recommended. White (1886, pp. 161-162) also recommends object lessons for secondary schools.

There also were increases in the numbers of secondary schools. There was a bias against teaching science in schools, particularly at the private schools (called Public Schools within Britain), where it was felt that a classical education was best. Nonetheless, the teaching of science which started at a near zero base at the beginning of nineteenth century had increased massively by the end of that century. During the twentieth century more students in more countries stayed at school longer and so throughout the twentieth century the amount of science taught has increased enormously, though in recent times there has been evidence that fewer school students in developed countries wish to specialise in science. For example, Byrne (2000, p.4) refers to the case of Eire.

There have been great changes in the content of science curricula, and there have also been huge changes in the methodology of teaching. With regard to textbooks, the earliest textbooks for children seem to have been catechisms of a question and answer format. The next popular style provided information through conversations usually recorded imaginary discourses between adults and children with adults answering children's questions. This is a little more interesting than the catechisms as it allows some room for character development. Finally, from about the middle of the nineteenth century, some attention was paid to teaching methodology and 'object lessons' were introduced to improve the quality of teaching (Salmon & Woodhull, 1894, p. 7). Salmon and Woodhull (1894) explain the aims behind object lessons, typical subjects and content for them and give numerous examples. In an object lesson, the teacher shows the children an object, such as a piece of chalk, and asks questions about it (Ross, 1872). Textbooks give examples of questions that the teacher might ask, so the textbook starts to direct the teacher into what was believed to be the best way to teach. Object lessons were extremely widely used so much so that according to Welton (1921, pp. 358-9), in 1899, ninety-five per cent of schools that took class subjects presented object lessons. Their use declined rapidly after this.

During the nineteenth century, the design of textbooks improved considerably with thought given to the order of teaching, numbered paragraphs, lessons or lectures, bold type for important ideas, glossaries, summaries at the end of chapters, diagrams which were simple early in the century, but became more complex, photographs and portraits, larger print and more widely spaced formats and the use

of colour. Much of the improvement accompanied the developments in printing technology. In addition, other economic issues, such as the lower cost of paper and the use of cloth bindings, rather than leather bindings allowed the economics of scale combined with an increase in demand to lower the cost of books.

The next section moves on to looking at specific instances of the generalisations above where they can be related to innovations in the teaching of chemistry particularly where they concern teaching physical and chemical change.

#### 4.1 Teaching the sciences—a woman chemistry textbook writer: Jane Marcet

In the teaching of the sciences, women textbook writers have played a vital role. Jane Marcet is one of the earliest of these writers and she gained her knowledge of chemistry from attendance at Humphry Davy's public lectures; her books still make good reading. Lindee (1991) points out that Marcet's chemistry book was theoretical rather than practical and that she followed Lavoisier's practice of considering electricity, light, and caloric to be 'imponderable agents'. She was conservative in clinging to the caloric theory, even after Davy had abandoned it. She explained chemical reactions in terms of aggregation, affinity, gravitation and repulsion after Newton's theories and she did not accept John Dalton's atomic theory. Michael Faraday read Jane Marcet's book *Conversations on chemistry* and it was this that attracted him to chemistry (Gooding & James, 1989, p. 11). Marcet's book was widely read and widely copied; Lindee (1991, p. 13) notes 23 American editions between 1806 and 1850. The overall number of copies of the various American editions of *Conversations on chemistry* is estimated at 160,000, showing that it was very popular. The book was usually listed under the name of the male editor and several of the editors strongly criticised the book they were editing. Amongst the editors of her work were Davy (1814), Keating, Comstock (Anon, 1820), Blake (Comstock, 1833) and Jones (1845). In France there were at least two editions of the work one of which was *Entretiens sur la chimie d'après les méthodes de MM. Thenard et Davy* (Anon, 1826). There is considerable human interest in this text as Caroline, one of the students, comments after Mrs B, who was tutor to the girls, describes the preparation and properties of hydrogen.

It must be a most extraordinary gas that will produce both fire and water.  
(Anon 1820, p. 136)

Caroline's comment shows considerable perspicacity as, apart from being a correct observation, it is also presumably a comment on Aristotle's four element theory, which would find difficulty in explaining the observation. Lindee (1991, p. 10) characterises Caroline as being 'an impetuous and sceptical student', whereas Emily is 'serious and bright'. Caroline's comment shows that chemistry had moved on even at a beginner's level since the middle ages. Knight (1986, pp. 94-98) makes an interesting comparison between Parkes (1812) who wrote his book as a catechism and Marcet who wrote her book as a conversation. Knight (1986, p.95) considers both books to be 'deeply loaded with theory'. This complex theorising can be seen as the start of a search by textbook writers to meld together accuracy, simplification and relevance in their books over the course of the nineteenth century.

## 4.2 Teaching the sciences—early American chemistry textbook writers

In the USA, Almira Phelps (Weeks & Dains, 1937) was another woman textbook writer. She had a long career as a teacher, principal and writer and wrote across a wide range of topics. In general, her chemistry textbooks were less popular than those of Marcet (Lindee, 1991, p. 21). This fact is surprising as she had considerable experience in teaching and made excellent practical suggestions. Elliott (1979) summed up her considerable contribution as follows:

As an educator, she helped to make more wide-spread the study of science by girls, while texts promoted acceptance of science as part of the American school curriculum. (p.204)

Other American chemistry textbook writers of the period were Benjamin Silliman Sr, John Webster, Amos Eaton, John Lee Comstock and Leonard D. Gale.

### 4.2.1 *Benjamin Silliman, Sr*

Benjamin Silliman was born in 1779 during the American War of Independence. At the time of his birth his father was in a British prison. Benjamin was a model

student, so hardworking and industrious that his class-mates called him 'Sober Ben' (Miles, 1961, p. 405). He taught for a while, started to study law, and was offered a position in Georgia. He had been spotted by Dwight, the President of Yale, who made him an offer when he was just 21, of being professor of chemistry at Yale at a time when Benjamin had not attended any course in chemistry at all (Miles, 1961, p. 406). Schiff, (1980, pp. 151-152) reports excerpts from Silliman's own notes explaining why he wished to take up science rather than law; he said this was because in the study of nature 'there is no falsehood', though this comment might appear somewhat naive in our times. Later Silliman was referred to 'as the most eminent of American teachers of natural science.' (George Fisher quoted in Miles, 1976, p. 438). He was allowed time to study for his new career and spent time in Philadelphia where he became friends with Robert Hare. Some time later Yale sent him to Britain to purchase \$10,000 worth of equipment and books as little of either were to be had in the United States. In Britain he met many of the famous chemists and for a time in London he studied in Frederick Accum's laboratory (Miles, 1961, pp. 409). His first text was an edited edition of Henry's *Epitome of chemistry* but his own work published later was not as successful (Miles, 1976, p. 438).

#### 4.2.2 John W Webster

Dr John W Webster was born in 1893 and became editor of the *Boston Journal of Philosophy and the Arts* (Webster, Ware & Treadwell, 1823). He was a good teacher, (Miles, 1976, p. 500) and well-liked by his students, publishing a textbook *Webster's manual* in 1826 Webster (1839). However, the reverse is asserted by Rosen (1982, p. 525), who states "Not only was Webster a bad teacher . . .". Similarly, Elliott (1979, p.269) says that "he was not greatly distinguished as a researcher or as a teacher of chemistry. . .".

Even though Webster was industrious and published a number of works, he lived beyond his means, borrowed money, and was hanged in 1850 for the murder and subsequent dismemberment of Francis Parkman, who had been one of his creditors (Miles, 1976, pp. 499-500). Rosen (1982, p. 525) claims Parkman to have been one of Webster's colleagues but Parkman was a wealthy landlord according to Miles (1976, pp. 499-500). Rosen (1982, p. 525) also says that Webster carried out an experiment so dangerous (using a large heap of sugar, potassium chlorate, ignited with

concentrated sulfuric acid) that it forced his students to jump out of the window. This would have been a remarkably powerful chemical change. The example of Webster shows that some historical literature sources are unreliable, and it is wise to be careful in putting too much credence in any one source.

#### 4.2.3 *Amos Eaton*

Amos Eaton was born in 1776, received a college education, taught for a while, and was then convicted for an alleged fraud. He took up a new career, and studied chemistry under Benjamin Silliman. He lectured for a year at Williams College and then became an itinerant lecturer, bringing science to the people by demonstrating simple experiments in physics and chemistry. He gave 40 courses in chemistry averaging 300 experiments each. He also helped and encouraged Almira Phelps (Section 4.2) with her teaching and writing. To give an idea of his energy, he lectured almost daily for 24 years until the year before his death; his intent was always to bring the 'sublime science of chemistry' within the reach of ordinary people (Miles, 1976, pp. 135-136).

#### 4.2.4 *John Lee Comstock*

John Lee Comstock was born in 1789 and received little formal education beyond elementary school. Initially he followed a medical apprenticeship, but although it is unclear how he obtained his expertise in chemistry, quite early in his career he considered himself a chemist and in 1819 he gave a course of public lectures in chemistry. He wrote four chemistry textbooks altogether and a total of 26 textbooks across the range of sciences (for example, chemistry (Comstock, 1825; 1845; 1854), natural philosophy (Comstock, 1847) and botany (Comstock, 1836), during his lifetime. His major contribution was to explain science to beginners in a way that they could understand. For example, Edward Livingston Youmans gave Comstock's books credit for his initial interest in chemistry.

#### 4.2.5 *Leonard D. Gale*

Leonard D. Gale (1800-1883) (Miles & Gould, 1994, pp. 107-108) wrote *Elements of chemistry* (Gale, 1837) which is one of the first to include the concept of physical and

chemical change. He had an interesting life, taking up teaching and public lecturing. He also wrote a natural philosophy textbook (Gale, 1843), sold sets of science apparatus, was a friend and scientific assistant to Samuel Morse (inventor of Morse Code), and later became a manufacturing chemist. He suffered shipwreck while taking up a position at the Patents Office, losing his library and scientific apparatus and barely escaping with his life.

### 4.3 Teaching the sciences—early British chemistry textbook writers

In Britain, Mary Somerville wrote *Connexion of the physical sciences* (Somerville, 1835), which is a useful text, though its content relates to physics more than chemistry. She was born as Mary Fairfax on December 26, 1780 in Jedburgh, Scotland being one of four children in her family who survived childhood. After a brief school education, she largely taught herself and she became one of the leading minds in mathematics and physical science. She wrote across a range of sciences and there are a number of biographies (Patterson, 1983) and biographical articles (Muir, 1994, p.478) about her.

Other British chemistry textbook writers of the period chosen as examples were Thomas Thompson (Klickstein, 1948, pp. 37-54; Ihde, 1964, p. 261), Jeremiah Joyce and Richard Phillips (Issitt 1996; Issitt, 1998a; 1998b), Frederick Accum (Brock, 1992, pp. 187-188), William Brande (Partington IV 1998, pp. 75-76), Thomas Graham (Odling, 1961, pp. 551-572; Stanley, 1991, p. 239), George Fownes (Partington IV, 1998, pp. 270- 271), August Wilhelm von Hoffmann (Asimov, 1975a, pp. 346-347) and Edward Frankland (Tilden, 1921, pp. 216- 227). The main difference between the exemplars chosen in Britain and those chosen in the USA is that all the British writers chosen were scientists first, generally well known for their scientific discoveries, whilst disseminating that knowledge through writing textbooks would be secondary. The books tend to be long, linguistically complex, original and accurate, but a little dull. On the other hand, as Williams (1996) points out:

The early American spirit of inevitable progress was as wide as the United States itself. The faith that society could lift itself by its bootstraps prompted an emphasis on applied science. (p. 1)

Williams (1996, p.1) also explains the great degree of enthusiasm for science in the United States in the early nineteenth century at public lectures, high schools and in homes at adult and adolescent levels, but also for home family reading and he describes three typical books for juvenile chemistry. Of course, many of the available chemistry books had been copied from British or European authors, but generally the American writers used these for reference and then wrote their own, which were often better products for younger readers.

#### 4.3.1 *Thomas Thomson*

Thomas Thomson studied chemistry under Joseph Black at Edinburgh and became Professor of chemistry at Glasgow University (Cole, 1988, pp. 530-531). He wrote a major textbook *First principles of chemistry*, though some of the experimental work it contained has been criticised on grounds of experimental accuracy (Cole, 1988, pp. 530-531). He wrote the first history of chemistry in the English language and in 1817 was offering courses in chemistry including laboratory instruction (Ihde, 1964, p. 261).

#### 4.3.2 *Jeremiah Joyce and Richard Phillips*

Jeremiah Joyce was a science writer who was employed by Richard Phillips, a publisher and probably rather an exploitative one. Joyce is remembered for his series of *Dialogues* (Joyce 1818; 1829) in the many science areas, explaining science simply to an unsophisticated audience. Issitt (1996) states that Joyce's scientific dialogues had a publishing history spanning nearly 100 years (1800-1892) and were thus a major force in popular science education. Issitt also points to Joyce as being the real author of two rival encyclopaedic dictionaries which were *The dictionary of arts and sciences* (1807) and *The British encyclopaedia or Dictionary of arts and sciences* (1809) indicating the amazing amount of work that Joyce produced.

The same sources also show that the works were actually compiled, edited and significantly written over the amazingly short period of 30 months by the same man - the dissenting scholar the Reverend Jeremiah Joyce (1763 - 1816). (Issitt, 1998b)



On the other hand his employer is scarcely remembered though Issitt (1998a) explains that Phillips had developed what he called an 'interrogative system of education'; it is far from certain if this scheme was genuinely educational or whether it was merely a money-making device.

#### 4.3.3 *Frederick Accum*

Frederick Accum, 1769-1838, was born in Buckeburg, Germany. He studied chemistry, arriving in London in 1793 where he wrote across a wide range of areas. He was largely an analytical chemist, but some of his earliest works are related to geology on the analysis of minerals. He wrote *A system of theoretical and practical chemistry* (Accum, 1803; Knight, 1989, p. 204) and later pioneered the introduction of gas lighting (Idhe, 1964, p. 452). His analyses also included various foods and he did much to arouse public opinion against unclean food and dishonest trading (Idhe, 1964, pp. 439-440; Coley, 2003, p. 17), particularly with regard to the adulteration of china tea. He also sold chemical kits (Brock, 1992 pp. 187-188) and gave popular lectures on chemistry. Frederick Accum's contributions that particularly relate to chemistry teaching are that he opened a private laboratory for students in London in 1800 (Idhe, 1964, p.262) and wrote a treatise, with wonderful illustrations, on the chemical apparatus of his time, intended for the audience at his lectures to study at home.

He also wrote popular books on chemistry as a recreation. Idhe (1964, p. 262) compares the careers of Frederick Accum and Amos Eaton and there are a number of similarities. Accum also tried to found a London Chemical Society wanting men with all levels of chemical competence to join but evidently this project was unsuccessful (Bud & Roberts, 1984, p. 24). Bud and Roberts (1984, pp. 24-25) also report that a similar venture attempted a few years later had many difficulties due to British class divisions. For example, Davy refused to offer help because he 'scorned' to shake hands with 'chimney sweepers'. This social problem was less noticeable in the United States and must have held back progress in chemistry in Britain.

#### 4.3.4 William Brande

William Brande was born in London in 1788, becoming a Fellow of the Royal Society in 1809. He succeeded Humphrey Davy as Professor of Chemistry at the Royal Institution whilst Michael Faraday became second professor under him (Partington IV, 1998, pp. 75-76). He was evidently very supportive (Partington IV, 1998, p. 100) of Faraday as he established his reputation. Brande wrote a number of textbooks, discovered naphthalene in coal tar, though did not name it and also had a second position as Master of the Mint. It is easy to believe that the few items that are recorded for historical figures, such as Brande, are the sum total of the work that they did. Nothing could be further from the truth! From a study of the contents of the journal *The chemist* (Anon, 1824), it can be seen that Brande gave a weekly lecture at the Royal Institution, which was printed in *The chemist*; this alone would have required considerable effort. Brock (1992 p.185) categorises textbooks of the nineteenth century as advanced, introductory or general. William Brande's textbook (Brande, 1830), *A manual of chemistry*, would certainly fall into the advanced category as would the main works of Thomas Thomson, Thomas Graham or George Fownes.

#### 4.3.5 Thomas Graham and George Fownes

Thomas Graham studied chemistry at the University of Glasgow under Thomas Thompson (Stanley, 1991, p. 239). Graham's father wanted his son to study religion rather than chemistry and visited Thomas's lodgings one day to find them full of chemistry books and apparatus. He smashed the apparatus and cut Thomas off from any inheritance and forbade him from visiting the family home (Stanley, 1991, p. 239). Thomas Graham wrote an original and interesting textbook *Elements of chemistry* (Partington IV, 1998, pp. 265-281) which Ramsay (1909, p. 59) considers was the 'best textbook of chemistry ever written'. He was evidently a popular though nervous lecturer. In 1837, he succeeded Turner at the newly formed (1828) University College, London (UCL) (Lebeck, 1996, pp. 10-13). Graham had a wide range of research interests in chemistry and is best known for his work on diffusion (Graham's law of diffusion). Lebeck (1996, p. 11) says that Graham's duties at UCL were mainly teaching chemistry to large numbers of often unruly students, who also were taught practical chemistry by George Fownes in an adjacent laboratory.

George Fownes was the author of a very popular textbook called *A manual of chemistry* (Fownes, 1852) and also a more elementary text (Fownes, 1849) but he suffered from ill-health and was unable to carry out his duties fully. He died, aged 34 years in 1849. Graham continued at UCL, which was suffering from financial difficulties, until 1855, when he, like Isaac Newton before him, was appointed Master of the Mint (Stanley, 1991, p. 242). The well-paid position at the Royal Mint allowed Graham to concentrate on his first love which was chemical research (Lebeck, 1996, p. 13).

#### 4.3.6 *August Wilhelm von Hofmann*

August Wilhelm von Hofmann was born in Giessen, Hesse, Germany in 1818 and studied law at university, but was persuaded by Liebig's brilliant teaching to study chemistry (Asimov, 1975a, pp. 346-347). Hofmann was invited by Prince Albert to lecture at the Royal College of Chemistry as its first Professor and Director and to advise the Royal Mint on chemical matters. He was an excellent lecturer and designed many interesting demonstrations. In 1848, the College had financial difficulties and was forced to move to less expensive premises. Hofmann continued as Director until 1864, when he returned to Germany as Professor of Chemistry at the University of Berlin. In Britain he established a considerable research reputation with his main interests being in coal tar derivatives, aniline (Travis, 1992, pp. 27-44) and the chemistry of amines. Lebeck (1996, p. 12) states that Hofmann and his students 'were largely responsible for the rise of chemical education in England'. As an educator, Hofmann made considerable use of models (Travis & Benfey, 1992, p. 108) and is known for his croquet ball models, linked by tubes to illustrate the combining power of atoms. His best known student was William Henry Perkin, the discoverer and eventually the manufacturer of aniline purple (Asimov, 1975a, pp. 421-422; Garfield, 2000). Hofmann wrote a textbook *Introduction to modern chemistry: experimental and theoretic* (Hofmann, 1865) and played a major part in providing a high profile for chemistry. William Odling was also one of Hofmann's students (Gay, 1997, note 53)

#### 4.3.7 Edward Frankland

Edward Frankland was born in 1825 in Garstang, Lancashire (Tilden, 1921, pp. 216-227). It is interesting to note that Tilden's brief biographical article makes no mention of the fact that Frankland was the illegitimate son of a local lawyer's son and the family parlourmaid (James, 1997, p. 25). Frankland's main biographer, Russell (1985; 1986; 1996), gives considerable detail of the young Frankland growing up and the effect that his background appears to have had on his own family life. Although illegitimate, his mother received an annuity from the Gorst family, so Frankland received a reasonable education and was so precocious that he knew his letters at the age of two (James, 1997, p. 25). Although he wanted to be a doctor, he could not afford the training and so wasted seven years seeking knowledge of science by the 'backdoor', apprenticed to a local pharmacist. He then went to London and obtained a position in Dr Lyon Playfair's analytical laboratory (Tilden, 1921, p. 219). He progressed so rapidly that Playfair offered him a post as a lecturer assistant. He had met the German chemist Kolbe, and went to Germany with him to work under Bunsen. After obtaining his doctorate, he worked with Liebig at Giessen. He married and obtained a post at the newly founded Owens College in Manchester in 1851. Then he moved back to London moving through a succession of posts until in 1865 he succeeded Hofmann (Gay, 1997, note 56) at the Royal College of Chemistry. He also worked with the Royal Commission on Rivers and Water Supply, which was time-consuming work. Frankland wrote a number of books including *Lecture notes for chemical students* (Frankland 1876) and *Inorganic chemistry* (Frankland & Japp, 1884). His book *How to teach chemistry: Hints to science teachers and students* (Frankland & Chaloner, 1875). showed his commitment to helping teachers and indicates that by this time there was a demand for chemistry teachers. Bud and Roberts (1984, p. 94) comment that both Frankland and Hofmann were pleased that teachers were keeping up with the latest chemical theories.

Frankland's main contribution to chemical theory is in the idea of valency, although he may not have been the first to use the term. He appears, however, to have had the essential idea of a fixed combining-value of radicles (Russell, 1971, p. 9: p. 39) which had developed from his studies in Germany on organic radicles. It is more difficult to assign priority to the actual first use of the term valency with the meaning that we now attach to it, but Frankland was certainly a major contributor.

One of Frankland's students was Henry Armstrong (Gay, 1997) whose work on chemical change will be described later (Section 4.6.1).

#### 4.4 Teaching the sciences—later American chemistry textbook writers

In the second half of the nineteenth century, American textbook writing really got under way. American chemistry textbook writers of the period chosen as examples were Benjamin Silliman Jr. (Miles 1976, pp. 438-440), Josiah P. Cooke (Miles, 1976, pp. 91-92), Edward Livingston Youmans (Miles, 1976, pp. 527-528), Le Roy Clark Cooley (Miles & Gould, 1994, pp. 48-49), Dorman Steele (Miles, 1976, pp. 454-455; Williams, 1994, pp. 54-58), Ira Remsen (Festa, 1980, pp. 893-894; Miles, 1976, pp. 402-403) and Rufus Phillips Williams (Miles & Gould, 1994, pp. 292-293).

The role that each of the later American textbook writers play in using the concept of physical and chemical change in their writing will now be described. Posterity appears to respect scientific discovery to a greater extent than it respects communicating the science that has been discovered to the next generation. There are considerably more biographical articles for scientists who also wrote textbooks than for those whose main occupation was communicating science through writing and teaching.

##### 4.4.1 *Benjamin Silliman, Jr*

Benjamin Silliman Junior was the son of the Benjamin Silliman Senior whose brief biography was included in Section 2.6.1. Initially, Silliman Jr followed an academic career (Webb, 1994, p. 9) not dissimilar to his father. However he also became a scientific consultant, advising petroleum and mining companies on the quality of their discoveries. One interesting aspect of this work was that he did research on the distillation of petroleum (a good example of a physical change) and had the idea of collecting the distillate in fractions. His studies on petroleum also laid the foundations for cracking petroleum (Miles, 1976, pp. 439), which is a good example of chemical change. Although he had some successes, he did come under suspicion from investors about his overly optimistic forecasts and eventually moved out of consultancy, as the ill-will from this work nearly ruined his academic career. In 1874 he presented an essay to a meeting of the American Chemical Society in which he

viewed 1845 as the beginning of a new era of scientific life in America in which chemistry played a major part (Scott, 1976, p. 11). The story of a few chemical educators below seems to bear out Silliman's view that there was considerably greater dynamism in chemistry in America in the latter part of the nineteenth century.

#### 4.4.2 *Josiah Parsons Cooke*

Josiah Parsons Cooke attended the public lectures of Benjamin Silliman Sr. as a boy and was so interested that he set up his own laboratory. He went to Harvard, graduating in 1848, and within two years he was appointed Professor of Chemistry and Minerology, but he had to pay for chemical experiments from his own pocket (Miles, 1976, p. 91). Cooke went to Europe to purchase books and equipment. He tried to encourage laboratory work and to avoid recitation as a means of teaching. He published both academic papers and books and is particularly well-known for his *First principles of chemical philosophy* (Cooke, 1870) and *The new chemistry* (Cooke, 1892). *The new chemistry* in its original 1870 edition contained an account of the new theories of chemistry that were just becoming accepted. Cooke thus gave the American chemical community access to the new knowledge at a comparatively early date and was in a sense an intermediary between the teaching community and the chemical research community. H. E. Armstrong (Anon, 1924, p. 150) said that he regretted that people no longer read *Cooke's new chemistry* as it was 'one of the most perfect, most beautifully written books on the subject in our possession'. Cooke continued teaching and experimenting until the year before his death in 1894 (Rosen, 1982, p. 525).

#### 4.4.3 *Edward Livingston Youmans and his Chemical Atlas*

Edward Livingston Youmans was a remarkable figure in the history of the American textbook, overcoming multitudinous adversities. Fiske (1894) has provided a complete biography of Youmans who was of humble origins. As a child he worked on the farm in summer and attended school in winter, so only obtained a minimal elementary education (Miles, 1976, p. 527). When he was 13 years old he and his teacher learned chemistry together by working through Comstock's well known *Elements of chemistry*. At 14 years old, after an illness, he was left only

partially sighted and actually blind for long periods of time (Miles, 1976, p. 527). Fiske (1894, pp. 40-41) gives some detail about the unsuccessful treatment of his eyes by a Ballston oculist who applied dangerous chemicals to his eyelids. As a result Youmans permanently lost the use of one eye and had intermittent vision in the other. For a while he scraped a living by writing reviews and essays but was largely dependent on the help of others.

At the same time he designed a wall chart in colour showing reactions taking place between atoms illustrated as squares. The areas of the squares were proportional to the atomic weights. The chart was large (5 foot by 6 foot), mounted on rollers and in 16 colours (Williams, 1996, p. 3). The wall chart sold as a teaching aid in schools in the 1850s and cost six dollars. The idea of a wall chart was not unique at that time but Youmans's efforts in this were amazing. Bucci (1998, pp. 161-184) has provided information about the origins of wall charts in science education. None of Youmans's original charts have survived.

Youmans also produced a *Chemical atlas* (Youmans, 1857; Oesper, 1957, p. 408) which uses the same diagrams as the wall chart but reduced in size (Williams, 1996, p. 3). More than 144,000 copies of the *Chemical atlas* sold from three editions (Oesper, 1957, p. 408) and today they sell at above US\$2000. Only one copy of the notes (Youmans, 1850) which were published with the chart has survived and this can be found at Harvard University Library (Williams, 1996, p. 4). The pictures from the atlas which were also in the chart can be found online (Williams, 1996, p. 6), but this online site is limited to subscribers to *The chemical educator*. Alternatively the pictures from the atlas are online at the University of Illinois at Urbana-Champaign Rare Book Room Exhibit (University of Illinois, 2000).

In 1850, Youmans wrote his textbook *A class-book of chemistry* (Youmans, 1851), the originality of which lies in the fact that in that the textbook included practical everyday chemistry; it immediately became a best seller, selling 150,000 copies. Youmans spent 20 years lecturing with huge success around in the Mid-West of the USA and Canada. He found time to start a journal called *Popular science monthly* and he also published the first anthology on science education entitled *The culture demanded by modern life* (Youmans et al., 1867). This anthology actually used a lot of materials from science educators in Britain, but it was another push towards improving science education in the United States.

#### 4.4.4 Le Roy Clark Cooley

Le Roy Clark Cooley appears to have had an unremarkable childhood. Later he worked as a teacher in mathematics and science at a number of schools, slowly increasing his qualifications. He was appointed as professor in 1870. Miles and Gould (1994, pp. 48-49) acknowledge that he was a 'great teacher' in whose hands 'chemistry and physics become humanities'. He was a long serving member of the New York Science Teachers' Association being president of the association for a time (Miles & Gould, 1994, pp. 48-49).

This study (see Section 7.4.2), when considering writers of both physics and chemistry school texts of the period, 1850-1870, shows that Cooley was the first author to start a junior chemistry book with a chapter on physical and chemical change. Others followed this lead, presumably because the idea was easier to understand than what was then being taught. I carried some further research (See Appendix 1, but not yet complete) in response to an enquiry from George N. Vlahakis of the Institute for Neohellenic Research. It appears that Cooley was also amongst the first textbook writers to mention energy or the conservation of energy in the index and Cooley (1880), says in his foreword that he had changed from his earlier edition to give prominence to the principle of energy. It seems that a process of reform in teaching methodologies was very much under way at the time and that Le Roy Cooley was implementing new teaching strategies in his textbooks. In 1885, Grove's work with a number of European collaborators on *The correlation and conservation of forces* (Grove et al., 1885), edited by E. L. Youmans (see Section 4.4.3), was published which shows the inter-convertibility of various types of energy including chemical affinity (force) (Grove et al., 1885, pp. 152-168).

Cooley promoted secondary school science teaching wherever and however he could. He wrote about teaching methodology, produced sound, well-structured school textbooks, designed new apparatus and emphasised experimental observation as the first stage in learning science. He continued this work over a long and successful academic life. However, apart from the reference of Miles and Gould (1994) cited and references in Nietz (1966), his life story is hardly recorded elsewhere. Consistent good teaching over time does not seem to rate highly in the celebrity stakes.



#### 4.4.5 *Joel Dorman Steele*

Joel Dorman Steele was born in Lima, New York, in 1836. He was evidently a diligent and industrious student (Williams, 1994, p. 56). After school he worked in publishing and teaching, finally attending Genesee Wesleyan College (Miles, 1976, p. 454). After graduation he worked at a number of schools and was recognised as a gifted teacher, but there is no evidence that he ever took science subjects in his degree or indeed that his A.M. (Masters of Arts) degree was awarded by Genesee Wesleyan College. Much later in life he received an honorary doctorate for excellence in teaching. During the American Civil War, he was appointed Captain but was severely wounded early in the war. His recovery took a long while, but eventually he returned to teaching.

Later he became Principal of a run-down school in New York, where he was respected as a first-rate teacher because instead of using standard texts, he used his own carefully prepared notes. The notes eventually became the source material for his books, which usually had the generic title *Fourteen weeks in . . .*. His books were immediately popular. He claimed no originality but he said that his contribution was 'simple interesting language' (Williams, 1994, pp. 56). He wrote these simple school texts in a variety of science subjects and in history in partnership with his wife. His emphasis was on practical science and its applications to everyday life. His texts were formatted more carefully than was common at the time with bold print headings to make reading and understanding easier. The books contain many diagrams and evidently (Miles, 1976, p. 454), seven of Steele's books were still in print in 1928. My own observations are that on the Ebay auction site Steele's books are the most common of the period available for sale, though I have not seen any advertised for sale printed after 1900. In general, after 1900 new texts had taken over, often using the ideas provided by the earlier textbook writers. Steele's later years were dogged by ill-health and he died aged 50 years in 1886.

#### 4.4.6 *Ira Remsen*

Ira Remsen was born in 1846 into a well-to-do New York family. His schooling was unremarkable. He obtained an A.B. (Bachelor of Arts) degree in 1865 (Miles, 1976, p. 402) and a M.D. degree in 1867. He then went to Germany to train in research in

chemistry and obtained his doctorate from the universities of Munich and Göttingen in 1870. He then moved to become an assistant to Rudolf Fittig, investigating the structure of the aromatic sulfonic acids (Festa, 1980, p. 893) at the University of Tübingen until 1872 when he returned to the United States to take a position in Williams College.

In 1876, he was appointed professor of chemistry and a foundation faculty member of Johns Hopkins University, Baltimore (Getman, 1939, p. 356). His drive created a research-based chemistry with an international reputation based on a continental model that he had experienced. He also founded and edited the *American Chemical Journal*. He is probably best known for the discovery of a new sweetening compound (later known as saccharin), which he and a post-doctoral student, Constantin Fahlberg, discovered; this was a continuation of his research with Fittig. It was not altogether a happy occasion (Getman, 1939, p. 357) as the patenting of the discovery was antithetical to Remsen's principles and caused considerable bitterness. However, in general Remsen was extremely well-liked by his students as is indicated by a former student (Clark, 1929, pp. 1282-1285). Remsen's textbooks were models of lucidity and it is as a teacher, a textbook writer, an educationalist, and a vitalising force in the promotion of chemistry that his fame rests, rather than as a chemical researcher.

#### 4.4.7 Rufus Phillips Williams

Rufus Phillips Williams' life is quite unlike that of Ira Remsen above in that he never achieved fame in chemical research, but was an excellent writer of school texts. He wrote his first chemical manual for high schools in 1888 (Miles & Gould, 1994, p. 292). Chemical manuals are a particular interest in this study (see Chapter 8), which is one reason for the inclusion of Williams' biography. Williams was born in 1851 on a farm in Massachusetts. There is little information about his early years, but he obtained his academic qualifications from Dartmouth College and Harvard. He worked as a teacher and school principal throughout his life. He took an active part in the work of the American Chemical Society. He wrote eight chemistry textbooks and laboratory manuals and several of these went through many editions. His early books relied largely on teaching through experiment. His aims, which included making students excited about chemistry, are quoted in Miles and Gould's brief

summary of his career (Miles & Gould, 1994, pp. 292-293). Williams also aimed to replace the superficial love of observation with a deeper love of explanation. Thus he eventually came to a view that perhaps only 30% to 50% per cent of a student's time should be spent in the laboratory. So, in spite of having been the first to produce a laboratory manual, he did not espouse the same passion for heurism as shown by H. E. Armstrong. Williams died at the age of sixty in 1911.

#### 4.5 Teaching the sciences—chemistry in UK: 1850 to the present

In the second half of the nineteenth century, there were many British textbook writers but few of them seem to have provided the same elements of novelty and inspiration as were evident in the books of the American chemistry textbook writers described above. The British chemistry textbook writers of the period who have been chosen as examples are William Odling (Fisher, 1996, pp. 146-162, Henry Enfield Roscoe (Daintith et al., 1994b, p. 764), Henry Edward Armstrong (Eyre, 1958) and Ida Freund (Benfey, 1968).

##### 4.5.1 *William Odling*

William Odling (Fisher, 1996, pp. 146-162) is of interest in that in his textbooks and popular expositions of chemistry he is amongst the earliest of textbook writers to use the contrasting pairs of physical and chemical change on several occasions (see Chapters 7 and 8). Odling was born in Southwark in 1829 (Partington IV, 1998, p. 461) and took a medical degree at London University becoming a demonstrator in Chemistry at Guy's Hospital in 1850. His rise in stature was rapid, as he succeeded Frankland at St Bartholomew's Hospital in 1863 (Rosen, 1957, p. 518), became Professor of Chemistry at the Royal Institution following Faraday in 1868 and finally became Professor of Chemistry at Oxford University in 1872, not retiring until 1912. He died in 1921, killed in an accident with a cyclist (Partington IV, 1998, p. 461). Odling was extremely active in the chemical organisations of the period, and very much interested in chemical research, but he was not a particularly good experimentalist: it may be this deficiency that has led to his scientific contribution being neglected (Fisher 1996, p. 160).

There was considerable friendship between British and German scientists of the period of which Odling was a part (Bud & Roberts, 1984, p. 107). He was also referred to by the French chemist Laurent as 'L'ami Odling' and he translated Laurent's influential text *Méthode de chimie* from French into English published as *Chemical method* in 1854 (Rosen, 1957, p. 517), removing a number of inconsistencies (Partington IV, 1998, p. 378).

Odling should be remembered for his efforts in 1857 towards creating a periodic table where he created a list of elements consisting of 13 groups (Brock, 1992 pp. 316-317) with related physical and chemical properties. However, as can be seen from earlier discussion in this chapter and a recent very informative article on the history of the periodic table (Scerri, 1998, pp. 56-61), Odling's name, unfortunately, is usually omitted from the list of those who are said to have contributed towards the discovery of the periodic nature of the physical and chemical properties of the chemical elements. However, other historians do acknowledge his work in this area (Brooks, 2000, p. 467). In 1860, Odling introduced the use of lines to represent valency bonds in structural formulae in organic chemistry (Holmyard, 1929, p. 108).

Fisher (1996, p. 146) believes that Odling played a major role in the reform of chemistry in England in the middle of the nineteenth century. Fisher (1996, pp. 150-160) analyses one of his major contributions, which was a paper entitled 'On the atomic weight of oxygen and water' and examines the modes of reasoning he used. The conclusion both from the internal evidence of this paper and from the reactions of his students, is that his arguments are always well-considered and precise. One point that is made very clearly is that Odling made simplicity a virtue. It is thus unsurprising that when writing textbooks such as *A manual of chemistry, descriptive and theoretical*. (Odling, 1861) or giving the Institute of Chemistry Christmas lectures, he simplified the variety of changes that might exist into two sorts only—physical and chemical.

Odling also gave other public lectures such as those with Huxley, Roscoe, Balfour Stewart and Gladstone which were presented in Manchester between 1871 and 1873. These lectures were published (Anon, 1873) and could be bought in paper covers for one penny each. He was one of the scientists in Britain to encourage the public understanding of science.

Occasionally the present, by chance, intrudes upon the study of the past providing some unexpected connection between the two. This can add individual relevance to research and I add this story as an aside; these events took place in 1991 prior to my interest in Odling. Whilst reading *Chemistry in Australia* in 1990, an article about old books (Collins, 1990, pp. 440-443) caught my eye. It was about a book, written by Alfred Smee who had invented a battery and had written a book about electro-chemistry. The author of the article, David Collins, asked (Collins, 1990, p. 443) 'Are there any Australian descendants of Alfred Smee?' In the text, (Collins, 1990, p. 441) mentions that Smee's daughter married Professor Odling of Oxford. At last, I saw a connection between past and present as one of my colleagues, then teaching at Northern Territory University was called David Odling-Smee. I showed him the article and there was some correspondence with both David Odling-Smee and David Collins finding some satisfaction in this interesting coincidence. Later, with my research into physical and chemical change I was surprised to find that Professor Odling was one of the first to use the phrase physical and chemical change in his writings. This completed the connection with my own research.

Odling was one of the British chemists at the Karlsruhe Congress (see Section 3.6.1). Having attended the Karlsruhe Congress, he was convinced by Canizzaro's arguments and fought tooth and nail to convince other British chemists of the truth of Canizzaro's views (Rosen, 1957, p. 518) and he was eventually successful. But it took 10 years before Canizzaro was invited to give the Faraday lecture before the Chemical Society on how to teach the new chemistry (Canizzaro, 1872, pp. 941-967).

Since Odling was amongst the first in the United Kingdom to use the concept of physical and chemical change in his textbooks and in his lectures to young people and since he had an excellent network of connections in Europe, I wondered if he might have had similar good relations in the United States of America. He certainly had academic connections with Youmans (see Section 4.4.3) as he wrote an article (Odling, 1876) about combustion in *Popular Science Monthly* edited by Youmans entitled 'The revived theory of phlogiston'. This article gives historical perspective on the old discredited phlogiston theory arguing that the adherents of the theory had some part of a modern truth of chemical combination. This is not the only connection, as he wrote an article on indium (Odling, 1873) which can be found in

*The science record* for 1873. Odling continued as Professor of Chemistry at Oxford until his retirement in 1912 (Muir, 1994, p. 387).

#### 4.5.2 *Henry Enfield Roscoe*

Henry Enfield Roscoe had a privileged start in life as his father was a barrister (Daintith et al., 1994b, p. 764). He studied chemistry firstly at University College, London and then under Bunsen at Heidelberg. He kept a cooperative partnership with Bunsen, who was a very affable man (Palmer, 1999) for most of his scientific career. Roscoe returned to England to become Professor of Chemistry at Owens College, Manchester, which had fallen on hard times with an intake of just 19 students (Daintith et al., 1994b, p. 764). He built the College up over time with the help of the local business community (Saltzman, 1999, pp. 34-41) to become a thriving centre of teaching and research. He was said to be an excellent teacher (Partington IV, 1998, p. 900). He organised lectures for the working classes and the unemployed during the cotton famine, which was a result of the blockade of cotton exports from the United States during the Civil War. As mentioned earlier (Section 4.5.1), Roscoe gave these lectures with Odling, Huxley, Balfour Stewart and Gladstone and other public-spirited scientists in Manchester between 1871 and 1873. If one looks at the text of the lectures (Roscoe, 1873, pp. 1-16) that Roscoe presented to the public it would seem that he made few concessions to those with only a rudimentary knowledge of science. Roscoe was a prolific author producing a number of textbooks of chemistry. An interesting feature of Roscoe's textbooks is that he wrote to cover all levels of education; he wrote a book for primary students (Roscoe, 1882), for secondary students (Roscoe, 1869), and for tertiary students (Roscoe & Schorlemmer, 1877). Schorlemmer was Roscoe's assistant at Owens College, was politically very radical (nicknamed 'the red chemist'), and a friend of both Marx and Engels (Kargon, 1977, p. 196) but was well-respected for his chemical knowledge (Benfey, 1992) as he had made a number of important discoveries in his own right. Roscoe was popular in Manchester and became a Liberal Member of Parliament between 1885 and 1889. He died in 1915.

#### 4.6 Henry Edward Armstrong (1848-1937): His life

There are four biographies of Armstrong namely Brown (1954), Eyre (1958), Brock (1973) and Van Praagh (1973). Of these, only Eyre (1958) gives the complete picture that includes his life, his scientific work and his educational work. It is noticeable that all the biographers are British and tend to be educationalists rather than scientists, so unsurprisingly the emphasis of these biographers is on Armstrong's educational work. However Armstrong made contributions both to science education and to science. His scientific contributions, though useful and thorough, were not revolutionary and indeed on matters of scientific fact he frequently opposed the theories that eventually became accepted science.

Henry Edward Armstrong was born at Lewisham, just outside London, the first of seven children (two of whom died in childhood) of Richard Armstrong and Mary Ann Biddle. Richard was a notary and Mary and he had romantically eloped a year before Henry's birth. Richard improved his income by setting up a business as a French commission agent and later entering the provision trade; there were hard times, but generally the business prospered. Henry had a privileged childhood with a spacious home and garden set in pleasant green fields. As he grew up, he played with a friend, Robert Adkin, who later married his sister. Henry enjoyed school at Colfe Grammar School in Lewisham. He was considered delicate and was sent off to Gibraltar for health reasons with his uncle (Eyre, 1958).

On his return in 1865, he entered the Royal College of Chemistry. Hofmann (Section 4.3.6) had been Head of the College for 20 years, but soon after Henry's arrival Hofmann moved to Berlin; Hofmann was replaced by Edward Frankland (Section 4.3.7). Hofmann had been a brilliant lecturer, but Frankland was a brilliant experimental chemist. Other lecturers were T. H. Huxley for biology, Ramsay for geology and Tyndall for physics. The Royal College of Chemistry was a very liberal place; Henry, for example, followed no particular course, but developed an interest in chemistry at which he worked hard for a little over two years. He did special work for Frankland, who was on a Royal Commission to inquire into the causes of pollution of UK rivers (Eyre, 1958). Henry had to work out a methodology for the task and carry out the experimental work. Evidently it was this learning experience that led directly to his advocacy of the heuristic method later in his life.

Frankland then suggested that Henry should go to Germany for further study and experience under Hermann Kolbe in Leipzig. He knew no German, so with characteristic thoroughness set about teaching himself the language. He successfully completed his studies in Germany and returned to UK in 1870 to take up a part-time position at St Bartholemew's Hospital Medical School. He then got an additional position teaching evening classes in analytical chemistry at The London Institution, Finsbury Circus. He took on a variety of other part-time jobs. In 1877 Henry married Louisa Lavers, whom he had known for some years. In 1884, his father died, aged 57, after a period of illness, during which his business was neglected; Henry had to spend a lot of time and energy sorting out the business to provide for his mother and an unmarried sister.

By 1885, Henry had a young family of three boys and two girls; he would stay home on Sundays to be with his children. He was also very much involved in the planning of the Central Institution, which was set up in South Kensington after some wrangling (today it is part of Imperial College, London, next to the Science Museum). He became the first Professor of Chemistry there and held the post until 1913 when at the age of 66 he retired and started a new career as writer and critic. He gave advice on chemical matters informally to the government during the First World War. Over the next 20 years, he continued writing and lecturing. His wife Louisa died in 1935 and Henry Edward Armstrong passed away on July 13, 1937 in his ninetieth year (Eyre, 1958).

As a person, he appears to have been quarrelsome and aggressive, very critical of himself and others, but he was much loved by his students because he spent a lot of time helping them. He might appear to be a 'Colonel Blimp' type, bombastic, loud and assertive—a type not currently liked. He strongly opposed women's entry to the sciences—in particular he opposed the entry of a colleague's wife, Mrs Henrietta Ayrton to the Royal Society and commented on the incident when he eventually wrote her obituary (Gratzer, 1996, p. 188). On a lighter note, he is said to have introduced the fashion for wearing coloured waistcoats when he was in his eighties (Brock, 1996c, p. 39).



#### 4.6.1 *Henry Edward Armstrong: His scientific work*

From 1868 to 1930 (Eyre, 1958 pp. 299-319) Armstrong produced high quality research that was indicated by a stream of papers. He worked on a number of chemical problems generally in the field of organic chemistry, which included the chemistry of the naphthalenes, the chemistry of camphor, the chemistry of food and the mechanism of chemical change.

Few www sites mention H. E. Armstrong, but Eric Weisstein's World of Scientific Biography site mentions him as a chemist rather than as an educationalist stating that he was an:

English organic chemist who challenged Arrhenius's ionic theory. Armstrong proposed an alternate theory in which water is a complex saturated with the gas "hydrone". He maintained that vapour pressure was a measure of the concentration of free hydrone molecules.

[http://scienceworld.wolfram.com/search/?words=h.+e.+armstrong&x=6&y=9&config=scienceworld\\_wolfram\\_com&restrict=http%3A%2F%2Fscienceworld.wolfram.com%2Fbiography](http://scienceworld.wolfram.com/search/?words=h.+e.+armstrong&x=6&y=9&config=scienceworld_wolfram_com&restrict=http%3A%2F%2Fscienceworld.wolfram.com%2Fbiography) (Accessed 8 Sept 2002)

His chemical work gave him fame, but probably he is best known for the fairly extensive set of scientific ideas that he opposed. He did not like the idea of the atom: he vehemently opposed the idea of the electron and the ion; he thought quantum theory to be nonsense, and so on. In fact he wrote to all the learned journals that would publish his letters to ridicule and subvert these ideas and those who supported them. For example, Armstrong criticises Bragg's idea that in sodium chloride there is a chess board pattern of ions. He says

It were time chemists took charge of chemistry once more and protected neophytes against the worship of false gods: at least taught them to ask for something more than chess-board evidence. (Armstrong, 1927, p. 478)

He does not accept the evidence for radioactivity

Professor Armstrong is almost alone among chemists, as Lord Kelvin is among physicists, in his hostility to the new doctrines. [radioactivity]  
(Soddy, 1906, p. 516)

And lastly he definitely does not accept the existence of ions.

Fortunately, perhaps, we have not been successful on the commercial side but far too many of us have fallen victims to "ionomania" and the disease has had dire effects, particularly in biological circles: the textbooks are so full of it that the infection will not easily be rooted out. (Armstrong, 1914, pp. 608-623)

In spite of the fact that he was so outspoken and so frequently proved to be scientifically incorrect, he was an accepted "expert" on matters scientific as is shown by his articles on chemistry in two separate editions of the *Encyclopaedia Britannica* and his presence on many influential scientific committees. His views on chemical change and on science education practice are the reason why I see Armstrong as a key figure in this history of chemical change. I would add that in 1998, I carried a minor research project (Palmer, 1998b; 1998c; 2001) to mark the 150<sup>th</sup> anniversary of the birth, of H. E. Armstrong, the questionnaire for which was placed on a number of web sites, for example:

<http://www.cquest.utoronto.ca/env/aera/aera-lists/aera-k/98-04/0059.html>  
(Accessed 8/09/2002)

#### 4.6.2 *Henry Edward Armstrong: His educational work*

Armstrong, from the age of about 18 years old, passionately wanted to work in the area of teaching and researching chemistry but being influential in education seems to be something that happened rather than something that he planned. Armstrong's views of education developed over time from his own experience and through contact with his colleagues at Finsbury College. An overall picture of the development of scientific institutions in this period can be found in many different accounts (Selleck, 1968; Jenkins, 1977; Gay, 1997). At Finsbury, Armstrong worked with William Ayrton (an electrical engineer), John Perry (a mechanical engineer and

mathematician) and E. C. Robins (architect). Together they proposed a new doctrine of heurism (Brock, 1996c, p. 38) (from the Greek *Eureka* which means *I have found out*). In chemistry Armstrong devised a new kind of course that started with observation of familiar phenomena such as combustion, then dealt with pure and applied organic and inorganic chemistry, followed by industrial chemistry, with experiments throughout. Students were always to go from the known to the unknown (Brock, 1996a, p. 48).

Due to his research, his addresses to the British Association and his position as secretary of the Chemical Society, he soon became involved in various government bodies and these recommended his methods be adopted.

For example, The Science and Art Department recommended (inter alia) that:

. . . the preparation for these examinations should stress experimental work and that this work should relate to the pupil's own everyday experience.

(Van Praagh, 1973)

At the turn of the century his ideas for introducing heurism to science teaching appeared to be achieving success. Amongst the Public (that is Independent) Schools, Christ's Hospital was the first to implement his ideas. Browne, a former assistant to Armstrong, and recommended to the school by Armstrong to take charge of science, was eager to make the scheme work and Armstrong visited the school regularly.

In 1898 Armstrong also gave courses for teachers to do experimental work themselves; he wrote a book called *The teaching of scientific method* in 1903. However by the time he revised the book in 1926 even Armstrong had to admit that his attempt to develop the experimental method was a practical failure (Jenkins, 1976, pp. 21-26). Since that time, practical science methodology has been rediscovered more than once as discovery method and guided discovery.

#### **4.7 Ida Freund: Biographical**

I have also researched the life of Ida Freund in some detail. She is central to this study in that her work very much related to chemical change and the methods of

teaching chemistry. Ida Freund wrote two books which are about chemical change: they also relate to teaching methodology. Thus I see comparisons between her work and that of Henry Edward Armstrong. I have limited evidence that they expressed opposite views on science education issues (Brock, 1996b, Footnote 71), indicating that Armstrong supported heurism whereas Freund opposed heurism. The problem here is that Armstrong was far from consistent in defining heurism and that Freund's painfully careful experimentation was hardly suited to science teaching for all. However both were extremely competent chemists with a passion for experimental work. Jenkins indicates that Armstrong and Freund also had opposed views on domestic science curricula (Bird, 1998; Jenkins, 1979, p. 175). In this case Armstrong's views were probably not soundly based on experience; it was a part of his personality to express strong views about 'everything'. Ida Freund had a wide variety of skills that would have enabled her to give instruction in domestic science had she wished to do so, but as will be seen later she was not supportive of domestic science curricula.

Ida Freund is interesting in that she has a strong character but little biographical detail is available concerning her life. Firstly, there seems to be no internet biography, though there is a Cambridge University Scholarship (Internet reference Newnham College) named after her. There is no other biography of Ida Freund and few of the scientific bibliographies mention her. Sources consist of Benfey's introduction (Benfey, 1968) to the 'Dover' reprint of her book *The study of chemical composition: An account of its method and historical development* (Freund, 1904). She is mentioned in some of the histories of the Women's Colleges of Cambridge. An easily available source is the preface by Hutchinson and Thomas of Freund's book *The experimental basis of chemistry: Suggestions for a series of experiments illustrative of the fundamental principles of chemistry* (Freund, 1920) which is a personal tribute by kind friends. There are a number of obituary notices and a new study of women chemists (Rayner-Canham & Rayner-Canham, 1998, pp. 69-71) is useful but provides little new information. Patricia Gould (1997b) has provided me with information about Ida Freund whilst she was researching women physicists of the period; there are a few other miscellaneous sources. A brief vignette of Ida Freund's very interesting life follows.

#### 4.7.1 *Ida Freund's early life*

Ida Freund was born in Vienna on 5 April 1863, but she was left an orphan when young and was raised there by her maternal grandmother (Palmer, 1998b). She attended a state school and then trained for teaching obtaining the Austrian State Diploma for teachers (Girton College, n.d.). After this her grandparents died one after the other, in spite of her 'nursing them tenderly' (Gardiner, 1914, p.34). Thus at the age of 18 she eventually came to keep house for her uncle Ludwig Strauss, a violinist, in England. Her uncle had influential friends who recommended that she be sent to Girton College in Cambridge and he had long recognised her talents; she prepared for the 'Little-Go' examinations at a private institution. Greek, Latin and mathematics were all new to her.

In July 1882 she was admitted to Girton, but it can hardly be said that this was what she wanted. In fact she bitterly opposed the idea of going to college (Welsh, 1914, p. 9). However, she did put her heart and soul into her work in science. Here she achieved a first division in both the first and the second part of the Natural Sciences Tripos in 1885/1886. It was a remarkable achievement considering that she was working in a second language and that at the time it was difficult for women to get advanced instruction in practical chemistry. Physics was her second subject for part of the Natural Sciences Tripos and she did this almost as brilliantly as her beloved chemistry.

#### 4.7.2 *Ida Freund's career*

In 1886 she became a lecturer at Cambridge Training College. In 1887 she was appointed demonstrator in chemistry at Newnham College. In 1890 she underwent an operation which left her lame for life (Welsh, 1914, p. 10) and returned to London to look after her uncle. Earlier sources (Wilson, 1905) say 'In her youth she had a cycling accident and lost a leg; she had an artificial one . . .'. In 1893 she returned to Cambridge with her uncle whose health was failing and resumed work at Newnham. Her uncle died in 1899.

The earliest piece of Freund's writing that I have found (Freund, 1882) is a very short piece about her chocolate periodic table, which she commends. She made a periodic table from Edinburgh Rock on a chocolate base and 'the elements were iced cakes each showing its name and atomic weight in icing . . . We divided it up between us' (Wilson 1905, p. 72). Freund reflects:

Whether it (her chocolate periodic table) is of a kind that would lend itself to extended use as an adjunct to the study of chemistry must be considered doubtful. (Freund, 1882, pp. 72-73)

I have edited out some of the detail about the care and skill with which she made this table, but it must have been a labour of love and evidently each year she prepared a different treat for her students. This example is certainly a precursor to much current work in making lessons interesting (often through food), so her pedagogy is excellent.

Yet I think she appears to have reservations about the accuracy of the periodic table from a theoretical perspective - perhaps not surprising as the table as then known was constructed on different principles from those used today (atomic weight was used rather than atomic number). However, this can be seen more clearly in one chapter of *The study of chemical composition* where she points out some of the periodic table's deficiencies (see Freund, 1904, pp. 504-505 re Wyruboff's criticisms). Her views on the periodic table come as a shock to those who see the periodic table as central to the study of school chemistry.

Her chief interest was her work at Newnham College, particularly practical chemistry. In 1903 she won the Gamble prize (Girton College, n.d.) for her essay on 'The history prior to 1800 of theories concerning the ultimate constitution of matter'. I have not been able to trace a record of the complete entry but it would seem likely that much of it is contained in her first book, which was entitled *The study of chemical composition* and was published in 1902. This book is a massive piece of work running to some 650 pages.

Considerable information is available about her teaching schedule:

The Cambridge University Reporter shows that she taught practical chemistry at the lab in Newnham for two hours, three mornings a week, from Easter Term 1887 until Lent Term 1898 inclusive. After this date, the timetable for chemistry seemed to alter considerably. For example, in Easter Term 1898 she lectured on Chemical Theory (treated historically) at the Balfour lab for 1 hour, three times a week; lectured on physical chemistry in a room at Newnham 8pm on Thursday evenings; practical chemistry classes as before. (Gould, 1997a)

#### 4.7.3 *Students' views of Miss Freund's life*

Some comments by friends and students:

Miss Freund was a terror to the first-year student with her sharp rebukes for thoughtless mistakes. One grew to love her as time went on, though we laughed at her emphatic and odd use of English. Yet how brave she was trundling her crippled leg and, I am sure often painful body about in her invalid chair smiling, urging, scolding us along to 'zat goal to which we are all travelling which is ze Tripos'. (Ball, 1905, p. 76)

In my day Miss Freund reigned supreme in the Chemistry Lab. and in the garden. She was a great character. (Wilson 1905, p. 72)

Everyone who worked with Miss Freund knows that her high standard and stringent requirements gave you a new idea of the demands of science; you were not allowed to think that you understood, when you did not understand, or to be satisfied with a result which was not the most accurate that you could obtain. (Gardiner, 1914, p. 35)

Gardiner (1914, p. 35) also refers to a student who speaks of Miss Freund's power to encourage the timid, showing them what they could achieve.

#### 4.7.4 *Ida Freund's pedagogy*

Her pedagogy was perhaps one of the most interesting facets of her life, yet it is not clear that she had any great influence on the direction that science education was taking at a time when debate in this area was fierce. As indicated earlier, she certainly seems to have crossed swords with Henry Edward Armstrong on the issues of heurism in science teaching and on the content of domestic science curricula. From a distance of 100 years the differences on heurism do not seem that great. Freund appears to be against discovery learning.

Miss Freund had a dread of thoughtless experimenting and slipshod thinking. She felt strongly that much that passes for training in science has little relation to scientific method and is of small educational value.  
(Hutchinson & Thomas, 1920, p. vi)

Surely, therefore, the more honest, intellectually bracing and eventually more fruitful course is to sweep away all delusions as to what pupils can discover for themselves. (Freund, 1920, p. 8)

But as things are, the attitude of many teachers of elementary chemistry who are considered most progressive and most truly scientific has much in common with the Alchemists of an earlier age. (Freund, 1920, p. 9)

These opinions may have been written specifically to annoy Armstrong and no doubt would have done so, but by the time when Freund's book was published he was already a spent force. Ironically one doubts that the sort of critical understanding that Freund was demanding that teachers provide for students, was brought any nearer by the gradual diminution of Armstrong's influence. In fact, the outcome was of cheaper, learn-by-rote science that would not have satisfied the ideals of either Armstrong or Freund. In the area of domestic science Ida Freund was also vocal:



But powerful opposing forces, including other women such as Ida Freund, who was herself a science graduate and a fellow of Girton College, Cambridge, ridiculed the idea that cooking could ever attain the status of science in her attacks on the King's College course during 1911-12. (Bird, 1998)

During her teaching career, Ida Freund was responsible for helping undergraduates pass Part 1 of the Natural Sciences Tripos in chemistry, where frequently they had not studied chemistry before, so she is one of the earliest science educators. In 1897 Ida Freund held a vacation course for physics teachers at Newnham College, because several of her former students who were now teaching 'complained of the scarcity and inferiority of the apparatus at their disposal'. They learned 'how to construct the simpler kinds of instruments for themselves.' (Gardner, 1921, pp. 121-122).

Perhaps Ida Freund's influence has been limited as she mainly worked at an individual level, concentrating her energies on a few students rather than getting involved in serving on committees and writing articles publicising her views.

Ida Freund retired due to ill health in 1912 and died in 1914, but up to the day before her death was still working on the manuscript for her book *The experimental basis of chemistry*. The Ida Freund Memorial fund was subscribed by friends after her death and given to Newnham to raise the standard of physical science teaching in schools by giving teachers opportunities for further study. This was in accordance with Freund's life-work.

#### 4.7.5 *Summing up Ida Freund's contribution to education*

It is said (Gould, 1997a) that her early education in Austria had been supportive of the educational and social progress of women, whereas English social conventions of the time were unsupportive. She was active in the women's suffrage movements, financially supported and knitted for the Southwark Settlement for the mentally handicapped and knitted for the soldiers in the Boer War.

Certainly her views on science education for girls were strongly and sincerely felt, but her views on scientific accuracy, effort and examination success would not endear to all in women's movements today. But it should be remembered that tempering her surface hardness, there was a deep compassion for people.

Whilst her uncle was alive, they used to go on trips around Britain and Europe together. After his death she went on cycling holidays to Europe—she used a tricycle, powered by her arms—and went as far afield as Scotland, Switzerland, Germany, Austria and Italy.

I think that there is something particularly remarkable about Ida Freund's life and I do find others hold the same view; for example, Crawford (1998) in an online review about the book by the Rayner-Canhams (Rayner-Canham & Rayner-Canham, 1998), picked out the small two page section on Ida Freund for special mention:

My other favourite was Ida Freund. At another session she made the periodic table out of cake, frosting and candy sticks. Sounds like my kind of chemistry class. (Crawford, 1998)

Ida Freund's interest in the teaching of chemistry, her concern for accurate practical work and her interest in chemical composition naturally led to her work on physical and chemical change. The book, *The experimental basis of chemistry*, was originally planned to have been 20 chapters in length, but her friends, Mr Hutchinson and Ms Beatrice Thomas, were only able to edit the first 10 chapters of the book which was published in 1920, six years after her death. Her total opus is just two books, but according to Pattison Muir, her work:

is to be classed among the really great works of chemical literature (Gardiner, 1914, p. 36).

#### **4.8 A history of science education worldwide**

Is there, can there be, a worldwide history of science education? It may be possible, but as yet I consider that it has not yet been written. Some bibliographies are

available (Brock, 1975; Jenkins, 1980) that indicate the main research articles. Histories of science education tend to look at the development of science teaching from either a British or an American perspective and these two perspectives differ in what is recorded about the development of science education and the way in which these developments occurred. These differences relate to the science education histories of Britain and America, whilst European and other national traditions are omitted altogether. For a British history of science education, a doctoral thesis (Uzzell, 1975) is particularly useful as it is extremely thorough (running to more than 500 pages) and referring to chemistry in particular. Thus little literature exists that attempts an integrated history of science education. Jenkins (1990) has attempted this, though he states:

. . . much remains to be done before the history of science education can take its place as an integral part of history. (Jenkins, 1990, p. 903)

I did attempt a small scale demonstration (Palmer, 1998c; 2001) to indicate the differences between British and American views on science education by using H. E. Armstrong's educational work as an example. The results were as might be expected in that British science educationalists were generally familiar with Armstrong's work and American science educationalists were not. Many factors influence pedagogical practice, giving slightly different histories of science education for each country. Here major factors will be discussed briefly to show changing demography, technology and social change influencing the science being taught in schools worldwide. For example, textbook design, progresses through stages from catechistical, through conversational texts, to object lessons, to simpler texts better spaced using bold type-faces and more pictures with colour added later and eventually to more practical work supported by separate practical manuals. This is fairly familiar in all educational systems, but timing between systems varies considerably. In moving from the general to the specific, it is probably true that the simplification of the complicated aggregation/elective attraction theory by Cooley in the United States and Odling in Britain coincided with heuristic ideals being expressed in both countries by Remsen in the United States and Armstrong in England. In other words, if schoolteachers (whose own chemical experience was limited) were to supervise students doing practical work in chemistry or to demonstrate experiments themselves, then it was essential that there were simple,

safe practical experiments to do. Whatever the virtues or otherwise of a theory of physical and chemical change, the curricular inclusion of physical and chemical change provided a number of simple safe experiments for student practical work and for those looking for practical applications of theory gave numerous relevant examples.

The middle of the nineteenth century in the United Kingdom was a time when chemical institutions were growing rapidly and chemical curricula were being fixed and examined at each level. There were evening classes where students could learn chemistry theoretically and in 1878 a practical examination was instituted (Bud & Roberts, 1984, p. 94). In Britain, the combination of written curricula, increasing numbers of examination boards setting examinations and textbooks writing for these examinations gave chemistry curricula for secondary schools a comparatively stable content that changed little between the 1870s and the 1960s.

H. E. Armstrong was critical of the examination system and the preparation of students for examinations even though this was what he was employed to do:

I had the good fortune to study chemistry in pre-examination days, when it was just possible to learn things in an honest way, without fear of being harmed for life by over-teaching and spoon-feeding, which, under our commercial system of education, now so often pass as training. I was therefore allowed and encouraged to learn to help myself and to think for myself, not overweighted with textbook knowledge. (Armstrong, 1912)

Static curricula due to unimaginative textbooks and examination pressures seems to explain the case in Britain, but it cannot be the case in the United States as the United States did not generally have these mechanisms. Perhaps it was two world wars and related depressions that gave both countries economies that were too impoverished to spend money on resources that would allow chemistry curricula to change rapidly. For whatever reason, it is true that when students started learning chemistry between 1870 and 1960 they usually started by learning about physical and chemical change. This statement will be modified after more detailed research in Chapter 7, but remains largely true.

#### 4.9 A summary of Chapter 4

This chapter has considered the changes in knowledge about the nature of matter over the past 2000 to 3000 years and the life histories of a number of the scientists, educationalists and writers responsible for this knowledge. The result at a secondary school level was that the concept of physical and chemical change was firmly embedded in chemistry curricula up to about the 1960s. The next chapter will look at the written opinions of a variety of scientists and science educators about physical and chemical change from a range of viewpoints.

## CHAPTER 5

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### DEBATING PHYSICAL AND CHEMICAL CHANGE

*Research Question 5: What is the debate about the distinction between physical and chemical change over the past 200 years and how has this debate changed with the increased understanding of chemical processes?*

#### 5.0 Definitions and debate

This chapter expands a number of the themes of the first chapter trying to clarify questions of definitions of physical and chemical change as a preparation for the debate about physical and chemical change. Heated discussion about physical and chemical change mostly occurs between chemists but sometimes between chemists and physicists. Some of those expressing opinions about physical and chemical change are those whose biographies have been provided in earlier chapters. The first idea was to look at the concept of physical and chemical change in the *Encyclopaedia Britannica* which acts simultaneously as a source of accuracy and definition, and potentially to see how the concept of physical and chemical change changes over time. (See Appendix 2).

#### 5.1 Searching the *Encyclopaedia Britannica* for the physical and chemical change concept

Scott (1971, pp. 9-11) indicates that he considered it useful to use the newly published *Encyclopaedia Britannica* of 1771 in order to find out about the state of scientific thought prior to Lavoisier. Gable (1979, pp. 375-376) adds to the picture by showing that the chemistry section of the 1771 *Encyclopaedia Britannica* was in fact almost an exact translation of Macquer's *Éléments de chimie théorique*. It thus provided an easily available source of chemical thought at a time when the phlogiston theory was accepted. In this section, the subject Chemistry will be compared in each new edition of the encyclopaedia from 1771 to 1930 with the aim of seeing how if at all, each edition represents the concept of physical and chemical change or the nearest equivalent concept used at the time.

Theoretically this should show thought about the nature of chemical change that would have been considered authoritative at the time that the article was written. The sum of all these articles should give a picture of the dynamic change in the concept of physical and chemical change. I will provide brief outline of each edition or of several editions together. The list of editions (Appendix 1) is a simplified picture of the editions held in the British Library, where I have included main editions and not supplements. Articles were written by scholars of the time and many are really books in themselves rather than articles.

#### 5.1.1 *The first edition*

The article on chemistry in the 1771 edition of more than 100 pages starts with a summary of Aristotelian theory (Air, fire, earth, water); it contains an explanation of phlogiston theory as current, though the author seems unconvinced by either the Aristotelian explanation or the phlogiston theory. Also included is the topic of affinity and elective attractions, salines, acids, alkalies and salts. The seven laws of affinity are said to be fundamental and it is asserted that explanations of all phenomena in chemistry can be deduced from them. The terms physical and chemical are not used, but the then current explanations of chemical change are to be found within the section on 'affinity'.

#### 5.1.2 *The second and the third editions*

The second edition is enlarged and improved and explains that when mixtures are heated some 'qualities' of the substances may cause them to join together and remain united. The cause of the qualities is unknown. Sir Isaac Newton called this unknown cause 'attraction'. The objects of chemistry are said to be salts, earths, metals, inflammable substances, water, animal and vegetable substances. The third edition of 1793 includes parts of the first and second editions with some new material but nothing new on 'affinity'.

#### 5.1.3 *The fourth, fifth and sixth editions*

The section on chemistry in the fourth edition of 1810 is expanded and its contents appear similar to many of the chemistry texts of the time. The fifth edition of 1817 and the sixth edition of 1823 appears, in general, similar to the fourth. The chemistry section for both editions starts with 'affinity' and each includes a history of the development of

the concept. It is noticeable that the phrases chemical affinity, chemical action, chemical change, chemical combination are used more or less synonymously and further that these phrases were used by chemists of an earlier era perhaps as far back as Boerhaave. The action of solvents bringing about solution was a matter of contention with Stahl who rejected the view expressed by Becker. The terms attraction of composition and heterogeneous attraction are used synonymously with the expression chemical affinity and Fourcroy's 10 laws of affinity are quoted.

#### 5.1.4 *The seventh, eighth and ninth editions*

There seems to be considerable change in the seventh edition of 1842. The earlier chemical history is scant and the later chemical history is fuller and much of the theory is included with the history. An interesting minor point is that in earlier editions Barchusen/Boerhaave were credited with the earliest use of the term 'affinity' (sixth edition, Volume 5, p. 430), but now it is Robert Hook who is given credit for first usage of the term affinity:

. . . first introduced to Chemistry by Dr Hook and caught with avidity by chemists on the Continent. (Volume 6, p. 356)

It is not of particular significance, but it may illustrate elements of nationalism creeping into these articles.

The eighth edition (1854) changes yet again and gives a detailed history of alchemy and early chemistry. This edition entitles a section chemical combination or chemical action. It is said that chemical action acts at insensible (means very small) distances: it is exerted between different types of matter and forms new substances. Further it is stated:

The evidence is found in changes of properties, both physical and chemical. (p. 439)

Later in the section there is an interesting discussion about allotropism (allotropy) and chemical change in which it is reported that a Dr Brown succeeded in converting 'carbon into silicon and iron into rhodium', though the author is rightly sceptical of these claims.



The ninth edition (1876) appears to be completely rewritten. By now the idea of affinity has almost disappeared and the phrase chemical action is usually substituted for the word affinity.

#### 5.1.5 *The tenth edition*

The author of the chemistry section of the tenth edition (1902-1903) was H. E. Armstrong (see Sections 4.6 to 4.6.2), a chemist and an educationalist. Armstrong does not repeat the whole history of chemistry yet again, but concentrates on those aspects where there had been significant research over the previous 25 years. One of Armstrong's sections is entitled chemical change; another is called physical properties. In the section on chemical change, Armstrong points out those absolutely pure materials do not react and that sometimes small amounts of impurity (and this is frequently water) allow reactions to proceed. This is one of Armstrong's favourite themes.

#### 5.1.6 *The eleventh, twelfth and thirteenth editions*

The writer of the chemistry section of the eleventh edition (1911) was Charles Everitt. The chemistry section of the twelfth edition of 1922 was again written by H. E. Armstrong, who discusses the rapid rate of advance of chemistry over the previous 50 years and makes a number of comments pertinent to the relationship between and definition of physics and chemistry. As examples of his views four of these comments follow:

The advance is mainly the outcome of studies in the borderland region between chemistry and physics and is due to much overlapping of enquiry

(Volume 30, 1922, p. 621)

No precise distinction can be drawn between the terms 'chemical' and 'physical'. The chemist has availed himself so fully of physical methods that he has made them his own and has difficulty in giving any precise meaning to the expression 'chemical property': nevertheless it has a clear connotation in his mind.

(Volume 30, 1922, p. 624)

The passage of water through its three states is too commonly represented as a series of physical changes; actually there can be little doubt that a complex series of structural changes is involved.

(Volume 30, 1922, p. 629)

The chemist in future will be associated either with the physicist or with the biologist, if not with both. (Volume 30, 1922, p. 637)

In the 1922 edition Armstrong (Volume 30, p. 629) gives a series of examples of chemical change and later claims that the theory that water is slightly dissociated (Arrhenius) is neither logical nor rational. Armstrong never accepted the ionic theory, though at the time he was writing ionic theory was well-established.

H. E. Armstrong also wrote the thirteenth edition of 1926. The section is completely rewritten (he would have been 78 years old at the time). Armstrong mentions a number of his usual concerns and manages one barbed remark at physicists having commended chemists on their consistency in using the term 'atom':

Physicists, thus far, have not made their minds up to use the terms (atoms) consistently. (Volume 1, p. 580)

#### 5.1.7 *The fourteenth and fifteenth editions*

Different parts of the fourteenth edition of 1926 have different authors and this edition contains a long section on the history of chemistry.

The fifteenth edition *New Encyclopaedia Britannica Macropaedia* has the following pertinent comment:

Hence, distinct from the historically developed ideas, a chemical reaction can now be defined as a process of change in which some bonds are broken and different bonds are formed. This definition includes all processes that involve a change of substance as well as many of the processes that involve a change of form, such as the freezing of water. (Volume 15, p. 1204)

#### 5.1.8 *Overall conclusion on using the Encyclopaedia Britannica as a research tool*

There has been some value in following an idea/concept through one reference type (*The Encyclopaedia Britannica*) over a long period of time. Disadvantages of the method for this topic are that in the earliest editions the concept of physical and chemical change did not exist, so the related concept of affinity was used instead. In some ways because

there are different authors, it is not certain that the view expressed in the *Encyclopaedia Britannia* was the general view of chemists of the time. In one case it was certain that the views of H.E. Armstrong on the topic of the dissociation of water were atypical of his times in 1921. The concept of physical and chemical change does not receive much attention in any of the editions of the *Encyclopaedia Britannia* though chemical change or one of its synonyms is frequently mentioned. It is noticeable that the written means of expressing chemical change (i.e. chemical equations) does change and become more meaningful to the modern observer through the editions of the *Encyclopaedia Britannia*. Specifically the following observations were made.

- Older theories of matter were noted and discarded through the centuries
- The certainty of explanations increased through the centuries
- Various synonyms for chemical change were used and these changed with time from attraction of composition to chemical reaction.
- In no instance were physical change and chemical change used together in the expression physical and chemical change.
- It is noticeable that the writer who mentions the idea of chemical change most frequently (H. E. Armstrong) is an educator as well as a chemist.

## 5.2 Synonyms used in textbooks for chemical change

Rufus P. Williams makes the following assertion about physical and chemical change at the start of his book *Elements of Chemistry*:

We must at the outset learn to distinguish between physical changes and chemical changes in order to understand the province of chemistry.

(Williams, 1897, p. 1)

Synonym for chemical change (CC)	Reference for example	Comment
1. Chemical affinity	Beck, 1 Beck, 1834, p22 Wilson, 1858, p. 25  Fownes, 1852, p. 201  Morton & Leeds, 1866, p. 123	Beck states that Nos 1,3 & 4 are synonyms. Wilson advises students to use the more metaphorical term 'chemical affinity' rather than 'chemical attraction'. We might define affinity to be a force by which new substances are generated. Defined as a force of attraction between particles acting at insensible distances
2. Chemical force Force of affinity	Wurtz, 1880, p. 12  Mulder, 1850, p. 5	'Chemical force or affinity is at the same time more intimate and more powerful.' 'Chemical force' is 'Force of affinity'
3. Chemical attraction	Donovan, 1832, p. 25	'It is distinguished by the name of <i>chemical attraction</i> , or simply by the term affinity.'
4. Attraction of composition or Affinity of composition	Parkes, 1812, p. 395	'What do you understand by attraction of composition or chemical affinity?'
5. Heterogeneous attraction	Webster, 1839, p. 3	'When an attraction operates on dissimilar particles and produces their union...this kind of attraction is distinguished as heterogeneous: it is also called chemical attraction or affinity.'
6. Chemical metamorphoses	Griffin, 1860, p. 37	This simply means chemical changes and usage in this book is the only occasion that I have seen the expression.
7. Chemical union	Williams, 1893, p. 7	'The chemical union of the two (C & S) forms a volatile liquid.'
8. Chemical action	Parkes, 1812, p. 24.  Jago, 1892, pp. 2-3. cf Jago, 1896, pp. 2-3.	Whenever a chemical action takes place, a real change is produced in the substance operated upon and that its identity is destroyed' In the 1892 book, a main heading chemical action, but by 1896 physical and chemical change had become the main heading.
9. Chemical reaction	Rolfe & Gillet, 1874, p. 11	'A chemical change of this kind is called a reaction, and may be expressed in the form of an equation.'
10. Chemical interaction	Smith, 1924, p. 7	'When such an alteration occurs it is called a <i>chemical change</i> , or <i>interaction</i> or <i>reaction</i> .'
11. Chemical combination	Roscoe & Lunt, 1893, p. 12	Chemical action and chemical reaction for the two types of chemical action, namely chemical combination and chemical decomposition.
12. Chemical phenomena	Ostwald, 1902, p. 1  Cooke, 1870, p. 3	The term 'chemical phenomena' is defined... '... and the phenomena are chemical'

Synonym for chemical change (CC)	Reference for example	Comment
13. Chemism	Shepard, 1895, p. 13  Williams, 1897 p. 8	Chemism and cohesion both draw particles together- chemism holds compounds together-cohesion holds elements together. The word chemism, was put forward by J. P. Cooke as a synonym of affinity and disappeared when affinity ceased common usage.
14. Chemical change	Reid, 1837, p. 7 Remsen, 1895, p. 2	'These last are chemical changes' Physical and chemical change was Remsen's main focus in his first chapter.
15. Chemical process	Ewing, 1809, p. 34 Cooke, 1892, p. 109  Black & Conant, 1924, p. 5	"Precipitation is another chemical process." 'In every chemical process molecules are either divided or constructed.' Used as a synonym of are chemical change
16. Chemical transformation	Steele, 1874, p. 20	'In chemistry we shall see how chemical changes are produced by transformations without loss of matter'
18 Atomic attraction	Avery, 1884a, pp. 4-5	Avery calls 'Chemical affinity' 'Atomic attraction'. Usage in this book is the only occasion that I have seen the expression.

**Figure 5.1** Synonyms for chemical change

This assertion may now seem extreme, but it was the view of chemical educators over a considerable of time. The implication is clearly that a student could not understand chemistry without first understanding physical and chemical change. The synonyms and expressions for chemical change or with an approximately similar meaning to chemical change used over the last two hundred years can be found in Figure 5.1. It is interesting to note that Reid (1837, p. 7) provides a sub-heading in his first chapter called 'Difference between chemical and mechanical change'. Reid's use of the comparison between chemical and mechanical change is a very early usage of the phrase. Hugo Reid (Reid, 1837, p. vii) was a school teacher in Glasgow, Scotland and had just started a chemical class for boys between seven and fourteen years of age at Glasgow High School. He also details the objects (objectives) of the teaching of this course. His book, called *The chemistry of nature*, uses comparatively simple language and clear explanations. In other words he is attempting to write the book in the light of his teaching experience and it is interesting to note that chemical and mechanical change is a part of his explanation of the nature of chemical combination.

Similarly Gale (1837) also shows early usage of the phrase, physical and chemical, as in the opening remarks of his book he states that:

All substances with which we are acquainted are endowed with two kinds of property, physical and chemical. The former belong to natural philosophy, the latter to chemistry. (Gale, 1837, p. 2)

Leonard Durnell Gale (Section 4.2.5), an American, who was a teacher, university lecturer, patent examiner and inventor's assistant had a very exciting life suffering fire, robbery and shipwreck (Miles & Gould, 1994 p. 107). In his book, *Elements of chemistry*, he compares physical and chemical properties.

Perhaps the fact that two individuals so separated by distance are comparing the physical/mechanical and the chemical at the same time indicates this way of seeing things was part of the established knowledge for both of them, yet for pedagogical simplicity in their writings they prefer it to discussing attraction of composition or affinity of composition. They both seem to be individuals ahead of their time.

### 5.3 Dictionary definitions of physical and chemical change

From early in the writing of this thesis, the concept of physical and chemical change has seemed as much a pedagogic and linguistic construction as a scientific one. If this is the case, it seemed reasonable to suppose that the way that dictionaries and other reference works refer to physical and chemical change might be a means of clarifying the concept.

Firstly, a large number of very general reference works were consulted with the aim of finding out if the word 'chemical' and the word 'physical' are connected at all in the world 'outside science'. Reference works included standard English dictionaries, thesauri, books of quotations, a guide to related words, a synonym finder, a key-words reference, a dictionary of contrasting pairs, a dictionary of English usage, a dictionary of ideas and a dictionary of modern thought. Little of substance was gleaned, but there were some indicators. Apart from standard definitions of chemistry (Turner, 1987) the dictionary does introduce the figurative usage of 'chemistry' as a mysterious change or process. The word chemical did not appear to

have a synonym whereas the word physical had many synonyms (Rodale, 1981). Again, in the guide to related words, the word chemical is not mentioned but the contrasting pair related to the word physical is given as spiritual. Rees (1994, p. 147) says that Sir David Frost started the phrase sexual chemistry or personal chemistry, denoting mystery and attraction, perhaps referring to an original quotation by G. B. Shaw from *You never can tell*. 'Let's call it chemistry . . . Well, you're attracting me irresistibly—chemically' (Quoted from Rees, 1994, p. 147). Shaw had learned the nineteenth century lesson that chemical action was an attractive force.

The main conclusion that can be drawn from consulting this wide variety of general reference works is that there is no evidence from these reference works of a connection between physical change and chemical change and little evidence that either of these terms is in common usage. In fact, the contrasting pairs chemistry/physics: chemists/physicists: chemical/physical seem unnoticed in the wider world of the English language.

However, perhaps a search of scientific reference works will yield more positive results. The following terms (affinity, cohesion, chemical change and physical change) have been checked in a variety of scientific reference works of various periods and the results tabulated. It was thought that the size of the reference work, its place of publication and the particular science being referenced might be factors in deciding whether physical and chemical change were included within the reference books or not. Appendix 2 includes these tabulated results.

### 5.3.1 *Physics and chemistry: Physicists and chemists: Physical and chemical properties: Physical and chemical change*

There appears to be very little confusion between physics and chemistry or with the occupations described as physicist and chemist, respectively. The fact that substances possess physical and chemical properties seems unremarkable, yet as will be seen later in this chapter the topic physical and chemical change causes considerable disagreement. As a matter of logic, this is surprising since all of these distinctions are equally difficult as there is no definition that distinguishes chemistry and physics absolutely. The next three sections attempt to show the

nature of the difficulty in defining physics and chemistry; physical and chemical properties; physicists and chemists.

### 5.3.2 *Physics and chemistry*

Lewis (1993, p. 254) having given a lengthy definition of chemistry in terms of its central concerns makes the point that chemistry is not an isolated discipline but merges into physics and biology. (Perhaps, Lewis should have added geology and astronomy too!). There is also a note that is quoted below:

Chemistry has been variously defined, to the point where definition has become a semantic exercise of questionable if not negative value. "Chemistry is the science of matter" and "Chemistry is a branch of physics" are two instances of such definitions. The first relegates physics to the background while the second accords it supremacy. (Lewis 1993, p. 254)

### 5.3.3 *Physical property and chemical property*

Deming and Arenson (1935, pp. 3-5) identify 18 sorts of physical properties but limit themselves to four sorts of chemical properties. Goostray and Karr (1943, p. 9) tabulate 13 physical properties and six chemical properties. A survey of texts that list physical and chemical properties show different numbers of properties stated to be either physical or chemical. Properties such as taste or smell can be defined as physical on some occasions and chemical on others.

### 5.3.4 *Physicist and chemist*

Becher (1993) produced a large scale study of various academic disciplines including physics and chemistry, observing the boundaries between them and also the similarities. In Figure 5.2 some differences between physicists and chemists that Becher obtained from his survey are recorded.



Page and characteristic	Physicists	Chemists
Inclusion of idols, p. 23.	Physicists display dust jackets of books by Einstein, Planck or Openheimer prominently	Chemists display three dimensional structures on their desks.
Problem solving techniques, p. 39.	Physicists look for deductive solutions to problems.	Chemists look for inductive solutions to problems
Arrogance, p. 75.	Physicists know that they are smart because of their subject has the hardest and most abstract reasoning.	Chemists feel defensive in relation to physicists but they feel superior to biologists.
The average age of Nobel Prize winners, p. 127.	Nobel Prize winning physicists had an average age of 45-46.	Nobel Prize winning chemists had an average age of 50

**Figure 5.2** Differences between physicists and chemists (from Becher, 1993)

#### 5.4 Elements of paradox

The element of paradox is deeply ingrained in this thesis (see Section 1.2) and will emerge in a number of aspects. A further aspect of paradox will now be mentioned. Chemists might be differentiated simplistically as those who are practically orientated and those who are theoretically orientated. Part of the nature of the paradox referred to in the title is that the phrase 'physical and chemical change' may be understood differently by these two different groups of chemists. Those distinctions may be somewhat overdrawn, but one part of the paradox is that both groups find that their understanding of physical and chemical change is different.

Gower, Daniels and Lloyd (1977, p. 286) investigated some major chemical concepts. One of the basic concepts about which they found disagreement was that of physical and chemical change. They found that there is a greater disagreement amongst practising chemists about the order of teaching of the empirically derived chemical concepts, as shown in a concept map, than there is in the order of concepts of theoretically derived concepts.

Theoreticians have a deep interest in the nature of the chemical bond (chemical change) which may be considered an illusion or paradox. The old crone/young woman illusion used to illustrate the paradox of wave particle duality (Bernstein & Shaik, 1988), which lies at the heart of chemical change, shows that by changing the viewpoint slightly a different perception may be revealed. Similarly, authors

express radically different views about the nature of the chemical bond (DeKock 1987; Ogilvie 1990), though in general these arguments are for a scientifically sophisticated audience. Since chemical bonding is at least a part of the concept of chemical change and since according to current studies the concept of chemical bonding is still incompletely understood, the concept of physical and chemical change cannot be completely understood. However, the concept of physical and chemical change still persists in most secondary school curricula at an elementary level, where everything is understood to be 'fact' and this itself is paradoxical.

A second aspect to the paradox relates to the pedagogical understanding of this topic. Many teachers have a model of a spiral curriculum, where topics are taught a number of times at increasingly difficult conceptual levels as the child gets older. Teachers do not necessarily feel unhappy about teaching partially true statements at a lower level, provided they know that a fuller explanation will be given to the children as they progress in the subject. However, learners do find the topic of physical and chemical change difficult and the way that the learners understand this paradoxical concept will be explored. Unravelling some of the aspects of the paradox of physical and chemical change may lead to an improvement of the learners' understanding.

A third aspect of the paradox is that the practical definition of physical and chemical change is inadequate and sometimes contradicts other basic chemical concepts. The definition will be critiqued briefly now but it is an area that will be considered on a number of occasions later in the thesis.

## **5.5 Definition of physical and chemical change**

A 'hard line' definition of physical and chemical change, typical of older textbooks, is shown in Figure 5.3. The inadequacies of this definition are largely self-evident. I will include it at this stage so that an idea of what is meant by physical and chemical change, as frequently taught at a middle school level, is provided.

Briefly, each of the parts of the definition suffer from logical or pedagogical inadequacies. For example, when considering the first criterion, what is meant by a new substance may not be obvious or when considering the second criterion, strictly

speaking, there are no changes in weight in either a physical or a chemical change if all reactants and products are weighed. I was certain that a better definition could be produced, so in the earliest papers I wrote, I tried to produce simple models as diagrams, which might be used in teaching. Figure 5.4 is a simplification of Figure 5.3 representing physical and chemical change as entirely distinct entities.

PHYSICAL CHANGE	CHEMICAL CHANGE
No substance formed or destroyed.	Substances changed - new substances formed.
No change in weight.	Change in weight.
Reverse change easy.	Reverse change difficult.
No energy produced although energy may be changed from one form to another.	Energy in the form of light or heat may be given out as a result of chemical change.

**Figure 5.3** Comparison of physical and chemical changes: A traditional view

PHYSICAL CHANGE	CHEMICAL CHANGE
-----------------	-----------------

**Figure 5.4** The simple model which has only physical change and chemical change opposed

The Venn diagram in Figure 5.5 was found in Atherton and Lawrence (1978); it expands on the simple model and adds clarity, including an intermediate category of reversible chemical change.

I then produced my own 'softer' improved version of how physical and chemical change might be defined (Palmer, 1989a). Here is the suggestion of an improved teaching model to explain types of change as a spectrum or continuum of change (Figure 5.6) and this might revise and update students' ideas at a Year 11 level. I have to say here that when I produced this idea in 1989, I thought the idea of a continuum was my own unique idea, but several of the respondents to my questionnaire (see Chapter 9) without seeing this suggestion say that this is what they think too.

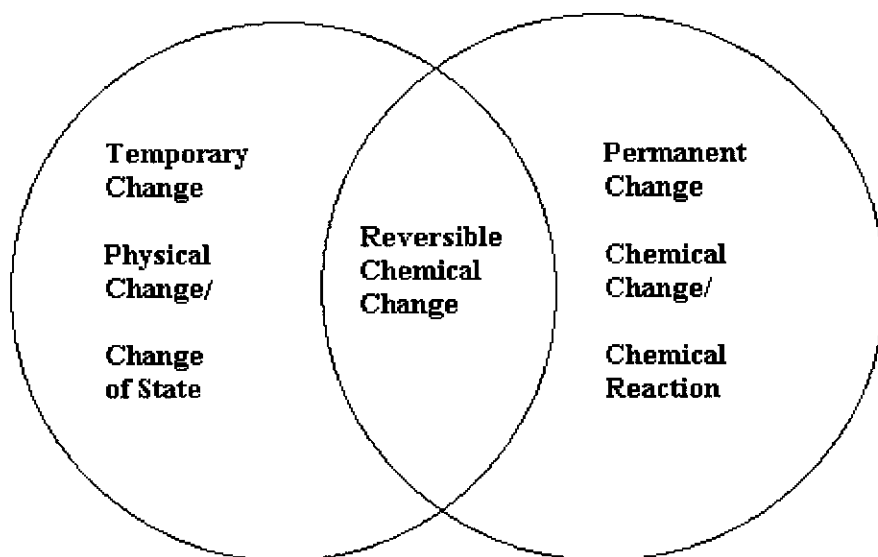


Figure 5.5 A Venn diagram of physical and chemical change

I now offer it merely as a way of representing a continuum of change without any claims of originality.

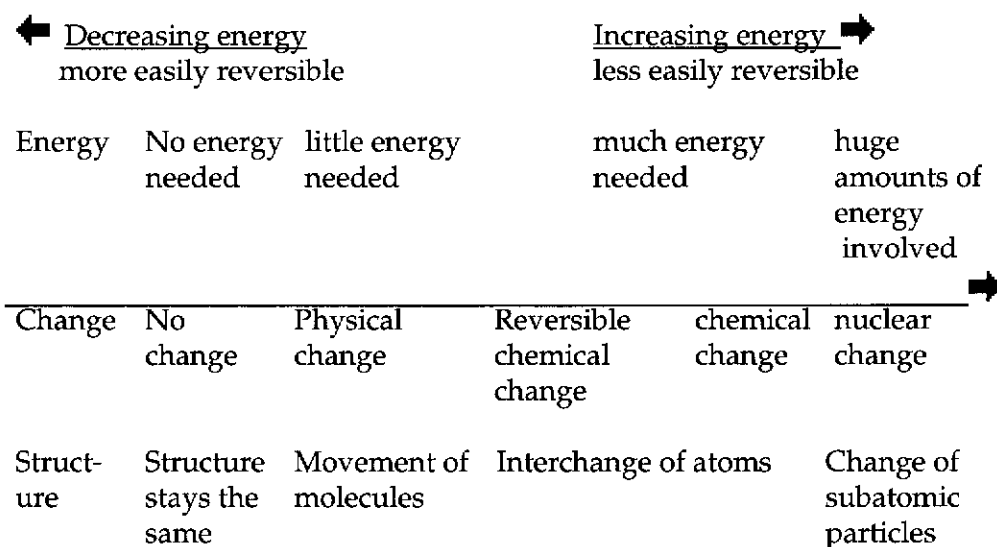


Figure 5.6 Spectrum of change or change continuum my view

However, whether the softer or harder versions of the definition based on practical criteria are chosen, it is still not possible to place all changes into one category or another on the basis of either definition. The paradox for the practical chemists is

that they have been using a pedagogically unsatisfactory definition since 1870 or so to teach students about the nature of matter. If logical and consistent definitions are pressed to the limit, they tend either to make all changes chemical or to make them all physical, dependent on how the definitions are applied.

Further, the topic of physical and chemical change has been the subject of a heated debate over a long period. I will now indicate the course of that debate by mentioning some of those influential in it and quoting their views.

#### 5.5.1 *Typical areas where the definitions of physical and chemical change fail*

The standard versions of the definition of physical and chemical change are adequate for the majority of changes but there are particular topics in chemistry where the definitions are not adequate. Although improving definitions may reduce the number of topics where the definitions are inadequate, I suspect that it is not possible to make definitions that define the border between physical and chemical change absolutely. So I tend to agree with Snyder (1996), who is a successful textbook author, when he says:

Thus while I do wish you success in your questionnaire, my own opinion is that attempting to distinguish rigorously between a physical change and a chemical change is at best a hopeless task. (Questionnaire response)

The key word in Snyder's assertion is rigorously and even if a rigorous definition is not possible, it should be possible to have a better definition than is at present available. In my view, the following topics give problems in the literature. It is not my intention to provide answers at this stage—rather some answers will become apparent later in the study, whilst for some questions there is no clear answer.

- Solution. Is a solute dissolving in a solvent a physical or a chemical change? This may be subdivided for solutions in water into ionic substances dissolving in water (salt) and into non-ionic (covalent) substances dissolving in water (sugar). For solvents other than water each case will need to be considered, but in general the dissolving of covalent solutes in covalent solvents is usually considered to be a physical change.

- Water of crystallisation. Is heating a crystal containing water of crystallisation a physical or a chemical change?
- Boiling or freezing pure substances. Is boiling or freezing water a physical or a chemical change? Is boiling or freezing other pure substances a physical and chemical change?
- Sublimation. Is sublimation a physical or a chemical change? Here one must be careful that the substance really sublimates. If a substance really sublimates, then this is a phase change (a physical change only).
- Allotropy. For elements, is the changing from one allotrope to another allotrope a physical or a chemical change?
- Polymorphism. For compounds is the changing from one polymorph to another polymorph a physical or a chemical change?
- Buckminsterfullerene. If the buckminsterfullerene molecule has metal atoms added within the soccer ball-like framework, so that they are permanently entrapped, this alters the properties of buckminsterfullerene considerably. Is this a physical or a chemical change?
- Irreversible physical change. Examples might be sawing wood, breaking glass or mixing gases that do not react chemically. These are stated to be physical changes, but the consideration of changes like these add to the difficulty of producing an adequate definition of physical and chemical change as these instances are not easily reversible.
- Berthollides. Berthollides are substances that do not have a fixed composition. Is the formation of a Berthollide a chemical change since these compounds do not obey one of the basic laws of chemistry?

In addition to these points there are two other important considerations, one scientific and one pedagogic.

Firstly, the answers to the issues raised above depend on whether one is to look at the phenomenon on the large scale with amounts of material being easily visible to the human eye and the human experience (macro scale) or on the atomic scale (micro scale).

The second problem is to decide at what level of student experience, that the teaching and learning is taking place. For example, one might be correct in

explaining to 16 year olds that water changing to steam could be considered as a chemical change due to the breaking of hydrogen bonds as they would have had experience of hydrogen bonding elsewhere in their curriculum. However the explanation of water changing to steam would be considered as a physical change if one were teaching eight year olds as no new substance would be apparent and the gaseous steam returns to being liquid water on cooling. For some, this apparent contradiction is so great that their conclusion would be not to teach the concept of physical and chemical change at all. Others would say that the concept of physical and chemical change should only be taught to children in primary school. Others would argue that the concept of physical and chemical change should only be taught to children when they had understood more about bonding and orbitals, late in secondary school. All these are understandable positions, yet the reality is that the concept of physical and chemical change is taught at all levels between kindergarten and first year university. Having seen what some issues may be, the study will now indicate what has actually been said publicly about the concept of physical and chemical change using any media.

## 5.6 The debate about of physical and chemical change (historical)

The very controversial nature of this topic is illustrated nicely by one of the respondents to the questionnaire who made this point by telling a story, which whether true or not, fits in well with the anecdotal reflective style that I am trying to use. Snyder (1996) recounts the story thus:

While I can't go into as much detail as the questionnaire would probably ask for, I can give you a brief statement on my views of chemical and physical change. It's best summed up in an anecdote, presumably true, I heard at the University of London.

According to this story, presented as factual, a particularly capable undergraduate student approached his chemistry professor, who was among a group of departmental colleagues at the moment. The student apologised for interrupting and asked quietly if the professor would simply tell him whether the dissolution of sodium chloride in water is an example of a physical or a chemical change.

The professor answered that it is a physical change. One of his colleagues heard the brief discussion and interrupted to point out that since the breaking of ionic bonds of the crystal and the formation of new bonds of solvation spheres were occurring, the change should properly be classified as chemical. At this point still another colleague joined in with the observation that, no, dissolution of a solid in a liquid is properly classified as a physical change. Another objected that it is, indeed a chemical change. The discussion grew in the number of participants, in the depth of emotion generated, and in volume.

Finally the embarrassed student mumbled a brief apology and left quietly.  
(Questionnaire response)

The more profound point of all this is that our classifications into categories such as physical and chemical are often based on arbitrary and malleable definitions of what can be considered chemical and what can be considered physical. The course of the debate about physical and chemical change in the twentieth century is now recounted historically.

Ida Freund's biography was provided in Sections 4.7 - 4.7.5. Her interest in the teaching of chemistry, her concern for accurate practical work and her interest in chemical composition naturally lead her to express views on physical and chemical change. Some of these views are quoted below as will some of H. E. Armstrong's views (see Sections 4.6 - 4.6.2). This gives a starting point of about the first decade of the twentieth century to show that from that time on there is almost continuous debate about the usefulness of the concept of on physical and chemical change.

#### 5.6.1 *Ida Freund's views about physical and chemical change*

Ida Freund's views are expressed mainly through her book *The experimental basis of chemistry*:

Then there are the debatable cases, i.e. instances of changes, about the classification of which as physical or chemical there is difficulty and difference of individual opinion.  
(Freund, 1920, p. 78)



A number of the changes about which there might be disagreement are mentioned. Then she changes style from being logical and quietly scientific to being quite sharp:

There has been a great deal of useless and time-wasting argument as to whether the change produced in solution should be classed as physical or chemical; the question when put thus it really quite independent of any hypotheses and theories concerning the state of the solute in solution, that is, of the condition of its constituent particles and of their relation to those of the solvent. In the present instance it is merely a question of adjustment between definition and actual phenomena: if, as is the case, we have by our own free choice decided upon a definition of chemical change which hinges on the formation of a new kind of matter possesses of new properties, then, applying these criteria, we have no choice but to class the process of solution as a chemical change. (Freund 1920, p. 79-80)

Two major issues may be gleaned from this. Firstly, Freund states that there is a lot of discussion about whether the dissolution of solutes in a solvent is a physical change or a chemical change. In Chapter 7, when considering affinity, I note discussion about the nature of solution in the 1860s and it remains an unresolved issue in more recent textbooks of the 1960s.

Secondly, she points out that the conclusion that is reached as to whether a change is physical or chemical, depends entirely on the definition that is given to physical and chemical change. However, many of those expressing views one way or the other forget this simple point.

#### 5.6.2 *H. E. Armstrong's views about physical and chemical change*

Armstrong (1910) frequently referred to the teaching of physical and chemical change. Below is an extract from a useful article in which Armstrong gives his views on how not to teach physical and chemical change:

At the outset of a chemical course, for instance, the university extension lecturer, in good old fashioned style, usually thinks it necessary to define chemical as distinct from physical change, instead of allowing such ideas to

grow up gradually and naturally, as Topsy did; forgetting that his hearers are entire strangers to such words as "physical" and "chemical". . . .

(Armstrong, 1910, pp. 382-383)

However, later in the same passage, Armstrong (1910) explains the way he thinks physical and chemical change ought to be taught:

Let me be constructive. At the beginning of the course, I would give no definition whatever—would say nothing about the difference between the changes; but having directed attention to the constant occurrence of change would suggest that changes should be studied . . . (Armstrong, 1910, p. 385)

Armstrong (1910, pp. 385-390), having got himself quite worked up, continues criticising his old foes such as textbooks, dogmatic teachers and the examination system but then explains at length how he would use the rusting of iron and the action of acid on zinc or iron to illustrate chemical change. However, he goes further and has his imaginary pupils constructing apparatus to give a constant flow of hydrogen in quantity to produce sufficient water to test its boiling and freezing point. He also has an imaginary school inspector praising and encouraging the pupil's efforts (Armstrong, 1910, p. 391). He makes the educationally sound points, that pupils who followed his heuristic methods, would become more self-sufficient and intelligent, learn to work cautiously and exactly, to be logical and guarded in their judgements and to understand scientific method. Were his educational methods to be viewed by experienced teachers today, they would be criticised on grounds of safety, time expended for limited cognitive gain and the practical classroom difficulties of equipment and resources that would be involved.

### 5.6.3 *Early British debates about physical and chemical change*

There is a record of a discussion about introducing chemical theory to school courses from 1924 in the *School Science Review* when E J Holmyard says that he adopts the Dalton plan by which he means 'atoms, atoms and more atoms'. He goes on to say that:

One great advantage of an early acquaintance with the atomic theory is that all the tedious differentiation between "mixtures and compounds", "physical and chemical change", which to the young appears dull, unreal and mere quibbling is cleared up in half an hour.

(E. J. Holmyard reported Anon, 1924, pp. 148-149)

E. J. Holmyard continued with his solution to the problem he outlined as follows:

A compound consists of one kind of molecule only, a mixture of at least two kinds. The deduction of the various differences which are the result of this fundamental distinction affords a useful exercise of the intelligence. Chemical and physical changes can be considered in the same manner.

(E. J. Holmyard reported Anon, 1924, pp. 148-149)

In this section, only the main points of a discussion are recorded by an unknown reporter, so arguments may be incompletely recorded. Holmyard's methodology was to falsify each of the historically incorrect chemical theories in turn—mercury/sulfur: phlogiston: oxygen theory. Although Holmyard does not appear to oppose the teaching of physical and chemical change, he considers it tedious. Generally the concept of physical and chemical change might be thought to fit in well with an historical approach, but the varying viewpoints show that there is no one historical approach and no one modern approach. Bradley (1940) wrote a witty discussion in the *School Science Review* in the form of a Socratic dialogue that points out a number of the traps into which the unwary may fall when trying to distinguish between physical and chemical change.

At about the same time (between 1941 and 1943) in the *School Science Review*, there is a debate about 'physical and chemical'. In the main article G. N. Copley (1941a) discusses physical and chemical change. He then questions whether the topic of physical and chemical change should be at the beginning or end of chemistry courses. Letters then elicit even stronger views as Copley then states that 'it is not rational to divide properties into physical and chemical types' because 'experiments show that properties vary continuously' (Copley, 1942a). He also considers that only the latest theories should be taught so that students need not 'unlearn to learn' (Copley, 1942b). In other words, he would oppose teaching chemistry historically. It

should be noted that some of these discussions relate to physical and chemical properties rather than physical and chemical change. L. H. Angus (1941; 1942; 1943) asserts that it is reasonable to teach physical and chemical properties.

One of the most celebrated books on lecture experiments is that by G. Fowles which contains a brief bibliography and history of other books of lecture experiments (Fowles, 1957, pp. 8-13). Amongst the experiments of which Fowles gives details he sometimes includes general teaching notes which is advice to teachers based on his own extensive experience. He gives moderate and reasoned advice about the teaching of physical and chemical change (Fowles, 1957, pp. 20-21). The advice is given at an interesting time in that it is just prior to the start in both the United Kingdom and the United States of many curriculum reform projects in chemistry. His heading is 'Chemical and physical changes teaching notes'. Fowles (1957) starts of in general terms:

When presenting these conceptions we meet an oft-recurring and difficult teaching problem. Shall we for the sake of clarity, simplicity and examination purposes be dogmatic and try to make a hard and fast distinction between these changes, or shall we not? (p. 20)

Fowles mentions the problems of solutions, sublimation and allotropy in particular which pose difficulties as classifying as either physical and chemical change (see Section 5.5.1). He then makes two suggestions for the successful teaching of physical and chemical change:

In my opinion it is unwise to inculcate in young pupils the idea that the distinction between physical and chemical change is one of profound theoretical significance. My own practice is to select illustrations which sharply distinguish the two types of change, to avoid stressing the importance of the classification and to admit the difficulty.

(Fowles, 1957, p. 20)

Fowles conclusion is simple:

We reach the conclusion that whether certain changes are chemical or physical depends on how we define these terms. (Fowles, 1957, p. 21)

In my view there is considerable wisdom in what Fowles had to say, but the next set of curriculum changes brought the debate to the boil once more.

Newbury (1966) (first edition 1935) offers similar advice to Fowles about teaching physical and chemical change which is really the traditional view put forward by the Science Teachers' Association.

Intelligent pupils often experience difficulty in the comparison of chemical and physical changes, owing to the lack of clear-cut distinction, and the teacher must be prepared for some awkward questions. (p. 213)

Newbury continues in a rather apologetic vein about a number of cases where the explanation will be difficult and in these cases (the case of classifying concentrated sulfuric for example), the teacher is to tell the students that the definition contained the word usually. This did seem an unsatisfactory state of affairs. However, new teaching methods for chemistry are now introduced as is explained in the next section.

#### 5.6.4 *Physical and chemical change and chemical education reform in the 1960s*

Frank Halliwell was the driving force behind the movement (called Nuffield Chemistry) to reform chemistry teaching in Britain in the 1960s. In general, reform meant removing old terms such as valency and physical and chemical change. In the United States of America there was similar reform with the Chemstudy group and the Chemical Bond Approach Project.

The term 'changes in the structure and properties of matter' might well be stressed to students as a means of bringing together chemistry, physics and biology. There is a great need to get away from many of the hackneyed terms of the past. As an example, 'physical and chemical changes' is an expression which can be positively harmful.

(Nyholm & Halliwell ,1967, p. 143)

When discussing any so-called physical or chemical change the questions should always be raised: 'Can this change occur?' and, 'Will this change occur?' The piece of paper on which this is printed can burn spontaneously to form carbon dioxide and water and evolve much energy. This is because it is thermodynamically feasible—it has a large ( $\Delta G$ ) of reaction. However, it does not burn at 25°C because of the large energy of activation.

(Nyholm & Halliwell, 1967, p. 144)

The customary opposition between the notions of physical change and chemical change is an increasing hindrance to creative thinking as pupils mature. . . This done, it should be possible to dispense with the terms of chemical change and physical change, which often conceal more than they reveal.

(Coulson, 1962, pp. 8-9)

The problem was stated by the authors of the Chemical Bond Approach Project (CBA, 1964) who carefully explain how the different opinions, that people express on this topic, can be reconciled.

In chemical change the reactants and products contain the same atoms but differ in the pattern in which the atoms are arranged. The definition of a chemical change in terms of atomic theory differs from the earlier operational definition of chemical change in terms of observable properties.

(CBA, 1964, p. 35)

Such a conceptual definition tells you what to think about rather than what to do. Chemical change may thus be given either an operational or a conceptual definition. These two definitions suggest that changes in properties are associated with changes in arrangement of atoms. It is important to note that the two kinds of definitions will sometimes refer to a given change in the same way and sometimes not. When liquid water changed to steam, the operational definition labelled this as a physical rather than a chemical change. Comparison of the arrangement of the molecules in liquid water suggests that at least this physical change does not differ in principle from the changes ordinarily called chemical.

(CBA, 1964, p. 35-36)

In 1969 Langford and Beebe published their book *The development of chemical principles* which had a rather different basis to most textbooks in that the authors try to focus on chemical ideas and the way that those ideas developed. They state in their preface:

Our conviction is that involving the student as a *critical* participant in the development of ideas should be given first priority.

(Langford & Beebe, 1995, preface)

The book was recently (1995) republished in the *Dover reprint* series which gives it some more authoritative position amongst United States texts. More to the point, in discussing physical and chemical change, Langford and Beebe (1995, p. 2) give a reason for including the concept of physical and chemical change in their course rather than asserting that it should be included. They say:

The first distinction that must be made is that between *chemical* and *physical* change, because the definition of pure substance depends on this distinction. The arguments are inevitably somewhat circular, since the distinction may only be made after some idea of what is a *pure* chemical substance has been given. (p. 2)

The new outbreak of the argument occurred in the early 1970s in the pages of the *Journal of Chemical Education* with the protagonists being Gensler (1970) and Strong (1970). The discussion was fairly dignified but did not really break new ground.

#### 5.6.5 *More recent debate about physical and chemical change in secondary education*

There was a flurry of correspondence in *Chemistry in Britain* about physical and chemical changes in 1982 caused by the reaction of a practising chemist, Professor D. P. N. Satchell, from the United Kingdom when he learnt that his son was being taught chemistry.

My son recently showed me his O-level chemistry textbook. He finds some of its introductory statements and definitions confusing. The book certainly surprised me. The early sections contain statements that are woolly or wrong

by present day standards; indeed, wrong in terms of facts given later in the book. Some difficulties arise because the authors introduce chemistry by distinguishing between chemical and physical processes. . . It is only after these topics have been covered that sections dealing with atoms and molecules are given. . . . (Satchell, 1982, p. 161)

Satchell continues in a more aggressive vein.

. . . Another example of needless early inaccuracy concerns the distinctions made between physical and chemical changes. For chemical changes we learn that:

- (i) a new kind of matter is always formed.
- (ii) the change is not easily reversed.
- (iii) a large heat change is usual.
- (iv) the products have different masses from the reactants.

The opposite situations are said to apply to physical changes. These criteria do not bear serious examination! Why bother with them in books at this level? The properties of substances and the various processes relevant to chemistry can be fully treated without labelling them physical and chemical.

(Satchell, 1982, p. 161)

Various members of the educational establishment such as Garforth (1982) and Lowrie (1982) seek to present a more balanced view of the situation; it should be pointed out that both are textbook writers. Garforth made a lengthy reply to Satchell's letter, pointing out changes in examination curricula and in modern textbooks, adding that more money is needed for the purchase of textbooks. With regards to physical and chemical changes, she wrote:

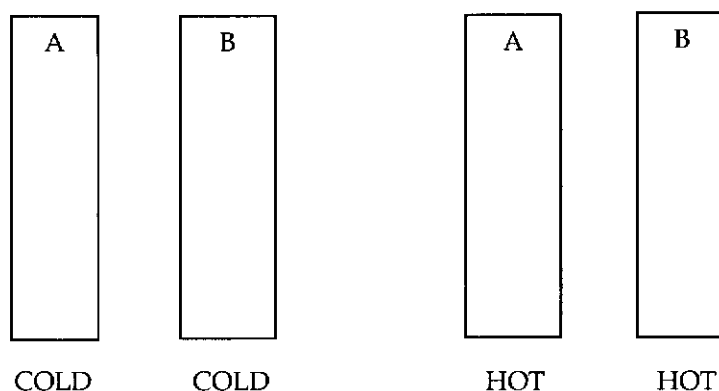
Incidentally, the 19th century distinctions between physical and chemical change, which he quotes are no longer required: the only criterion for chemical being that a new substance is formed. (Garforth, 1982, p. 340)



Lowrie (1982, pp. 340-341) states that he believes that Satchell's description of recent textbooks statements on physical and chemical change are inaccurate. Lowrie surveyed 18 O-level texts published since 1970 and found that none treated physical and chemical change in the manner described.

#### 5.6.6 *Brosnan's paradox*

Very much more recently still Brosnan (1999) puts forward an interesting set of chemical and physical changes which he asks us to classify; I have called this Brosnan's paradox. In this example, even an experienced chemist might well make an error in attempting to assign which reactions involved physical change and which involved chemical change. In fact his example is a more complex situation of a paradox (see Section 5.4). The problem is presented to graduate students training to be teachers. Here is the problem expressed diagrammatically (see Figure 5.7):



**Figure 5.7** Brosnan's Paradox

- Initially test-tube A contains solid lead nitrate and a solution of potassium iodide when cold.
- Initially test-tube B contains solid lead iodide and a solution of potassium nitrate when cold.
- Both test-tubes are heated to near boiling
- Test-tubes A and B now both contain lead, nitrate, potassium and iodide ions in solution.
- Both test-tubes are cooled to room temperature.
- In both test-tubes the lead iodide precipitates out and the potassium and nitrate ions stay in solution.

Evidently the student-teachers that Brosnan was teaching came to the conclusion that what happened on cooling was a physical change in one beaker and was a chemical change in the other beaker using the following argument.

In one case we have dissolved and then precipitated lead iodide from a mixture of lead iodide and potassium nitrate—a physical change according to the students. In the other case, we have made lead iodide from a mixture of lead nitrate and potassium iodide—which they agreed was a chemical change.

(Brosnan, 1999) at <http://www.rsc.org:86/read?491,101> (Accessed 7/4/99)

Brosnan then asks his students where the chemical change occurred. The conclusion that they reached is that dissolution occurred in both beakers on heating the mixtures (only physical changes). It was agreed that the contents of both beakers were the same after heating. Students agreed that a physical change occurred on cooling the first beaker as the original lead iodide was simply precipitated to form solid lead iodide again. They agreed that in the second beaker there had have been a chemical change as a new substance had been formed. This is, of course, ridiculous as the same change cannot be simultaneously a physical change and a chemical change. This is again another paradox. Brosnan provides an excellent analysis of this situation on the sub-micro scale pointing out quite correctly that the ions present throughout are identical with the only difference being whether the ions are free in solution are fixed as ions in a solid.

I would like to look at this on the macro-scale, which Brosnan does not do. Are there enough clues in carrying out the experiment practically through careful observation to decide whether changes are physical or chemical? I think there are, but whether or not I am correct does not detract from Brosnan's powerful pedagogical arguments which follow.

Three points strike me about this example:

- I have memories of qualitative analysis where one confirmatory test for lead is adding potassium iodide to the soluble lead salt seeing a yellow precipitate, which indicates lead, followed by heating the solution and

cooling it again, when beautiful glistening golden spangles of lead iodide confirm the presence of lead.

- I think historically of Berthollet's misconceptions concerning chemical combination after his observations of sodium carbonate on the shores of the salt water lakes in Egypt (Section 3.3.1) and relate this to Guldberg and Waage's law of mass action (Section 3.7).
- I remember reports of some chemical education research work on solid lead nitrate and potassium iodide (de Vos & Verdonk, 1985a; 1985b). The experiment described in the first paper uses the chemical reaction between solid lead nitrate and solid potassium iodide. There is a brilliant yellow mark where the two solids come into contact. The second experiment describes the same chemicals reacting in solution.

The major observation is that the substance lead(II) iodide whether existing as a solid or in aqueous solution has a yellow colour. Thus seeing yellow in solid or in solution where there was previously no yellow colour before will indicate a chemical change.

If a crystal of the solid lead nitrate in test-tube A which has been in the presence of potassium iodide solution is examined under a magnifying when still cold, the crystal will be seen to possess an outer yellow coating of lead(II) iodide, showing a chemical reaction has taken place. However, it may be easier to see the reaction in A taking place in two stages—firstly the lead(II) nitrate dissolving so that there is a solution of lead(II) nitrate in water at room temperature—secondly the solutions of lead nitrate and of potassium iodide being mixed together. This simplifies the situation as students should realise that the contents of both test tubes consist of the same substances (lead(II) iodide as a precipitate and potassium nitrate). Thus after an initial chemical reaction in test tube A, all further reactions are physical changes if viewed on a macro-scale or as chemical changes if viewed on a sub-micro scale. The problem was made artificially complex to accentuate the element of paradox.

However, Brosnan is correct in saying that the solution to this paradox is beyond beginning chemists and perhaps beyond new graduates too. Like many problems it is solved on the basis of experience. His final argument is very strong:

I believe that the distinction between chemical and physical change only makes sense if you already understand the chemistry, it does not help you to understand it. If you do understand the chemistry you do not need these terms since you already know what is going on. And there are many cases where both terms can be applied to the same change. So what is the point of using them?

(Accessed 7/4/99) (Brosnan, 1999) at <http://www.rsc.org:86/read?491,101>

#### 5.6.7 *More recent debate about physical and chemical change in primary education*

It is curious but amongst primary educators the concept of physical and chemical change seems accepted and welcomed. There seem to be no worries that the concept of physical and chemical change will cause problems for students at some later stage. For example, Revell (1995) from the Northamptonshire local education authority was in charge of a project to explain physical and chemical change through cooking. He writes:

Children need to learn to distinguish between physical change and chemical change and later from this idea of chemical change to develop an understanding of chemical reactions. (Revell, 1995, p. viii)

The Northamptonshire local education authority has produced an excellent book and project materials on physical and chemical change using cooking as an example. This is accepted in Britain due to physical and chemical change being included in the National Curriculum (Department of Education & Science, 1991) with cooking being specifically mentioned at 'level 2'.

#### 5.7 **Online debates about physical and chemical change**

Emails to news sites, to specialist list-servers (Palmer, 1996b) or homework chat lines can be said to be the modern equivalent to letters to learned journals (though these digital forms of communication have virtually no editorial checks). So far the debate about concept of physical and chemical change has been seen in terms of the printed word. It should be remembered that sending messages to news sites, specialist list-servers or homework chat lines as a means of communication is considerably more ephemeral than sending letters to learned journals. However, if

the educational value is seen in terms of those interested in chemistry participating in active discussion that is of value to their own learning, then this objection is trivial in comparison to the advantages obtained. In addition there are very large numbers of web sites (Section 5.7.4) giving information about physical and chemical change, some as instruction, some as experiments, some as questions. Many of these sites ask for responses, some just provide information, some provide ongoing interaction. It is the very large volume of internet sites that make me consider that whatever the outcome of a debate about the usefulness of the concept of physical and chemical change, the concept itself will be continually reinforced from the internet and its continued longevity is now ensured.

#### 5.7.1 *The debate via news sites*

As exemplars of a discussion on physical and chemical change on a news site, I will provide three emails. These three emails to 'science chemistry news' (sci.chem) were the result of a *Deja vu* search carried out on 17 May 1999 for emails originally sent in 1995. However, it should be noted that these files are no longer available at the *Deja vu* site (all material prior to 1999 is said to be temporarily withdrawn). It represents three opinions as examples of the way in which debate about controversial issues is carried out currently.

The first message, Figure 5.8 (News article 1), is stated to be about solution but really concerns allotropy as the discussion had moved on. Both topics cause difficulties for clear classification into the category of physical change or chemical change. What is of particular interest is the way in which the historically old concept of physical and chemical change has a variety of new explanations such as crystal structure and orbital theory superimposed upon it. It is hardly surprising that the theory is less than adequate for the task (see Section 3.7.3 on the Braggs' and Hodgkin's work on crystallography).

In the second message, News article 2 (Figure 5.9) the question "When you dissolve a salt in water (and it dissociates), is that a chemical or a physical change?" is asked. J. N. W. answers this in News article 2, whilst I add a different viewpoint in News article 3 (Figure 5.10). Overall the exchange went on for some weeks; I have copies of most of this discussion.

Forum: sci.chem.  
Thread: Solution  
Message: 32 of 61  
Subject: Re: Solution  
Date: 1995/06/05  
Author: J. A.

In article <Pine.SGI.3.91.950602144135.9582C-100000@cv4.chem.purdue.edu>,

> On 31 May 1995, J. N W. wrote:

> A phase change, regardless of the substance changing phase, is always a physical change.

> Provided that the substance is not altered chemically with the phase change (i.e., decomposition

> or polymerisation).

> Ok, I agree, but how should we treat the phase change where the chemical structure changes

> (diamond <--> graphite, S8 <--> S4, etc.)? This is not the "same species in the different state",

> it's now different substance.

It's been a long time since I thought about such things, but here is what I remember, the change you refer to graphite-diamond etc. implies a chemical change, you see graphite-diamond, white phosphorus to yellow phosphorus etc are the same chemical element with different structures (bonding) they are called allotropes, for example, in graphite C goes from sp<sup>2</sup> to sp<sup>3</sup> in diamond, bonds break and reform, I would call this a chemical change, not a phase change. Do you know what crystallography is, well it simply is structural characterisation of crystalline solids, let say a crystal is determined to crystallise in a fcc structure like diamond, (this example is hypothetical), now cool it down and say our analysis shows the structure of the molecules themselves are unchanged but the crystal falls into a different class called bcc, this is a phase change (a physical change) though it remained a solid all the time.

### Figure 5.8 News article 1 from news sites debate\*

\*The content of all these articles remains unchanged, but editorial changes to spacing format and spelling, have been made. Full names of authors have been replaced by initials.

Forum: sci.chem  
Thread: chemical or physical change?  
Message: 35 of 61  
Subject: Re: chemical or physical change?  
Date: 1995/05/26  
Author: J. N W

L. R. P wrote:

> Here's a question a student came up with:

> When you dissolve a salt in water (and it dissociates), is that a chemical or a physical >change?

I would say this is a physical change only because no chemistry has been performed. It's simply a phase change, solid to aqueous.

> What about when you heat a hydrate to drive off the water?

This is more tricky. I would say this is a chemical change because you have changed the species chemically. It's no longer CuSO<sub>4</sub>\*6H<sub>2</sub>O, it's just plain CuSO<sub>4</sub> now. You have removed one component of the original compound.

J. N. W.

Physical Chemistry Graduate Student, University of Nebraska - Lincoln

### Figure 5.9 News article 2 from news sites debate\*

Thread: chemical or physical change?  
 Message: 31 of 61  
 Subject: Re: chemical or physical change?  
 Date: 1995/06/10  
 Author: W. P. P.

J. N W. wrote  
 >It's no longer  $\text{CuSO}_4 \cdot 6\text{H}_2\text{O}$ , it's just plain  $\text{CuSO}_4$  now.  
 Just to correct a minor error first:  
 Hydrated copper II Sulphate has a formula  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$  (not  $\text{CuSO}_4 \cdot 6\text{H}_2\text{O}$ )

L. R. P. wrote:  
 > Here's a question a student came up with:  
 > When you dissolve a salt in water (and it dissociates), is that a chemical or a physical change?  
 > I would say this is a physical change only because no chemistry has been performed. It's simply  
 > a phase change, solid to aqueous.

This question and the answer given are interesting in that in my opinion, the differences between physical and chemical change are matters of definition. Specifically it depends whether the definition is looking at the change in terms of macro-chemistry (at the visible level) or in terms of micro-chemistry (at the atomic level)

At the macro level the salt can be obtained from the solution exactly as it was before it dissolved, fulfilling the criterion of reversibility that is said to be typical of a physical change.

At the micro-level the act of dissolving an electrolyte in water will usually change the ionic species formed (water molecules will cluster around the ions). It can thus be stated the change is a chemical change because a new chemical species has been formed. The fact that overall the original salt can be recovered merely reverses that chemical change.

These arguments are old ones and may be confusing to tyro chemists, but I hold the view that there are many common classifications in chemistry, where the definitions that beginners start with, change with the student's understanding and maturity. In the end this is no bad thing, but I welcome other views.

> What about when you heat a hydrate to drive off the water?  
 > Yes! Difficult to argue this is anything than a chemical change.

W. P. P.- Faculty of Education, Northern Territory University, DARWIN, NT 0909

**Figure 5.10** News article 3 from news sites debate\*

### 5.7.2 *The debate via listservers*

I have frequently been both an observer and a participant on the Chemed-L listserver in which a changing number (usually about a thousand) of enthusiastic chemistry teachers who discuss issues involving chemistry. I have found being a member of this list to be a most valuable experience. The archives are available back to 1996 at the following URL: <http://www.optc.com/chemed-l-thread/>

In most years the question of physical and chemical change gets raised at least once so here I have chosen a discussion of October, 1999 as an example of a debate on

physical and chemical change. From the earlier URL, the Chemed-L Thread Index for October, 1999 is found or the URL below may be contacted directly:

<http://www.optc.com/chemed-l-thread/Thread4456.html>

Subject: chem or phys change  
From: J. S.  
Date: Wednesday, October 6, 1999 8:52:43 AM

I had a student look up "baking a cake" on the Internet and she found a source that claims that baking food is actually a physical change. Our text says that it is chemical. I have always believed that it is chemical because the substances' identities are changed. Is this true? Surely the eggs and sugar and baking soda all undergo some type of chemical reaction upon being heated.

We all know that sugar undergoes a chemical change upon heating. Is the heat from baking high enough to cause this....

Thanks in advance for replies!

J. S. :) AP Biology, Chem 1 and Chem 2 teacher

**Figure 5.11** A question from a listserv

Subject: Re: chem or phys change  
From: D. D.  
Date: Tuesday, October 12, 1999 5:19:15 PM

Of course it is both, though most of the changes you mention are chemical.

I wonder why we make such an issue of physical vs. chemical change in beginning science. I know we want students to understand that there are different kinds of change, but the definition we try to use to explain the differences to students are often flawed.

In what way is it obvious that the identity of a substance does NOT change in a physical change? Example: ice does not have any of the same obvious characteristics as water. It would appear that it has changed.

We of course know that the change does not involve any change in MOLECULAR structure, which is why we really identify this as a physical change. When we decompose water through electrolysis, the atoms do rearrange to make new molecules, which is why we really identify this as a chemical change.

But we didn't reach that conclusion on the basis of a simple examination of observable properties. It is a conclusion reached on the basis of a lot of evidence. The simple test of reversibility given in many textbooks isn't really all that clear. Most texts would say we can't un-cook an egg, which means it is chemical change (but you can recombine  $H_2$  and  $O_2$  to make  $H_2O$ , so does that mean electrolysis is not chemical?)

I teach my students that one test is never enough, and that we have to look at a lot of things to make this decision. One of the main ones is the amount of energy involved in the process (chemical changes often being 50+ times greater than physical).

Like most things in chemistry (polar/non-polar, ionic/non-ionic, organic/ inorganic etc.) we want to polarise everything. It makes it easy in one way, but it also obfuscates the reality that very few things are really all that distinct (where does a polar molecule suddenly become classified as ionic?) As long as we understand that there are different kinds of change, some involving rearrangement of atoms, others not, but all of them involving changes in potential energy, does it matter whether we call it physical or chemical?

**Figure 5.12** One of several answers from a listserv



In answering the question about cooking cakes, the author D. D. makes some excellent points and generally feels that some model such as the Figure 5.6 (Spectrum of change or change continuum) would be appropriate.

### 5.7.3 *The debate via homework chat lines*

Sheffield Hallam University runs a chat line for school students at URL:

<http://www.shu.ac.uk/schools/sci/sol/cgi/answers/jh03.htm>

(Accessed on 17 August 2000 at 6.49 pm).

All sorts of questions are asked of 'Schools online - Ask a Scientist' (Figure 5.13).

Using a search for the words physical and chemical change, the following is one of the results obtained.

<p>Ask a Scientist Reversing the change from solid to liquid when burning a candle...</p> <p><b>STUDENT QUESTION</b> We are trying to find out if we can reverse the change from solid to liquid when burning a candle. We are measuring weight of candle before and after burning to determine any loss of solid during burning. We are confused. Is the gas reversible back into solid? Or is there some sort of chemical reaction going on, have we lost the solid forever?</p> <p><b>SCIENTIST ANSWER</b> You have almost answered this yourselves. When you stopped burning the candle the gas did not recombine to form a candle again. There was a drop in the mass of the candle.</p> <p>The other clue comes from something you have taken for granted. What do you see when the candle burns? You spotted that there is a loss in the mass of the candle, and that there is gas lost. Try switching out the lights... The candle is releasing light as it burns. Try placing a thermometer near (not in!) the flame... Heat is also being released to the candle's surroundings.</p> <p>After the candle has stopped burning, it does not return to its initial state. The gas, light and heat are lost to the surroundings. This indicates that there is indeed a chemical reaction going on. Some of the wax in the candle is combining with oxygen in the atmosphere to give carbon-dioxide gas and water vapour. The reaction is exothermic - it releases heat, and light is also released.</p> <p>Try heating the candle up in a beaker, weighing the candle and beaker before and after heating. The candle melts and changes shape, but no gas, heat or light is released. In addition, the candle returns to its original state (i.e. wax), albeit a different shape, after cooling. Unless you are heating it really hot, no mass is lost. Is this a physical or chemical reaction?</p> <p>Interestingly, it is the wax of the candle which burns to produce the light and heat - and not the wick. The wick provides the heat and energy required to vaporise the wax. The wax vapour then reacts releasing gas, heat and light. It's a bit like starting a bonfire with a match. Try burning the wick or wax separately.</p>
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**Figure 5.13** Response to ask a scientist

This question is strange since in secondary school chemistry in Britain I have the impression that physical and chemical change is not taught in opposition (as a

contrasting pair). This question looks as though it is about physical and chemical change, but without using the words physical and chemical change solves the problem in the traditional way.

#### 5.7.4 *Physical and chemical change on the www*

<p>URL: <a href="http://explorer.scrtec.org/explorer/explorer-db/browse/dynamic/Natural^Science/index.html">http://explorer.scrtec.org/explorer/explorer-db/browse/dynamic/Natural^Science/index.html</a> Title: Natural Science/Physical Science/Matter and Energy/Physical Change Aim/type: University of Kansas lists 52 sites for physical and chemical change Relevance: A good starting point.</p>
<p>URL: <a href="http://www.hcc.hawaii.edu/hccinfo/instruct/div5/sci/sci122/atomic/matter/matchph.html">http://www.hcc.hawaii.edu/hccinfo/instruct/div5/sci/sci122/atomic/matter/matchph.html</a> Title: SCIENCE 122Honolulu Community College Aim/type: Main points of lectures for upper secondary/adult learning Relevance: Includes assessment examples ( like a book)</p>
<p>URL: <a href="http://www.nyu.edu/pages/mathmol/textbook/whatismatter.html">http://www.nyu.edu/pages/mathmol/textbook/whatismatter.html</a> Title: What is Matter Aim/type: GRADE 4/ Teacher questions to lead students to physical and chemical change Relevance: Resource material for primary teachers</p>
<p>URL: <a href="http://ofcn.org/cyber.serv/academy/ace/sci/cecsci/cecsci183.html">http://ofcn.org/cyber.serv/academy/ace/sci/cecsci/cecsci183.html</a> Title: CHEMICAL CHANGES Aim/type: Lower secondary/ Laboratory experiments. Relevance: Looks at chemical change only</p>
<p>URL: <a href="http://www.sou.edu/chem/ch201/ch1/1_16.htm">http://www.sou.edu/chem/ch201/ch1/1_16.htm</a> Title: Problem 1.16 A match is lit and held under a cold piece of metal. The following observations are made. . . . Aim/type: Assessment example at US university. Relevance: Answer to problem given and is misleading.</p>
<p>URL: <a href="http://www.iit.edu/~smile/ch8714.html">http://www.iit.edu/~smile/ch8714.html</a> Title: Physical and Chemical Changes In Matter. Aim/type: Primary/ cooking. Relevance: An outline of a number of activities.</p>
<p>URL: <a href="http://nesen.unl.edu/teacher/activities/geology/weathering.html">http://nesen.unl.edu/teacher/activities/geology/weathering.html</a> Title: A Simple Demonstration of Chemical and Physical Weathering. Aim/type: Secondary/ Laboratory experiment. Relevance: Widens scope to include earth science.</p>

**Figure 5.14** Table of www sites for physical and chemical change as examples

The remarkable feature illustrated in Figure 5.14, is the number and variety of www sites that include a section on physical and chemical change. It is true that there is quite a high casualty rate amongst www sites, but it seems that new sites appear as fast or faster than old sites disappear. The reader should try entering the words "physical and chemical change", in inverted commas into any one of the well known search engines and she/he will be overwhelmed by the amount of information available, though it should be noted that much is inaccurate or suggested experiments may be unsafe. For

the record I will include a small number of URLs where the information may be of interest. (All accessed on 21 January 2001) (see Figure 5.12)

### **5.8 Summary: Some hypotheses about views on physical and chemical change**

What is remarkable is the strength of these views and others similarly expressed. What does this indicate about the topic of physical and chemical change? Why is there so much intense debate? Could it be that there are particular interests to be protected? These thoughts were part of the source of the four hypotheses that will be introduced later.

Arguments about the usefulness of the concept of physical and chemical change in the literature have been surprising in their intensity. In order to explain the intensity of feeling in the literature about physical and chemical change, at an early stage in this study, I wanted to investigate with the following possible explanations for the longevity of the concept of physical and chemical change. These possible were called the four hypotheses and are included below:

- (1) The concept is a remainder of an 'Aristotelian' theory of matter, kept by the natural conservatism of scientists.
- (2) The opposition of physical and chemical change in textbooks is a pedagogical device, so that it is easier for students to learn related concepts.
- (3) The concept is often illustrated by a number of exciting and interesting experiments that appeal to those teachers who see themselves as being practically orientated.
- (4) The concept is a device used by chemists to define the boundary between chemistry and physics to the advantage of chemistry, so that young people will tend to choose chemistry as a subject to study rather than physics.

These hypotheses are not mutually exclusive and there may be other reasons for the longevity of the concept of physical and chemical change. The hypotheses were used in the construction of a questionnaire which is discussed in Chapter 9.

## CHAPTER 6

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### EDUCATIONAL RESEARCH CONCERNING PHYSICAL AND CHEMICAL CHANGE

*Research Question 6: What does science education research say about children's/students' learning of physical and chemical change?*

#### 6.0 Research on physical and chemical change

Research on physical and chemical change can be concerned with the scientific aspects, the historical aspects, the pedagogical aspects, the sociological aspects or the linguistic aspects of the phrase. The study is broad-based and thus includes research from these different viewpoints.

#### 6.1 The science of physical and chemical change

There is the science of the explanation of physical and chemical change and it should be observed that there can be separate scientific explanations of physical change and chemical change. However, there is strictly no compelling scientific reason for the phrase physical and chemical change to be treated as a single entity. Much of the material in this study written so far seeks to explain why physical change and chemical change have been treated together, but the justification is not on scientific grounds. Scientifically, the topic of physical and chemical change includes at its most general all physics and all chemistry. In particular, the early chapters of this study contain a history of scientific discoveries and discoverers in physics and chemistry which act as exemplars of physical and chemical change.

##### 6.1.1 *The history of physical and chemical change*

The discoverers and the discoveries which they have made have contributed to an understanding of physical and chemical change. Again considerable attention has been paid to this aspect. The history of physical and chemical change makes up much of Chapters 2, 3 and 4.

### 6.1.2 *The pedagogy of physical and chemical change*

Whether to teach the concept of physical and chemical change or not and how to teach it, should it be decided to teach the concept, are important issues of pedagogy. A fundamental aim of educational researchers is to find out what knowledge the learners construct for themselves and this is seen as an integral part of modern pedagogy following Ausubel's dictum.

If I had to reduce all educational psychology to just one principle, I would say this: the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.

(Ausubel, 1968, p. vi)

Although some aspects of pedagogy will be considered, the main focus of this study is teaching and learning the concept of physical and chemical change. This chapter highlights the research on the teaching and learning of physical and chemical change.

### 6.1.3 *The sociology of physical and chemical change*

Sociological issues relating to the concept of physical and chemical change come to the fore in a variety of ways. Certainly the stories of the scientists and textbook writers and their motivations feature as sociological themes. Likewise, several of the four hypotheses (see Section 5.8) have sociological issues underlying them. The concern for a better public understanding of science is also a sociological issue (see Section 10.4).

### 6.1.4 *The language of physical and chemical change*

Considerable effort has been spent on the ways in which scientific dictionaries and encyclopaedias define physical and chemical change. None of these attempts have led to clear unambiguous explanations of what physical and chemical change is and the situation has thus been defined as paradoxical. My research has concerned both the language and the philosophy of science. Explanation may be considered as mainly a problem of language, but it is also a problem of science and of pedagogy.

### 6.1.5 *The role of the textbook*

Explanation of physical and chemical change may involve some or all of the above aspects. In explaining physical and chemical change we must also look at the way that the concept of physical and chemical change is taught and the way in which it is learned.

The chemistry textbook has been seen in this thesis as a major form of evidence about the teaching of physical and chemical change. This chapter will try to put together information about some aspects of the way in which students learn about physical and chemical change. One difficulty with this research is that, like most science concepts, different understandings of physical and chemical change would be expected with students of different ages and it is unrealistic to expect a single understanding of physical and chemical change common to children of all ages between five and 18. As I look at the research, it does appear to me that the understanding that the researcher expected is not always clarified beforehand. Even research which is intended to be based on evidence and to be logically reasoned can be found to be replete with assertions of opinion, as was shown in Chapter 5.

## 6.2 **Research on textbooks**

What research is there on chemistry or physics textbooks considered historically? Some aspects of this textbook research will be mentioned where they are considered relevant to this study. Firstly, many recent historical studies of chemistry textbooks are contained in an edited volume by Lundgren and Bensaude-Vincent (2000). This would form an excellent starting point for anyone carrying out research on science textbooks.

In earlier times textbook studies were generally a quiet and little visited area in educational research but currently this area of research into school textbooks is growing and its literature is increasing. There have been a few controversial studies on textbooks, such as Nelkin's classic (Nelkin, 1977) on the role of textbooks in the evolution/creationism controversy. The book does not discuss issues relevant to the topic of physical and chemical change, but it does illustrate how the school textbook and the content of the science curriculum can become a matter of public debate.

Textbook research is a fine turn of phrase, but it contains a whole range of different aims. What is worse is that there is often a lack of definition as to what a textbook is? For example, Knight says:

We shall find that the frontiers between these different aspects of chemistry, and between textbooks and more popular works, are hazy, especially at first, but by about 1850 these categories are much clearer. (Knight, 2000, p. 188)

Brock (1975, pp. 67-99) explains some of the uncertainties of textbook studies and makes some suggestions for topics to be explored:

The study of science textbooks is another potentially fruitful subject. What were the major texts of chemistry, biology (physiography) and natural philosophy in use during different periods in British schools and universities? It is easy to find out what books were published, but less easy to decide which ones were actually read and used. . . . Probably one of the more striking features of textbook publishing is the way minor (but successful) writers gutted and popularised the texts of 'authorities'. . . . But why and how do certain books get written? What is their natural history and survival rate? How do new textbooks break into the market? (Brock, 1975, p. 75)

Even now, a quarter of a century after Brock (1975) expressed those doubts, Brooke (2000) says:

Despite the remarkable growth, in both scope and sophistication, of research activity in the history of science, the study of scientific textbooks has proved a relatively unattractive focus of investigation. (p. 1)

However in 1998, Brooke said:

...I should like to consider what a historian of science might want to say about the study of scientific textbooks. A moment's reflection shows that there is a rich vein here to be tapped. (Brooke, 1998, [www reference](#))

In one paper, Brooke indicates that the study of textbooks has been relatively unattractive, in another that it is a rich vein to be tapped. Whilst the statements are not absolutely contradictory, these assertions indicate Brooke's interest in the study of textbooks, though he has reservations.

One of the basic requirements of the research is to know what textbooks have been written. This was the first problem mentioned by Brock. My solution has been to use the well known bibliographies of chemical literature such as Bolton (1899); Cole (1988), and Ferguson (1906). These bibliographies list books, mainly textbooks, and give more information about them. This is a partial solution as the other questions that Brock (1975) puts are still not systematically solved.

There is considerable criticism of textbooks. For example:

The withdrawal of some of the worthless text-books with which scholars are now overburdened will in itself be an advance. . . (Armstrong 1910, p. 274).

The syllabus was so impossible and the books so poor that I felt impelled to write to the press in Sydney, making not only some trenchant criticisms...

(Alexander, 1969, p. 1)

Or more recently, Stephen Lower (1996) has prophesied the demise of the textbook.

The theme of this presentation is that the era of the conventional textbook is rapidly coming to an end, and that those of us who care about the quality of science education should be doing our best to help speed its demise. (Lower, 1996, www reference)

An interesting thesis by Mangery (1959) provides useful information about chemistry textbooks used in the American secondary schools before 1890. His supervisor was Dr John A. Nietz whose book *The evolution of American secondary school textbooks* has been most valuable for this study and whose collection (titles only) is available on the World Wide Web. Mangery (1959) noted the early usage of the terms physical and chemical by Gale (1837) (Section 4.2.5) where Gale (1837) wrote 'all substances with which we are acquainted are endowed with two kinds of



properties, physical and chemical'. Mangery (1959, p. 52) calls the work characteristic of the period, but my research has shown in the texts they wrote few others distinguishing between physical and chemical.

### 6.2.1 *Some American research on science textbooks*

Some early research which included the topic of physical and chemical change in textbooks was carried out by Brown (1923, pp. 203-211). He chose 14 elementary chemistry textbooks and checked their content. Physical and chemical change and physical and chemical properties were amongst the topic headings considered and they were found in all 14 textbooks. There were on average, two practical exercises per book on physical and chemical change. Weckel (1922, pp. 44-51) carried out very similar research but on general science books rather than chemistry texts. There was considered to be considerable uniformity in aims, purposes and subject matter between the 14 books examined. Fundamental concepts and topics found in all 14 books were atmospheric pressure, thermometers and humidity. Physical and chemical change was found in eight out of 14 books. Neither result is particularly surprising but the results do confirm that physical and chemical change was almost universally used by writers of chemistry texts at the time and indicates that it was probably used less by writers in other science disciplines.

Bailar (1993, pp. 695-698), who is himself a well-known textbook writer, gives an overview of the general changes in American textbooks of inorganic chemistry over the period 1910-1990: physical and chemical change is not mentioned. The absence of physical and chemical change amongst issues of importance provides a note of caution to this study as many chemists do not see the presence or absence of physical and chemical change in textbooks as important one way or the other.

### 6.2.2 *Some British research on science textbooks*

One British researcher (Bassey) has written extensively on the chemistry textbook. and I have traced six of his studies (Bassey, 1960, pp. 13-17; 1964a, pp. 538-540; 1964b, pp. 594-599; 1965a, pp. 21-25; 1965b, pp. 74-79; 1965c, pp. 115-121). Generally, the studies consist of reports regarding the then current chemistry books (except the first study of 42 books) relating to physical, organic or inorganic chemistry, each

considered separately. It is again noticeable that there was no mention of physical and chemical change, though in this case it is only likely to be mentioned in Bassey's review of O-level books (Bassey, 1960).

More recently, D. P. Newton has researched the science textbook. In one study, Newton (1986, pp. 3-15) looked at a number of textbooks to find the degree of human interest in them by counting the number of references made to scientists. He concluded that texts were generally pretty dehumanised! This is of interest to my research in that I am including considerable biographical interest. In a second study, Newton and Gott (1989, pp. 249-258) examined nine recently published general science textbooks to see how well their claims to teach process stand up to analysis. They commented on the teacher-like role of the textbook:

The surrogate role of the textbook is not always appreciated, even by writers themselves. In selecting the information, the message or 'text' of a lesson, digesting or ordering it, and presenting it in a form suitable for teaching and learning, writers produce material, which to some extent, has the role of the teacher. (p. 250)

In conclusion, the authors (Newton & Gott, 1989) say that in general the textbooks use many practical activities, but claim that they are used to promote concept acquisition rather than process skills.

### 6.2.3 *Some Australian research on science textbooks*

Amongst Australian literature on textbooks, papers by Lynch and Strube (1983, pp. 233-243), Strube (1984, pp. 181-191) and Lynch and Strube (1985, pp. 31-41) advise on the necessity of reading the prefaces to textbooks. This advice was useful as a reminder to be sure that the writer's aims in writing the text were understood. Strube (1984) rightly points out that textbook writers did not always carry out their aims in practice. Lynch and Strube (1985, pp. 32-33) examined several hundred early science texts written from the mid to late nineteenth century and classified them into four recognisable types catechetical, conversational, experimentalist and formalist. They also consider the simplification of language to be an important feature of science texts to make them 'accessible to the masses' (Lynch & Strube,

1985, p. 34). Tulip and Cooke (1991) also have researched Australian science textbooks.

#### 6.2.4 *Some research on science textbooks online*

In addition, to the research on older texts, I have tried to keep up with comment on more recent texts using the Internet. There are three examples here:

- *The textbook colloquium* is a site where any and every aspect of textbooks can be investigated. An example of articles from their journal *Paradigm* is included on their website.

<http://www.open.ac.uk/OU/Academic/Arts/TEXTCOLL/> (Accessed 14/09/02)

Further investigation of the site leads to the abstract of a paper of mine entitled 'The world wide web and chemistry textbooks on line' at URL

<http://www.open.ac.uk/OU/Academic/Arts/TEXTCOLL/paper3.html>  
(Accessed 14/09/02)

This article (Palmer, 1998d) indicated work in progress in 1998 to attempt to get historically interesting chemistry textbooks online. Unfortunately, this goal has not yet been successful as the firm which made an offer to start this project has since withdrawn its support.

- A second example is *The textbook league*. The web site of *The textbook league* is at URL <http://www.textbookleague.org/> (Accessed 14/09/02)

The site is for those with an interest in school textbooks. The site claims to offer independent, expert reviews of current textbooks. The league also publishes a bimonthly bulletin, *The textbook letter* (TTL) to which I subscribe, though it is somewhat behind schedule. The league's website has a number of useful features. The league reviews textbooks in many subjects but the online site allows the reviews to be grouped by subject. Teachers recommending a textbook for their classes could thus see all the reviews of chemistry books, for example. I would

comment that the reviewers are extremely traditional and outspoken in their views with generally adverse comments about books written for lower ability students, or expressing opinions favouring multiculturalism or feminism. For example, the review for one well-known text has the heading 'This weak, silly book is suitable for no one'.

Another feature is the ability to search all the reviews for any word or phrase. I searched the site separately for physical change and chemical change. Only one review was found which commented on physical change or chemical change. The comment was on both. When the books (general-science series for high schools) entitled *Science probe I* and *Science probe II* were critiqued, the reviewer stated that:

Here the student is supposed to tell whether paint, when it 'dries,' undergoes a physical change or a chemical change. In fact, it undergoes both. (Lerner, 1998, p. 40)

It is interesting to note that textbooks are still making mistakes about physical and chemical change. It may be more significant to note, however, that a journal whose role is critiquing textbooks does not criticise the use of the terms physical and chemical change, only the inaccurate use of these terms. In my view the question of whether a change is a physical or a chemical one would not be considered acceptable by reviewers in modern secondary textbooks in the United Kingdom and probably not in Australia either.

- The third textbook site is now organised by the Journal of Chemical Education (J.C.E.) though it was formerly run as a private initiative by Dr Hal Harris.

<http://www.umsl.edu/~chemist/books/texts.html> (Accessed 14/09/02)

It is the most informative of the sites in terms of the numbers of chemistry texts available with other advantages such as the publishers pages being directly linked to the book titles, as well as JCE book reviews where available. The TTL reviews point in greater detail to errors than the JCE reviews, so searching the JCE reviews

for specific comments on the way that chemical change was introduced yielded no results whatsoever.

#### 6.2.5 *A final comment on research on science textbooks*

As a final comment on textbook research I will quote from a letter in the *New Scientist* (Travenius, 1993, p. 47): "I think it would be a good thing to re-read old textbooks every other generation to learn new things. . . ." I have certainly gained a great deal of knowledge from my research on old texts.

#### 6.2.6 *Research on textbook writers*

This is a less travelled road for research, but there are a number of biographies of textbook writers. Some of these are purely biographical or autobiographical, whilst a few concentrate on both the writer and some analysis of the texts that they wrote. Generally the biographies are of writers who were also established scientists as well as textbook writers. Textbook writers receive little public recognition but there are exceptions.

In 1979/1980, the journal *Science Education* ran a series of articles on science textbook writers, for example, Gerald Spellman Craig (Champagne & Klopfer, 1980, pp. 7-24). This particular article is of interest in that it records some of the materials for elementary schools that Craig included from his doctoral thesis (p. 13) and from his teachers' texts (p. 12), which are directly concerned with physical and chemical change. Craig is said to have chosen the materials with care to fit his philosophy of teaching children about those things that impinged upon their environment. Craig's texts (for example, Craig, 1940; Craig & Hyde, 1946) were not the first texts for elementary students published, but previous texts tended to be readers emphasising nature stories. Champagne and Klopfer's research has provided a good base for seeing the change in science curricula through the life of one textbook writer with sufficient data to find out what content was included in his books.

### 6.2.7 *Motivation of science textbook writers*

Basolo (1977) gives some reasons why textbook writers set out to write texts in the first place. He says:

We authors are only human and we have many reasons for writing textbooks. The reason most often given is that the book was written for the student who deserves a better textbook than the ones that are presently available. (p. 267)

Another author who comments on textbook writers motivations for writing books is the British physics textbook writer, G. R. Noakes. Noakes (1969, p. 67) admits that the thought of extra income might have been a factor, but success initially seemed so improbable that the main impetus was producing a textbook on light that would be more suitable for his students than existing texts.

## 6.3 **Earlier research on physical and chemical change**

Physical and chemical change has long been an area of disagreement, dispute and assertion in the science education community. This aspect of teaching physical and chemical change was explored thoroughly in Chapter 5. The possibility was raised (hypothesis 4, Section 5.8) that the disagreement was due to some sort of ideological warfare between chemists and physicists as to whether chemistry or physics was the 'better subject', the easier subject, or the 'more important subject'. It may be said that these are pointless and sterile debates, but they are in a sense still with us (see Becher, 1993). Historically many of these debates occurred at the turn of the twentieth century and were manifested in the United States in the report of the Committee of Ten of the National Education Association (Committee of Ten, 1902).

To research this, I have found a number of books about the teaching of chemistry, the teaching of science or the histories of science teaching. The form of the argument is expressed as to the discussion as to whether chemistry should be taught before physics or whether physics should be taught before chemistry.

For example, Smith and Hall (1916) discusses the evidence in Committee of Ten Report and the comparisons in the report of physics and chemistry in the curriculum (p. 28) and whether physics or chemistry should be taught first (p. 29). The Committee of Ten (majority report) considered chemistry should be taught first which Smith and Hall say is precisely the reverse of the logical order and they say that everyone concedes this. Professor Waggener put in a minority report arguing the reverse of the main report. Waggener evidently argued that physics is the natural precursor of chemistry and that chemical phenomena were of a higher order of difficulty than those of physics. Smith and Hall (1916) further to report Wagener's arguments:

When any chemical operation is to be carried out, its success invariably depends upon attention to matters belonging strictly to the domain of physics. (p. 30)

This discussion continued at length but Smith and Hall (1916) in relation to teaching physical and chemical change, state:

The substance may melt, and the pupil must ascertain whether this is simply a physical change or whether it involves a chemical change also. (p. 31)

One example given was the melting of ammonium nitrate to decide whether the bubbles are due to the liquid boiling or whether they are caused by chemical decomposition. From this distance in time the general argument seems of little consequence, but the heating of ammonium nitrate is a moderately hazardous reaction (Lewis, 1993, p. 67) not suited to student practical work. Smith and Hall (1916, pp. 69-72) explain how teachers might approach the teaching of this topic. Their emphasis appears to be on familiarisation of pupils to the physical properties of substances so that they can observe changes in these properties during a chemical change. Deboer (1991) has provided a brief summary of the main recommendations of the Committee of Ten (pp. 40-43) and brief biographies of Alexander Smith (pp. 54-58) and Edwin Hall (pp. 59-62). Smith was the author of several major texts (Smith & Hale, 1910; Smith, 1924) and was generally in agreement with the heuristic views of H. E. Armstrong (Section 5.6.2).

Other histories of chemistry and science teaching with mainly an American perspective (Collette, 1973; DeBoer, 1991; Woodburn & Obourn, 1965) can be used to give a general picture of chemistry with only very occasional insights into how physical and chemical change should be taught. Books such as Smith and Hall (1916) which was discussed previously provide considerable detail about the teaching of physical and chemical change. Science methodology books (Fowles, 1957; Frank, 1927; Scovell, 1895; Westaway, 1942) tend to give greater detail of the chemistry curriculum and the practical details of how to teach it and there are other more recent methodology books in the same category. Nonetheless, few researchers have looked at children's understanding of particular concepts such as physical and chemical change, prior to the work of Voelker in 1967-8. Most of what exists, even in books on methodology, is assertion based on the individual's experience.

### 6.3.1 *Research on physical and chemical change (overview): Voelker's research*

I can find little before the 1960s in terms of organised scientific research about whether or how to teach physical and chemical change, or at what age. In the USA, researchers have shown that children's understanding of physical and chemical change is poorly developed prior to the age of 12 years (Pella & Voelker, 1967-1968, p. 323; Voelker, 1975). The original study and the replication study represent the best evidence available for not teaching physical and chemical change before 12 years of age. It is interesting to observe that though the research appears to be meticulous and replicated, which is a rarity in itself, the results appear to have been completely ignored by the education community. In an article specifically aimed at elementary school teachers, Voelker (1970) tries to present balanced arguments for and against teaching the concept of physical and chemical change to elementary school children as well as presenting his data. He makes one telling point against teaching physical and chemical change at an elementary level (or indeed any other level) which is that the classification has become of 'little interest or usefulness' and as such categorisations are no longer 'pursued actively' by chemists.

This is yet another aspect of the paradox in the teaching of the concept physical and chemical change, which is that there is currently a view that if the concept is to be introduced at all, then it is appropriate in years 4 to 7 in elementary schools, which disregards the earlier research evidence from Voelker. So Voelker's very careful



research appears to have had little influence on whether or not the topic of physical and chemical change is taught in elementary schools.

Is there a reason why this research has been ignored? Perhaps it is because there is some evidence for an opposite view. McClelland (1982) quotes evidence from research in the 1960s that "quite young children can form usable concepts of molecules". But it is more likely that there are practical factors, which are responsible for the change, such as more science now being taught at primary level and a feeling that secondary curricula are overcrowded. This has resulted in some science content being moved from the secondary years to the elementary years.

There have been very many attempts to prepare materials about physical and chemical change that are specifically aimed to teach the topic at an elementary level. For example, in the United Kingdom, the British Broadcasting Company (BBC) in 1995-96 prepared six sets of materials for inservicing practicing teachers in science, one of which was entitled *Materials: Chemical and physical change* (BBC, 1995).

### 6.3.2 *Research from various perspectives*

There is now a massive amount of data covering materials produced by educational researchers from many countries. The next few sections will indicate where the research started, what the early researchers and others investigated, some relevant doctoral theses, some of my own research and a discussion of some summaries of current research on physical and chemical change.

### 6.3.3 *Sources of research from a constructivist perspective*

One starting point to find research that considers student alternative frameworks in science (children's ideas in science) is to look at an appropriate bibliography. This may be combined with references from one's own reading of relevant journals, or searches using search engines on the www or using the various educational indices. The literature on research in this area of science is massive.

I chose Reinders Duit's *Bibliography on student's alternative frameworks and science education* as my starting point (Pfundt & Duit, 1991). I updated the information available by using an English version online edition dated March 2000:

<ftp://physlrnr.boisestate.edu/plrserve/pub/physlrnr>

(Accessed 10 November 2000)

The document was 309 pages long in close-typed print with probably over 3000 references to constructivist research. My first step was to cut this down to those that might relate to chemistry which was not difficult as Duit (2000) had already indicated classified chemical items in his bibliography. I then cut down this list further including articles that may relate to children's/students' understandings of physical and chemical change, their understandings of change of state and their understandings of atoms and molecules and kinetic theory. This left me with a list of about 100 references which cover the broad themes indicated above.

I then added other relevant references to this list. I included another much shorter list of references for chemistry and physics which can be found at the University of Toronto site. These are good but have not been updated since 1998:

*References for misconceptions in chemistry* at URL:

<http://www.oise.utoronto.ca/~science/chemmisc.htm>

*And References for misconceptions in physics* at URL

<http://www.oise.utoronto.ca/~science/phymisc.htm>

In addition other references were added from my reading journals in print (such as *Science Education*, *Research in Science Education* and *Journal of Chemical Education*) and also online journals (such as *The Chemical Educator* at URL

<http://link.springer-ny.com/link/service/journals/00897/index.htm>,

*The Electronic Journal of Science Education* at URL,

<http://unr.edu/homepage/jcannon/ejse/ejse.html>

*HYLE, An International Journal for the Philosophy of Chemistry* at URL  
<http://www.uni-karlsruhe.de/~philosophie/hyle.html>,

*Chemistry education: Research and practice* at URL <http://www.uoi.gr/cerpl>).

Overall the online resources are fast catching up with print-based materials with many of the online journals being fully refereed.

Finally there are references from conference papers and online conference papers where the site called 'Meaningful Learning Research Group Home Page' is particularly useful at URL:

<http://www2.ucsc.edu/mlrg/mlrghome.html>.

This URL is the linking page for the four sets of misconceptions proceedings, namely, *Misconceptions Proceedings The First Misconceptions Proceedings, The Second Misconceptions Proceedings, The Third Misconceptions Proceedings* and *From Misconceptions to Constructed Understanding - The Fourth Misconceptions Proceedings*. The site is organised by Professor Joseph Novak and his team and many of the papers from the conferences are online. With such a wide choice of relevant articles, I will comment on a very small proportion of the total research in this area. I will attempt to cover a wider variety of the research by looking at some views of those who have attempted to combine the results of several researchers.

#### 6.3.4 *Research groups working from a constructivist perspective*

From a constructivist viewpoint, there are many studies of children's learning about physical and chemical change. Studies started in the early 1980s and I have been fortunate to have access to a number of materials - some of which are easily available, some of which the researchers have been kind enough to send me and some of which I have purchased. In the early 1980s four groups, which achieved pre-eminence in constructivist research in science, can be considered by the countries in which they worked: Sweden (Andersson & Renstrom; Göteborg University); New Zealand (Osborne & Schollum; Waikato University); the United Kingdom (Driver & Scott; Leeds University); and the USA (Novak & Gowin; Cornell University). It should also be noted that this is a very rough guide to those

involved and events have certainly changed the key researchers and the institutions where they work. I will be considering just the topics in elementary chemistry on physical and chemical change and also on the particulate nature of matter, though these researchers worked on a much wider framework. It should be observed that the research groups carried out research into children's ideas in science, and some also of them produced materials for the use of teachers to know what it meant to teach in a constructivist mode. The projects undertaken by the research groups had various acronyms – Leeds was CLIS (Children's Learning in Science); Waikato was LISP (The Learning in Science Project); Göteborg was the EKNA group; Cornell has now become the MLRG (Meaningful Learning Research Group).

The seven essential features of constructivism were explained in a brief pamphlet by Scott, Dyson and Gayter (1987). These were said to be:

- What is already in the learners' mind matters.
- Individuals construct their own meaning.
- The construction of meaning is a continuous and active process.
- Learning may involve conceptual change.
- The construction of meaning does not always lead to belief.
- Learners have the final responsibility for their learning.
- Some constructed meaning is shared. (pp. 7-8)

There are considerable variations between researchers as to a fixed definition of constructivism. Pereira (1996, pp. 26-28) has provided a similar set of advice for Australian teachers using a Western Australian model. There tend to be similar patterns of young persons' ideas in science (Driver, Guesne & Tiberghien, 1985, p. 8) held irrespective of geographical situation and the possible extension of this to historical periods will be investigated in Chapter 8, but the above discussion will suffice here.

### 6.3.5 *The Swedish Research Group*

During the 1980's, the EKNA group produced a series of reports on various aspects of science education. I was in contact with Dr Andersson and he sent me copies of some reports that related to chemical change. These were 'Oxidation of steel wool' (Andersson & Renstrom, 1982) and 'Chemical reactions' (Andersson, 1984). The British group (Leeds) and Swedish group (Göteborg) co-operated on a number of projects available in English.

The research on steel wool was undertaken with 593 Swedish upper school students fairly evenly distributed amongst Forms 5, 6, 7, 8, and 9. The experiment is evidently in most Swedish chemistry textbooks. The main chemical principal is that oxygen from the air combines with steel wool forming iron oxide which weighs more than the steel wool. The activity was performed by an investigator in the presence of the normal teacher as a demonstration experiment. Sometimes the students were asked to predict what will happen and at other times they describe what they have seen. At the end, the students answers were collected in and analysed. Additionally, the investigator carried out interviews with individual students. It is noticeable that in explaining the results, the researchers take great care over the possibility of language confusing the students (the word – steel-wool) and they also make a number of historical comparisons. Andersson and Renstrom (1982, p. 17) classify the students' explanations into two types – physical and chemical. I have used their classification of pupils' ideas of chemical reactions in Chapter 8 to classify the students' ideas found in the very old chemistry manuals.

In the discussion of the results, they comment that the students (about one third) who give a physical explanation have missed the point, whilst the slightly smaller group who provide chemical explanations give explanations that are incomplete or erroneous. The suggested solution is "to explain to students the similarities and differences between chemistry and physics in a more explicit fashion' which is interesting as it is precisely what books of the nineteenth century did.

Andersson (1984) produced a report entitled *Chemical reactions*. The problem was clearly stated:

The main problem that concerns us is how to get students (aged 13-16 years) to assimilate chemistry more effectively than they do at present.  
(p. 1)

In the time since that was written, it is not certain that we are any closer to an answer. Andersson (1984, p.3) believes that the 'central task of chemistry is to describe and explain the conditions for chemical reactions'

This research was the result of setting five written problems relating to practical situations about conservation (in a Piagetian sense) to pupils in Forms 7, 8 and 9 totaling more than 2500 students. The questions were in a multiple choice format but each question asked for a reason why the answer was given. The discussion and results refer to these questions and to research done by others at other times. Andersson (1984, p. 7) comes to a conclusion that student conceptions of chemical reactions can be classified into four categories, namely: 'it is just like that', displacement, modification and transmutation.

The categories are considered both in the macroscopic and in the atomic world. In considering the results of the written tests, I observed that the numbers of responses seemed low compared with the number of participants; it appeared to me that in some cases response rates were less than 10%, which would make me wary of drawing any strong conclusions. Nonetheless, the categories that Andersson has provided have been used as a base for subsequent research.

In a paper, presumably based on this report, Andersson, (1986, pp. 549-563) adds the category 'chemical interaction' as a fifth category for classifying chemical reactions.

#### *6.3.6 The New Zealand Research Group*

One of the early papers produced by the Waikato group was about physical change. The group were kind enough to send me a number of their working papers. Cosgrove and Osborne (1981) produced an interesting working paper which uses the technique of the 'interview about events' method which the group pioneered. They had earlier introduced the technique of the 'interview about instances' method

(Gilbert & Osborne, 1980, pp. 244-251) and both methods are now routinely used in interviews with students. In the interviews with 43 students covering an age range of 8 to 17 years, the students were individually shown instances of boiling, melting, dissolving, evaporating and condensing. The students' responses to a fixed interview schedule were recorded. The typed record of the interviews is the data set from the research and there is a brief discussion on the results. One feature is the lack in the discussion of a scientific definition of physical change. As has been pointed out earlier, almost all these events may well be classified as physical change when observed at the macro scale, whereas they are arguably chemical when considered on the atomic scale. It is interesting to note that this possibility seems not to have been considered. It is indeed very early research in this area as the authors have little previous research to build upon. They say:

With respect to the topic of physical change, this also emphasizes that for some, possibly many children, the distinction between physical and chemical change is not a scientific distinction.

(Cosgrove & Osborne, 1981, p. 28)

Schollum (1981) produced the working paper on chemical change, which followed a similar methodology to the paper on physical change. Five every-day chemical reactions were chosen for the interviews about instances. The children's opinions make interesting reading. As the result of this research and another survey with 500 students, Schollum (1981, p. 20) concludes that the students are confused as to the difference between physical change and chemical change. In reading the working paper, I did not note that the researcher clearly stated what he considered the scientific definition of physical and chemical change nor whether the results of dissolving sugar in water (p.19) are considered a physical change, a chemical change or both or neither. In this regard Schollum, (1981; 1982) states that the children's view of physical and chemical change differs from the scientific view, but this assumes that there is one correct scientific view, which I have shown is just not the case. Scientists have different views because the definitions of physical and chemical change are not adequate for all circumstances. The LISP Project produced 55 working papers altogether on different aspects of science education for 11-14 year olds (Osborne & Schollum, 1983, p. 13) and also produced inservice materials for teachers Schollum (1982, p. 9). The inservice materials introduced the chemical

change of burning to teachers (Schollum & Happs, 1982, pp. 84-88). A number of related topics including children's ideas on the particulate nature of matter were also researched (Osborne & Schollum, 1983, pp. 13-24).

Finally the book, *Learning in science: The implications of children's science*, produced as a result of this project though dated, remains an excellent introduction to constructivism in science education (Osborne & Freyberg, 1985).

### 6.3.7 *The British Research Group*

The British research group at Leeds University has been undertaking alternative frameworks research and producing books and materials since 1980. One might see the start of this alternative frameworks project as the conference on Cognitive Development Research in Science and Mathematics organised by the School of Education at Leeds and sponsored by UNESCO through Shiela Haggis (Archenhold, Driver, Orton & Wood-Robinson, 1979).

The Children's Learning in Science (CLIS) group has produced *The pupil as scientist* (Driver, 1983), and *Children's ideas in science* (Driver, Guesne & Tiberghien, 1985). The group has been regularly producing papers over the past 20 years at the Association for Science Education conferences, in science educational journals and in international fora. They have also produced teacher education packages, for example *CLIS in the classroom-approaches to the teaching of the particulate theory of matter* (Particles Working Group of The Children's Learning in Science Project, 1987), *A case study of the teaching and learning about particle theory: A constructivist teaching scheme in action* (Johnston & Driver, undated), *A case study of the teaching and learning about plant nutrition: A constructivist teaching scheme in action* (Oldham, Driver & Holding, 1991) and *Making sense of secondary science-support materials for teachers* (Driver, Squires, Rushworth & Wood-Robinson, 1994a).

England and Wales have a National Curriculum introduced after considerable debate in 1989 (Department of Education and Science (DES), 1989) and revised in 1991 (DES, 1991) and several times since then. The Curriculum in England and Wales in science and other subjects is thus centrally controlled, based on the 1988 Education Reform Act (DES, 1991, p. i). The support materials produced by CLIS



thus conform to the needs of the English and Welsh education communities as regulated by law at the time. The ideas basic to physical and chemical change can be found at all Key stages, attainment target 3 (materials and their properties) at most levels and partially in attainment target 4 (physical processes). It is unusual in the British education system to find physical and chemical change expressed as contrasting pairs at secondary level, though it may still be found in some primary courses. An exception is the National Curriculum document (DES, 1991, p. 28) talks of physical and chemical processes in respect of oil (Key stage 4: AT3: level 8).

Bearing this in mind, the document *Making sense of secondary science - support materials for teachers* deals with the concept of states of matter (Driver et al., 1994a, pp. 159-172) having previously considered materials. The section on chemical changes follows states of matter (Driver et al., 1994a, pp. 173-187) and is followed by a section called particles. What is presented is an order of teaching and extracts from the National Curriculum and they include the extensive research done by the group under sections of children's prior ideas and the challenge to pupils which discuss the pedagogic problems that teachers will encounter using a constructivist framework. Omitting physical and chemical change expressed as contrasting pairs has clear advantages in that the types of simple classification question 'Is this a physical or a chemical change?' where there are real arguments amongst experts about the correct answer no longer needs to be asked. Nonetheless, one question about 'new substance' remains. The authors state that:

pupils need to recognise that a *new* substance is not easily changed back into the original substances from which it came. (Driver et al., 1994a, p. 179)

This is a dubious statement chemically and can be traced to the National Curriculum's emphasis on permanent change for chemical change, for example, where the term 'change permanently' is used as the contrasting pair to melting or solidifying (DES, 1991, p. 10).

In commenting on documents such as this, it is not difficult to find various points that can be challenged, but overall *Making sense of secondary science - support materials for teachers* is an extremely valuable addition to the literature in that it relates constructivist research to current curriculum materials.

In *A case study of the teaching and learning about particle theory: A constructivist teaching scheme in action* (Johnston & Driver, undated, p. 12), I find general support for my ideas on a public understanding of science in Section 1.5 entitled 'The construction of public knowledge' when the authors state:

The above perspective which considers each individual's knowledge as something which is personally and socially constructed can be extended to include a view of public knowledge (including scientific knowledge) as something which is also a human construction. (p. 12)

#### 6.3.8 *The American Research Group*

Professor Joseph Novak and his team have organised a series of conferences that focus on children's ideas in science over the years and they maintain a useful website (see Section 6.3.1). Perhaps their greatest contribution has been in the production of methodologies that teachers can use to help students with metacognition. Novak and his group have been engaged in organising tri-annual conferences on misconceptions, encouraging the work on concept mapping (Novak & Gowin, 1994) and in promoting the use of an influential metacognitive device called Gowin's Vee (Novak, 1990; Novak & Iuli, 1995).

### 6.4 **Other research on physical and chemical change**

The research on physical and chemical change from a constructivist viewpoint has extended considerably since its starting point in the 1980s. The next few sections will mention research, both large and small scale, which I think is relevant to this thesis. As indicated in Section 6.3.2, there is a large amount of constructivist research on types of chemical change or on types of physical change, and considerably less if only the work that concentrates on physical and chemical change as a contrasting pair only is considered. Including papers on matter, substance, states of matter, chemical bonding or the particulate nature of matter widens the scope even more. For example, in Germany, Lichtfeldt (1996) has been involved in a long term project to determine pupils' alternative frameworks on particles and atoms. This appears to link the concept of particles normally

considered prior to introducing physical and chemical change with atomic structure particles normally considered after introducing physical and chemical change.

Additionally, research tends to centre on the learning of students within a particular age range. In different countries, physical and chemical change can be taught anywhere between early primary schooling and first year university. Research is also frequently carried out on students who are training to be teachers.

#### *6.4.1 Research on physical and chemical change with experienced primary teachers*

Kruger and Summers (1989) examined the understandings of scientific concepts using interviews about instance technique (Gilbert & Osborne, 1980, pp. 244-251) and recording the responses with in-service teachers including head teachers and deputy head teachers. The research covered a broad content area of changes in materials. In general, they exposed the weaknesses of primary teachers' knowledge of kinetic theory and found it similar in many ways to that of primary students. Kruger and Summers (1989, p. 27) wondered how successful any primary school science program in the United Kingdom might be involving conceptual science. A more optimistic study (Harlen, 1996, p. 12) considers that primary teachers have 'latent understanding waiting to be awakened'. There was little mention of the phrase physical and chemical change though Kruger and Summers (1989, p. 22-23) explore these changes with one card showing a lighted candle and find a mixed set of responses. The irreversible nature of burning was only recognised by five of the 19 teachers, whilst only one called it chemical change.

#### *6.4.2 How do learners differentiate between physical and chemical change?*

Stavradou and Solomonidou (1989) in their research with Greek students looked at the ways that the students categorized the physical and chemical transformations of matter. The researchers considered 18 phenomena (nine chemical and nine physical) which were everyday events. Here again there are questions as to whether adding salt to soup or boiling water are chemical or physical changes: the researchers classify them as physical changes. I find myself in the uncomfortable position of believing that an eight year old would rightly classify these reactions as physical changes, but that a 17 year old studying chemistry should no longer be

satisfied with this answer. This view would make cross-age studies almost impossible to carry out. In this study, there were 15 pupils between the age of 8 and 17. In Greece, students start physics and chemistry when they are 13-14 years old. Students were asked to look at the list of changes, and to group together items on the list that had something in common. Students were interviewed individually about the reasons for their groupings. The small number of participants, the open ended nature of the task and the wide age range make conclusions difficult to draw but the researchers conclude that reversibility of change was a significant factor in the groupings that students made in drawing up their lists.

This is a tentative finding, but the researchers were quite unambiguous in their conclusion that using irreversibility of the event as the criterion for the happening being a chemical change was a successful strategy for these students in this example. Choice of any other criterion was an unsuccessful strategy. Chemists know that there are many chemical reactions which are reversible, so the student's strategy will never be accepted, but it is instructive to know how students see the problem.

Stavradou and Solomonidou (1998, pp. 205-221) extended their research in this area using similar but more developed techniques. They attempted to see how the pupils' concept of physical and chemical change changed with the age of the student. These authors state that when the microscopic/atomic level is being considered "the chemical reaction concept functions in opposition to the concept of physical phenomenon or 'physical reaction' "(p. 219).

However, in practice the five students aged 18 years who were interviewed did not appear to use criteria to differentiate between physical and chemical change, but tended to use existing school knowledge. The research agenda does seem to be progressing as it is being recognised that the concepts of older students should have developed from what they needed at primary level. One of the conclusions is that the concept of 'chemical substance' should be developed better in starting to teach chemistry. This theme is taken by several researchers such as Johnson (1996, pp. 41-45; 2000, pp. 719-738).

#### 6.4.3 *Wide-ranging research concerning chemical change, phase change and other chemical concepts*

Some research is narrowly focussed, whilst other research agendas seek answers to a variety of issues. The research described in this section is of the latter variety. Abraham, Williamson and Westbrook (1994, pp. 147-165) tested 100 junior high school students (Grade 9), 100 senior high school students (Grades 11 and 12) and 100 college students (first year university doing general chemistry). The instructors confirmed that each of the groups had previously covered the content of research questions in some form. The concepts on which the research questions were based were chemical change, dissolution of a solid conservation of atoms, periodicity and phase change. In addition, a battery of other tests was given including reasoning tests which placed students in one of four Piagetian stages (concrete, transitional, early formal and fully formal). The study is of great interest, though it appears to be based on group results with written answers to printed materials. I suspect that the results of such research can be influenced by factors such as motivation outside the control of the researchers to a greater extent than individual interviews. The question on chemical change referred to explaining why there was a black coating on a glass rod which was held in a candle flame. Abraham et al. (1994) make the following comments on the student responses to this item:

Misconceptions concerning chemical change were held by 73.3% of the students, whereas 9.3% had no understanding. The most common misconception was that burning a candle was a physical change . . . This misconception was held by 27% of the students sampled. (p. 157)

Other common misconceptions were that either the wick burning or the supposed charring of the glass rod had caused the black coating on the glass rod. It seems that these responses, though incorrect, could form the basis for imaginative teaching by thinking up experiments to test the truth of these ideas. In the end they are good ideas – they just happen to be mistaken.

According to these researchers only 12% of students had any understanding of the phase change concept, based on students being asked to explain why there was no change in temperature as an ice cube melted. Whether that feature of phase change

is the aspect that comes to mind for most students when thinking about phase change is arguable. I would expect a different question would have provided different results.

In their conclusions, Abraham et al. (1994, p. 163) make the important point that even the university students seldom make use of atomic and molecular explanations in illustrating the practical experience-based observations about which they are asked to comment. This could reflect the sort of teaching that they have received. Of the five concepts, it is noticeable that both chemical change and phase change had the lowest percentages of students who exhibited a sound understanding.

The research of Artee and Varjola (1998, pp. 305-316) involved testing students in the 7th grade, the 8th grade, senior high school and university. This research appears to be based to some extent on the earlier research of Abraham et al. (1994), but has been modified. The specific chemical questions were replaced with more general questions. In the high school sample, half the respondents did not write anything, perhaps as a protest against being compelled to learn chemistry.

It is of interest to note that Artee and Varjola (1998, p. 314) consider 'dissolving, melting and glowing' to be physical changes, so the comment below is unsurprising.

Nearly 20% of the 7th and 8th graders and 10% of the senior secondary students regarded dissolving and change of state as chemical reactions.  
(p. 312)

The researchers also say that:

About 80% of the 18 pupils interviewed could not make a clear difference between physical and chemical changes. They approved both melting of ice or dissolving of salt and fermentation of berry juice or rusting of iron as examples of chemical change.  
(Artee & Varjola, 1998, p. 312)

The problem is that the students who gave these answers are arguably correct in terms of chemistry, though they may be correct for the wrong reasons.

The research of Isaacs (1992) is of interest in that it represents one of the few studies in science education research carried out by a practicing teacher in the Northern Territory. It also is in the category of broad based research testing children's ideas in a variety of sciences. The research was carried out in a number of different classes (Year 8, Year 9 and Year 10) in a private school in Darwin where Pat Isaacs worked and also included some Northern Territory students training to be teachers. The test questions were derived from a variety of sources including *Learning in science: The implications of children's science* (Osborne & Freyberg, 1985). The results from this research can thus be compared with those of the New Zealand researchers, though the students ages were not obtained in the Darwin research.

In regard to data about physical and chemical change, only four questions relate to physical and chemical change - 17, 18, 19 and 23. A graph of the percentage of items correct against question number for each of the four groups on a single graph gives a simple way of comparing performance between groups and also of seeing at a glance which questions give the greatest difficulty. The four questions referred to above were amongst the most difficult for students to answer amongst all groups and are of interest in that generally the school students scores are better than or the same as the scores of the teachers in training for these questions. Generally, the prospective teachers' group did better than the school students.

The research described in this section indicates that there are difficulties for students in the topic of physical and chemical change.

#### 6.4.4 *Research connecting chemical change with other more advanced chemical concepts such as atomic structure and bonding*

Several major research initiatives attempt to connect the elementary ideas of physical and chemical change (typically occurring in the first chapters of a textbook or being taught in primary schools) with more advanced concepts of atomic structure and bonding. Barker and Millar (2000, pp. 1171-1200) choose such an

approach in a major longitudinal study relating to the British curriculum development known as Salters Advanced Chemistry.

Reynolds and Brosnan, (2000) detail their research using computer-generated sentences (generated randomly) relating to physical and chemical change with most sentences having logical faults needing correction. The researchers ask the students varying from Year 7 to Year 12 to correct these sentences and to point out to the researchers where the mistakes lie, whilst explaining their own thinking.

In Australia, studies by Harrison and Treagust (1996; 2000) and Tan and Treagust (1999, pp. 75-83) also link the earlier concepts held by students with more advanced work on structure and bonding.

In the United Kingdom, Taber (2000) addresses university teachers and provides the constructivist background for the early teaching of chemistry. Then a very full discussion by Taber (2001) first briefly develops a chemical philosophy and then builds up the sequence of chemical ideas after students have understood that substances maintain their identity through a change of state (physical change) and that the products are different substances to the reactants (chemical change). However, this conception involves concepts far more complex than physical and chemical change.

Taber has put together a number of ideas from his research in a two volume publication, produced by the Royal Society of Chemistry, which are interesting (Taber, 2002a: 2002b). There is a section specifically about the teaching and learning of physical and chemical change (Taber, 2002a, pp. 97-100). Taber (2002a, Note 13, p. 28) indicates that an understanding of physical and chemical change is still required of junior secondary pupils in the United Kingdom, quoting the 1999 version of the National Curriculum. Nevertheless, he indicates that the distinction between physical and chemical change is problematic for teachers and learners. He sets out criteria for distinction between physical and chemical change (p.98) not greatly different from those explained in Section 5.5.1 and he points out that all these criteria are problematic and that the commonly used reversibility criterion is inherently tautological (p. 100). He gives what I suppose is the key justification for



teaching pupils about physical and chemical change, which is that sometimes chemists find it a useful distinction (p .99).

#### 6.4.5 *What research is there on physical and chemical properties?*

The lack of relationship between properties of matter at an atomic scale as compared with the macro scale is illustrated by Ben-Zvi, Bat-Sheva and Silberstein (1986) finding out if students considered that a copper atom was malleable (a physical property). This paper is illustrative of a truth to which I cannot think of exceptions, that there really are no physical properties at an atomic scale as physical properties are bulk properties, whereas chemical properties can be those of a comparatively small number of atoms or molecules.

Thinking that physical properties at the micro level are similar to those experienced at the macro level is a common alternative conception, believed by many students. For example, students believe that phosphorus atoms are yellow or that naphthalene molecules smell (Andersson, 1990, p. 66; Wandersee, Mintzes & Novak, 1994, p. 184).

This leads to a further paradox that it is only in large scale (macro) situations that physical and chemical properties can be distinguished from each other because the concept of a physical property has no meaning at an atomic scale.

#### 6.5 **Some doctoral theses on physical and chemical change**

I have considered a number of doctoral theses as in many ways they provide considerably greater detail than is usually available in the articles that are derived from them. The theses include all the evidence which is used, whereas articles can omit steps in the arguments presented; additionally there is usually less existing comment on theses. All the theses I refer to involve large scale testing and interviews to find out what students actually think about physical and chemical change. Yet the three theses and articles relating to them are very different. Two concern Africa which is of particular interest to me because of my own Nigerian experiences. The thesis by Hesse looks at the detailed understandings of physical

and chemical change by three students linking his interpretation of their ideas to older streams of research as represented by Piagetian views on conservation.

#### 6.5.1 *The doctoral dissertation of Keith Ross (1990)*

Keith Ross is interested in chemical changes, in particular in the process of burning and in the views that specific groups of people have of these changes. He was someone who was interested in my thesis about physical and chemical change and sent me copies of the materials that he produced (Ross; 1990a). Ross's (1990b) dissertation is entitled *A cross cultural study of people's understanding of the functioning of fuels and the process of burning*. He has also produced a number of pamphlets, such as Ross (1990c), to publicise his ideas. The work of Ross (1990b; 1991) is instructive in dealing with the archetypal chemical change – fire and the associated concepts of burning, oxidation, energy and the production of oxides from burning in a cross-cultural context, examining British, Nigerian and Gambian views about burning, including the ideas of firemen. Ross (1990b) argues correctly that the energy produced in combustion is not related to the fuel alone, which is perhaps the popular view, but to the fuel-oxygen system. For example, this would be assumed in a public understanding of the number of calories allegedly contained in different types of food. He believes that a correct public understanding of science is important. Ross (1990b) also argues that burning is a two-part process (part endothermic and part exothermic) and invents two new words 'char-burn' and 'flame-burn' to describe these processes. Ross says that he was influenced in coming to these views by the fact that the Mandinka language in Gambia has two different words for burning that appear to correspond with a scientific view. Ross (1991) sees burning as a constructive rather than a destructive process, since the oxidation of substances causes oxides to be formed. Interestingly (but unsurprisingly?), the firemen saw burning as a destructive process, although Ross (1991) considers that they have a good understanding of combustion. Combustion is one important type of chemical change, significant because historically much of the understanding of chemical change came about through the study of combustion reactions. The significance of Ross's dissertation to this current work is his emphasis on the importance of a public understanding of science and of appropriate language and pedagogy as a means of bringing this understanding closer.

### 6.5.2 *The doctoral dissertation of Jane Igbibo Alamina (1992)*

This traditional thesis explores the perceptions of 108 Nigerian senior secondary students equally divided by gender and by class (Years 9, 10 and 11 equivalents) in categorising physical and chemical change. Two chemical changes are shown to all students individually with the researcher (Alamina, 1992) in a quiet room and a set of simple questions were asked about the student's observations and conclusions of these changes. In the first case the researcher lit a piece of paper and in the second case two solutions were mixed (copper(II) sulphate and lead(II) nitrate) in a test-tube and some turbidity was observed. The same interview schedule was asked of each student. Students were also asked to make various drawings and to draw what they thought they would see if they had X-ray eyes. The researcher thus had recorded interviews and a considerable number of drawings, which provided different types of data for analysis. It all sounds so easy, but having worked in Nigeria for a long time, I am full of admiration for the researcher in obtaining a full set of data from her field work. I know that there would have been so many difficulties and distractions in completing this very thorough study. This study is looking at physical and chemical change from the interview data and elementary atomic theory from the student's drawings and making connections.

Alamina (1992) carefully describes the historical development of chemical change and comes to the following conclusion:

Thus any distinction between chemical and physical processes, which does not involve sub-microscopic particles, inter-atomic bonds, and inter-molecular bonds may be misleading. (p. 66)

Considering the age range of the pupils this may well be a valid conclusion, but the slippery nature of the concept of physical and chemical change again becomes apparent. Much of the results considers physical and chemical change and is expressed in these terms.

The sixth interview question (p. 302) for the first change (burning paper) and the second interview question (p. 303) for the second change (precipitation) ask what type of change had occurred. The results are categorised, where possible, into

physical change and chemical change. For the experiment involving burning paper (p. 132), out of 102 students 84 classified burning paper as a chemical change, 14 classified burning paper as a physical change, and the answers of four students could not be classified. It is notable that the average is obtained from three age ranges and that the oldest (groups with most schooling correctly classify burning paper as a chemical change (97% as compared with 71% for the youngest grouping). The data were interview-based so it also includes the reasons that students gave for their classification (pp. 133-138) which is extremely interesting and informative. For example (p. 137), a student explains that she would classify burning paper as a physical change because she could see it as an observable physically manipulated process whereas letting an ice block melt in a room would be a chemical process as it happened without apparent intervention.

The results of the experiment (p. 186) involving precipitation are similar with an average of 74% of students classifying precipitation as a chemical change. It is noticeable that there is much greater similarity between the three age groups and that the percentage of students seeing precipitation as a chemical change is considerably less than the percentage of students seeing burning paper as a chemical change. Alamina did note (p. 185) that students classified precipitation as a chemical change both because they thought it was a reversible reaction and because it was not a reversible reaction or because of the difficulty of reversing the change. In other words, there is the problem of obtaining correct results for wrong reasons. Alamina (1992) states:

Generally the pattern of pupil's responses suggested no common fundamental understanding on which to base a relation between the two transformations- burning and precipitation as chemical changes. Pupil's transformation types were mainly context specific. (p. 240)

Alamina (1992, p. 239) bases her classification on Anderson's categories of transformations, which are transmutation, displacement/transmutation and chemical reaction (Section 6.3.3). Alamina (1992, p. 266) looks at the implications for pedagogy raising issues of textbooks (pp. 267-268) and linguistic issues (pp. 268-269). On page 272, an example of a question, all too common, (unfortunately) is given. It is in multiple choice format and asks 'Which of the following is a chemical

change?'. The options given are: a. Dissolving salt in water, b. Filtering a mixture of sand and salt, c. Burning of charcoal, d. Boiling water, e. Magnetising iron nails

Alamina correctly recognises the dilemma that both researchers, teachers and students all face when answering a question like this. She says that on grounds of reversibility, answer (c) burning of charcoal is correct leaving dissolving salt and boiling water as physical changes, when they are arguably chemical changes. Alamina actually states (a), (b) and (c) to be chemical changes but she has made a typographical error and she means (a), (c) and (d) to be chemical changes or if the argument were carried a stage further, the answer might be (a), (b), (c) and (d), as (b) also involves salt dissolving in water.

What should be done about this confusion? Alamina (1992) says:

If the dilemma is to be overcome, it will be necessary to ensure that textbooks and other learning materials present a consistent interpretation of chemical change. (p. 272)

Alamina's research indicates her awareness of the problems of definition, but the solution given to the problem is an oversimplification which is understandable since the academic range of the pupils tested is over three years of secondary schooling whilst the concept of physical and chemical change is taught in some form or other at all levels of schooling from Year 1 in primary schools to university level. What is certain is that the concept of physical and chemical change is taught differently and understood differently at different educational levels. As will be seen later, the emphases in teaching the concept of physical and chemical change vary from country to country or sometimes even from area to area in the same country. Textbooks are written to cater for local needs.

Overall, Alamina clearly recognises and states the problems in understanding the concept of physical and chemical change; she has carried out interesting research in difficult conditions in this area. She showed that the great majority of students she interviewed could correctly identify burning and precipitation as chemical changes; she tabulated the criteria that students used to identify burning (p. 133) and precipitation (p. 185) as a chemical change; and finally she indicated common

student alternative frameworks. Overall, I think this is a valuable and perhaps neglected contribution to the literature.

### 6.5.3 *The doctoral dissertation of Joseph J Hesse III and related work*

Hesse (1987a) made a significant attempt to find out what difficulties three students had with the concept of chemical change. Generally Hesse is more interested in chemical change, but he does consider physical change (p. 38) and Piaget/Inhelder's work on conservation (p. 122).

Joseph J. Hesse III and Charles W. Anderson (his supervisor) presented results of intensive clinical interviews with 11 high school chemistry students in an article on chemical change (Hesse & Anderson, 1992, pp. 277-299). An earlier paper on the same area is also of interest (Hesse, 1987b). The background to the thesis and the two articles follows.

Eleven students were selected from 180 junior and senior high school students covering a wide range of ability who were tested after finishing a unit on chemical change. The article details the cognitive processes used by just three of these students and it is these intensive interviews which differentiates this research from the other doctoral studies mentioned. The research also focuses on chemical change rather than on the concept of physical and chemical change, though physical change is mentioned. The chemical changes, demonstrated by the interviewer, about which the students were interviewed were the rusting of an iron nail, the heating of copper in a Bunsen flame, and the burning of a wooden splint. These reactions were chosen as they all involve a gas as product or reactant. Bill (one of the three students who was fully interviewed) sees chemical change as an intricate form of physical change. It is interesting to note that Schollum's and Andersson's earlier work noted similar confusion for some students.

The researchers wished to look particularly at the idea of conservation using the well established Piagetian research on conservation dating back to 1940s. It should be remembered that quite a large percentage of the science education research of the 1970s was concerned with Piaget's theories, so it is not surprising that the new

research paradigm should attempt to find links with the established paradigm. For example, Hesse and Anderson (1992) state:

For example, students of 12 -13 years conserved mass when a ball of clay was reshaped, but had difficulty conserving matter during a more complex physical change like dissolving. (p. 279)

This statement conflicts with other researchers like Alamina (1992) who generally see dissolving as a chemical change. There is again the question of whether dissolving is a physical or a chemical change, but in this case it is not the subjects of research but the researchers, who see things differently. Results from research by Hesse and Anderson (1992) indicate that students commonly experience difficulties in chemical knowledge, conservation reasoning, and explanatory competence.

#### **6.6 My own research leading to further research on understanding physical and chemical change**

Because the teaching of physical and chemical change is usually near the beginning of traditional chemistry curricula, it has been a part of my teaching for a long time, but it was when teaching at Goroka Teachers College in Papua New Guinea (see Section 1.4.1) that I will now expand upon, as this was the research which led me to start considering physical and chemical change as being a concept that might have some difficulties for Papua New Guinean students.

At that time I was part of a research group under the leadership of Dr Michael Wilson from the University of Papua New Guinea (Port Moresby) who were co-operating together as part of the Second International Science Survey (SISS). This was a major international survey of which the work in PNG was a very small part, but we were able to add sub-projects to the main survey. Wilson has provided several useful articles (Wilson, 1984; 1986) about the organisation of the SISS in PNG.

I asked that the teachers who were teaching the students who did the SISS test also did the test themselves and answered various questionnaires. These papers were marked with the student test and I eventually received the detailed results. The

results did indicate that chemistry was one of the greatest areas of difficulty for teachers and that the scores of about 25% for teachers were of concern in terms of their knowledge of chemistry. I then carried out some analysis of individual questions and eventually came to the conclusion that Papua New Guinean students had difficulties in answering questions about physical and chemical change. As an example, some analysis was carried out on a single question containing a basic generalisation in chemistry, in the context of similar questions from previous research which also tested this generalisation.

The most difficult question in Test 2M was Q18 which asks:

Two given elements combine to form a poisonous compound. Which of the following conclusions about the properties of these two elements can be drawn from this information?

- A. Both elements are certainly poisonous.
- B. At least one element is certainly poisonous.
- C. One element is poisonous, the other is not.
- D. Neither element is poisonous.
- E. No conclusions can be made. (Palmer, 1986, pp. 173-174)

The general principle for teachers and pupils to understand is: 'The properties of a compound are different from those of its constituent elements'. I went on to show that similar questions had been used in earlier tests – one 16 years earlier by MacKay (1968) and the test was repeated for remedial students at Lae University of Technology (Boeha, 1980). In both instances, the results for the question were poor with numbers of students obtaining correct responses being close to what would have been obtained by chance. For me the conclusion was not something that was proven, but rather that some students certainly found the concept of physical and chemical change and related concepts difficult, so I was determined to research the topic further.



### 6.6.1 *My research intended to be linked to physical and chemical change*

From 1990 onwards I asked students to complete the assignment that appears in Appendix 4. It was for students in the Diploma of Teaching program and Graduate Diploma in Secondary Education program. They were to remember notable people and events that had influenced them in science. The hope was that the students would remember the interesting and exciting things that they had done in chemistry with strong recollections of the experiments that related to physical and chemical change.

Over four years from all groups, 138 assignments were returned and assignments by female students were very much in the majority (78%). There was the expected concentration of female students on biology and the tendency to find the physical sciences too hard, or in some cases female students felt that they were excluded from the physical sciences by unsympathetic male teachers. Only four out of 138 assignments contain memories of actual physical science experiments (see Figure 6.1). The only significant memory common to many students were the memories of rat dissections. It is interesting to observe that two of the four memories of physical science come from males. The research (Palmer, 1995d) can be downloaded from the following URL (accessed 15/6/01) which contains the significant student comments in the appendices.

<http://info.mq.edu.au/Educ/atea/palmerw.htm>

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93/A/22F Her most vivid memory is of her new fresh from college male Year 5 teacher's experiments on a balcony outside the classroom with a chemistry set as a reward for good behaviour. She says "they were designed to enthuse us to science, but all they served to do was to reinforce the view that science was too hard for me!" "Our experiments were never experiments as such, but rather clumsy mixings of whatever happened to be around. None of us ever considered what we were doing... -we just did it. I have one awful memory of accidentally making a test tube explode. I have no idea how it happened, all I know is that I burst into tears and never liked to go out on to the balcony after that because I was afraid it would happen again.

92/B/07M "Secondary school science began with some heroic experiments. In physics, a teacher made a barometer with mercury. In chemistry "interest was spurred on by experiments that flared and popped in the fume-cupboard..."

91/C/04F "The physics teacher worked hard at shining torches through prisms and drawing beautifully labeled diagrams". " My chemistry teacher was an old dragon, though I did enjoy burning magnesium and sodium...". "Science is the knowledge and understanding of the nature of the world and beyond."

91/C/08M ...in Years 8 and 9, I struggled not with the difficulty of the subject; but with the boredom of the way it was presented. Our first science lesson I remember as being really enthralling ... The teacher did all sorts of exciting things with coloured water and acid, things to capture our attention on that first day. That, unfortunately, is where the excitement ended."

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**Figure 6.1** Assignments that contain memories of actual physical science experiments

The reality of this research is that it did not indicate that students generally had any favourable memories of physical and chemical change. What memories they had of chemistry were generally unfavourable. Nonetheless, the research was worthwhile though not directly very relevant to the thesis; it did however warn against accepting hypotheses about student enjoyment of chemistry over-readily.

### 6.6.2 *My research on biography and auto-biography in chemistry*

The few examples that follow are part of a piece of research that I undertook to search a variety of sources of the famous or of the unknown to see where either physical change or chemical change, usually in the context of remembering events at school or learning experiences, was used. Sources are very varied and included autobiography, literature, newspaper articles, published letters, e-mailed histories to listservers, the www. To date I have collected together 57 items of varying quality, but all of which appear to be accounts of real events. The overall purpose is to indicate that physical change and chemical change are a part of the lives of ordinary people. I include 10 of these items which may be found as Appendix 5 to illustrate this point. The majority of the excerpts relate to chemical changes with memorable explosions, beautiful crystals and unpleasant smells featuring strongly in these brief histories.

- *Quote 1* The first excerpt (James, 1980, pp. 86-87) is one of a number taken from the autobiography of Clive James who is a TV interviewer and personality. It illustrates how chemical change needs to be managed safely with the writing containing including the element of humour, through observing a teacher's trauma.
- *Quote 3* The next quote is again autobiographical taken from an Australian minor classic *I can jump puddles* by Alan Marshall. Here the scientific concept of air pressure would be a physical change.
- *Quote 4* In this exemplar an influential science teacher, Van Praagh (1978), remembers his own earliest experiences of science. Van Praagh taught for part of his career at Christ's Hospital school and was a biographer of Henry Edward Armstrong (see Section 4.6). I also remember him giving a series of lectures organised by the British Council in Nigeria near where I taught (see Section 1.4). and recollect the difficulties he had in an unfamiliar laboratory of getting the bunsen burner to light.
- *Quote 8* Relates to the preparation of unpleasant smelling gases, which is very definitely the province of chemical change. Again there appears to be

some element of humour in what is really an appalling lack of consideration for safe practice.

- *Quote 10* Is a small part of a very long autobiographical section (Hodgkin, 1988), where the Nobel Prize winner Dorothy Hodgkin explains the reasons why she became interested in chemistry. Again we have the example of preparing crystals of copper sulfate or potassium aluminium sulfate as beautiful chemical changes which Dorothy Hodgkin believes was the reason she chose chemistry as a career. It is interesting to reflect on these faint links between events of past and present. The beauty of crystals is a common theme attracting many famous and unknown chemists to chemistry. The crystallisation of copper sulfate for me has to be a chemical change, but that would not be universally agreed.
- In *Quote 12*, the nine year old James Clerk Maxwell, set to become the Professor of Experimental Physics at Cambridge University, shows a precocious interest in science with the physical changes involved in spinning brightly coloured tops fascinating him (Anon, 1991). Later in life, he actually made discoveries in the science of colour perception (Asimov, 1975, pp. 398-399). He is best known for deriving Maxwell's equations, which relate to electromagnetic theory.
- *Quote 13* shows that even local newspapers can be a source of examples of physical and chemical change. In this case a well-known experiment which involves physical change goes wrong and is probably remembered for that reason.
- *Quote 15* is a typical historical account of a violent chemical change which came to my attention by e-mail, though it is in fact an article in the *Journal of Chemical education*.
- *Quote 31* actually provides examples of both physical and chemical change. Wladimir Engelhardt eventually became a biochemist, but recollects carrying out experiments in physics and chemistry from the time that he was at primary school (Engelhardt, 1990). The source is one of three huge

volumes entitled *Life and science, the excitement and fascination of science: Reflections by eminent scientists*, which is a very rich source for the recollections of scientists.

- *Quote 56* The final quote from this selection of physical changes and chemical changes is a chemical change which is really quite a cruel usage of chemistry (Feedback, 1995). The teacher deliberately gives instructions which will harm the students, though not seriously. This and some of the other quotations gives an indication of some of the science teaching of the past.

This is an interesting area of continuing research which shows that physical change and chemical change is a part of everyday life and supports the idea that it is a useful concept in the public understanding of science.

It is perhaps unfortunate that the tentative conclusions that I reached from two pieces of research that I have undertaken apparently point in different directions. In the research on whether students training to be teachers actually remember anything about physical and chemical change, the results appeared to be that there are very few students who remember anything about it. The richness of the data from literature, biography and autobiography would apparently point in the opposite direction. However, even looking at biographies of scientists who are asked to recollect their schooldays quotable passages might only be found in one out of 10 cases. The commonality of the two pieces of research might be that a very few people, observing the excitement of physical and chemical changes, may have influenced their choice of career or at least have provided interesting memories.

## **6.7 Research which reviews several earlier studies**

A number of studies in chronological order (Andersson, 1990; Naklkeh, 1992; Driver, Squires, Rushworth & Wood-Robinson, 1994b; Gabel, 1994; Griffiths, 1994; Watson & Dillon, 1996; Taber, 2002a) review several experimental studies together. These generally balance a blending of a theoretical understanding of physical and chemical change with the learner's worldview. Such reviews can be very helpful. For example, in Chapter 7, I will be applying the criteria developed by Griffiths

(1994), on the basis four papers on physical and chemical change and two papers on combustion, to analyse student manuals. As a result of his earlier analysis (Taber, 2002a), it is also worth noting that Taber (2002b, pp.1-25) provides strategies and exercises for teaching the earliest concepts in chemistry.

#### *6.7.1 A final thought about the research in this chapter*

In this section, I have examined the research on physical and chemical change under several different headings and themes. The current research style for considering a wide variety of chemical concepts is still very much a matter of identifying students' alternative concepts. A number of these research studies have been discussed in this chapter. In the case of studies concerned with questioning students about physical and chemical change either based on written objective tests or on observing experimental instances, I felt that more care should have been taken by the researchers to be clear what are the scientific conceptions appropriate to particular age groups.

## CHAPTER 7

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### TEXTBOOKS AND PHYSICAL AND CHEMICAL CHANGE

#### *Research Questions:*

7.1 *Is there any discernible trend in the way that textbooks deal with physical and chemical change and has this altered over the last two hundred years?*

7.2 *Did textbook authors who wrote both chemistry and physics (natural philosophy) textbooks introduce the concept of physical and chemical change into their natural philosophy/physics texts more frequently than those authors who only wrote physics textbooks?*

#### **7.0 Further information on science textbooks: Two studies**

What is a textbook? Even this deceptively simple question does not have an easy answer (see Section 6.1). One answer would relate to the function of the book, the increase in scientific knowledge, and the technology of printing. Historically there was a time when human beings could know virtually all the knowledge that there was, so comparatively few books could store that knowledge and a few others discuss the philosophy and implications of that knowledge. The only way of making additional copies of books was copying by hand, so the variety of books remained limited with the libraries of monasteries generally being the places where this knowledge was stored. Hand copied books were expensive luxury items for the few people who could read. Much of the knowledge of the early Greek authors is only available because the manuscripts were stored by Arabic scholars (see Section 2.4) and the knowledge used as a basis for Arabic science. This was the situation up to the fifteenth century when there was a comparatively small scientific literature, available to comparatively few people. There were not at that time separate sciences, but the nearest to what would now be called chemistry would be alchemy, which had a substantial literature of its own.

Then the technology changed as in 1456 Gutenberg printed the Bible using moveable metallic type. There was from this point in time a slow intellectual awakening combined with the ability to publish the views of authors in books which were more widely available, so that experiments of one author could be repeated and commented upon by the next generation of scientists. Nonetheless, these books were generally written with an aim of adding to knowledge, rather than with the aim of teaching students, though there are exceptions. It was only in the nineteenth century when a public demand for science books was created, that science textbooks for use in schools became commonplace. The story of the chemistry textbook and many science textbook authors makes up the content of Chapters 2, 3 and 4. This study continues with two analyses of physics and chemistry textbooks written in the past 200 years.

## **7.1 Physical and chemical change in school textbooks**

In the first study reported in this chapter, 527 chemistry/science textbooks from a variety of countries and written at all levels of education were examined to see how they dealt with the topic of physical and chemical change. Textbooks have continued to cover this topic for about 200 years. What evidence do school textbooks contain about the purposes and methods of teaching this topic? Is its coverage in textbooks increasing or decreasing? When was physical and chemical change first taught and is it still appropriate to teach this topic? These and other related questions are considered in this study.

### *7.1.1 Observing physical change and chemical change in school science textbooks*

Observations of school science textbooks showed that some textbooks mention physical change and chemical change together, using them as a means of classification of all types of change, whereas other books treat them separately or mention them in different parts of the book under a bewildering variety of names. It is not possible to have a science/chemistry textbook that avoids all mention (overt or covert) of physical and chemical change. For example, the word 'physical change' may not be mentioned, but if the ideas of moving, heating, magnetising, grinding, mixing, evaporating are present, then physical change is implied. Physical change would also be implied if light or electricity were passed through it.



If, for example, the text names a chemical compound, includes an equation, describes a substance decomposing on heating, or gives a theoretical explanation of chemical bonding, then a chemical change is implied. This is pursuing the topic to a logical, but not a very practical conclusion. If this implied definition was accepted, then the idea of chemical and physical change is a part of all science textbooks as a matter of course. However, it would not necessarily mean that the sort of change observed when grinding a solid to a powder (a physical change) was compared and contrasted with the sort of change seen when a new substance was formed after heating a mixture of substances (chemical change). Some textbooks do present 'physical and chemical change' in contrasting pairs and presumably this is for a good reason. What seems probable is that physical and chemical change is as much a way of teaching and classifying as it is a scientific concept. When categorising textbooks, those that contrasted physical change and chemical change were considered as a group compared with those that mentioned physical change or chemical change separately or do not mention them overtly at all.

The fact that the topic 'physical and chemical change' had been a regular part of textbooks was obvious at an early stage of this research. Initially, textbooks published after 1850 were examined because this date corresponds roughly to the commencement of use of the term physical and chemical change. However, older textbooks also have been examined as a variety of other phrases such as cohesion and affinity seem to pre-date the use of the phrase physical and chemical change and appear to have approximately the same meaning.

Subsequently, a range of chemistry/science textbooks from 1830 to 1994 were examined to see how they dealt with the topic of physical and chemical change in order to answer the following questions: What evidence do school textbooks contain about the purposes and methods of teaching this topic? Is its coverage in textbooks increasing or decreasing? When was physical and chemical change first taught and is it still appropriate to teach this topic? The data presented allow a tentative conclusion and conjecture is made concerning future research directions.

### 7.1.2 Definition of physical and chemical change

Defining physical and chemical change accurately is difficult. Earlier chapters especially Chapter 5 have attempted this. Among the problems related to understanding the concept of physical and chemical change are: (1) the concept has no single satisfactory definition; (2) the words used to define 'physical and chemical change' vary over time and at any one time a number of such words are often current; and (3) the understanding of the concept itself also varies over time and at different levels of teaching.

A definition of the sort that is likely to be found in school textbooks is taken from an old, but popular, Australian textbook (Boden, 1961). The definition consists of four criteria which may be used to distinguish physical and chemical change. These criteria represent a traditional view that all changes can be categorised as either physical or chemical and this view is in itself problematic. The criteria are meant to be practical ways in which a student new to chemistry can tell if a change is physical or chemical (see Section 5.5). Students might well have been asked to learn these definitions by heart. A clue that this memory work was common practice is the suggested use of the mnemonic (MISE) (mass, irreversible, substance, energy) to help students remember the difference between physical and chemical change (Atkinson, 1974). A critique of the four criteria in which certain features are identified as unsatisfactory for an accurate definition of physical and chemical change now follows. (Note - The criterion for physical change is given first with the criterion for chemical change given after the slash):

*Criterion 1: No substance formed or destroyed / Substances changed-new substances formed.*

This criterion is unsatisfactory because the learner has to have considerable chemical experience before deciding whether or not a new substance is formed. When water changes to ice, it is difficult to know whether ice is a new substance or not. To the naive observer, ice certainly looks different to water and the observer might be tempted to call ice a new substance. As will be seen later, this particular commonly quoted example can cause considerable disagreement.

*Criterion 2: No change in weight / Change in weight.*

This particular criterion is of dubious value (generally it is untrue) and really only applies to the case where one or more of the products of chemical change is a gas that is not included in the weighing. In all circumstances, Lavoisier's Law of Conservation of Mass applies. This criterion appears to be limited in application that it should not be included with the other criteria. However, it is part of the definition given in some textbooks.

*Criterion 3: Reverse change easy/Reverse change difficult.*

Generally, this is a helpful definition for students, but there are exceptions and it is possible to apply the criterion incorrectly. For example, in the case of salt being dissolved in water to form a solution of brine, the fact that the salt can be recovered by boiling all the water off is used by some books to prove that the dissolution of salt in water is a physical change. However, consideration of the problem on an atomic scale would lead to the conclusion that the dissolution of salt in water was a chemical change. There are textbooks supporting this view too:

The dissolution of an ionic solid in water is often regarded as a physical process, because a solid can be recovered by evaporation. However, in solution the ions are hydrated. . . . If we define a chemical change as one in which a new species are formed, the dissolution of calcium chromate in water can be regarded as a chemical change. (Bucat, 1987, p. 686)

The following two quotations are on the same page of Baker and Allen (1965):

The tearing of paper, melting of ice, or dissolving of salt and sugar in water are all examples of physical changes. (p. 28)

A chemical change involves electron cloud interactions between the atoms of the matter involved. (p. 28)

One quotation states that salt dissolving in water is considered to be a physical change and the other quotation states that chemical change is defined in terms of a completely different model of the nature of matter. The second quotation would cause one to define dissolving salt in water as a chemical change. Applying the

second quotation to the dissolution of salt in water might cause this dissolution to be called a chemical change.

The definition as a physical change also partially contradicts the view of solution expressed earlier in the same chapter (p. 14). One could come to the conclusion that it is not only students but also authors who have difficulty in understanding the definitions of physical and chemical change. To be fair, the error of considering that the dissolution of sodium chloride in water is a physical change is a common one and it could be argued that at an introductory level it was an appropriate classification, but some element of consistency is necessary.

*Criterion 4: No energy produced although energy may be changed from one form to another/ Energy in the form of light or heat may be given out as a result of chemical change.*

It is not always true that all chemical reactions produce or require more heat energy than all physical changes. Although there would be many exceptions, this is generally a helpful supplementary criterion for students. However, those so-called physical changes that require anomalously high amounts of energy may be suspected of being chemical rather than physical changes. A short look at any book of data such as Aylward and Findlay (1977) will show up such anomalies.

### *7.1.3 The hypercard stack: Recording physical change and chemical change in school science textbooks*

School textbooks were obtained from a variety of sources and photocopies were made from each book including the title pages, the preface and the pages that describe physical and chemical change, if the book has such a section. The information was categorised in a number of different ways and entered onto a hypercard stack. Hypercard was an early database that was one of the few existing systems available at the time (1991) and it was free. Currently if I were starting afresh, I would use a different system. The main factor was the consideration of distinguishing whether or not physical and chemical change were found close together in the book, so that they were compared and contrasted or whether they were some way apart, so that they were treated individually. In the latter case, the card was marked by an "S" for "separate" or in the former case it was marked with a "T" for "together." This would appear to be a very easy criterion to decide, but there

were cases where the decision was by no means obvious. This categorisation was used in constructing the graph of percentages of books that contrast physical and chemical change compared to those that do not contrast physical and chemical change (Figure 7.1). In old books (generally 19th century), the words 'physical and chemical change' are not used but the words 'cohesion' and 'affinity' are sometimes contrasted in the same way or a variety of other phrases with a similar meaning may be contrasted. In categorising textbooks "S" or "T", the words 'cohesion', 'affinity' and the like are counted in the same way as 'physical and chemical change'. Later, there is considerably more discussion about what was meant by the words 'cohesion' and 'affinity' during different periods in the history of chemistry.

There is a question of how to decide which school chemistry/science textbook at which levels to include in the hypercard stack. The process used was to examine texts where there was reasonable expectation that some would include a section (however short) on physical and chemical change. For example, no third year university, physical chemistry or organic chemistry books were examined, but introductory college chemistry books, books on inorganic chemistry and a few practical chemistry books were included. A number of physical science texts (e.g., Addicoat, 1967; Brinckerhoff, Cross, Watson & Brandwein, 1963) and one geology text (Brandwein, Brovey, Greenstone & Yasso, 1975) were also included. A number of specialist chemistry texts written for nurses, health professionals, agricultural students, miners and beauticians were included. The view taken overall was to include a wide variety of chemistry and science textbooks, varied by level, type and country of origin. Although this strategy may not provide an accurate picture of how common the teaching of physical and chemical change was in schools at a particular date, it is believed that a viable picture was obtained. Decisions related to the selection of school chemistry/science textbooks for analysis now are briefly described.

The data were obtained from 527 textbooks from a variety of countries, levels and types of book. From 1830 to the present, the number of books examined and the number of the books that show physical and chemical change in contrast (or some phrases with a similar meaning in contrasting pairs) were recorded at intervals of 10 years. The data obtained, shown in Figure 7.1, give a general indication of whether some, most, or all books in given 10 year periods treated physical and chemical

change together or not. It has to be pointed out that the sample size of early books and the most recent books is small, but as research continues this will improve.

#### 7.1.4 *Physical change and chemical change in school science textbooks: Results and discussion*

Between 1830 and 1994 most chemistry textbooks have contrasted physical and chemical change (or some other words that we consider have the same meaning). Three features can be observed from Figures 7.1 and 7.2.

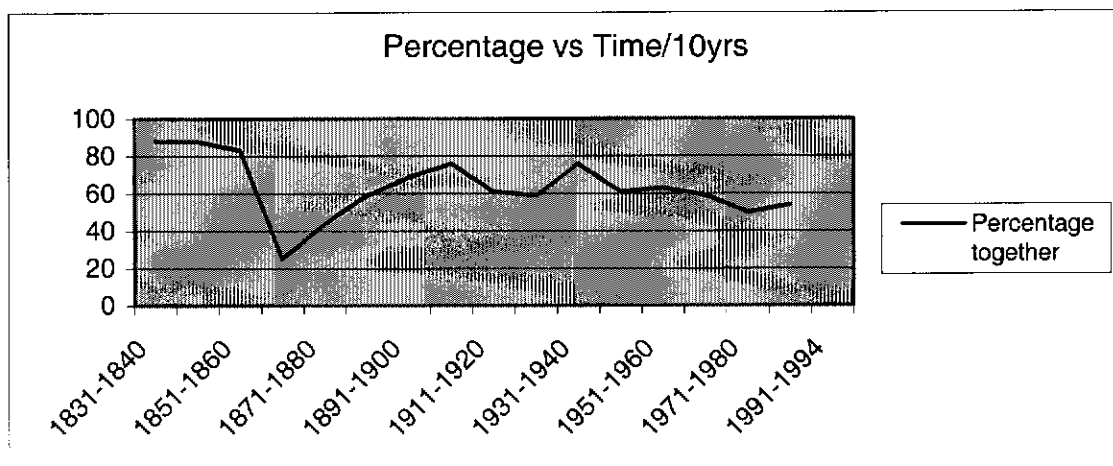
- a) The slope of the graph in Figure 7.2 during this period may indicate a gradual change in view amongst textbook writers such that fewer were using the contrasting of physical and chemical change as a teaching aid.
- b) A dramatic decrease in the percentage of texts contrasting physical and chemical change between 1860 and 1880 may indicate a sudden change in view amongst textbook writers during this period.

10 Year Period	Physical & Chemical Change Together	Physical & Chemical Change Total	Percentage (%) Together Total
1831 - 1840	7	8	88
1841 - 1850	7	8	88
1851 - 1860	5	6	83
1861 - 1870	1	4	25
1871 - 1880	4	9	44
1881 - 1890	13	44	59
1891 - 1900	9	13	69
1901 - 1910	13	17	76
1911 - 1920	11	18	61
1921 - 1930	9	13	59
1931 - 1940	13	17	76
1941 - 1950	11	18	61
1951 - 1960	22	35	63
1961 - 1970	57	96	59
1971 - 1980	60	120	50
1981 - 1990	61	114	54
1990 - 1994	0	9	0

**Figure 7.1:** The percentage of chemistry books found in 10 year periods that treat physical and chemical change together

- c) A dramatic decrease in the percentage of texts using physical and chemical change contrasted after 1990 may indicate a sudden change in view amongst textbook writers, so that fewer writers are now using this approach as teaching/learning aid.

However, one should be wary about the conclusions (b) and (c) since, at this stage of the research, they are based on small samples. Nonetheless, the trend of the data is strong enough to indicate that the 1860s and the last few years were both times when the ways in which writers explained the concept of physical and chemical change were being re-formulated.



**Figure 7.2:** A graph of the percentage of textbooks that treat physical and chemical change together in 10 year intervals

#### 7.1.5 *Physical change and chemical change in school science textbooks: Further analysis*

To analyse the early textbooks further, one needs to see how the language and the concepts implied in the language resulted in changes in the textbooks during the period 1800 to 1900. (Textbooks earlier than 1830 are discussed here but have not been tabulated as they are few in number.) The contrasting of physical change (called cohesion) and chemical change (called affinity) occurs in many books of this period, but a variety of other terms are used as well. This aspect of the study starts with Boerhaave (1728) because, firstly, it is the oldest textbook currently analysed as an original text and, secondly, two other authors credit Boerhaave as being the first to recognise what is now called physical and chemical change. Graham (1847) claims that Boerhaave was the first to use the word affinity in the sense of chemical combination, though other writers give credit to even earlier usage. However, Boerhaave is the author of one of the earliest student textbooks, and he had a greater

understanding than most chemists of his day of what chemical combination involved. Read (1947, p. 145) states that Boerhaave "distinguishes between chemical union and mechanical admixture". In modern parlance, he could tell the difference between a mixture and a compound. Most textbooks treat the mixing of substances as being a physical change, so perhaps we can say that Boerhaave's book was thus the first textbook to recognise, in part, the difference between physical and chemical change.

However, Lavoisier's textbook, *Elements of chemistry* (1790), defined elements, started to standardise chemical nomenclature, buried the "phlogiston theory", and put forward a more coherent concept of chemical change. Lavoisier could thus be seen as someone who clarified the concept of chemical change and brought the concept much closer to the one which we have today. It also is interesting to note that Lavoisier's first major work was *Opuscules physiques et chimiques (Physical and chemical essays)*, published in 1774 (McKie, 1952). It is worthwhile noting the contrasting of the words 'physical' and 'chemical', not as part of the phrase 'physical and chemical change', but simply as an early date where the contrasting pairs are used.

Between 1800 and 1850 texts are generally consistent in using the phrases 'cohesion and chemical affinity' in contrasting pairs much in the same way as physical and chemical change are now used. Between 1850 and 1878 these same words appear, but with some additional new words. In particular, it is observed that the word 'affinity' is used less frequently. There are a number of possible explanations for this, the main one being that the period is a time of ferment and change in terms of theories of chemical combination. Briefly, "Theory of Types," "Dualistic Theory" and "Structural Theory" (Brock, 1992) were matters of heated debate at about that time. An indication of the debate, relevant to the issue of chemical change, is that one dictionary of chemistry (Watts, 1874) was critical of a handbook of chemistry (Gmelin, 1848) with regard to the way it used the word "affinity". Watts (1874) expressed his concern to ensure that definitions were correct and stated that "The terms affinity and chemical combination are not used by all writers in exactly the same sense" (Watts, 1874).



Watts' criticism was that Gmelin (1848) used the idea of uniformity to the senses after combination as the test of affinity and thus included solutions as being chemical compounds. Thus, as late as 1874 there was not unanimity about the meaning of chemical affinity. The problem is that the word 'affinity' was insufficiently precise, so this is likely to have been an additional reason for seeking a change. Around this time, a number of new words came into being, such as the word 'chemism' used by the American chemist, Ira Remsen. He used the new word in the earliest of his books (Remsen, 1877), but it is not used in his later textbooks, where he uses the then typical distinction between physical and chemical change (Remsen, 1886, 1908, 1917).

In the English-speaking world, Roscoe and Schorlemmer (1877) appear to be amongst the earliest authors to contrast the words physical and chemical. The first textbook to contrast physical and chemical change (using those actual words) is a book by Valentin (Principal Assistant at the Royal College of Chemistry, Science Schools, South Kensington) in 1879. Valentin (1879) mentions in his introduction that he had based his theoretical explanations on Von Richter's *Introduction to inorganic chemistry* (a German work). In a later edition of an American translation of Von Richter's (1890) *A textbook of inorganic chemistry*, the author contrasted physical phenomena and chemical phenomena, so a German/continental origin of the idea is possible.

There is also evidence that inclusion of the phrase physical and chemical change into the majority of textbooks over a long period of time relates to the coincidence of Valentin being employed in a senior teaching role within a government department that also set the examinations. Turner (1927) states that an examination system was promoted by the Science and Art Department in science subjects at about this time (1872). It may have played a considerable part in establishing the concept of physical and chemical change into science curricula. For example Turner (1927) goes on to state that:

The boys were familiar with much of the ground by such a large textbook as Roscoe and Schorlemmer's *Treatise on chemistry*. But the whole trend of teaching was towards the acquisition of knowledge which could be readily reproduced in examination papers. (p. 116)

### 7.1.6 *Physical change and chemical change in school science textbooks*

Although the ideas concerning the teaching and learning of physical and chemical change evident in textbooks are not complete, it has been demonstrated that information can be collected and ordered in a coherent way. Clearly, studying textbooks of the past may provide clues as to the best ways of teaching physical and chemical change in the future.

What evidence do school textbooks contain about the purposes and methods of teaching physical and chemical change? Textbooks seldom justify the content they cover in philosophical terms. Usually justification is that the content of the book follows the requirements of some particular examination. The authors would justify the teaching of physical and chemical change in terms of it being practice at the skill/process of classification. The use of the terms physical and chemical change in school textbooks show fairly conclusively that in recent times the coverage is decreasing (see Figure 7.1).

When was physical and chemical change first taught? Here the answer is somewhat more vague. Boerhaave was one of the first chemists to have gained some inkling of what was involved in chemical change, and this understanding was certainly clarified by Lavoisier. As stated in Section 3.3.1 some historians date the distinction between physical and chemical change being made clear to the Berthollet/Proust controversy which raged between 1800 and 1805 (Duhem, 2002, pp. 41-42; Pattison Muir, 1889, p. 3; Mauskopf, 1972, p. 170). I have found some isolated use of the expression of school textbooks of about 1840 such as Leonard D. Gale (Section 4.2.5). Evidence so far indicates that it was not until the 1870s that the words 'physical and chemical change' appeared in UK school textbooks. Some earlier usage in France or Germany is suspected, because I have found a book in French entitled *Cours abrégé de leçons de chymie* by J. B. Meilleur (1832) who was a Canadian doctor and educator (Lortie, 1991). A further connection with the study is that Meilleur went to university in the United States and was taught by Amos Eaton (Section 4.2.3). The book defines the traditional terms of cohesion and affinity very nearly classifies changes as physical or chemical (Meilleur, 1832, p. 20), but not quite! This leads me to suspect that there may be other works of the same period that really do classify changes as physical or chemical.

Once this phrase was established (and probably examinations had a role in this), most school textbooks until the 1990s used the concept. More recently the usage of the concept appears to have decreased. Whether or not it is appropriate to teach the concept of physical and chemical change remains a matter of opinion and future research. Chapter 9 will investigate the opinions of chemists, teachers and teacher educators about this on a worldwide basis.

#### *7.1.7 The four hypotheses revisited: Conjecture for future research*

There may be reasons other than pedagogical ones for distinguishing between physical and chemical change. However, there may be non-scientific or sociological explanations for the lengthy period that 'physical and chemical change' has stayed in junior chemistry and general science textbooks. Four possible alternative hypotheses may explain the longevity of the concept 'physical and chemical change' in school science/chemistry textbooks. In the questionnaire (see Chapter 9), these hypotheses formed the basis of several questions. It is possible that more than one of these hypotheses is true or that there are additional explanations. However, the study of textbooks may throw some light on the truth or falsity of the hypotheses which are now discussed.

*Hypothesis 1: The concept of physical and chemical change is a remnant of an 'Aristotelian' theory of matter, retained by the natural conservatism of scientists.*

Many theories of matter have evolved over the past two and a half thousand years, so that at different periods in human history the dominant concept of matter has been very different. Chronologies of these theories usually start with the view of Thales of Miletus, who lived in about 500 BC, that all matter was made of water (Mierzecki, 1990) and move through a bewildering variety of theories, to a comparatively modern view of matter, such as the Bohr/Rutherford theory of about 1915 (Ihde, 1964, p. 500) that tends to be the basis of the theory current in school textbooks (see Section 2.1.2). The current scientific view of the nature of matter has moved a long way from the Bohr/Rutherford theory, but there is still no certainty about the absolute nature of matter (Mierzecki, 1990) and perhaps there never will be.

There is, however, at least one part of the Greek philosophies of the nature of matter being described in contrasting terms that remains in the concept of physical and chemical change. That is, Aristotle's (and Western civilisation for the next two thousand years) belief that matter was made of the 'elements' called air, fire, earth and water. These had properties related to them and the four elements and their related properties were expressed as two pairs of opposites. The words physical and chemical in the phrase physical and chemical change are also opposites with characteristics that are contrasted in a similar way to 'Aristotelian' theory.

There is another different sense in which the concept of 'physical and chemical change' has taken over pre-existing Greek ideas of atoms. In many textbooks, mainly of the 1960s vintage and later, the idea of moving atoms and molecules is an essential part of the explanation of 'physical and chemical change'. This is perhaps only a weak linkage in that the early Greek understanding of atoms is very different to current understandings.

*Hypothesis 2: The distinction between physical and chemical change in textbooks is a pedagogical device, so that it is easier for students to learn related concepts.*

It is very noticeable that the words physical and chemical change do not occur as a theory of matter in histories of chemistry or even in the majority of chemistry books written for scientists. The phrase 'physical and chemical change' is not usually found in research papers though there are exceptions (Dewar, 1911). Otherwise, the term is only found in school textbooks and sometimes in books for adults considering the nature of matter in historical or general terms. The term is absent from most dictionaries of science. The phrase seems to be more or less used in books for those who are chemistry novices. The phrase physical and chemical change is frequently found in school textbooks over a long period of time. These claims can be checked by the reader in terms of their own observations.

It is this negative evidence that makes it likely that the concept of 'physical and chemical change' is a pedagogical device for teaching in schools rather than an essential idea developed from a logical structure of chemistry. Although the concept of physical and chemical change, or some phrase with a similar meaning, has been in textbooks for over two hundred years, there have always been some books that avoid the contrast between physical and chemical change.

*Hypothesis 3: The concept of physical and chemical change can be illustrated by a number of exciting and interesting experiments that appeal to those teachers who see themselves as being practically orientated*

This hypothesis is more sociological in nature and evidence regarding it tends to come from sources other than textbooks, such as anecdotal evidence and letters to journals about why physical and chemical change should or should not be included in textbooks and taught in schools (Gensler, 1970; Satchell, 1982).

*Hypothesis 4: The concept of physical and chemical change is a device used by chemists to define the boundary between chemistry and physics to the advantage of chemistry, so that young people will tend to choose chemistry as a subject to study rather than physics.*

This hypothesis is one that people generally find strange yet it is not difficult to document from old textbooks. The definitions of physical and chemical change were very much a part of defining the boundary of what is 'chemistry' and what is 'physics'. Two examples of this follow, but the practice was common, so many others could have been chosen.

The study of physical changes constitutes the domain of Physics and the study of chemical changes constitutes the domain of Chemistry. These two kinds of change are not always easy to distinguish, and Physics and Chemistry are two closely interwoven branches of science.

(Jamieson, 1917, pp. 52-53)

Changes of this kind, in which form and properties only undergo modification, without any alteration in composition, are called *Physical changes*, and the study of this class of phenomena comes under the domain of Physical Science. . . .Changes of this class, in composition as well as properties, are called *Chemical changes* and the study of the laws which govern and bring about such changes constitute the Science of Chemistry.

(Lewes & Brame, 1925, pp. 1-2)

The relationships between physicists and chemists over the past 200 years have certainly been variable. If we consider Lavoisier to have started modern chemistry, then we can date chemistry as a separate science from about 1780. Up to the turn of the 20th century, we can see chemists as being very much on the defensive and thus they wished to ensure that the subject had clear boundaries (Nye, 1993). More recently the concern about whether chemistry might become absorbed into physics has evaporated and chemists are confident of playing a role in a subject that is a discipline in its own right.

On the question of whether chemists have used the existence of an apparent boundary between the subjects, to make chemistry appear more attractive than physics to students at school, which is the second part of this hypothesis, there is little direct evidence. It is certainly true that, in general, physics books do not usually mention 'physical and chemical change'. Only one physics book was located that mentions physical and chemical change (Dull, Clark, Metcalfe & Williams, 1960), but there may well be others. The absence of discussion of physical and chemical change in physics textbooks indicates either that the authors do not find the concept helpful pedagogically or that they do not wish to emphasise the differences between physics and chemistry.

These four hypotheses are tentative at this stage, and it may be that they are not in a format where formal proof is possible. However, they do represent the foundation of further research in this area.

The four hypotheses will be considered further in Chapter 9, but the study continues with more detailed analysis of information, which may be obtained from school textbooks. The next sections attempt to find clues to the question posed in Section 7.1.6 which asked about when the concept of physical and chemical change was first used in school textbooks. It seemed reasonable to me to suppose that authors who wrote both physics and chemistry school textbooks might be more likely to introduce the concept of physical and chemical change than those who wrote just physics or just chemistry texts. As may be seen from the next section the results proved to be interesting. There are strong connections with the next section and the biographies of science textbook writers to be found in Chapter 4.

## 7.2 Textbooks of nineteenth century by writers who have written both physics (natural philosophy) texts and chemistry texts

The authors discussed in this and the following sections have written school textbooks that are about both physics and chemistry during the period 1800 to 1900. Prior to 1800 and in the early period of the nineteenth century books often included all the physical sciences. But during the nineteenth century as a whole, a comparatively large number of science textbook writers published separate chemistry and physics (natural philosophy) textbooks with numbers of these writers increasing as the century progressed. Coincidentally this period is also the time when the concept of physical and chemical change was establishing itself in chemistry textbooks and mention of the concept becomes almost universal in chemistry textbooks in the early twentieth century. However, during the twentieth century there appear to be fewer authors writing both physics and chemistry texts; authors in that period and since that time tend to write either chemistry textbooks or physics textbooks as the subjects became more specialised. In general, physics textbooks do not mention physical and chemical change.

Did textbook authors who wrote both chemistry and physics (natural philosophy) textbooks introduce the concept of physical and chemical change more frequently than those authors who only wrote physics textbooks? My hypothesis is that authors who wrote both will tend to include more chemical concepts in their physics books than those authors who only write physics texts. I will look at the examples below to see how these authors treat physical and chemical change. The study of this particular set of authors clarifies the meaning of physical and chemical change and also of some trends in physics and chemistry textbooks over the nineteenth century.

For each named author there will first be comments about their textbook on natural philosophy (physics) followed by comments about their textbook on chemistry. Following Nietz (1966) in his section on natural philosophy, the time span of the nineteenth century will be divided into early–1800-1830; middle–1830-1850; late middle–1850-1870; and end of century–1870-1900. These time scales are approximations only, as some books remain in print for 50 years or more, authors write books at different times in their careers and Nietz (1966) himself chooses

different divisions of the century dependent on whether he is considering chemistry and natural philosophy books.

### 7.2.1 *Writers of both physics and chemistry texts: Early period 1800-1830*

The writers discussed below have all written both physics and chemistry texts in the early part of the nineteenth century and in many cases have written texts about other branches of science too. Several of the writers have their brief biographies in chapter 4.

### 7.2.2 *Jane Marcet*

Both Marcet's books follow a conversational style. The conversation in this and other Marcet textbooks is between Mrs B who provides the answers and Emily and Caroline who pose the questions. She assumes that her students will have some knowledge of natural philosophy before starting chemistry. Marcet's work was extensively plagiarized for over half a century because of its amazing popularity. There are many versions of *Conversations in chemistry* where Marcet's name is not mentioned in the title but where the male author is the apparent author of the whole work. Examples are Davy (1814), Comstock (1833), Jones (1845) and others. Amongst these others there is a French version (Anon, 1826) where the characters are Mme De Beaumont, Caroline and Gustave. Marcet's self-effacing preface seems to be included in most versions.

In her text on natural philosophy, Marcet (1820, p. 19) comments that heat is intimately connected with chemistry and that she has Mrs B say that she will defer comment until Emily studies that subject. This appears to be the sole reference to chemistry in the book.

In her introduction (Davy, 1814), Mrs B goes through popular misconceptions and errors regarding chemistry and corrects them one by one. For example, Marcet speaking as Mrs B explains that pharmacy is just a branch of chemistry and the alchemy was the work of misguided philosophers. Next she considers heat and light (the imponderables, p. 60-63) whilst the remainder of the book deals with chemical compounds.



### 7.2.3 Reverend J. L. Blake

Blake published Jane Marcet's *Conversations on natural philosophy*, but improved upon it by the addition of questions, notes and a dictionary of philosophical terms (Nietz, 1966, p. 115). He also wrote questions for Comstock's textbook featuring Jane Marcet's *Conversations on chemistry*.

### 7.2.4 Reverend J. Joyce

These are small books each covering just one aspect of natural philosophy. In his books Rev J. Joyce (Joyce 1808; 1812; 1829) imparts information to his readers through conversations between Emma, her brother, Charles and their father (in Joyce, 1812; 1829, mechanics) or through conversations between Charles, James and their tutor (in Joyce, 1808 and Joyce, 1829, astronomy). There appears to be no mention of chemistry in any of the natural philosophy volumes seen.

Joyce (1818) teaches his readers through conversations between Charles, Emma and their tutor. Volume II contains descriptive chemistry. The theory of chemical affinity is in Volume I, and it would be expected that the definitions given would be typical of the period.

### 7.2.5 Reverend David Blair

The books published under the name of Reverend David Blair are actually the work of Sir Richard Phillips (Nietz, 1966, p. 113). Evidently Sir Richard Phillips had been critical of the British government and had been imprisoned for this (Nietz, 1966, p. 113).

Blair (1821, p. 12) is a natural philosophy text that states that there are five kinds of attraction, which are cohesion, gravitation, electricity, magnetism and chemical attraction. If one examines these, the first four kinds of attraction would appear to relate to physics, so it can be said that there is physical attraction and chemical attraction. Blair (1821, p. 12) also contains a glossary and 30 pages of questions. Blair (1826) is a similar text but it is more detailed with diagrams distributed throughout the text rather than as many diagrams on single plates. Blair (1819) is a

small chemistry textbook which also contains a glossary and 16 pages of questions (Nietz, 1966, p. 140).

### 7.3 Writers of both physics and chemistry texts: Early period–middle period 1830-1850

The writers discussed below have all written both physics and chemistry texts in the early middle part of the nineteenth century and in many cases have written texts about other branches of science too. The biographies of several of the writers are included in chapter 4.

#### 7.3.1 *Mrs Almira Lincoln Phelps*

Almira Lincoln Phelps was extremely active in trying to teach and to write about teaching in a way that students could understand. She wrote

The Author (herself) of this little book, after having spent many years of her life in teaching, and many in writing for the young, is more than ever impressed with a sense of the importance of interesting them in their scholastic pursuits. (Phelps 1866, p. vi)

Phelps was a prolific author with books on geology (Phelps, 1832) and botany (Phelps, 1856) as well as two each on chemistry and natural philosophy which are discussed below.

Phelps (1866) scarcely mentions chemistry in this natural philosophy text except to name it as an area of knowledge and to mention the study of chemistry as providing evidence for the existence of atoms. In her introduction, Phelps (1844) explains the benefits of chemistry and she states that:

The properties of matter are either physical or chemical; the former are considered in Natural Philosophy, the latter in chemistry.

(Phelps, 1844, p. 15)

Next she deals with the imponderables (heat, light and electricity), then inorganic chemistry followed by organic chemistry. At the start of the book, the various forms of affinity are considered.

Phelps (1857) also wrote a simpler account for beginners to chemistry than her 1844 text which catered for college students. In her introduction for teachers, Phelps (1857) states that when she was teaching at the Female Seminary at Troy she required pupils to perform experiments and to give lectures to other students on given subjects. This would be considered good practice today. No special mention was made of physical and chemical change in this work.

### 7.3.2 John Lee Comstock

Comstock was a prolific writer producing 26 textbooks at various levels of difficulty across the sciences. His *Elements of chemistry* sold quarter of a million copies and his *System of natural philosophy* in its various editions sold nearly a million copies (Miles & Gould, 1994, p. 46). It is noticeable that Comstock's books are the most plentiful science texts available of his time in the second-hand market. He influenced later textbook writers as Edward L. Youmans who claimed that Comstock's *Elements of chemistry* had inspired his interest in science (Miles & Gould, 1994, p. 46).

In his natural philosophy text, Comstock (1847) comments on the properties of bodies and the various forms of attraction and on chemical attraction or chemical affinity (p. 19) which is said to take place between particles of different kinds. There is little else about chemistry except in describing the battery, electro-gilding and photography.

Comstock's first book was *A grammar of chemistry* which was an improved version of Rev D. Blair's book of the same title. Comstock (1833) revised and edited Jane Marcet's very popular work called *Conversations on chemistry*. In his *Elements of chemistry*, Comstock (1845) writes "Natural science has been divided into two great branches. . ." (p. 9), which he considers to be natural philosophy and chemistry or chemical philosophy.

He then deals with the imponderables (caloric and galvanism) in the first chapters, followed in subsequent chapters by the different types and affinity followed by a standard chemistry of the elements. Standard descriptions of chemical affinity are given in all three books. One can see this book as typical of many textbooks of this period, in that the first part of chemistry books is about physics and the second part about chemistry. Could this be a forerunner of dividing all possible phenomena into physical and chemical?

### 7.3.3 *Reverend J. W. M'Gauley*

M'Gauley (1850, Volume 1, p.3) mentions chemical attraction briefly and chemical action in relation to optics in some detail (pp. 191-202), in relation to electricity (pp. 245-247) and in relation to galvanism (pp. 254-282). M'Gauley (1850, Volume 2, p. 12) mentions chemical changes and how they may be represented. In general, Rev J. W. M'Gauley gives more than average space to chemistry in volume one on natural philosophy, but does not connect his natural philosophy and chemistry sections to any significant extent.

### 7.3.4 *John Johnston*

In his natural philosophy text, Johnston (1850, p. 14) gives exemplars of various types of attraction which were gravitation, capillary attraction, electrical attraction, magnetic attraction, and chemical attraction or affinity and he comments "...the discussion of affinity belongs entirely to chemistry". Little further attention is paid to 'chemistry' until the final pages of the book (pp. 301-302) where the author discusses the cause of the Aurora Borealis and refers the reader to his work on chemistry.

In a later natural philosophy text, Johnston (1876) is writing for younger pupils and provides the information in a question and answer mode often called the catechetical or memoritor method (Nietz, 1966, p. 114). In Lesson 1 on mechanics (question 3), Johnston (1876) asks "In what does it (natural philosophy) differ from Chemistry?" The answer given would tax the understanding of any young person beginning the study of natural philosophy:

It differs from chemistry in this, that it treats the laws governing the relations of masses to each other, while chemistry treats of the laws governing the relations of the particles or atoms to each other. (Johnston, 1876, p. 9)

There is further mention of chemical action under galvanism (Johnston, 1876, p. 161).

Johnston (1853) provides an introduction to his chemistry textbook, in which he describes natural history, natural philosophy and chemistry as the three great branches of science and defines each in turn. His book then follows the order of Turner's chemistry in introducing the imponderables (heat, light and electricity). This is effectively having a brief natural philosophy section, prior to starting chemistry with the topic of affinity and continuing with the various types of affinity.

#### 7.3.5 Benjamin Silliman

Benjamin Silliman was Professor of General and Applied Chemistry at Yale University where his father had also been the Professor of Chemistry (Miles, 1976, pp. 437-439). In the 13 books he quotes in the introduction as being used in the preparation of this book on physics/natural philosophy, two are on chemical physics. Perhaps unsurprisingly, he introduces the terms physical and chemical change very early in the book (Silliman, 1871, p. 3). Items numbers 8 and 9 in the first chapter are physical and chemical properties of matter and physics and chemistry. Benjamin Silliman appears to have attached some importance in teaching the differences between physics and chemistry. He does also point out the importance of both areas and states (p. 4) that "Physical knowledge therefore naturally precedes chemical".

In his book entitled *First principles of chemistry*, Silliman (1853, p. 16) states that there are three great principles or forces, namely attraction, repulsion and vitality. He goes on to say that attraction is divided into mechanical and chemical and further that mechanical attraction belongs to physics and that chemical attraction "constitutes the appropriate business of the chemist" (p. 17). He acknowledges that chemistry students need to study physics and indeed spends about one quarter of the book on matters we would call physics before proceeding with chemistry. What

is instructive here is that one of the great figures of American chemistry explains why changes can be seen as physical or chemical.

#### 7.3.6 *Thomas Tate*

*Electricity* (Tate, 1854) by Thomas Tate is being considered as a book concerned with a portion of natural philosophy rather than a portion concerned with chemistry, but the distinction was not clear in the 1850s. It is a little book almost entirely devoted to experiments with no mention of chemical change or affinity.

Neither of the two experimental chemistry books by Tate (1850) and Tate (1859) contain much theory but both mention six kinds of attraction-cohesion, gravitation, electricity, magnetism and chemical attraction (c.f. Blair, 1826) plus capillary attraction. Tate (1859, p. 4) indicates that chemical attraction and chemical affinity are alternative terms and that chemical affinity differs from the other types of attraction.

### 7.4 **Late Middle Period 1850-1870**

The writers discussed in this section have all written both physics and chemistry texts in the late middle part of the nineteenth century. Often they have written texts about other branches of science or concerned themselves with the public understanding of science.

#### 7.4.1 *David A. Wells*

Wells has written texts on chemistry, natural philosophy and physical science. Wells (1872) starts his text on natural philosophy by distinguishing between physics (natural philosophy) and chemistry. He gives a fairly standard differentiation between the two sciences and then continues the distinction more philosophically as a set of extended notes. His distinction briefly here is that in natural philosophy the truths of all its laws may be proved by direct observation, whereas this is not necessarily the case in chemistry. Wells consistently uses the atomic/molecular nature of matter and brings the chemical viewpoint into this work more frequently

than most of his fellow writers of natural philosophy texts. Wells wrote all his texts in a question/answer format.

This book (Wells, 1857) on 'common things' physical science is aimed at younger students than his other texts but aims to intermix the chemistry and physics portions though there is an emphasis on physics. This was still in the question answer format with questions at a more elementary level. Only some 10 pages out of 323 pages are on so-called "Familiar chemistry", which very much relates to facts.

In this book, Wells (1868) starts with a series of definitions which includes natural philosophy/chemistry (pp. 20-21) and physical and chemical properties (p. 21), but it does not include physical and chemical change as this concept had not yet become common.

Wells was originally an economist (Nietz, 1966, p. 122) and had great success with his school science textbooks. He was also interested in science as it affected the community. For example, he intervened publicly but unsuccessfully in the trial of John Hendrickson who was eventually hanged for the alleged murder of his wife, after evidence of poison was supposedly found. However, the chemical evidence was flawed. Wells obtained confirmatory evidence of this from the best chemists in America including Benjamin Silliman Senior and Benjamin Silliman Junior who concluded that the toxicological analysis was in error (Miles & Gould, 1994, p. 247). Wells also edited the *Annual of scientific discovery* (Wells, 1862) which was produced each year from 1851.

#### 7.4.2 Leroy C. Cooley

Cooley (1881b) includes in the first chapter of his chemistry text an extensive section (two pages) on the differences between physical and chemical properties. On page 16 the term 'chemism' (and chemical affinity) is explained. Cooley (1881a) includes in the first chapter of his natural philosophy text the differences between physical and chemical properties and then states that "the chemical properties of matter are to be described in the science of chemistry; we need give no further attention to them now. Nonetheless on page 165 he uses the term 'chemical action' prior to explaining electricity.

Cooley (1873) starts his chemistry text for beginners with a chapter on physical and chemical change illustrated by simple experiments. It should be noted that this book is for grade schools rather than academic classes, but it is a revolutionary starting point since it simplifies the vast amount of conceptually difficult work on affinities, types of chemical affinity and chemical forces. It is the first text that I have noted to simplify and clarify elementary chemistry at a stroke in this way. Although more academic works still choose to include affinity, chemical force, chemism, etc., the pedagogic innovation of physical and chemical change now takes off in earnest. Cooley (1881) starts his more substantive work for academic classes with a chapter on physical and chemical change and includes reviews and questions. It is interesting to note that Nietz (1966, p. 147) considers that Cooley kept the learner in mind whilst writing his textbooks. This is important as it is evidence that Cooley, when he revolutionised the chemistry textbook, used an emphasis on physical and chemical change as a part of that revolutionary strategy. This indicates that physical and chemical change is more of a pedagogic tool than it is a scientific concept.

#### 7.4.3 *Joel Dorman Steele*

Steele was one of the most popular science textbook writers of his period. His 15 different science texts sold more than a million copies (Miles, 1976, pp.454). In his book on natural philosophy in a footnote Steele (1878, p. 35) states that "chemical affinity produces chemical changes and its consideration belongs entirely to chemistry". Two pages later, Steele refers the reader to his book *Fourteen weeks on chemistry*. Other mentions of 'chemical effects' are found under electrolysis, but in general the 1878 text avoids chemistry and chemical explanations.

In his chemistry text, Steele (1874) who was a deeply religious man (Miles, 1976, pp. 454), starts by introducing chemical affinity and says of it.

The attraction is not a mere freak of nature, but a force imparted to matter by God himself for wise and beneficent purposes. (Steele, 1874, p. 18)

Generally, however, the text is atheoretical with the majority of the book relating to the properties of the elements and their compounds.



In his opening paragraph, Steele (1897) differentiates physical and chemical phenomena or change (p. 1) and on page 2 introduces the terms chemism and chemical affinity as synonyms. On page 4, molecules and atoms are introduced and immediately related to physical and chemical change respectively.

#### 7.4.4 *William J. Rolfe and J. A. Gillet*

There appears to be no mention of any chemistry/chemical change in the natural philosophy text of Rolfe and Gillet (1868), but in the preface they do opine that:

Consideration of chemistry, electricity, sound, light and heat belongs to a more advanced course and should not be introduced at all in a *first* book.

(p. iv)

Rolfe and Gillet (1871) in the preface chide elementary physics textbook writers generally for being out of date particularly in heat, electricity and chemistry:

In chemistry this revolution has been so complete that the present theories of the science are known as "Modern Chemistry".

(p. iii)

Rolfe and Gillet (1874) say in their introduction that this is an easier and briefer work than their other textbooks. There appears to be no mention of chemical change or physical change in this book, but affinity or chemical force is defined briefly (p. 8).

#### 7.4.5 *Gustavus Hinrichs*

Gustavus Hinrichs wrote a school text in chemistry and mineralogy (Hinrichs, 1871) and a text in physics (Hinrichs, 1870). These texts are remarkable for being ahead of their time and they are not mentioned by Nietz (1966), so it is unlikely that they achieved popularity or influence. Hinrichs was born in 1836, moved from his province in German, where there was a civil war, to the United States and settled in Davenport, Iowa in 1861 (Miles & Gould, 1994, pp. 137-139). On his arrival in Iowa,

Hinrichs first taught languages in the local high school. A year later he taught modern languages at the University of Iowa. A year later he was appointed first professor of natural philosophy, chemistry and modern languages, and shortly after that taught only science. He continued to work at the University of Iowa for 25 years building up a science laboratory with an international reputation. A new university administration slashed his budget in order to concentrate on the 'classics'. The series of disagreements resulting from this eventually led to Hinrichs' dismissal from the university. Hinrichs was also active in publications and research. Perhaps his greatest claim to fame is that he devised a form of periodic table which predated the work of Lothar Meyer and Mendeleef (Miles & Gould, 1994, p. 137), yet even this work is little known today. He also was a strong advocate of practical science in schools. He said in the preface to his physics text:

It is generally admitted by those qualified to judge, that the teaching of elementary science in our schools is not carried out in a scientific spirit. Recitation from a textbook, with occasional exhibition of experiments and specimens, is not calculated to give the beginner conviction in the truth stated, or to initiate him into the method of scientific investigation. In regard to science, our schools are not above the middle ages.

(Hinrichs, 1870, preface)

He writes to give advice to science teachers:

The teacher should give his personal attention to each student – make regular rounds passing from one to the other. He should notice everything the student does – commend what deserves commendation and carefully correct errors in handling apparatus, in writing, in calculation etc. (Hinrichs, 1870, p. 162)

Hinrichs' physics text is notable in that it contains a major section on solution and crystallography (Hinrichs, 1870, p. 82-100). The other interesting feature of his books is the section of blank leaves at the end for students to write up their experiments. This appears to be a precursor of the manuals, which are discussed in Chapter 8.

## 7.5 End of century period 1870-1900

The writers discussed in this section have all written both physics and chemistry texts in the late middle part of the nineteenth century. Often they have written texts about other branches of science too.

### 7.5.1 *Sidney Augustus Norton*

Norton (1870) writes a fairly traditional natural philosophy though he does include (p. 10) the ideas of physical changes or forces and chemical changes or forces both included in the same section. The next section (p. 11) treats physical properties and chemical properties followed by definitions of natural philosophy (or physics) and chemistry. He then introduces the idea of chemical physics, which is unusual in an elementary text. However, the word "affinity" is still used as well as chemical change and as an illustration that Norton does not like discarding old ideas, he still has a section on (higher) vital forces (p. 9). The Wohler synthesis of 1828 (Asimov, 1975a, p. 304) was said to have put an end to the idea of vitalism, but even in 1870 it is still alive, though modified in this textbook. Nietz (1966, p. 126) also comments on Norton's use of old and new terms in his textbooks.

Norton (1878) has written another of those texts which uses a wide variety of existing and older terms and mixes them together so that there is not a clear teaching strategy. He does start in the first paragraph with the idea of chemical change, but within that paragraph the terms chemical action and phenomena. Physical and chemical properties are compared, but there is no mention of physical change. In the next chapter we have ideas of chemical force, affinity, cohesion, adhesion etc. which gives the impression of muddled, unclear thought.

### 7.5.2 *Thomas R. Baker*

Thomas R. Baker was a professor of physics and chemistry at the State Normal School at Millersville, Pennsylvania, so it is perhaps unsurprising that he wrote texts in both areas. In his natural philosophy, the Baker (1881, pp. 13-14) text gives definitions and examples of physical and chemical changes followed by a section on

physical and chemical properties. The questions at the end of the chapter include a question (p. 25, Q. 5) on physical and chemical change.

In his chemistry text, Baker (1894, pp. 8-14) states that physical properties arise from physical changes and that chemical properties arise from chemical changes. This is a tautology, but such instances sometimes go unnoticed in school books. The concepts do not appear to be used much subsequently, but it is interesting to note that this author places the topic of solution under chemical processes.

### 7.5.3 *Elroy M. Avery*

Avery gives his occupation as a physical science textbook author, so presumably made his living from his writing rather than from teaching or research, which was the case for most textbook writers. Together with Steele, he must have been one of the most prolific writers of his period as his books are readily available second-hand today. In his book *First principles of natural philosophy*, Avery (1884b, p. 8) asks what a physical change is and replies that it is a change that 'does not change the nature of the molecule.' In Section 12 of his book Avery defines physical and chemical properties: Avery's definition of physics (Section 13) is then in terms of physical properties and physical changes.

In his book *Elementary physics*, Avery (1897, p. 9) briefly explains the terms physical and chemical change and in the questions at the end of the chapter (p. 10, Question 10) there is a question asking for an original illustration of a physical and a chemical change. Chemical changes are mentioned again in relation to photography (p. 195) and to electrolysis (p. 288).

It could be said that in his chemistry text, Avery (1884a) attempts to use all the traditional methods for explaining what he calls "The Domain of Chemistry" which is the title his first chapter. He uses the concept of physical and chemical change (p. 5), but also has sections on chemism (p. 4), chemical affinity (p. 4) and chemical action (p. 7) and also sections on "elementary and compound substances" (p. 3) and mixtures and compounds (p. 8-9). It would seem to the modern eye that by giving all these ways of seeing things the author must have caused confusion rather than clarity to students just starting chemistry because of this morass of similar concepts.

The chemistry text by Avery (1893) with a new title appears to have its first Chapter "The Domain of Chemistry" in identically the same words as the earlier text, so identical comments apply. It is interesting to note that Nietz (1966, p. 127) comments favourably and at length about Avery's physics/ natural philosophy books whereas his chemistry texts only get a brief mention.

#### 7.5.4 *Albert L. Arey*

Physiography as a subject contains quite a lot of science mainly physics, so it was interesting to see what a writer of chemistry texts would bring to physiography. There appears to be no reference to physical and chemical change or indeed hardly any mention of chemistry throughout the book.

Arey (1900) mainly uses the term 'chemical action' but on the second page of the book he defines physical and chemical change, and provides examples. He points out that "every chemical change is accompanied by a physical change" (p. 2). Later he defines chemical affinity stating that "a reaction is due to chemical affinity and causes a chemical change" (p. 13).

#### 7.5.5 *Friedrich Wilhelm Ostwald*

The title indicated that this might be a textbook by the famous physical chemist, best known for his dilution law and the theory of acid base indicators (Jenkins-Jones (1997, pp. 366-367) about physics/natural philosophy. However the book is a philosophical work which is only partially concerned with science. Ostwald does comment on the existence of chemistry as a separate discipline and he says:

...the chemist's methods of reasoning and working are so different from those of the physicist that a division seems to be in order for that reason also.

(Ostwald, 1910, p. 159)

Ostwald (1902, p. 1) starts his book on inorganic chemistry by explaining the difference between physical and chemical phenomena, though he believed that these differences were not 'sharply defined'.

### 7.5.6 *Lothrop D. Higgins*

The term physics is by now increasingly used rather than natural philosophy. The final chapter of *Lessons in physics* (Higgins, 1905, pp. 338-355) is on chemistry. Chemistry and physics are defined (Higgins, 1905, p. 147) and in the same section chemical change is explained but without reference to physical change.

Higgins (1905) writes a first science textbook with the first part of the book dealing with physics and the second first part of the book dealing with chemistry. The second paragraph of the chemistry section compares physical and chemical change. The idea of chemical affinity is introduced later in the same chapter.

## 7.6 Summary

Scientific knowledge increased greatly over the course of the nineteenth century, so books needed to contain more information. Elementary and secondary education also grew rapidly so scientific information needed to be provided at these levels. Chemistry and physics became increasingly popular as school subjects. Chemists began to see chemistry as a separate subject containing worthwhile knowledge. General standards of literacy increased so books were needed for those who wanted to educate themselves. Paper was comparatively expensive early in the 19th century and it was difficult to produce illustrations, and coloured illustration was very difficult and expensive to produce. Gradually over the course of the century, these factors and others helped to change the nature of the textbook in content, in format and in pedagogy.

In the early books, print was small and close together: there were no illustrations in the cheaper books while the more expensive books had plates (several illustrations together bound in), but there was virtually no use of colour (only in very costly books). In terms of pedagogy, complex ideas could be introduced in any order without adequate explanation. These ideas were first presented as continuous prose with few breaks, which makes reading difficult, for example (Ewing, 1809). Over time, various ideas were introduced to make the presentation of the material easier, for example:

- (a) Material introduced by the catechetical or memoritor method (Johnston, 1876; Parkes, 1812).

Here one imagines that the teacher reads the question and the children chant the answer from memory. This method may be effective at training memory, but it is likely to do little for understanding. I have found a book that claimed to be *A catechism of practical chemistry* (Kerney, 1864), which seems like an oxymoron.

- (b) Material using the conversational method (Joyce, 1808; Marcet, 1820).

The conversational method was not an invention of Marcet's though she used the methodology well. I have found a French work of 50 years earlier (Le Prince de Beaumont, 1757) which was translated into English by 1781 then going by the name of *The young misses magazine*. The conversational method was a more flexible methodology and did allow some human interest.

- (c) A variation on passing on information through producing texts of the conversation between adults and children was to produce the textbook as a series of letters which was used by Patricia Wakefield to teach elementary botany (Wakefield, 1807).

- (d) Material using the numbered paragraph method (Blair, 1821)

- (e) Producing shorter books Average length of secondary school text books decreases from 401 pages between 1841-1890 (Nietz, 1966, p. 151, Table 7)

- (f) By the end of the century the latest idea was object lessons which were often little better than the catechisms that they replaced. Hinrichs comment (Hinrichs, 1870, preface) on the teaching methodologies used in elementary schools is very telling.

In the areas of content and pedagogy considering the topic of physical and chemical change, Silliman (1853) amongst others indicates how the earlier complex of types of

attraction – gravitation, capillary attraction, electrical attraction, magnetic attraction, and chemical attraction or affinity – can be considered just as mechanical and chemical attractions. This had the advantage of simplifying what students needed to know. The evidence points to the first effective implementation of this idea being by Cooley in his chemistry text for beginners (Cooley, 1873) which starts with a chapter on physical and chemical change illustrated by simple experiments. Textbooks prior to this book (Cooley, 1873) had only provided a few lines on physical and chemical change, but subsequent to Cooley's text of 1873 there would usually be a full paragraph and often the first chapter of the textbook would be allowed to explain physical and chemical change.

The question put at the beginning of this section was "Did textbook authors who wrote both chemistry and physics (natural philosophy) textbooks introduce the concept of physical and chemical change into their natural philosophy/physics texts more frequently than those authors who only wrote physics textbooks?"

It is apparent that authors who wrote both chemistry and natural philosophy textbooks included more chemistry in their natural philosophy textbooks than those who had only written natural philosophy textbooks (Four out of the 10 books examined in the period 1850 -1900). Amongst authors who have written only natural philosophy textbooks I have found only one in this period who has included the concept of physical and chemical change (Houston, 1879, p. 11). Others do not include the concept of physical and chemical change.

### 7.6.1 *Towards Chapter 8*

In Chapter 8 the study will continue considering historical information from textbooks, but with two case studies relating to practical work in science. The first part of the chapter consists of a study of the work on physical and chemical change in American student manuals in the late nineteenth and early twentieth century. The second part of the chapter consists of a study of the way in which reactions between sulfur and other elements have been used in illustrating physical and chemical change in practical work in schools.



## CHAPTER 8

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### PRACTICAL WORK RELATING TO PHYSICAL AND CHEMICAL CHANGE: TWO CASE STUDIES

#### *Research Questions:*

8.1 *What can we learn about student misconceptions relating to the concept of physical and chemical change from student laboratory manuals (1890-1950)?*

8.2 *What can we learn from the history of the experiments using iron and sulfur to illustrate the differentiated concept of physical and chemical change?*

#### **8.0 A foreword to Chapter 8**

This chapter consists of two case studies, both of which relate to practical work and which largely involve textbook studies. In the study of laboratory manuals completed by students, the thesis is that study of what the students wrote at the time will be a way of investigating what the students' misconceptions were. Perhaps it will be possible to answer the question as to whether or not the students' misconceptions of physical and chemical change alter with time.

The hypercard data used in Chapter 7 also contained information about which experiments the textbooks chose to illustrate the differences between physical and chemical change. Experiments with metals (particularly iron) and sulfur were by far the commonest examples. The case study considers the long history of sulfur as an exemplar of chemical change.

#### **8.1 The practical manual during the period 1890 –1950: Introduction**

From the literature studied I am not aware of previous studies that examine student alternative conceptions (misconceptions) historically, though the literature does claim some geographical and cross-cultural consistency in student misconceptions.

The research in this paper will attempt to find common alternative conceptions (misconceptions) about physical and chemical change in the written work recorded in students' experimental chemistry manuals in the United States of America between 1890 and 1950. There are problems in attempting to do this. For example, a number of different texts using different experiments are used in this study. The question here is whether the materials provided for student learning were sufficiently similar in all cases for there to have been a common learning experience. There may be room to discuss this, but a number of well regarded studies have not thought this to be an essential prerequisite. A further problem lies in assessing whether each piece of work represents the original thought of each individual student and was not, for example, merely copied from the blackboard. This cannot be proven, but the idiosyncratic nature of the writing often provides a high degree of probability that the student work analysed was original.

I include as Appendix 8 some conclusions of recent research summaries that put together the results from studies of student alternative conceptions about physical and chemical change. I will try to compare this with the alternative conceptions about physical and chemical change recorded in student practical work of the late nineteenth and early twentieth century to see if student alternative conceptions have changed with time.

### 8.1.1 *Carrie Southard*

I had been considering for a long time as to ways in which it might be possible to learn more about the ideas that children had about physical and chemical change in the past. In collecting chemistry books generally in mid 1999 I purchased a practical laboratory manual (Stevens, 1895), which had been completed by a student called Carrie Southard, a junior at Columbus North High School, Columbus, Ohio during 1896. Reading carefully through her work, I decided it would be possible to say something about her ideas on physical and chemical change. There are two factors that helped me reach that conclusion. Firstly, the very open-ended way that the practical laboratory manual was organised and secondly, the exceptionally thorough way in which the manual was completed by the student. Good teaching and good learning!

### 8.1.2 Carrie Southard's notebook

To explain this further, I will indicate the way in which the manual was constructed. Detailed instructions for experiments were not provided: there were two opposing pages for each experiment. The left hand page was entitled Laboratory Notes and contained the following headings: Experiment No: Date: Materials used: Notes. The right hand page was entitled: Completed Notes and contained the following headings: Experiment No: Date: Object: Operations: Conclusion.

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Laboratory Notes (P.1)(Carrie Southard)

Experiment No: 1                      Date: 9-17

Materials used: Platinum wire and magnesium

Notes: The wire becomes red-hot. The wire appears to get larger. The wire does not melt. The wire does not change any. Magnesium when burned becomes white and very light and also gives off a smoke when burned. The object is to illustrate chemical and physical changes.

Conclusion: Platinum when subjected to heat undergoes physical change and magnesium undergoes a chemical change.

Completed Notes (P.2) (Carrie Southard)

Experiment No: 1                      Date: 9-17

Object: The object was to illustrate the diff(erence) between chemical and physical changes which took place.

Operations: I placed a platinum wire in a bunsen flame and found that the wire got red hot and appeared to get larger and also that it did not change colour any. I next took a piece of magnesium ribbon and put it in the flame and found that when burned it gave off a smoke. There was also a very light ashes left and white in colour.

Conclusion: Platinum when subjected to heat undergoes a physical change and magnesium undergoes a chemical change.

Overall in the manual the first four experiments are:

1. The object was to illustrate the diff(erences) between chemical and physical changes which took place.
  2. To illustrate chemical action by contact. (Uses marble and hydrochloric acid)
  3. To ascertain whether pinewood is a simple or compound substance.
  4. To illustrate the difference between a mechanical mixture and a chemical compound.
- 

**Figure 8.1** An example of student writing in a laboratory notebook 1896-1897

The student (Carrie Southard) completed 131 experiments in one year, starting in September 1896, and finishing in April 1897 (the last few experiments are not dated

or numbered). The style is certainly that of a student writing rather than those of a teacher dictating notes and she uses the personal pronoun frequently. Nonetheless, one cannot be certain that the notes are just her own thoughts; the teacher may have given some advice that was copied down. The physical and chemical change experiment is the first in the manual and this will be included in Figure 8.1 as an example of student writing of the period.

### 8.1.3 *Comments on Carrie Southard's understanding of physical and chemical change*

All four of these experiments give further exemplars of the concept of chemical change, though the concept of physical change is only clarified in experiment 1 and perhaps in experiment 4 if mechanically mixing substances is seen as a physical change. Experiment 1 is one experiment that has traditionally been used to distinguish between physical and chemical change.

Supposedly it is simple and obvious: heating the platinum wire is an example of a physical change as it only gets hot and then cools again (should this really be two physical changes?). Really careful observation might reveal that the platinum wire became brittle after prolonged exposure to the flame, caused by platinum absorbing hydrogen and there might be considerable discussion about the nature of this change.

The magnesium was heated in air and ignited which is an example of a chemical change (but with careful observation does not the magnesium first get hot- physical change - and then start to melt - physical change - prior to igniting. Sometimes with these simple experiments it is an advantage to know what one is supposed to observe!

What concepts has the student shown that she has understood?

1. She has met the terms chemical and physical change.
2. She has observed chemical and physical changes taking place with reasonably accurate observations.

3. She has shown that she can use the definition of chemical and physical change that she has learned to differentiate between the two in one fairly straightforward case.

She appears to have grasped the main points of this experiment. In experiment 2, which is about the reaction of dilute hydrochloric acid on marble chips, Carrie writes in her laboratory notes "It immediately commenced to boil and foam and it was white". Here we have the problem of language use, where if the observation is taken literally, then she is referring to boiling, which would be classed as a physical change. However, it is more likely that she is saying that what she observes is incessant bubbling which seems like boiling. In her completed notes section she repeats this statement and adds that "This boiling made the glass a slight degree warmer...". This provides an element of doubt about her understanding.

In experiment 3, observations and conclusions seem reasonable. In experiment 4, which is about the properties of iron filings and sulfur after heating as compared with their properties before heating, observations are generally correct, though the description is limited.

The conclusion reached shows a major error (alternative conception), though it could be just unfamiliarity with the scientific use of common words, but she writes "The mixture was a mechanical mixture and not a chemical compound. The sulfur part of it mixed with the iron to form the sulfide of iron". Had the word 'combined' been used instead of the word 'mixed', I would have concluded that she understood the concept of chemical change.

An error of syntax that Carrie makes several times in her first four experiments is to use the word 'burned' instead of the word 'heated'. e.g. "Next I placed some more of this mixture in a test tube and burned it". However, if it is assumed she started chemistry in September, she is consistently using the word 'heated' by November. This shows that the variety of experiments performed improved her facility with scientific language and also with scientific concepts. The concept of chemical change is continually reinforced throughout the year, though there is little or no use of the concept of physical change.

#### 8.1.4 *Methodology: Analysing other students' work*

Having seen one piece of student's work, I wondered if others could be obtained, so that conclusions could be drawn more widely.

My next step was to collect together all the laboratory manuals that I could both from my own library, by making purchases from book dealers using the 'Bookfinders' site at URL <http://www.bookfinder.com/> which claims 15,000 book dealers with 15 million books all recorded and searchable through a single search engine and also by bidding for books in the Ebay auctions site at URL <http://www.ebay.com/>. This has certainly been a learning experience. Firstly, books that are written in tend to be discarded rather than sold. Any writing by students in books is seen as a grave disadvantage by dealers, who look for books in a pristine state. My own collection had a fair number of practical books, but none that were written in. The book dealers' www pages needed thorough searching at regular intervals, e-mails asking for further information, and a decision whether or not to purchase often on inadequate information. E-bay has been quite good, but in general out of the 500 chemistry books offered a week, only one or two are suitable.

Initially I was unsure of what I wanted, but after a time I found that the books most easily available and most likely to contain student's work are called chemistry laboratory manuals. In general, these contain an experiment on the left hand page of the textbook and a blank page, on which the student can enter experimental results on the right hand page. These books are generally not very imaginative, but have developed over time.

#### 8.1.5 *A history of practical manuals*

The earliest practical manuals were probably alchemical recipe books. There are texts from the early 19th century (Henry, 1817) that emphasise the practical nature of chemistry, but they also contain much theory. After the 1860s there is a greater variety of books emphasising practical chemistry, some for special groups such as medical students (Odling, 1869) or agricultural students (Coleman & Addyman, 1893) and some for those beginning chemistry (Appleton, 1878; Ripper, 1885; Stockhardt & Heaton, 1887). It is perhaps from this latter group that chemistry laboratory manuals developed.

French (1886) looks like a transitional example consisting of many experiments in the traditional three column format (experiment, observation, conclusion) with the first column printed and the subsequent columns being completed by the student. The problem with this type of practical manual (at least in this case) is that there seems no theoretical input apparent.

Well known American authors like Williams, Dennis and Clark, Remsen, McPherson and Henderson, Newell and Brownlee, Fuller, Hancock, Sohon, and Whitsit, etc., produced successful school chemistry texts. Hessler and Smith (1902, ii, Preface) date school chemistry laboratories in the USA from the 1880s with a consequent increase in school textbooks with laboratory manuals following soon after. Hessler and Smith (1902) may be in error as I would certainly class the physics book (Hinrichs, 1870) and the chemistry/mineralogy book (Hinrichs, 1871) as laboratory manuals (Section 7.4.5). Initially by popular demand and then as a matter of course, chemistry laboratory manuals were produced to accompany the new textbooks. Hessler and Smith (1902) detail the common faults in laboratory manuals which theirs is claimed to avoid. They did this by producing laboratory exercises (a miniature manual) at the back of their textbook and sold the whole as a single book. They also provided a handbook for teachers. However, their ideas did not achieve general favour, though a few authors continued this practice (Rosenholtz, 1932).

Generally teachers/schools chose a textbook. Teachers found that they could use the adopted textbook in theory lessons and its accompanying laboratory manual in practical lessons. By the numbers of these old books still available, they must have achieved great popularity in America (USA), but strangely they never seem to have been very popular in the United Kingdom or elsewhere. All the actual examples of chemistry laboratory manuals containing student writing that I have collected are from USA. The usage generally involved students completing the blank pages or blank spaces in pencil. In some schools these pencilled answers were erased at the end of the year and the books used again. In the United Kingdom, the general practice was to have books which contained theory and practical work together, or alternatively separate practical books, but in either case students used to write up their experiments in blank note books. Such student note books do not appear to

have been saved, though some information can be found online at the website of "The Science Teacher Festival in 2001".

<http://www.shu.ac.uk/schools/ed/stf/pupilswork/framesets/photosof.htm>

(Accessed 22 September 2002)

The UK also had a tendency to have more chemistry practical books that were associated with qualitative analysis.

The great majority of textbooks contain a section on physical and chemical change, so the majority of accompanying laboratory manuals contain an experiment on physical and chemical change or an experiment on mixtures and compounds. This will be an essential feature for the manuals to be analysed. Manuals should also have considerable student practical work written up. Analysis will be limited to manuals printed prior to 1950, which gives a minimum age of input of 50 years.

From the manuals actually obtained, the most common and thus the most popular seems to have been Brownlee, Fuller, Hancock, Sohon and Whitsit though they had slightly different manuals for their different books. The other very popular manual was McPherson and Henderson. Both these books lasted with revisions from the 1900s to the 1930s and Brownlee, Fuller, Hancock, Sohon and Whitsit was certainly in print in 1956. In this small sample Dennis and Clark also seems to have been a popular early manual. Other manuals also were used but varied in popularity over the period. Authors like Williams produced two different manuals, one for general chemistry and one for inorganic chemistry.

#### *8.1.6 A preliminary analysis of some chemical laboratory manuals*

Appendix 10 lists the 39 chemical laboratory manuals that were available. In order to analyse student learning, the student needs to have written something relevant in the manual under the section on physical and chemical change or on the section on mixtures and compounds. Although manuals vary, one or other of these sections, sometimes both, are usually present.



Of the 39 manuals observed, only 15 could be analysed in terms of student learning. The manuals/notes that can be examined are manuals numbers 5, 8, 9, 10, 11, 12, 16, 18, 22, 23, 26, 27, 29, 32 and 34.

#### *8.1.7 Current student alternative conceptions literature: What does it say about physical and chemical changes?*

A number of studies have been carried out on physical and chemical changes over the past 20 years. Each has identified common alternative conceptions, but the alternative conceptions identified vary dependant on the study. Some typical results of a variety of studies will be provided in Appendix 8.

On examining the results of this research project, I have decided on the simplest method for categorising the 15 manuals. This is because, I have previously read through these manuals and the vast majority of the content is observation with only small amounts of explanation. It is possible that some of the observations which the students have made are incorrect, but this does not amount to an alternative conception. It is with the explanatory part of the results that alternative conceptions may be found. My four categories initially will be no explanation: explanations of a physical nature: explanations of a chemical nature: other. These categories will be for experiments about physical and chemical change separately to those for mixtures and compounds. An analysis of student alternative conceptions about physical and chemical change may be found in Appendix 11A considered where possible under the four categories stated above. The table for of student alternative conceptions about mixtures and compounds may be found in Appendix 11B.

The results, in finding student alternative conceptions are very limited for a variety of reasons.

1. Often the authors of manuals only ask students to carry out experiments and make observations.
2. Where they do ask students questions that demand explanations, the students often omit those explanations.

In either case, since it is only explanations that offer fertile ground for finding student alternative conceptions, it is unlikely that many manuals will contain much evidence of student alternative conceptions.

3. Of the 39 manuals containing student writing of some sort, I only noted two that had been signed as marked by teachers.

It might be thought that students may take less care in completing their work if teachers do not check it thoroughly.

Appendices 11A and 11B list the details the 15 manuals available under the four categories. Only numbers 8, 9, 10, 11 & 34 may need to be looked at again to see if the students have alternative conceptions. Carrie Southard was Number 8 and her notes were discussed in Section 8.1.1.

#### 8.1.8 *Alta Lemmon: Student Number 9*

Student Number 9 was Alta Lemmon from Carthage, Indiana. She carried out experiments on Section 4 (Williams, 1896a) taken from the manual, *Laboratory manual of general chemistry*, entitled 'The molecular state' which involved dissolving sugar in water, filtering the solution and tasting the filtrate. The experiments are performed and no explanation is required. In Section 5 (Williams, 1896a), part of the filtrate has been kept from Section 4 and sulfuric acid is added. A black colour was observed, though several observations requested in the text were omitted. The text asks if the phenomenon was a physical and chemical change. Alta correctly states it to be a chemical change, but spoils it by stating that 'The sulphuric acid destroyed the atoms of sugar'.

Is this just a careless statement or does it really indicate fundamental misunderstandings about the nature of chemical change? One might believe it was just carelessness, but in Section 6 (Williams, 1896a) in the traditional experiment heating copper and sulfur. Alta writes:

...and found both the brimstone and Cu turnings turned to CuS. This shows that an atom of S united with an atom of Cu to form an atom of CuS.

(Alta Lemmon)

It would seem that this hard working student (she completes most of the manual) has problems in understanding the differences between atoms and molecules and this gives doubts as to whether her concepts of physical and chemical change or mixtures and compounds are clear either. However, at the end of experiment 100 she is writing in a fuller and more confident style.

#### 8.1.9 *Eric Austin: Student Number 10*

Student 10 is Eric Austin who used another of the manuals by Williams called *Laboratory manual of inorganic chemistry* (Williams, 1896b). Eric completed a high proportion of this manual. In this case, Section 9 is entitled 'the physical division of matter' which also involved dissolving sugar in water, filtering the solution and tasting the filtrate. Eric's observations are confused and he considers that the sugar water has changed to water on filtering the solution, which he calls a chemical change rather than a physical change. Section 9 is entitled 'the chemical division of matter' and is again the dehydration of sugar which Eric correctly concludes is a chemical change.

However, the evidence is quite clear that Eric had his own alternative conceptions of physical change.

#### 8.1.10 *Ralph C Zindel: Student Number 11*

In the traditional experiment with iron and sulfur relating to mixtures and compounds, Ralph Zindel (Dennis & Clarke, 1902, p. 13) writes:

When the mixture is heated the substances (iron and sulphur) unite and form a metal. A chemical (change) takes place... Ralph Zindel

Presumably Ralph Zindel has just made a careless error in using the word 'metal', because he describes the new substance as a compound in the next sentence.

#### 8.1.11 *Anna L Ficerchia: Student Number 34*

The final possible student alternative conception was number 34 (Anna L Ficerchia) but this student has made an error of observation when adding dilute hydrochloric acid to the new substance formed by heating iron and sulfur. She observed that the gas produced was odourless and concluded that the gas was hydrogen, whereas the expected result would have been that the gas was the foul-smelling hydrogen sulfide. It would seem that in this case the student did not have an alternative conception originally, but may well have been led to one as a result of incorrect observation.

#### 8.1.12 *Summarising the results of analysing the manuals*

The results of the observations of manuals for students numbers 8, 9, 10, 11 & 34 were compared with the collection of modern alternative conceptions as reported by Griffiths (1994), (see study 6 in Appendix 8) and other research. There is insufficient evidence to classify students 8, 11 & 34 as having some specific alternative conception. However, student 9 fails to distinguish correctly between atoms and molecules on two occasions and this is a commonly identified problem in the literature (Alamina, 1992, p. 201). Student 10 appears to believe that sugar dissolving in water is a chemical change, which is a common alternative conception (see criterion 16 in Griffiths, 1994).

Overall the method was extremely interesting to trial, but has not been as successful as I would have wished. Roughly only about 10% of manuals are likely to yield any results, but there are alternative conceptions in student work from the past identical with student alternative conceptions of today. I believe this method to be one untried before and could be used with greater numbers of manuals to investigate historical alternative conception related to physical and chemical change more thoroughly or to investigate any other topic common in student manuals.

The next section will consider practical work used to illustrate physical and chemical change.

## 8.2 A case study of the iron filings and sulfur experiment: Introduction

As is apparent from earlier sections, one of the common features of chemistry courses, physical science courses or general science courses has been that over the years the majority of school textbooks have explained the meaning of physical and chemical change to the students who use the books. Very old textbooks tend to use the word 'cohesion' which seems to have a meaning similar to the modern expression 'physical change', but there are a variety of other names that can be used. Also older textbooks tend to use the word 'affinity' or 'chemical affinity' whereas modern usage is 'chemical change', but again there are a variety of other names that can be used. The expressions 'physical properties' and 'chemical properties' are frequently used in chemistry and other sciences and it should be noted that ideas of physical and chemical change are necessary to define these terms. There are many problems of definition, which have been major issues in this study. However, to recapitulate, physical and chemical change are usually differentiated on some or all of the following grounds:

- i) The formation of a new substance.
- ii) The reversibility of the process.
- iii) The evolution or absorption of energy during the change.
- iv) A change of colour.
- v) An apparent change of mass during the change (usually where gases are produced).
- vi) Molecular/ionic structure changing or not changing.

Because following these six criteria does not always lead to a clear conclusion being reached as to whether a change is physical or chemical, the area is often one for debate and those learning chemistry become confused and irritated by the fact there sometimes seems to be no 'right' answer. My belief is that this uncertainty does allow room for discussion, which can be used positively to create interest in chemistry (Taber, 2002, pp. 22-23). There are many experiments that can be done by students or demonstrated by the teacher and overall the topic is an interesting one with which to begin chemistry. Textbooks will use some of the criteria above, but generally they indicate their own working definitions through the use of a variety of

examples. It is the examples that the textbooks choose and the historical context of these examples that are the main subject of this paper.

### 8.2.1 *Changes in books and teaching style*

The examples chosen to illustrate physical and chemical change are generally of two types:

- i) Practical instances taken from everyday life experiences: switching on a light; burning wood. The teacher can use the students' everyday experiences as the source of examples to differentiate physical and chemical change.
  
- ii) Demonstrations/experiments to be carried out by teachers/students in the classroom with which they may not be familiar. The teacher can choose to create experiences for students in the laboratory as the source of examples to differentiate physical and chemical change. Demonstration experiments became quite complex when the teaching of physical and chemical change was popular, for example a chemical-physical change demonstration apparatus of 1945 (Marion, 1945, p. 169), which separately allowed a weight to fall breaking a plate and ignited flash powder.

Teachers have at their disposal a variety of visually exciting and interesting reactions that will be memorable to the student, but these are not always used.

A textbook by Holmyard (1951, pp. 13-15) was chosen as an example, because he gives several examples of physical and chemical change and states clearly whether he considers them to be physical change or chemical change. He is incorrect in fact on some of these, but his book is similar to many others in this respect. He chooses nine physical changes and two chemical changes. He gives the following examples of physical change: a bullet passing through one's shoulder; water into ice; water into steam; magnetising iron; de-magnetising iron; electrifying an object; a lamp's filament glowing white-hot; dissolving sugar in water; dissolving salt in water. He gives the following examples of chemical change: burning magnesium; burning coal. Which examples would the teacher choose to demonstrate and which would the teacher consider to be part of the students' experience? The teacher might demonstrate boiling water and burning magnesium and assume that students had

seen the other changes. How well has the author/teacher utilised the opportunities available? Probably most experienced teachers would consider the choice mentioned to be somewhat dull and conservative and could think up more exciting and thought-provoking examples.

There is another feature that may not be entirely obvious when first considering Holmyard's examples of physical change. This feature results from the evolution of the concept historically. Probably the bullet passing through a shoulder, magnetising iron, de-magnetising iron, electrifying an object and the filament glowing because of the electric current flowing through it are considered physical changes because they relate to physics as a subject. This was a definition in earlier textbooks. The examples of turning water into ice or water into steam are changes in state and have always historically related to the degree of cohesion in matter, which was the old word with a similar meaning to physical change. Mixing things together such as sand and salt is also an example of a physical change (Petrucci & Wismer, 1983). Holmyard has the example of salt or sugar dissolving in water as a mixture, but this always has been and still is a contentious example, as most teachers consider dissolving salt in water a chemical change. The major point to note is that carefully observing the examples given in textbooks shows physical change to be a variety of concepts and not a single concept. This is seldom explained to learners.

Gower, Daniels and Lloyd (1977) related the empirical concepts (generally ideas involving macro experimental chemistry, which would often be chapter headings in the early chapters of elementary textbooks) to each other in one table. The items in the empirical table were:

- The concept of matter.
- The concept of a mixture.
- The concept of physical state.
- The concept of a chemical change.
- The concept of a physical change.
- The concept of an element.
- The concept of a compound.

These researchers separately related the theoretical concepts (generally ideas involving micro/representational concepts such as atoms and molecules) to each other in another table. A fairly small number of students was tested with a chemistry test made up of questions involving these concepts. Using the principles of the Gagné hierarchy of one concept needing to be understood in order to understand the higher level concept, they checked their theoretical models against the models that they constructed from the students' results, with a fair measure of agreement for the empirical table. Perhaps what is important is that the researchers, in their reading of elementary textbooks and in their discussion with colleagues considered that these are all vital understandings for new chemists. What is more, students appeared to be clear about the interrelationship between these concepts.

### *8.2.2 Using 'Hypercard' for information on practical experiments from textbooks*

The data in 'Hypercard' (see Chapter 7) also recorded the experiments used to illustrate physical and chemical change. There is a tendency for textbooks to choose examples where the same material undergoes the physical and chemical changes. For example, iron is magnetised (physical): iron rusts (chemical); or melting wax (physical): burning a candle (chemical), etc. One of the most frequently performed experiments is the reaction between iron and sulfur, or copper and sulfur, or zinc and sulfur. These are mentioned as examples in about eight per cent of textbooks.

It is interesting to note that demonstration/class experiments to be performed by teacher or student using iron or other metals with sulfur are used to illustrate two elementary but related chemical concepts. These are the differences between mixtures and compounds (or elements and compounds) and the differences between physical and chemical change. The following diagram illustrates the overall concepts to be explained.



### A CLASSIFICATION SCHEME FOR MATTER

(Taken from Petrucci & Wismer, 1983)

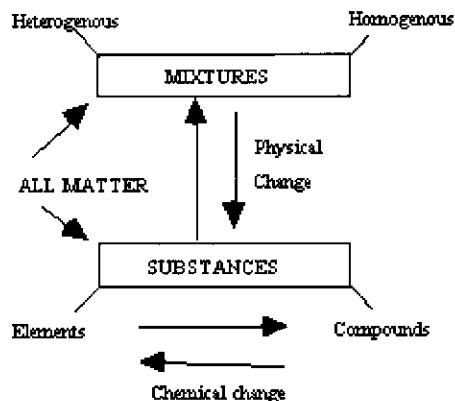


Figure 8.2 A classification for matter

Diagrams like that in Figure 8.2 are moderately common in American textbooks (for example, Brown & Le May, 1981). The diagrams indicate that physical and chemical change and mixtures/compounds are related but different concepts and make that difference clear to the students. I believe that such diagrams are helpful in students' overall understanding and generally such diagrams are not included in United Kingdom or Australian books. The weakness of such diagrams is that they do not explain all the aspects of physical change very well.

However a United Kingdom text (Freemantle & Tidy, 1987) does actually use a simplified diagram for the very example that is being discussed. In the diagram, the mixing of iron and sulfur is said of itself to be a physical change, so that the iron filings and sulfur/iron(II) sulfide experiment can be used both as an example of mixture/compound and also of a physical/chemical change. The authors say "Mixing iron and sulphur is not a chemical change but a physical change since a new substance is not formed" (Freemantle & Tidy, 1987, p. 7).

Some authors take the view that physical and chemical change is an unnecessary concept and their books often use the iron filings/sulfur experiment to explain mixtures/compounds. Other books explain both concepts either using the iron filings/sulfur experiment twice in some cases or not at all in others.

### 8.2.3 *The iron sulfur experiment: Theory*

Most chemical reactions considered in secondary schools are Daltonian reactions where the products of these reactions are formed in accordance with the Law of Definite Proportions. The reaction between iron and sulfur does not form a compound that follows this law and is called a 'Berthollide' compound following a suggestion by Kurnakov early in the twentieth century (Crosland, 1971, p. 152). Indeed iron(II) sulfide has a composition which varies between about  $\text{Fe}_{0.858}\text{S}$  and  $\text{FeS}$ . It is said to be a good example of a well characterised non-stoichiometric sulfide (Cotton & Wilkinson, 1962, p. 415).

The reaction between iron and sulfur is thus an example of chemical change, but presumably almost every time that the reaction is performed, the product is different. Here a simple model is assumed in which the iron and the sulfur fill most of the regular positions in the giant lattice and the interstices are filled to differing extents with sulfur atoms in different experiments. It is paradoxical that the oft-quoted example of chemical change is in fact a compound of variable composition, as this is not the understanding that students are supposed to acquire, when they start chemistry. Other examples of chemical change found in textbooks include the formation of zinc sulfide and copper(II) sulfide and these are also Berthollide compounds. Iron, sulfur and the reactions they undergo have an interesting history that will be considered in the next section.

### 8.2.4 *Early history of iron, sulfur and iron pyrites*

Iron has a long history (Meyer, 1906, p. 15): it has been used in Egypt for 5000 years. Snape (1989, p. 116) puts the earliest usage of iron as decoration as dating from 5500 years ago, but probably the source of this iron was from a meteorite as the iron contain nine per cent nickel. Three thousand years ago iron decorations were produced from its ore haematite ( $\text{Fe}_2\text{O}_3$ ). Sulfur (Snape, p. 75) is one of nine elements that has been known for at least 2000 years. It should be recognised that there are a number of different compounds of iron and sulfur and it is important to note that it is not easy to obtain metallic iron from iron sulfides, so they are not generally used as ores. The sulfides of iron that will be mentioned are iron(II) sulfide, made from iron and sulfur, but of variable composition, that evidently exists in magnetic and non-magnetic forms. Iron pyrites/marcasite are two different forms of the

compound  $\text{FeS}_2$ . Iron pyrites has a golden colour and looks very like gold so it is often called 'fool's gold' as it has little commercial value, though it can sometimes be a clue as to the presence of real gold (St John, 1984, p. 53).

Alchemists, from the tenth century onwards were familiar with 'fool's gold' and they used it with other substances as a recipe for making real gold (Toulmin & Goodfield, 1968, p. 147). Barclay (1947, p. 17) thinks that the cause of this misapprehension by alchemists was that they considered sulfides like pyrites (iron sulfide) to be inferior metals. They knew that sulfur could be removed from them and therefore thought that removing even more sulfur might yield the even more perfect metals of silver and gold. Albertus Magnus (1206-1280) (Section 2.5.1) was certainly familiar with a number of metallic sulfides, including iron and copper pyrites and gave them a collective name of 'marcasitoe'. Meyer (p. 59) considers that at this point in time the alchemists would have known about the formation of several metallic sulfides from their components and this should have helped them learn more about their composition. However artificial iron(II) sulfide is not the same as, and does not look similar to, iron pyrites, so the relationships between them would have been difficult to elucidate.

Sulfur was used by alchemists in one of the preliminary steps to produce gold from base metals (Salzburg, 1991, p. 45). Salzburg says that they used it "to kill the metal: alchemists either heated it (the metal) at moderate temperatures to oxidise it, or treated it with sulfur or sulfide solutions." In this, the alchemists seem very distant from the present age. Yet at that time, the technology for smelting iron was changing rapidly and at the end of the twelfth century huge amounts of iron were needed. For example, Richard the Lion-Heart needed 50,000 horseshoes for his cavalry for the Crusades (Salzburg, 1991, p. 83). Glauber (1604-1688) in his writings explains how sulfuric acid (vitriol) could be obtained from the naturally occurring iron pyrites/ marcasite (both  $\text{FeS}_2$ ) (Lowry, 1936, pp. 8-9). This is interesting, but it would soon become an inadequate source for the production of vitriol.

Boyle (1661) also seems familiar with copper and iron ores and perhaps the following is a reference to copper or iron ores that can occasionally catch alight, probably by bacterial action on the sulfur. The accidental ignition of ore heaps is still a problem today.

I might ask the like question concerning light, which is not only to be found in the kindled sulphur of mixt bodies but (not to mention those sorts of rotten woods and rotten fish that shine in the dark) in the tails of living glow-wormes and in the vast bodies of the sun and stars. (Boyle, 1661, p. 169)

#### 8.2.5 *Iron, sulfur and volcanoes*

The smell of sulfur compounds near volcanoes has linked sulfur with volcanic activity over a long period of time. Anderson (1880, p. 83) comments that early writers on geology thought that the heat produced by volcanoes might come from the burning of underground beds of sulfur or coal, etc. Lemery (1645-1715), the "well-known author of 'Cours de Chymie'" (Picton, 1889), knew of the reaction between iron, sulfur and water and the similarity of this action to a volcano. He thought that this did not only cause 'artificial volcanoes' but thought that this was also the cause of real volcanoes (Krafft, 1993, p. 47). It is interesting that young Emile (described in a later section) also has the same thought (Fabre, 1922, pp. 6-25).

Krafft (p. 47 & p. 52) also states the scientists Hooke (1635-1703) and Lister (1638-1712) and later Buffon (1707-1788) thought that volcanic activity was caused by pyrite and sulfur coming into contact with air and salt from sea water, which was the explanation for why volcanoes were usually near to the sea. Marcel Krafft (the author of a delightful book on the history of geology) and his wife, Katia, a geochemist, both died whilst photographing the eruption of Mount Unzen in Japan on 3 June 1991.

Toulmin and Goodfield (1968, p. 238) and Singer (1990, p. 145) publish a copy of Geoffroy's table of chemical affinities of 1718 that includes both iron and sulfur, showing that at that date chemists were familiar with the reaction. Etienne Francois Geoffroy (1672-1731) is quoted as saying (Singer, 1990, p. 335) that "... metals were arranged in order of their affinity for sulphur." Singer (p. 145) provides a brief explanation of how the table can be used. It is also extremely interesting to note that Tobern Olaf Bergman (1735-1784) (Section 3.2.4) extended Geoffroy's affinity tables by carrying out reactions separately in a wet way and in a dry way. This would indicate that Bergman would have observed the reaction of iron and sulfur heated together as well as iron and sulfur reacting in the presence of water.

The Proust/Berthollet controversy (Section 3.3.1) is explained by Salzburg (1991, pp. 208-210). Proust believed that the elements in compounds were in fixed proportions by weight. Berthollet believed these proportions varied. In his book of readings about the nature of matter, Crosland (1971) comments:

In the early twentieth century Berthollet's view of the variability of chemical compounds was vindicated by the discovery of interstitial compounds, that is, substances which differed slightly from the normal chemical compound by the incorporation of a few odd atoms in the crystal lattice. (p. 152)

Lowry (1936, pp. 298-9) gives further information about Proust's problems with iron sulfide and the artificial sulfide of iron. He shows that Proust uses iron sulfide as an example of a compound that follows the law of definite proportions where it does not. Even as late as 1927, Darrow (p. 23) misinterprets history by giving incorrect details of the Proust experiments. Proust was in reality correct in his statements, but he was wrong in his reasoning. Darrow sees him as being absolutely correct:

This controversy resulted in the establishment of the fundamental Law of Definite Proportions. That law spells the difference between a haphazard world of utter chaos and one of dependable stability. (Darrow, 1927, p. 22)

The quotations above give some indication of the long history of iron and sulfur experiments from pre-history to the times when textbooks can be used as a primary source of evidence.

#### 8.2.6 *Iron, sulfur and iron pyrites demonstrations from the textbooks*

The selection of science textbooks chosen for more detailed comment are typical (or deliberately atypical) of their kind in a variety of ways. They are intended to be representative of textbooks in the following aspects:

- i) to cover books over the period 1800-1995.
- ii) to cover books published in the United Kingdom, the United States of America and Australia.

- iii) to cover textbooks varying in academic level between primary school and university.
- iv) to cover books in general science and chemistry.
- v) to consider books that use the example of iron and sulfur forming iron(II) sulfide as an example of the distinction between a mixture and compound or as an example of physical and chemical change or as examples of both.
- vi) to consider books that use the example of the reactions of copper and sulfur forming copper(II) sulfide and zinc and sulfur forming zinc sulfide.

### 8.2.7 *Iron, sulfur and iron pyrites demonstrations from the textbooks: Early period*

The earliest reference to the experiment on heating metals with sulfur found from the research into chemistry/science is a description by Shaw (1755) which shows that he was familiar with the experiment. It was entitled 'Experiment 3' and the requirements were two pounds of iron filings and two pounds of sulfur. Shaw was the author of the first edition of Boerhaave's lectures which he translated from the Dutch, based on a student's notes of Boerhaave's lectures (Knight, 1989, p. 82). He was the eighteenth century editor of Boyle's works (Brock, 1992, p. 64) and the translator of Stahl's book *Philosophical Principles of Universal Chemistry* (Knight, 1989, p. 83). He wrote:

The mixture never fails to take fire if the quantity be large....but if the heat continue sufficiently long the whole mass will be changed to one uniform substance. (Shaw, 1755, pp. 423-424)

The experiment was not used in the text to explain any obvious definition of affinity or cohesion, yet from the description given there does seem to be some rudimentary theoretical understanding of affinity (chemical change) implied. Thorpe (1896) states that Le Sage in 1758 explained chemical phenomena through the iron filings and sulfur experiment.

### 8.2.8 *Iron, sulfur and iron pyrites demonstrations from the textbooks: Middle period*

The example of the iron filings/sulfur experiment is given and used by Donovan (1832, p. 29) to explain the concept of mixture/compound and the three-way action of cohesion, heat and affinity. At the time when Donovan was writing, the current wisdom was that unlike substances had natural affinities to different degrees, and that the reason that they did not combine was that the substances were prevented by forces of cohesion. When heat was applied this overcame the forces of cohesion and chemical affinity was then active, causing chemical combination. However, Donovan's ideas of mixture/compound are incorrect, as he said that zinc filings and copper filings when shaken together are a mechanical mixture, but when melted would form brass, which was said to be a compound. At the time at which Donovan was writing, this was one of many points of disagreement amongst chemists.

Draper (1851) generally had a less theoretical approach and described as a part of inorganic chemistry three ways of producing reactions between iron and sulfur. One of these is described thus:

Dr Hare has shown that if a gun barrel be heated red-hot at the breach, and a piece of sulphur dropped into it, the muzzle being closed with a cork, an ignited jet of sulphur vapor issues forth from the touch hole, in which if a bunch of iron wire be held, it takes fire and burns brilliantly.

(Draper, 1851, p. 214)

Draper (1851, p. 280) also explained that white hot iron will act upon roll sulfur and the melted globules can be caught in a bucket of water. He also stated that iron sulfide can be prepared by the action of the iron filings on sulfur.

Barff (1871) differentiated between a mechanical mixture and a chemical compound using the chemical combination of copper and sulfur as an example, as did Jago (1890, pp. 6-7), though he used the same example with slightly different words: For example "the distinction between a mechanical mixture and chemical union". Pilley (1901, p. 32) uses the example of copper and sulfur forming copper(II) sulfide as an example of chemical change/synthesis.

The first experiment that Valentin (1876, p. 21) describes is with gunpowder. He uses the ideas of physical and chemical change and mechanical mixture/chemical combination together in describing/ explaining the gunpowder and also the iron filings/sulfur experiment. Valentin was amongst the first textbook writers to oppose physical and chemical change. Valentin (pp. 55-6) also includes the experiment to make iron(II) sulfide by rubbing sulfur on a thin white hot iron plate followed by an experiment to produce sulfur from iron pyrites. He goes on to describe the action of dilute acid on iron(II) sulfide to produce hydrogen sulfide, pointing out that the reaction does not work with iron pyrites. Valentin has a very practical approach in his text with a wide variety of chemical experiments.

Frankland and Japp (1884) in their textbook on inorganic chemistry use the example of iron and sulfur to distinguish between mechanical mixture and chemical action.

Mechanical mixture however intimate does not conceal the properties of iron or sulphur ...But after the substances have been subjected to chemical action, the most powerful microscope is incompetent to detect either sulphur or iron... (p. 2)

Frankland (Section 4.3.7) was a chemist of considerable note renowned for his work on organometallic chemistry and his theoretical contributions to the concept of valency. He was born in humble circumstances and taught himself chemistry whilst working as a pharmacist's apprentice (Russell, 1986).

Newsholme (1894, p. 94) wrote a textbook at a Grade 5 level for primary schools which consists of a number of object lessons. The author would have intended that the teacher should carry out the standard experiment showing the students copper and sulfur, mixing them, and showing that they could be separated. The teacher would then heat the mixture in a test tube over a spirit lamp, demonstrating that after heating the copper and sulfur could not be separated. This establishes the difference between a chemical compound and a mere mixture. One may well wonder if many teachers in primary schools in the 1890s actually had the facilities to demonstrate this experiment. Thornton (1897, p. 209) in his textbook for secondary schools, used the same reaction to demonstrate the difference between a chemical compound and mixture. The book is interesting in that the author separately defines



physical and chemical change, chemical decomposition, chemical combination, compounds, and chemical attraction or chemical affinity. This seems to show that at this time when new expressions such as 'physical and chemical change' were being introduced, there was a reluctance to scrap the old expressions such as 'chemical affinity'. It seems as though there were too many definitions chasing too few concepts.

Briggs (1899, Section III, p. 12) uses that the reaction between iron filings and sulfur as an example of the difference between a mechanical mixture and a chemical compound. There are no particular points of interest except to note that the example occurs after an explanation of physical and chemical change and that the author states "...chemical combination has taken place between the iron and sulfur in the proportions of the atomic weights of these elements ". In other words Briggs has forgotten (or feels it inappropriate to mention at this level) that the iron filings and sulfur reaction is Berthollide not Daltonian and it is therefore unlikely that the elements of iron and sulfur will be combined in the ratio of their atomic weights.

#### *8.2.9 Iron, sulfur and iron pyrites demonstrations from the textbooks: Later period*

Ostwald (1902, p. 7) used the example of the reaction between iron and sulfur to demonstrate the difference between physical and chemical processes. Ostwald, (pp. 576-77) also gave considerable additional information on other ways of demonstrating the reaction between iron and sulfur. He mentioned the reaction of sulfur in a crucible, stirred with a red-hot iron rod, and also moistening iron filings and sulfur which react to form an hydrated iron sulfide. The reaction starts slowly, but can become incandescent. This is one of only three instances where I have found this reaction mentioned. Ostwald's view quoted below confirms the comments of Krafft (1993).

Such experiments were formerly often made in imitation of volcanic phenomena. since, the lava of natural volcanoes does not consist of iron sulphide, it is only the case of external resemblance.

(Ostwald, 1902, p. 576-77)

Ostwald (pp. 576-77) also gives the following information about iron pyrites. Perhaps the fact that he did not believe in the atomic theory, except as a convenient fiction at the time he wrote the textbook (Ostwald, pp. 146-148), would have made the explanation in terms of interstitial atoms difficult for him to accept.

Iron sulphide occurs native as magnetic pyrites in yellow-brown masses, with a metallic lustre. These have very nearly the composition of the simple iron sulphide, but always contain a slight excess of sulphur. How this deviation from the law of constant proportions is to be interpreted has not yet been explained. (Ostwald, 1902, pp. 576-77)

Andrade and Huxley (1934, p. 152) wrote a science book for members of the general public interested in self-improvement. They use the example of iron and sulfur forming iron(II) sulfide (mentioned as being iron pyrites/fool's gold) as an example of the distinction between a mixture and compound. In this they are incorrect as the iron sulfide formed in the experiment does not have the same composition as the mineral, iron pyrites.

The textbook by Bishop and Locket (1951, pp. 10-15) was written in 1936 and was the book I can recollect using at school in the United Kingdom in the 1950s (see Section 1.3.3). An Australian edition was published in 1944 and since the 1936 preface is unaltered, it could well be assumed that the book remained unchanged over 15-20 years. It treats physical and chemical change first, followed by mixtures and compounds without any very obvious connections being made. The iron filings/sulfur experiment is then left as an exercise to carry out. One of the problems taken from a 1931 examination at the end of the chapter asks directly about the experiment. One can thus see an emphasis on memory and stability with a lack of cultural sensitivity, as there is no indication that any change needed to be made for a new generation in the United Kingdom or a different culture in Australia.

The comments made about the book by Bishop and Locket (1951) above also largely apply to Holmyard (1951, p. 15), whose book was originally published in 1933. Even in 1951 Holmyard (p. 17) says "...in the iron sulphide, the iron and sulphur are firmly bound together by the mysterious force of 'chemical attraction'". This sort of description is typical of texts of the previous century, because if one thinks of the

knowledge available in the 1950s, the statement is simply untrue. The author (p. 15) uses the example of iron and sulfur forming iron(II) sulfide as an example of the distinction between a mixture and compound.

Lugg and Rowney's textbook (1965) and Abbott's (1967) are two books, one from Australia and one from the United Kingdom, typical of many, where the authors 'go to town' on iron and sulfur experiments. Both books use the example of iron and sulfur forming iron(II) sulfide as an example of the distinction between a mixture and compound (Lugg and Rowney, 1965, pp. 130-131; Abbott, 1967, pp. 16-17) and also as an example of physical and chemical change (Lugg & Rowney, 1965, p. 143; Abbott, 1967, p. 9). It can be argued that this is unnecessary duplication or alternatively that it is merely emphasising a point for clarity.

Beauchamp, Mayfield and Hurd (1968) wrote a book for the junior secondary school typical of its period in the United States. I think that a number of American texts of the period represent a high point of clarity about elementary chemical concepts. There is deliberate progress through mixtures, elements and compounds, atomic and molecular theories to physical and chemical change over several chapters, complete with exercises, summaries, etc. In Beauchamp, Mayfield and Hurd (p. 63), the iron filings sulfur experiment is given as an exercise to carry out as an example of physical and chemical change. It is also carefully explained and used to introduce equations. A more recent textbook (Hunter, Simpson, Stranks, Canwell & Boden, 1983) looks at the physical and chemical properties of gold and fool's gold – iron pyrites, a compound of iron and sulfur. The authors briefly explain chemical change (diagram, p. 4), but do not mention physical change. The authors use the iron filings and sulfur experiment to differentiate mixtures and compounds and as an example of chemical change (diagram, p. 4).

Similarly Hein (1982, p. 70) uses the iron filings and sulfur experiment to differentiate mixtures and compounds, whilst he (Hein, pp. 51-4) uses different examples to explain physical and chemical change. Hein (1982, p. 70) states that iron sulphide is formed in the change, but this is incorrectly said to be "a compound of fixed composition". Hunter et al. (1983) claim that:

We can say that this kind of examination deals with the chemical properties of the substance because it involves chemical change, but the borderline between physical properties and chemical properties is not always distinct. In table 1.1 it can be seen why amateur prospectors sometimes confuse valueless fool's gold (pyrites, iron sulphide) with gold when they examine a mineral only superficially. (p. 12)

I have noted in the 1990s a definite trend for books published in the United Kingdom to avoid the concept of physical and chemical change at a lower and upper secondary level. This is I suspect, a trend that probably existed prior to the UK National Curriculum, but the trend has increased due to the National Curriculum's recommendations, which are that physical and chemical change be introduced in the primary school. In the USA, physical and chemical change tends to be mentioned both at a lower and upper secondary level. In Australia I think that we are closer to an American pattern, though I suspect it is now getting unusual to talk about physical and chemical change at an upper secondary level. These changes may see the end of the iron filings and sulfur experiment, but not, I think, for a few years yet.

### **8.3 Iron, sulfur and iron(II) sulfide: Alternative experiments**

The usual way to show chemical change between iron filings and sulfur experimentally is to heat the two substances together in test tube. This has been what has occurred in the majority of cases cited above. In my experience neither students nor new teachers find this easy to do in practice. One frequently finds that students or new teachers allow the sulfur to ignite and poison the atmosphere of the laboratory with sulfur dioxide, which is a very poisonous gas. A few years ago a teacher in a Northern Territory school, after performing this as a class experiment, phoned me to say that one of his students had fainted after exposure to sulfur dioxide gas and he wanted to know how poisonous it was. I told him that it was very poisonous, with a threshold limit value/time weighted average value (TLV-TWA) of 2 p.p.m. (Association for Science Education, 1981, p. 24).

There is an alternative to this experiment that I have found in old textbooks (for example, Ostwald, 1902, pp. 576-577; Fabre, 1922, p. 14) that is really very

impressive in its simplicity and which I have not seen mentioned in any recent text. It would seem quite suitable to me for primary schools where fume hoods and fans are unlikely to be available. A book for children by Fabre (1922) explains the simple chemistry of the experiment through the conversations between two boys (Jules and Emile) and their uncle (Uncle Paul). Some brief excerpts follow:

So saying, he put the mixture of iron filings and sulphur into a bowl, added a little water, and kneaded the mass with his fingers until it formed a thick paste. Then he took a bottle of clear glass, an old discarded bottle that had once contained some sort of syrup or medicine, and filled it with the paste. Finally, in order to heat the mass somewhat, the bottle thus filled was set in the sun... (Fabre, 1922, p. 14)

A quarter of an hour had not passed before something remarkable took place: the contents of the bottle, at first greenish in color from the yellow of the sulphur and the gray of the iron, began gradually to turn black and present the appearance of soot, while at the same time jets of vapor accompanied by hissing sounds escaped from the mouth of the bottle and small quantities of the black substance were ejected as if by the force of an explosion. (Fabre, 1922, p. 14)

The equipment asked for could be found at home (or in a primary school). The boys are in fact the author's own children and so there is a real biographical interest in the story as it develops (Fabre, 1922, pp. 6-25). The language of the story may sound a little stilted today, but it adds real personal feeling to the chemistry. Jean-Henri Fabre (1823-1915) was a famous French entomologist (Teale, 1985), who wrote many books for children to popularise science (Britannica, 1985) mainly during the period 1872-1893 as a source of income, because he was very poor (Brice, 1987).

Emile is so excited that he says "I'd leave my grammar any time to help make an artificial volcano" One can see the similarity between this remark and that of the early French scientist, Lemery, who thought that this was the explanation for real volcanic eruptions. The obvious answer quoted previously (Ostwald, pp. 576-77) indicates that a brief look will show that lava does not consist of iron(II) sulfide.

My belief, having tried both experiments, is that the use iron filings, sulfur and water as a paste outside in the sun, is a good alternative to heating iron filings and sulfur in a test tube over a bunsen. I have not seen the alternative method mentioned in any textbook since Fabre, so I would like to resurrect a sixty year old experiment, but I may be too late if it is to be used to differentiate physical and chemical change!

I note that Shakhshiri (1983, p. 56) says that the iron/sulfur reaction, though it has been extensively studied, has still not been completely disentangled. His authoritative view is that this reaction should never be used to distinguish physical and chemical change. Nonetheless it could still continue to be used to distinguish between mixtures, elements and compounds, so there is hope that Fabre's alternative experiment may be used in classrooms in the future.

#### **8.4 Preview of Chapter 9**

Having looked at some case studies, The study now returns to the question of whether those with a professional interest in science believe that the concept of physical and chemical change should be taught in schools or not.

## CHAPTER 9

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### THE QUESTIONNAIRE

*Research Question 9: Is there a divergence of views between scientists and science educators over the science of physical and chemical change?*

#### 9.0 The need for a questionnaire

The chapters of the thesis so far relate to personal reflection, to historical issues, to linguistic issues, to pedagogic issues and to the educational research of others. In this chapter of the thesis, the aim is to see what those in the world community who use the concept of physical and chemical change think of its use in teaching and learning. A questionnaire was constructed to find out what various groups concerned with chemical education might think of the teaching and learning of physical and chemical change.

The development of this questionnaire presented a number of problems. These were:

- i. I knew that amongst experienced teachers the topic of physical and chemical change was controversial.
- ii. I wanted a lot of information from the questionnaire and was sure that I wished to avoid both the simple yes/no replies questions and three or five point Likert-style answers to questions.
- iii. Because the case study of textbooks (Chapter 7) includes the United States, Australia, and Britain and books from other countries, where possible, I wanted to make the survey as international as possible.
- iv. I was aware at the start of the possibility of using the Internet for sending and receiving questionnaires, but I did not anticipate how powerful a tool, it would prove to be.

- v. I intended to write a questionnaire suited to different groups of people, who would have different areas of expertise. I wished to utilise equally the valuable the craft-knowledge of teachers, the educational knowledge of teacher educators, the content knowledge of university lecturers, and the perspectives of historians of science. I also wanted some contribution from educational specialists of other sciences and of scientists working outside the educational world.

### 9.1 Methods of questionnaire construction

With these thoughts in mind I constructed the questionnaire containing 58 questions and an introduction including definitions and some references quotations and earlier research findings: I trialed this with about ten colleagues enrolled in various postgraduate science education courses at Curtin University. In the end, I only received two responses.

I read round the topic of questionnaire construction including (Anderson with Arsenault, 2000; Educational Computing Services, 1990; Wiersma, 1986) but the advice I received did not seem to give my respondents the freedom to answer the questions that I felt they would need. I produced coded questionnaires, shorter questionnaires and different questionnaires for different respondents, but was not satisfied with any of my efforts.

There was worse to come. I redesigned the questionnaire with boxes to define the spaces for answers and took some copies with me when I gave a lunch-time seminar at Faculty of Education, King's College, London entitled 'The paradox of physical and chemical change: An initial view', with postgraduate students and staff on 8 December, 1992. The talk appeared to be reasonably successful, but the questionnaires were criticised as being too long and with boxes around the questions, making the questionnaire look too enclosed.

Some time later, I found a London University Master's thesis (Dunlop, 1991). Dunlop was also looking at a complex chemical topic in which he was searching for unifying themes in chemistry. The ideas were abstract and he used the device of seeking expert advice. He contacted a number of noted chemistry educators by



phone, and asked if he could interview them. He then gave his interviews asking standard questions or if an interview was not practicable, he wrote a standard letter. The actual numbers are not provided, but the author states that:

I decided the personal approach was preferable to other, less personal approaches, like sending out hundreds of questionnaires to people I would have no other contact with. (Dunlop, 1991, p. 52)

### 9.1.1 *Redevelopment of the questionnaire*

As I looked at the letters and transcripts of interviews he had recorded, I understood the magnitude of the experience and authority that these recorded views represented, as I knew about half the respondents personally or by reputation. Dunlop's thesis gave me an idea which I thought that I could develop.

I changed the questionnaire in the following ways.

- I rewrote the introduction dividing into sections so that it would contain the research references and definitions, with the idea that all respondents would be replying with a set of common understandings as a starting point. I also felt that the background information might be genuinely interesting to respondents.
- I cut down the number of questions and reformatted the questionnaire so that there was no space to answer questions. Respondents were invited to answer questions on a separate sheet. There were then five pages of information and five pages of questions.
- The questions (numbers of questions in brackets) were in sections. These were:
  - General information about respondents (6)
  - A history section (4)
  - A personal section (4)
  - Definition of physical and chemical change (5)
  - The teaching of physical and chemical change in schools (13)

More pedagogy and the boundary between physics and chemistry (6)  
A section for book authors only (4)

- One feature I decided upon was that either I would interview the respondents, or give them the questionnaire personally and explain how to use it at a conference or some such meeting.

### *9.1.2 Early responses to the questionnaire*

I started with the new questionnaire in January but was unsuccessful in getting responses, probably because I did not circulate the questionnaire widely enough. In November 1995, I made a new start. At this time I attended two history of science conferences in Minnesota and in January 1996 attended the annual Association of Science Education (ASE) meeting. I also conducted an interview with Dr Alex Johnstone and had discussed the topic with Dr David Knight at Durham. Dr Knight preferred the written questionnaire to a tape recorded interview. At this stage, I had given out personally about 30 questionnaires and replies had started coming in quite well.

During the first half of 1996, I decided to extend the project, so that respondents came from suitably diverse backgrounds. I had been a member of the Chemed-L listserver group for some years. I was familiar with the names of those who responded fairly frequently, and through their replies was fairly sure which members of the group had a wide experience and knowledge of chemistry. I then wrote a standard e-mail letter (Appendix 3) to selected individuals from the Chemed-L. The letter does point out that the questionnaire is lengthy and I found about half those to whom I wrote said that they would reply. More than half of those who said that they would reply actually responded. In general I was very pleased with these responses, pleasantly surprised that so many people gave so much time to this questionnaire.

I further extended the list to include some 'History and Philosophy of Science and Science Teaching (HPSST)' listserver members, some 'Chemconf listserver' members, some British Society for the History of Science (BSHS) members, some Australasian Science Education Research Association (ASERA) members, some local

Northern Territory (NT) science teachers, some colleagues from the Science and Mathematics Education Centre (SMEC) at Curtin University and to some friends overseas. This strategy was less successful and I received proportionately fewer responses from this strategy. I had wanted to make the survey truly worldwide and the last attempts tended to be people outside Britain, the United States and Australia, so I felt this strategy was worthwhile. Language difficulties, technically unreliable systems and various other factors have tended to reduce overseas responses. In the end I received 80 returns, more than half of those who promised a response, but probably below one third of those to whom invitations had been sent.

Throughout the process of making invitations, I encouraged responses by allowing as much freedom as possible to respondents in the way that they responded. I pointed out that not all questions need be answered. (I eventually accepted about four short written responses that did not answer the questionnaire specifically, but which explained a viewpoint). I also accepted the response by whatever means it was dispatched (e-mail, e-mail attachment, disc, taped interview or a tape sent by the respondent, typed, or handwritten): I also sent up to three reminders.

### *9.1.3 Overall analysis of results*

I interviewed on tape and had transcribed interviews with Dr Alex Johnstone (as stated), Dr Robert Bucat (University of Western Australia), Dr Glen Chittleborough (University of South Australia) and Mr Tom Kenney (USA), who preferred to tape his response. These are the longest responses running to 20 pages or more. Other responses are generally about three to four pages long. The total quantity of material is about 350 pages. In this study the analysis of the results will be to look at the various sections and describe the range of views. I should say here that the wealth of experience of the respondents, their qualifications, and their interest is the guarantee of the reliability of the conclusions, though this is dependent on my interpreting the data correctly. I do not feel that any conclusion can have statistical validity: 80 respondents drawn from the world's science education community at all levels is hardly likely to achieve this. However, the sample is largely drawn from those who communicate their opinions to others to others, whether by the internet or at conferences and are therefore likely to be influential. I will give a brief overview of the results of this research (Palmer, 1996a).

I have not analysed each question separately; rather I have reported interesting and relevant responses from some of the questions. The respondents did not attempt all questions and some gave overall opinions without specifying questions. When reporting responses #12 represents the twelfth respondent; it should be noted that the responses remain confidential as #12 was the twelfth person to submit the questionnaire, whilst the named list of respondents is in alphabetical order.

## **9.2 General information about respondents from Section 1 of the questionnaire**

Appendix 12 is copy of the questionnaire including both the information sheet and the survey. Appendix 13 lists the names of those kind enough to take part in this survey in alphabetical order. Appendix 14 lists the respondents in terms of how they responded to the questionnaire, their country, the sector/level in which they work, and their subjects.

Australia (29%), USA (25%) and UK (16%) were the countries most strongly represented. The remaining 30% of replies were spread around 19 other countries. The male/female ratio in the survey was 82.5% to 17.5 %. This is unbalanced, but it is at least partially attributable to the reality of the gender balance in tertiary chemical education. Part of the survey also required access to and use of listserv groups. Because of movement between sectors these figures would only be approximate: about 28% of the sample was involved in teaching (primary and secondary): 26% were involved in teacher education: 41% lectured at a tertiary level and less than 5% worked in industry or research. The great majority of the respondents (90%) were at least partly involved with chemistry as a subject. There were about 5% of respondents for whom physics was a main subject and also about 5% of history of science respondents.

Overall the academic level of respondents was very high with 58% of respondents having a doctoral degree. Most of the remainder had masters degrees and several were currently pursuing doctoral studies. Eight professors/associate professors took part in the survey. All participants had a first degree. I did not ask directly about experience, but there were several who confessed to more than 30 years experience: I would estimate that overall the group would average 15-20 years

experience per person. The question is what does this well-qualified and highly educationally experienced group think about whether physical and chemical change should be taught in schools or not? However, the first section starts with history of science.

### 9.3 Questions about the history of physical and chemical change

In this as in other sections, there are few generally held views as each opinion is expressed differently. Even in the case where some propositions are overwhelmingly supported, I feel that these are assertions and that it is not right to say that the minority are wrong.

#### 9.3.1 Questions 7, 8 and 9

In Question 7, participants were asked to associate the name of a scientist with physical and chemical change. Generally the reply was negative (only 21 answers with names). I will put a list of scores down as an obvious illustration that this is not the way to decide this point.

Lavoisier	8 mentions
Dalton	7 mentions
Boyle	3 mentions
Boerhaave	1 mention
Venel	1 mention
Vernon Harcourt	1 mention
Einstein	1 mention

My view was that one of the earliest scientists to grasp some portion of the concept of physical and chemical change was Boerhaave (Section 2.6.9) though I agree with the majority that Lavoisier had a major role in the development of the concept. It is interesting to note that in Chapters 2 and 3 each of the other scientists, apart from Einstein, receives a mention for playing some part in the development of the concept of physical and chemical change. The majority mentioned Lavoisier and Dalton. One can conclude that those without a specialist knowledge, but with a good general knowledge of chemistry give Lavoisier and/or Dalton almost all the

credit for the understanding of physical and chemical change. The majority view is not necessarily correct, but on this occasion, the view that Lavoisier helped most in our understanding of physical and chemical change coincides with my view. However, I think that in Section 3.3.5 of this study a case is made for Dalton having slowed down progress in the understanding of chemical change.

Question 8 is more broadly based asking whether teachers were broadly sympathetic to the use of historical material in teaching school chemistry. This must be a 'motherhood' view nowadays. There was only one partially opposing view:

- #39 (i) Some historical context is useful, but should be minimal.  
(ii) Students need to spend time on basic principles and how to apply them.

The opposite view was put strongly:

- #77 I am very much for the idea of using the development and establishment of ideas in a historical context. I often assign questions and areas of private study on the basis of 'how do we know?'

Surprisingly the historians with the support of some others added 'caveats' that the history should be soundly taught. However, in the questionnaire as a whole this was the question answered with the greatest degree of unanimity.

Question 9 was for the specialist historian and most respondents ignored it.

### 9.3.2 *Question 10*

Question 10 asked why the concept of had lasted so long. In Chapter 5 (Sections 5.8 and 7.1.7) four hypotheses were put forward for the longevity of the concept of physical and chemical change. Respondents were asked whether these hypotheses explained the longevity of the concept of physical and chemical change. Four possible explanations were suggested, though respondents were free to offer their own alternative explanations. The explanations provided were as follows.

- (1) The concept is a remainder of an 'Aristotelian' theory of matter, kept by the natural conservatism of scientists.
- (2) The opposition of 'physical and chemical change' in textbooks is a pedagogical device, so that it is easier for students to learn related concepts.
- (3) The concept is often illustrated by a number of exciting and interesting experiments that appeal to those teachers who see themselves as being practically orientated.
- (4) The concept is a device used by chemists to define the boundary between chemistry and physics to the advantage of chemistry, so that young people will tend to choose chemistry as a subject to study rather than physics.

Most respondents answered this question. A very few respondents put alternative hypotheses forward and those offered tended to relate to teachers avoiding change as they were traditional. Respondent #65 explains it this way:

Not really, I feel that it has stayed persistent because no one really writes a new textbook. They just start with what they had as an undergraduate or what they teach in today and try to 'tweak' it a little. In the USA, I think part of the blame is a course that we teach in virtually every state at some grade level(s), Physical Science. This course is normally composed as 1/2 a year of chemistry and 1/2 a year of physics. It is often taught twice once in the early junior high years, grade 5-7, and a second time early in the high school years, grade 9 or 10. This course is usually presented as a non-mathematical or non-rigorous presentation of the 'essential' parts of chemistry and physics. It obviously cannot reach the depth of understanding to teach 'all' of the important concepts in chemistry and physics and is therefore a survey type course. Chemical change and physical change fit in very nicely as a definitional type of introduction to the differences between physical change and chemical change.

Respondent #77 sees it this way:

I tend to agree with the proposition in Section C(4). The phrase is meaningless in the light of current knowledge. It should be ignored, hoping that those who believe in it, or worse, trying to propagate it, soon die out.

The actual figures for this are as follows:

Those choosing just one hypothesis.

Only hypothesis 1	3 mentions.
Only hypothesis 2	24 mentions.
Only hypothesis 3	3 mentions.
Only hypothesis 4	0 mentions.

Some chose several different hypotheses together or even all four at a time.

Hypothesis 1 with others	4 mentions.
Hypothesis 2 with others	12 mentions.
Hypothesis 3 with others	13 mentions.
Hypothesis 4 with others	11 mentions.

Altogether hypothesis 1 total	7 mentions.
Altogether hypothesis 2 total	36 mentions.
Altogether hypothesis 3 total	16 mentions.
Altogether hypothesis 4 total	11 mentions.

It may be concluded that the majority of respondents believe that the use of the phrase 'physical and chemical change' in textbooks is a pedagogical device to enable students to understand chemical change better. Each of the hypotheses has some evidence to support it, but, if limited to one hypothesis only, this would be my opinion too.

#### 9.4 A personal history section: Question 12

The purpose of this section is to provide some experiences from respondents to see how well they remember physical and chemical change from their schooldays.



Chapter 1 consisted of my own recollections of the concept of physical and chemical change. Questions 11 and 12 were intended to explore this dimension with each respondent. There were few responses to Question 11, which leaves Question 12 as the central question in this section.

Question 12 asks about what respondents remember from being taught about being taught physical and chemical change from their own school days. About 25 out of 80 respondents had some specific recollection of being taught physical and chemical change, but most respondents recollect little. I have recorded what each respondent wrote under a number of different categories. Some responses appeared to be bound up with some feeling (emotion) such as enjoyment, excitement or boredom. From others there is a straight description of what they remember: some of these descriptions were of the iron filings/sulfur experiment or copper turnings/sulfur experiment (see Chapter 8). It is interesting to note that here, where in theory, there is a single experiment that respondents should remember, in fact respondent's memories of this experiment are very different. Others remember how they learned the topic or how they acquired a pre-knowledge of the topic or the problems they had with the definition of physical and chemical change. Thus respondents replies were categorised under five headings which are emotion, plain description, iron filings/sulfur experiment, pre-knowledge and problems with the definition. The category of emotion was sub-divided into enjoyment, excitement and boredom.

#### 9.4.1 *Emotion: Enjoyment*

- #3 The topic was exactly 'physical and chemical change'. We were given several substances to observe their change after heating in the flame. The entire process was enjoyable because the colour and appearance associated with each change was attractive.
- #40 I enjoyed chemistry, And I enjoyed doing experiments which had spectacular results! I never made bombs or rockets - a friend of the family had lost a hand and an eye while making explosives at school, and he was an object lesson. My chief interest was in the growing of crystals. Later on, I enjoyed visiting chemical plants such as BHP, CSIRO and the Sulfide Corporation with my father, who was a supplier of scientific instruments. I

do not remember any disasters, and some of my experiments at home resulted in satisfying outcomes. I was fortunate in having thorough teachers in my early years of high school: I read a great deal (Sherwood Taylor was a great source of enjoyment to me) and I went ahead of the class in this. Priestley, Lavoisier and Joseph Black were real people to me.

#71 Physical change: The realisation that water can change from solid - liquid and gas. Three states of water (solid, liquid and gas), the burning of sulfur, rusting of 'bush-knife' chemical reactions such as precipitation. I found chemical reactions which produce precipitates very fascinating indeed. Observing what happens when two chemicals are mixed or reacted together. e.g. silver nitrate + ammonium chloride.

#78 Burning of magnesium. Interesting.

#### 9.4.2 *Emotion: Excitement*

#15 The only chemical change experiment that I remember was with this same Mr. Jenkins. He mixed a barrel of aluminium scraps with something else and created a simulated volcano with some kind of detonation device. The whole school was out to watch, but we were so far away (for safety) that we couldn't really see anything.

#41 Physical/chemical change was taught in Chemistry every year. The only exciting event occurred when a 'recalcitrant' student threw a lump of sodium into a sink full of water. The physical and chemical changes paled into insignificance when compared to the emotional changes occurring in the teacher.

#### 9.4.3 *Emotion: Boredom*

#18 Taught in the first or second year at a Grammar School in the early 1950s ie. to 11 or 12 year olds. It was a dry-as-dust blackboard exposition by the chemistry teacher.

#21 No recollection of first time. But what is remembered about these (sic physical and chemical changes) is boredom. 'Who cares' is the question that comes to mind. Not that these (sic physical and chemical change) are not important, but I do not believe that they can be taught without an understanding of bonding, both inter and intra molecular.

#### 9.4.4 *Emotion: Description*

#1 Physical change: change of state.

Physical and Chemical change: Iron filings and sulfur.

Physical: Mixing Fe and S Chemical: Heating the mixture.

The properties of the mixture and compound were compared.

#22 Physical and chemical change was introduced to me in a science lesson in Year 8 about half way through the year. We were using a practical textbook called *Discovery in Science, Practical Book 1* by Baldock, R. N., Chittleborough, G., Eberhard, S. T. et al (1967). I still have a copy of Book 2 if you require a fuller reference. The lessons were pretty straightforward, clinical. Examples as you described, were used e.g. boiling water, burning a match or paper.

#29 Yes, Mrs Mason, our science teacher did talk about solids, liquids and gases (ice, water and steam) demonstrated variation in space occupied and explained it on blackboard using particle theory (Year 8?)

#34 I had my first lesson on physical and chemical change when I was 14.

#56 I can't remember being taught it for the first time, except that I know it must have been in Year 8. It is difficult to remember whether what I think was connected with physical and chemical changes really was. I remember heating things and dissolving things as generally involving physical changes because you could go back to the original appearance, etc.

#### 9.4.5 *Emotion: Iron filings/sulfur experiment*

#1 Mentioned above

#38 I remember my first lesson in junior chemistry (1959). It was on mixtures and compounds, and that was where the emphasis was, although the concepts of physical and chemical change were embedded within it, as one example was on iron filings and sulfur - before reaction being separated with the use of a magnet. During the lesson the teacher burned a piece of magnesium. I think it was probably then that I decided that chemistry was the most fascinating subject of all. I think that there are far fewer problems with the 'mixtures and compounds' concepts than with 'physical and chemical change', though there are still fuzzy areas.

#43 Yes, I perfectly remember the experiment with sulfur and iron (eighth grade at the school).

#53 No, not specifically the first time. I can recall the teacher demonstrating the properties of iron and sulfur, then mixing them and demonstrating the properties of the mixture and ultimately separating them (magnetically, as I recall). He then combined them by heating and demonstrated the properties of the resulting compound. This could well have been the first time that I was exposed to the topic.

#57 Yes. It is exciting; the burning of magnesium in air to form white, MgO or the burning of Cu and S to form CuS.

#79 I remember iron sulfur mixture (magnets, trained ants, etc), and the smell of H<sub>2</sub>S!

#### 9.4.6 *Emotion: Rote learning*

#73 Usual stuff of learning definitions, which I now reject. I do not remember much of specific lessons, only that I could parrot off the answers.

#75 ...Teachers who depend on chalk and blackboard can teach this topic very effectively. I still remember learning the physical change and chemical change in school and how I tried to learn some of those comparisons by heart....

9.4.7 *Emotion: Pre-knowledge*

#37 I don't recall the concept of physical and chemical change being taught for the first time. I was well aware of the distinction from experiments I had done with my chemistry set.

9.4.8 *Emotion: Problems with the definition*

#9 I can remember being taught physical and chemical change at school. The thing that used to bug me about the physical and chemical change taught to me as a kid at school, they always used to make a great play about the reversibility of the physical change. I remember saying to the teacher well what about tearing up paper or breaking a glass. Where is the reversibility in that? There used to be some sort of stutterings and mutterings and being told to shut up and be quiet.

#14 Sad!! It did not make sense and I found many examples that did not fit the tidy little definition. This made the teacher very angry at and with me. I also enjoyed this game as well.

#30 No, I don't remember when I learned it. I do remember discussing it with my father for quite some time afterwards, however. He is also a chemist. I remember trying to come up with examples of changes that could not be easily categorised.

It is difficult to summarise the views on physical and chemical change expressed above, but they are very much polarised. One wonders how different people see things so differently. Some were excited by the simple but effective experiments on physical and chemical change, whilst others remember a sense of enjoyment. Some thought it all very boring. Six of the respondents remember the experiment using

iron and sulfur. This shows that it was the most common experiment on physical and chemical change. Several respondents remember that even as students that they had problems with the definitions of physical and chemical change.

#### 9.5 A personal history section: Question 14

There was little response to Question 13 relating to the specific interests or career decisions that respondents had when they were at school. Question 14 links with Question 30 on issues, but adds the personal dimension where the respondent states how physical and chemical change has influenced them. It tends to be the place where those who agree with the teaching physical and chemical change start to diverge from those who disagree with the teaching physical and chemical change.

In Question 14 respondents come to reflect on how the experiences they have described when learning about physical and chemical changes may have influenced their thinking about the 'big issues' in science. At this point in the questionnaire we see the divide opening between those who favour teaching physical and chemical change and those who do not. Respondents speak very strongly on either side of this debate. At this point I will re-introduce the story (see Section 5.6) from one of the respondents (Professor Carl Snyder), that vividly illustrates the nature of the debate. The story is said to be true, but whether true or apocryphal, it could easily have happened. I like this story for a number of reasons, largely because I want this study to use anecdotes where appropriate to make clear points that aid discussion. The major point of this would seem to me that in terms of science to be taught at a particular level, it is possible to hold a respectable academic opinion on either side of the divide.

The views that follow are considered views of experienced professionals. The views are categorised as those who think it is important to teach the concept of physical and chemical change those who think it is important not to teach the concept of physical and chemical change, those who wish to teach about a continuum of physical and chemical change and in a category of its own an answer which is itself a question. There appears to be more of the group in favour of physical and chemical change at the moment, but not all views have been listed here. There is a case with which I have some sympathy for using the concept of physical and

chemical change to provide the theoretical basis for decision-making in case studies of major issues for student discussion. However, at this point it is the turn of the respondents to express their views.

9.5.1 *Question 14: For physical and chemical change*

- #2 Yes! I think it is as you can't understand issues to do with the permanence of atoms, hence pollutants- see the Robin Millar chapter on the Public Understanding of Science in the *ASE Teacher's Handbook*.
- #4 Environmental concerns probably involve for me a clear imagery of the persistence of certain chemical species like DDT or chlorofluorocarbons as basically not chemically changed in their transport through water or air.
- #6 What an impossible question! I guess it's an awareness of the different scale of physical/chemical force.
- #22 ...The concept is pertinent to the big chemical picture as in most cases we are describing chemical changes and altering the balance of naturally occurring chemical cycles which involve chemical changes.
- #26 The issues raised above; if I see something I try to explain it, initially, in terms of physical or chemical change (e.g., erosion, bush fire, explosions).
- #37 Certainly it is potentially useful for the general public to have some understanding of chemical reactions. Ozone depletion, global warming, energy transformations, etc. all involve chemical changes. An important issue is the difficulty of chemically reversing some of the environmental damage that has already occurred.
- #39 There is a tendency to look at complex problems initially in terms of whether they involve chemical reactions or not. Knowing the answer doesn't have to change how interesting the problem is, but it does help one to bring the right tools to bear in order to begin solving it. Operational science involves a

systematic approach and chemical versus physical changes are part of the traditional fabric of science.

- #42 Yes I do believe that the underlying conceptual explanations related to chemical changes where there is a change of substances compared to (at least my current understanding of) physical changes where no such change occurs does assist in understanding such matters as the depletion of the ozone layer etc.
- #43 I think it was a good opportunity for me to start classifying the phenomena surrounding us. I think now that this was a good push to start thinking about the world.
- #48 Think it is important for chemists to try to have the community understand the differences, particularly when we are talking about environmental pollution and other factors that give chemistry a bad press.
- #57 Yes. The concept of physical/chemical change has implications on our current thinking of chemistry.
- #59 Yes I think the concepts of physical and chemical change are of value. Especially when coupled with ideas of conservation of mass and energy, these ideas allow us to see how pollution etc. is detrimental to our surroundings.
- #60 - relates physical and chemical changes to everyday happenings. Influenced by the presentation of topics and concepts.
- #65 I think the molecular change = chemical change is essential to scientist solving/discussing all of your examples. Therefore, if we are going to ask students to participate as either potential scientist or even informed voters, they must be able to think about chemical changes at the molecular nature.
- #71 Certainly, yes. The understanding that a chemical change involves the formation of a new product is realised by students when you start taking



about the burning of plastics in oxygen - the product is hazardous. It is easier to (sic present the) idea about a chemical change - the evolution of a new product. In this case, the evolution of a poisonous gas. You see people in the rural areas in non-western countries who do not appreciate why burning of plastic is bad because they do not know the chemistry of it. Unless they understand the explanation of a chemical change and the likely products, it is meaningless to continue to tell these fellows that the burning of plastic produces a hazardous gas or atmosphere

#72 Again, I think the concept is really about chemical reaction, and this is an essential concept of chemistry which has to be understood, either for school/laboratory reactions or for the out-of-school/environmental reactions that you mention....I think that the concept of physical and chemical change should be tailored to the context of environmental reactions in terms of additional concepts such as reaction cycles, (ir)reversibility and catalysis.

#79 Outside of chemistry, I still think in terms of reversible and irreversible change.

9.5.2 *Question 14: Against physical and chemical change*

#9 World issues – I do not find it a useful concept at all any more. It is not a distinction I find helpful to my thinking at all.

#18 No. It seemed, at one time, to present a justification for the separation of physics and chemistry in schools and universities.

#27 It hasn't been particularly helpful to me personally.

#29 Not really. I don't think it has really influenced my thinking at all. It was just something else to think about!

#34 Now, I refuse the concepts of physical and chemical changes. There is no clear frontier between both. The modern knowledge on atomic, molecular, and solid state structure, and on the interaction between particles, has

convinced me that it is impossible to assure in any case when new substances are created (chemical change). The concept of 'substance' is not well founded in chemistry. No clear border exists between chemistry and physics.

- #46 No, except maybe to analyse how inadequate some of the definitions are, thereby beginning a lesson on critical thinking.
- #53 The concept possibly has limited value as a way of getting young students to think about change, but in view of its very serious shortcomings it is probably better not to use it. I do not believe that it has any real value in helping scientists or the general public understand major world issues. I am not aware of any influence on my thinking that I can attribute to the concept.
- #56 No, I don't think it is. I think it is a misleading distinction because all changes in matter involve changes in forces between particles and their energy and to call some changes physical implies that there are no changes in forces. I think my feelings have crystallised over the last ten years while teaching senior chemistry and I now feel the distinction should not be made at all.
- #66 I can't think of any way that chemical and physical change play a particularly important role in explaining everyday chemistry. The issue I raised above just about covers it. How do you talk about the difference in what happens to water when you heat it to get a gas and what happens when you pass an electric current through it and get a gas?
- #67 No. Personally I leave it out altogether. In my view it is unhelpful in general and of no particular use in dealing with any of the matters you mention in the question, nor does it give any helpful insights. It has been one of the things that has pushed me to look for better ways of teaching chemistry. I explain this more fully in a later answer.

9.5.3 *Question 14: A continuum of physical and chemical change*

- #12 They represent extremes on a continuum of understanding. As a dichotomy they are useless and probably damaging; as extremes of a range they can help beginners to think about the territory in between.
- #30 I don't think I can answer this question. I don't think about the world this way. I think the value of teaching/learning about chemical and physical changes lies in seeing them as two ends of a continuum and recognising that many processes fall somewhere between the two absolutes.
- #52 Actually, no. I see a continuum of interaction energies strong on one end (leading generally to chemical change) and weak on the other (leading to physical change).

9.5.4 *Question 14: Physical and chemical change: A query*

- #33 This dual relationship of matter has caused me to wonder why so often scientific concepts occur as a Yin-Yang relationship. For example: physical/chemical; homogeneous/ heterogeneous; covalent/ ionic; endothermic/exothermic; cation/ anion; proton/ electron; etc.

There is again considerable polarisation between those who support the teaching of physical and chemical changes and those who do not. The middle ground is occupied by a small minority of respondents.

9.5.5 *Respondents' views on the definition of physical and chemical change*

Questions 15-18 relate to the logical problems with the simple table of observations that allowed physical changes to be distinguished from chemical changes. I have to agree that the particular table chosen links an oversimplified pattern with an authoritarian philosophy,

i.e., the idea that 'changes are of only two types - they are either physical or chemical'. Each of the definitions, whether relating to the formation of new

substances, the energy evolved, the masses of the substances produced, or the reversibility of the reaction were flawed as stated and the respondents pointed out many logical shortcomings in the definitions. Such definitions were common in textbooks up to 1970s but more recently only the definition that relates to the formation of new substances is used and the idea of physical and chemical change is given less prominence.

Question 19 however was a key question for me as it represents the point of view that whether we use them or not, we should attempt to have in place a set of logically consistent definitions.

The phrase 'Physical and chemical properties' is used in many contexts and the most common definition of the phrase uses an understanding of what is meant by physical and chemical change. I feel that textbooks which use the phrase 'Physical and chemical properties', but neither define the phrase in some other way nor explain the meaning of by physical and chemical change are escaping the difficult issues involved. In my view, explaining the words 'physical and chemical' is equally difficult when explaining 'physical and chemical properties' as it is explaining the phrase 'physical and chemical change'.

Unfortunately my wording and exemplars appeared to mislead respondents, so I think many respondents missed my argument.

I did receive some suggestions as to how this problem could be overcome. These were:

#19 I think we could re-define physical properties as those related to structure, where other materials are specifically excluded (melt, crack, bend, get hot, conduct ...), and chemical properties as those relating to interaction of matter (diffuse, dissolve, react). In the geographical example, physical erosion would be impact of energy, including forces from other matter that does not otherwise interfere, like a hammer impact (sand, air/wind, frost would all be physical)

- #22 Physical and chemical changes are okay provided science (and other areas such as geography) are precise about defining physical and chemical properties upon which concepts of physical and chemical change rely.
- #28 I do use the terms but without the great emphasis used in the past and I do not try to distinguish too strongly between them.
- #31 In ordinary discussion of science, I think we will likely continue to use 'physical' and 'chemical' loosely, and I don't see a real harm in that. I think the problem arises in school situations in which the so-called distinctions are emphasised unduly. Dissolution of a cliff of carbonate by acid rain I might consider a chemical erosion, while its destruction by wind forces I would still call a physical erosion.
- #35 No, but it would be more sensible to use the phrase Scientific properties and just list the properties such as m.p., b.p. solubility, etc. This would allow for other aspects such as biological properties or changes to be accommodated.
- #36 Physical and chemical - once again we talk about chemical and physical properties as well as chemical and physical changes. Again I think if we talk in terms of a spectrum might be better attuned.
- #37 I suppose that interactions that fall on a continuum create problems in classification. For example, are van der Waals forces or hydrogen bonds chemical or physical interactions? I guess I would have to say that the basis for all chemical change is physical interaction. At the atomic level, the distinction disappears. It is only useful when discussing bulk properties, just as the distinction between physical and chemical properties becomes an issue only in aggregates of atoms.
- #38 I think that once students have understood the basis (in terms of microscopic descriptions) of the various kinds of changes we wish to discuss, we can tell them that certain changes or properties have traditionally been regarded as physical or chemical, without trying to propose all-encompassing definitions – in the same way as the concepts of 'metal' or 'non-metal' retain their

general usefulness, although it may be difficult to define these in such a way that every element fits neatly into one category or another. Stress that this is simply a matter of convenience, so that we can refer collectively to various phenomena without having to list them separately. Quite early in their science education, students have probably encountered many other examples of arbitrary choices and human conventions, ranging from the direction defined as positive for an electric current to the numbering of the groups in the periodic table.

- #42 Intuitively 'no' because I believe I currently use such expressions automatically when discussing the types of examples to which (19) refers.
- #45 Yes: physical and chemical properties. In this case, the difference depends on whether the property can be detected with the senses or not. I cannot think of a broad definition of 'physical and chemical' at this moment.
- #47 Properties shared by a bulk of particles (physical) and properties shared by every single particle (chemical).
- #53 No!! The terms 'physical properties' and 'chemical properties' can be defined by individual specification.
- #59 To define physical and chemical properties, I use an analogy of people. Physical properties are things such as hair colour, eye colour, height, etc. Chemical properties would be things such as their personality, how do they interact with other people, (and form chemicals, how do they react with other substances)
- #66 Physical and chemical are used to modify change, properties, weathering, and all such, but I have never sensed a need to define the meaning in any way other than 'a change in which you maintain the same basic unit of matter' vs. 'a change that results in the rearrangement of atoms into different basic units.'

- #67 No. However the idea of listing the properties of a substance in two groups based on whether the property depends upon other substances being present or not. For example, melting point can be measured independently of the presence of another substance. Solubility cannot. (I personally see this as a chemical property. Chemical properties include reactions with other substances. To ask the question, 'Is another substance needed for the property to be determined?' allows me to pop it into the right column.
- #72 Chemical properties relate to the reaction possibilities of a substance while physical properties do not. I suppose the same applies to the changes of substances/properties in geology. I also found in older textbooks the terms chemical solutions e.g. salt in water or Fe in HCl versus physical solution e.g. sugar in water. And we have the chemical atom/ bond/ equilibria/ energy versus the physical atom/ bond/ equilibria/ energy. There also exist the terms chemi-sorption and physi-sorption in catalysis related to bonds differing in terms of energy. There may be others too. I suppose you could rephrase the concept of chemical and physical change in terms of reaction, energy, corpuscles and chemical bonding.
- #73 It seems to me that we can clearly describe change at molecular and macroscopic levels, but there may be little to be gained from classifying as physical or chemical, except in a very loose way. According to the classification almost all changes are somewhat ambiguous. Physical and chemical properties are also a bog.
- #77 I rather not discuss a non-issue, such as this.
- #79 I teach geology currently, and do distinguish between physical and chemical weathering. I do not treat the distinction as of importance: my approach is more that rocks may be broken down by both physical and chemical means.

## 9.6 Respondents' views on the teaching of physical and chemical change in schools

Question 20 is a key question in the sense that it asks when and if physical and chemical change should be taught in schools. Whatever the result is in terms of numbers of those who favour physical and chemical change being taught traditionally and those who would like to see the concept of physical and chemical change put on the scrap heap of history, those numbers cannot have any statistical significance: they are simply the opinions of this sample of people. It was surprisingly difficult to put some replies in the category yes or no. The numbers were 49 who favoured physical and chemical change being taught traditionally, and 20 who opposed physical and chemical change being taught traditionally. Some respondents did not answer either Question 20 or any other question that clarified their view.

### 9.6.1 Respondents' views on the boundary between physics and chemistry

Also there would be many on either side of that yes /no border who would not have a strong view for or against, whose view depended on contexts not specified in the questionnaire. The chemists really have the view that the important change for students to understand is chemical change, and many are unconvinced that the use of physical and chemical change as contrasting pairs makes chemical change easier for students to understand.

I stopped analysis at this point in the questionnaire as the numbers of responses to the later questions declined rapidly and in reading the replies that were provided, few new points emerged.

## 9.7 Summary of Chapter 9

I have to say that it seemed to me that the balance of the academic argument favoured the view that the days of teaching physical and chemical change were numbered at a secondary or tertiary level, though in terms of numbers the opposite view was more popular.



The research question 'Is there a divergence of views between scientists and science educators over the science of physical and chemical change?' – was in retrospect the wrong question to ask. As the data were examined, neither scientists nor science educators appeared to have a generalisable viewpoint. What respondents provided was a very mixed set of views, as can be seen from the quotations provided. Sometimes individual participants will give a firm answer to one question in the questionnaire and modify this view in the answer to another question. The questionnaire was extremely useful in showing that very strong views exist agreeing with Dr Satchell that the concept of physical and chemical change should be abandoned forthwith, but this view is expressed by a minority of respondents.

Perhaps over the next 20 years the concept of physical and chemical change will put on a 'new persona', for about the fourth time in its history, becoming a rough and ready concept that children learn early on without much in the way of definition that says that something 'special' has happened when an egg is boiled or a cake is baked.

## CHAPTER 10

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### WHAT NEXT? DOES THE EXPRESSION PHYSICAL AND CHEMICAL CHANGE HAVE A FUTURE?

*Research Question 10: Does the expression physical and chemical change have a future?*

#### 10.0 Physical and chemical change: Recapitulation

This is the final chapter of the study which attempts to look at the concept of physical and chemical change in a wider context. Previous chapters have related to my own experience of physical and chemical change, the history of physical and chemical change and the story of those who researched in this area or wrote textbooks about physical and chemical change. Questions about the definition and usage of physical and chemical change have been raised, whilst issues that relate to the controversies that the concept has caused have been documented. A variety of case studies have been provided and criticisms have been made of some earlier research on physical and chemical change.

In the end, the discussion comes back to what should be taught in schools and at what level should it be taught and how it should be taught. The answer to this depends on whether a concept of the difference between physical and chemical change would help the average child, when adult, into being able to express his or her own views about some of the major issues that confront humanity. Could this be one of the useful generalisations that with other broad concepts might assist the 'man in the street'?

No one idea or principle can answer all questions. However, the two major ideas are that of larger amounts of energy being involved with chemical change than with physical change and a greater probability that once a chemical change has taken place it will be more difficult to reverse than a physical change. Even so, the criterion of greater energy being involved in a chemical change is not always true and the reversibility test is said to be tautologous (Taber, 2002a), yet it seems to be the major criterion in schools (Stavradou & Solomonidou, 1989). For example, I

visited a school recently to supervise a student teacher teaching a Grade 8 class (Nightcliff High School on 26/10/02) and noted that the NTU student teacher, when referring in class to his lesson of the previous week on physical and chemical change, reminded the students of the reversibility criterion as the means of distinguishing between physical and chemical changes. This is probably common practice.

As has been seen already in the study, none of these criteria are absolute, but they can provide general guidance. What about the claim that teaching the concept of physical and chemical change will help people understand some of the 'big issues' of the day? There can be no absolute proof of this, but generally the idea of physical and chemical change to help in the public understanding of sciences was provided as a reason in the questionnaire (Chapter 9) for its teaching. There was some enthusiasm for this position shown by about half those expressing a view. A short essay by Goodenough (1999) attempts to negate this view on logical grounds as she points out that members of the public trying to decide 'big issues' with insufficient scientific background may easily be misled by 'false experts'. I note the introductory paragraphs of many of the older texts are extraordinarily enthusiastic about the importance of physical and chemical change in natural events.

And man's ingenuity and imagination are often stimulated to attempt explanations of the facts discovered about substances, and these explanations form the hypotheses and theories about chemistry.

(Linebarger, 1904, p. 4)

School curricula worldwide are in a state of flux. Most primary curricula whether recent or not contain 'natural and processed material' or some similar phrase where the concept of physical and chemical change tends to be introduced. There are fascinating ideas introduced by different books, some of which might be major sources of future alternative conceptions where in a fairy story, which is part of a science lesson for Year 3 children, 'oobleck' is changed into water (Fleer & Hardy, 1996, p. 53). There are other materials that involve cooking food and eating as an example of chemical change which will provide a popular start for chemistry.

Crocker and Fleege (1993, p. 34) suggest that it is difficult to teach middle-school and upper elementary students about physical and chemical change in a way that does not confuse or mislead, because such students still 'actively construct their own knowledge through real experiences instead of simply acquiring abstract knowledge'. Crocker and Fleege (1993) then suggest appropriate activities which they believe provide real experiences with different compositions a cornstarch/water mix where there are only physical changes and for oobleck where there are chemical changes. The lengthy paper by Krnel, Watson and Glazar (1998) comes to theoretical conclusions based on a reading of the extensive educational research on 'matter'. In general, this is supportive of the activities suggested by Crocker and Fleege (1993) that younger children should do more activities with liquids, gases, sand or flour and colour where there is a greater emphasis on the intensive properties of matter.

Nevertheless, some children's books and resources focus entirely on physical and chemical change and a selection of examples of such books are listed in the next section.

### **10.1 Physical and chemical change: Primary schools**

Teaching science in primary schools and to some extent in the lower part of secondary schools is in the case of some students the last occasion when they can learn the language, principles and concepts of science. In more developed countries, students may be separated from science a little later on leaving school or not doing science because they take some non-science speciality. In less developed countries, students will leave school earlier, so it is in the primary school that perhaps a lifetime's science is learned.

Books show the evidence that physical and chemical change are very much a part of primary science and have existed as part of primary science for a considerable length of time. The following books/resources tend to emphasise physical and chemical change.

Schaffer (1996) has designed a well-made card-set of four cardboard sheets attached together and folded, printed in colour on both sides, said to be aimed at upper

elementary students. The outer folded sheets can be detached if desired and students can write up their experiments on these sheets if required. Students completing these exercises should obtain a reasonable understanding of physical and chemical change. It is difficult to know how widespread the use of such materials is in the USA, but its existence and easy availability makes me think that they might be used in better-resourced schools.

Gore (2000) produced a 26-page book for Grades 4-8 in Canada. A series of activities are suggested using simple materials to illustrate a variety of different physical and chemical changes. The last section is a set of test questions which appear to be quite well formulated. The final question (Question, p. 24) could be a good discussion question, but it might be a little hard even for Grade 8 students, though the text has prepared them for it. The question asks why sugar dissolving in water is considered a physical change and an 'Alka-Seltzer' tablet dissolving in water is considered a chemical change. It makes me reflect on how carelessly we use the word dissolve and how hard mastering chemical concepts can be when the language is confusing.

The following books tend to emphasise chemical change rather than physical and chemical change. The very well regarded *Ladybird Books* had a number of science texts relating both to physics and to chemistry such as *Magnets and electricity*, *Simple mechanics*, *Light, Air and Simple chemistry* by John and Dorothy Paull, all published in Britain in 1982.

Another British book entitled *Chemical change* (Jarvis, 1994) is aimed at Key stage 4 (junior secondary level). It does start with the concept of physical and chemical change, but after the first page does not mention physical change again.

A recent American book for grades 5-9 is entitled *Physical & chemical change* (Ortlebb & Cadice, 1993). It is excellent for this level containing activities, transparencies in colour and a teaching guide. Another American book entitled *Chemical changes* (Rosen, 1992) is more at a secondary level though the book does not specify the age range applicable. It does, however, contain a section on the differences between physical and chemical change. Back in 1990, I reviewed an Australian publication called *Chemical change* (Whisson, 1989). I was not impressed by it and gave it a less than generous review (Palmer, 1990b). For practical work, also secondary, Beran

(1996) has produced a student practical manual with a title indicating an emphasis on physical and chemical changes.

One interesting feature in primary school is the increasing connection between science content and literature. I believe this to be a worthwhile trend and note that this can provide an excellent way of introducing science concepts. For example, in their book *Teaching physical science through children's literature*, (Gertz, Portman & Sarquis, 1996), the authors link specific children's books to particular scientific concepts. The concept of solids, liquids and gases is linked to the book *The rainbow fish* by Marcus Pfister. Additional scientific materials are made by students and are called glitter wands and these contain solids, liquids and gases. Quite a variety of these books now exist (Butzow, Butzow & Kuhar, 1994; Butzow, Butzow & Kennedy 1998; Butzow, Butzow & Ben-Zvi, 2000) and these relate children's books with most science concepts commonly in primary school curricula, providing a wealth of material for primary school teaching.

## 10.2 Physical and chemical change: A chemical philosophy and the public understanding of science

Briefly it should be stated that an understanding of philosophical problems, relating to the study of chemistry and its nature have gained in popularity in recent years, with the following new initiatives.

- The start of an in-print journal *Foundations of chemistry*
- An online journal *Hyle--International Journal for Philosophy of Chemistry*, at URL <http://www.hyle.org/>
- An online listserver for those interested in chemical philosophy
- The formation of an International Society for the Philosophy of Chemistry with an annual conference
- A number of recent books. For example Van Brakel (2000)
- Recent translations of older works relating to a philosophy of chemistry (Fulcanelli, 1999).

Perhaps this does not relate directly to the public understanding of science but those contributing opinions to the listserver also tend to offer opinions in other more

public domains. From time to time discussions occur where the use of the word physical and the word chemical feature frequently. Discussions on the periodic table, for example, tend to generate this usage. Also there are frequent discussions about the ways in which the study of physics differs from the study of chemistry. I have included a letter (Appendix 15) from Dr Brian Salter-Duke, a colleague of the Northern Territory University, to the listserver on chemical philosophy to illustrate just how close together for example, chemical physics and physical chemistry might be. Finally, I would like to look again at the considerable use made of the expression physical and chemical change, physical and chemical, and the words physical and chemical separately.

### 10.3 Physical and chemical change, its use in scientific papers and the www

I believe that the use of the words physical and chemical are essential for those members of the public who wish to read and understand scientific literature. This can be demonstrated by seeing how frequently the phrase physical and chemical is used in the title or in the abstract or the body of scientific articles.

Figure 10.1 indicates the wide range of scientific articles that use the phrase physical and chemical in their title. There is no claim that the list is exhaustive and was developed using the Northern Territory University Library Expanded Academic Search ASAP (Gale Group, a Thomson Corporation Company); 607 citations were accessed on 20/12/02. A few citations were accessed using the Northern Light search engine which includes some full academic papers. Figure 10.2 uses the same data but lists articles that use the words physical and chemical in the text though not necessarily together. One can expand the list hugely by listing scientific articles that use only the word physical or the word chemical. Many fewer scientific articles use the phrase physical and chemical change. This seems to be a phrase mainly used in science texts and by science educators, but whether the adjectives physical and chemical are used to describe change, characterisation, fertility, evidence or properties, the same problems of logic or paradox arise with these descriptors. It seems to me that in the public understanding of science it is best to be satisfied with a fairly general meaning of physical and chemical.

Shahzad Afzal, Mohammad Younas, & Khadim Hussain (1999). Physical and chemical characterisation of the agricultural lands of the Soan-Sakesar Valley, Salt Range, Pakistan. (Statistical Data Included). *Australian Journal of Soil Research*, 37(6), 1035.

M.J. Bell, P.W. Moody, R.D. Connolly, & B.J. Bridge (1998). The role of active fractions of soil organic matter in physical and chemical fertility of Ferrosols. *Australian Journal of Soil Research*, 36(5), 809-20.

Grant M. Young, Victor Von Brunn, Digby J.C. Gold, & W.E.L. Minter (1998). Earth's oldest reported glaciation: physical and chemical evidence from the Archean Mozaan Group (~2.9 Ga) of South Africa. *Journal of Geology*, 106(5), 523-38

A.M. Whitbread, Rod D.B. Lefroy, & Grame J. Blair (1998). A survey of the impact of cropping on soil physical and chemical properties in north-western New South Wales. *Australian Journal of Soil Research*, 36(4), 669-682.

Marek Zreda (1998). Physical and chemical hydrogeology, 2d ed. (book reviews) *Ground Water*, 36(4), 550-552.

J. Rosner, A. Klik, & W. Loiskandl. (1998). Effects of temporary and permanent soil cover on grape yield and soil chemical and physical properties, *Journal of Soil and Water Conservation*, 53(3), 249-254.

Dennis Rouvray (1997). Semiconductor Nanoclusters: Physical, Chemical and Catalytic Aspects. (Book reviews) *Chemistry and Industry*, 21, 872(1)

Ronald Weinberger & Florian Kerber (1997). Planetary nebulae: Understanding the physical and chemical evolution of dying stars. (Cover Story). *Science*, 276(5317), 1382- 1387.

J. M. Edmond (1996). Seafloor hydrothermal systems: Physical, chemical, biological, and geological interactions. (book reviews) *Science*, 271(5255), 1508- 1509.

Robert H. Tykot (1993). Absolute Age Determination: Physical and Chemical Dating Methods and Their Application. (book reviews) *American Antiquity*, 58(4), 769-771.

Cornelis A.M. Rietmeijer, John W. Krebs, Paul M. Feorino, & Franklyn N. Judson. (1988). Condoms as physical and chemical barriers against human immunodeficiency virus. *JAMA, The Journal of the American Medical Association*, 259(12), 1851-53.

M.G. Johnson. S. Ko, M.E. Janes, & N.S. Hettiarachchy (2001). Physical and chemical properties of edible films containing nisin and their action against *Listeria monocytogenes*, *Journal of Food Science*, 66(7), 1006-12.

A. Clough, & J. O. Skjemstad. (2000). Physical and chemical protection of soil organic carbon in three agricultural soils with different contents of calcium carbonate. *Australian Journal of Soil Research*, 38(5), 1005.

Cooperband, Leslie R., & Middleton, June H. (1996). Changes in chemical, physical and biological properties, *Compost Science & Utilization*, 4(4), 24-35

**Figure 10.1** Recent scientific articles that use the phrase physical and chemical in the title of article (in no special order)

Figure 10.2 indicates the wide range of scientific articles that use the phrase physical and chemical in the body or abstract of the article. Such articles are very common.



G. Ding, J.M. Novak, D. Amarasiriwardena, P.G. Hunt, & B. Xing (2002) Oil organic matter characteristics as affected by tillage management. *Soil Science Society of America Journal*, 66(2), 421(9).

T. Neil Irvine, Jens Christian, O. Andersen, & C. Kent Brooks (1998). Included blocks (and blocks within blocks) in the Skaergaard intrusion: geologic relations and the origins of rhythmic modally graded layers. *The Geological Society of America Bulletin*, 110(11), 1398-1403.

Holger Stunitz (1998). Syndeformational recrystallization-dynamic or compositionally induced? *Contributions to Mineralogy and Petrology*, 131(2-3), 219-237.

Simon Hadlington (1993). Caterpillars that roll their own. (change in chemical composition of leaf buds bound by caterpillars for food), *New Scientist*, 137(1864), 17.

Tuncer B. Edil, Linda K. Sandstrom, & P.M. Berthouex (1992). Interaction of inorganic leachate with compacted pozzolanic fly ash. *Journal of Geotechnical Engineering*, 118(9), 1410-1431.

Raymond E. Samuel, E.D. Salmon, & Robin W. Briehl. (1990). Nucleation and growth of fibres and gel formation in sickle cell haemoglobin. *Nature*, 345(6278), 833-836.

Flavio Roces (2002) Individual complexity and self-organization in foraging by leaf-cutting ants. *The Biological Bulletin*, 202(3), 306-314.

W.M. Post, R.C. Izaurralde, & L.K. Mann, N. (2001). Bliss Monitoring and verifying changes of organic carbon in soil. *Climatic Change*, 51(1), 73-74.

Shankararaman Chellam, & Dennis A. Clifford (2002). Physical-chemical treatment of groundwater contaminated by leachate from surface disposal of uranium tailings. *Journal of Environmental Engineering*, 128(10), 942-53.

Timothy P. Wilson & Donald F. Palmer *The chemistry of water pollution* Magill Survey of Science: Physical Science Series (Document Type: Encyclopedia Entry).

**Figure 10.2.** Recent scientific articles that use the phrase physical and chemical in the body or abstract of the article (in no special order)

I then tried a further search using "Current Contents ISI" for a scientific literature search using all editions all years as the search instructions. A tabulation of results is presented as Figure 10.3.

Search	Statement	Hits
1 <sup>st</sup> Search	Physical And Chemical Change	3
2 <sup>nd</sup> Search	Physical And Chemical Change	18
3 <sup>rd</sup> Search	Physical And Chemical	12023

**Figure 10.3:** Current Contents ISI Searches

The comments on the results of the earlier searches have already been indicated and are confirmed by these results that an understanding of the meaning of the words physical and chemical is needed.

#### 10.4 Physical and chemical change and the public understanding of science

I will try to introduce some thoughts about the concepts of physical and chemical change and the way that the public might understand them by considering some Northern Australian scientific issues as case studies about chemical change in the Northern Territory (Palmer, 1998e). I presented these to a meeting of science journalists, science educators and scientists that I attended in Berlin in 1998 (Science without Frontiers, 5th International Conference of the PCST-Network). I will also take as an example an example from St Helens (UK) where the Pilkington's exhibition entitled 'The World of Glass' specifically avoids distinguishing between of physical and chemical change in order to help the general public understand the world of glass.

Sometimes the word 'relevance' appears in discussions about what should or should not be in science curricula. It is often thought that science curricula should link more directly to the science that appears in the media. This idea is not without its merits and most teachers do try to illustrate some of the concepts that they are teaching to events in the media. I would like to suggest an additional link, but in the opposite direction. That is, journalists might attempt explanations of the science involved in their stories that relate to the educational level common to the majority of readers of their particular newspaper or journal. This implies that journalists should try as a part of their own professionalism to obtain an understanding of what science concepts are taught at what educational levels.

If journalists were to accept this principle then they would need to know what scientific principles were generally taught at what levels in schools. Or to rephrase this, what should ordinary citizens now be expected to know as a result to know as a result of their schooling? Some authors have tried to answer this question. Appendix 16 lists the answers that two writers of a textbook – Hazen and Trefil, 1994 – gave. Making lists of scientific concepts that all citizens should understand can be a wonderful game, open to any number of players who may wish to add to or adapt these suggestions. What is clear however is that the concepts in Hazen and Trefil's list are large overarching concepts and that more detail would be needed as to exactly what sub-concepts ordinary citizens need to know.

#### 10.4.1 Chemical change and the public understanding of science

What is a chemical change? Chemical change is a change that occurs when two or more substances (reactants) interact with each other, resulting in the production of different substances (products) with different chemical compositions. A simple example of a chemical change is the burning of carbon in oxygen to produce carbon dioxide. (Lafferty & Rowe, 1994)

Interestingly enough, Lewis (1993) who edits a different dictionary, *Hawley's condensed chemical dictionary* gives a different definition of chemical change which relates to atoms, ions, etc. The author also distinguishes chemical change from physical change and furthermore adds a new class of physico-chemical changes for cases where it is difficult to tell the difference. Sharp (1987) who edits *The Penguin dictionary of chemistry* does not include a definition of chemical change at all.

This study has considered the teaching of physical and chemical change and these three examples very much illustrate that there is a lack of agreement about definitions. In Chapter 9, I described the responses to a detailed questionnaire to science educators worldwide, which provided a wide variety of responses, but about half of the respondents felt that explaining the concept of physical and chemical change in school could help the children understand some of the major issues confronting humanity today. So, how should we help children understand about chemical change in schools?

There is also a constant change in school curricula as more science is discovered and as some parts of these discoveries are transformed into material to be included in new curricula. To make way for new curriculum materials, old material is either discarded or taught to increasingly younger age groups in a less sophisticated form. The topic 'physical and chemical change' is embedding itself in primary school curricula, in Australia, USA and UK and it tends to be repeated in junior secondary school. In the USA, physical and chemical change seems embedded in texts for older groups. Also there are increasing numbers of web-sites which provide experiments on physical and chemical change.

The net result of this is that although there are strong arguments as to why the concept of physical and chemical change is inadequate, it will continue to be taught in primary and junior secondary classes and reinforced through teaching on the world wide web. In simple and probably scientifically inaccurate terms, students and the general public will have the idea that there are two types of change that can effect matter -physical and chemical.

Physical changes can usually be reversed without using large amounts of energy being involved whereas chemical changes will usually involve much larger amounts of energy and will thus be much harder to reverse. In practical cases, understanding one principle on its own will not do much because most real world situations will involve several different principles to provide understanding, but this is a start. Perhaps when considering some environmental damage the public will realise that if a chemical change has occurred then the damage will be more difficult to put right. Even this limited view of what public perceptions would be is an acceptable advance on what the public now knows. Three short case studies illustrate aspects of the concept of physical and chemical change being a part of major issues which impinge upon the public understanding of science.

#### *10.4.2 Case study: Glass and physical and chemical change*

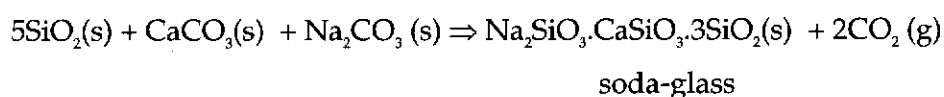
When in Britain in January 2002, I visited Pilkington Glass at St Helens. There is a permanent exhibition about glass open to the public. It was a very interesting exhibition containing lovely early glass artefacts (excellent in every respect) and it included a lot of historical information about glass, glass blowing demonstrations and a film with special effects. The four exhibitions about the constituents of glass all started with the following statement:

basically glass is super-cooled liquid sand.

This statement raises questions about the nature of physical and chemical change. Having written so much about the differences between physical and chemical change, this statement horrified me as I considered it to be incorrect or at least oversimplified on many grounds. Chemically most glass is not sand. Also glass is not a liquid (of any sort). This appears to be the view of the most recent and

authoritative sources, though many texts contradict this view. One supposes that the introductory word basically is used to modify these statements to make it easier for a scientifically illiterate public to understand the exhibitions, but in my view the statement tends to hinder understanding. Glass chemistry is not simple and even recent articles, texts and dictionaries give opposing views. However, it did show me that there is a purpose for our public science education starting in schools to try to explain the differences between physical and chemical change. This at least gives the ordinary person a basis on which to ask further questions.

To show the problematic nature of the statement that 'glass is super-cooled liquid sand', I will review some of the evidence about the nature of glass. Glass is said to have originated with the Phoenicians/Canaanites near the modern port of Haifa in about 3000BC. Sass (1998, p. 99) expresses the view that glass is a supercooled (frozen) liquid. He points out that there is a naturally occurring black translucent glass called obsidian (Sass, 1998, p. 102) which is formed when molten sand from deep underground cools. He also states that the earliest glassmakers used sand (silica) which contained about 9% lime. It was then heated with natron (sodium carbonate) (Sass, 1998, p. 104), which formed a glass of lower melting point than the glass formed when molten silica cools. Soda-glass is the main type of glass for common usage: 90% (Atkins & Jones, 1997, p. 756) of all glass (the substance we commonly call glass) used is soda-glass which is chemically different glass to the glass formed from the cooling of molten sand. In terms of chemistry, Bucat (1987, pp. 289-290) gives the following equation as representing the formation of soda-glass, when sand, limestone and soda ash are heated together.



This equation indicates that a chemical change occurs when soda-glass is made, which shows that the statement about glass being supercooled liquid sand is an over-simplification as the statement would be indicative of a physical change.

The next issue is whether glass is a supercooled liquid or a solid. Lapp (1963, p. 106) states that glass is 'a form of matter difficult to classify'. Fine (1991) and Walker (1991, p. 390) studiously avoid using the words solid or liquid when referring to

glass. Sass (1998, p. 104), Lewis (1993, p. 561), and Barnes-Svarney (1995, p. 236) consider glass to be a supercooled liquid whilst Atkins and Jones, (1997, p. 756) consider glass to be 'an ionic solid with an amorphous structure, resembling a liquid'. A much stronger statement comes from Hawkes (2000, pp. 846-848) in his article entitled 'glass doesn't flow and doesn't crystallise and it isn't a liquid'. The view that Hawkes (2000) has is apparent from his title. It is interesting that he supports his views from the practical evidence from a variety of sources that glass does not flow. For example, he provides evidence that the often repeated view that medieval church glass is thicker at the bottom of windows than at the top is incorrect. It is stated that the glass is thicker at the bottom, showing that it has flowed over hundreds of years and that glass is thus a liquid, albeit a very viscous one. Those supporting the view that glass is a liquid tend to use arguments about the molecular structure of glass, which is a very abstract argument. There are different views about the nature of glass; these are partly caused by failure to decide whether the discussion is about the class of substances 'glasses' or about the most common of these called soda-glass. Another cause for differing views is that consideration of whether glass is a liquid or not depends on whether the definition of a liquid is based on abstract or practical considerations. There is a considerable similarity with paradoxical definitions in considering the nature of glass to those in the earlier chapters considering definitions for physical and chemical change.

#### *10.4.3 Case study: Mining in the Northern Territory and physical and chemical change*

Northern Australia comprises the northern parts of Queensland and Western Australia and the Northern Territory. I will however relate most of the information in this case study to the Northern Territory. The generalisation for the northern part of the continent is that it is mineral rich and lacking in population. The Northern Territory is 1 346 200 sq kms in area (about one sixth of the land area of Australia) with less than 1% of the population of Australia - about 180,000 people (Protocol & Affairs Branch, 1998). Known mineral resources include bauxite: gold; manganese: zinc, lead, silver: diamonds: bismuth, copper, galena, mica, molybdenum, ochre, opal, palladium, platinum, etc: uranium; crude oil: natural gas (Protocol & Affairs Branch, 1998). In considering these major issues, it will soon be seen that other concepts are needed to understand them, but in each case some understanding of physical and chemical change is also required.

Mining involves both physical and chemical change – the digging of the ore from the ground, grinding it and carrying it to the site for separation of the ore: these are largely physical processes. The separation of the ore from the rock may be a physical or a chemical process or may combine both. On the other hand, the production of the metal from the ore will be a chemical process. The metal may be shaped and made into some finished product and this is likely to be a physical process. There are different processes involved in obtaining each of the Northern Territory's products, though frequently the ore is exported and the final stages of processing carried out in some other country. Probably, the most controversial of the mining ventures is uranium mining and this is an important industry in the Territory.

#### *10.4.4 Case study: Mining in the Northern Territory - Uranium*

Uranium mining at the Ranger mine in Kakadu is certainly controversial, but probably not for scientific reasons. It is actually a well run mine, controversial because it is situated within the boundaries of a National Park though the small area it occupies has been excised from the park.

General information favouring a nuclear industry can be found at (www1), (www2) and (www3). Web sites putting an opposite point of view are at (www4) and (www5). More or less neutral is (www6) which is the web site run by the Office of the Supervising Scientist. Within the web site (www2) there are separate sections which look at the chemistry of uranium extraction, which would be of interest to Year 12 students doing chemistry. There is also a separate site on the physics of nuclear industry, which would be of interest to Year 12 students doing either physics or chemistry. It may be of interest to refer back to my model – Figure 5.6 – Spectrum of change or change continuum-my view.

I also found a number of pure science research articles relating uranium and chemical change. In this example, the following statement was included in the abstract:

Waste can be gaseous, liquid or solid and varies greatly as to the degree of chemical and physical hazard. In the case of radioactive waste, the

radiotoxicity decays with time and there is chemical change, two of the parameters that illustrate that waste disposal is indeed a dynamic process.

(Duncan, 2002, p. 75).

It is noticeable that even papers at the cutting edge of research currently need a concept of chemical change developed in school science.

Making headway in understanding the arguments in the whole complex of scientific arguments is hard work and involves understanding many different scientific principles. The concept of physical and chemical change is only one of many useful concepts which the public ought to know.

#### *10.4.5 Case study: Mining in the Northern Territory - Oil and gas*

Crude oil is produced offshore and is refined outside the Northern Territory. Fractional distillation would be a physical process, whilst catalytic conversion would be a chemical process. As an aside, the leaded petrol that the Northern Territory uses has a very high percentage of lead in it. It is not a problem in that not many cars still use leaded fuel, but the lead compounds formed as a result of combustion of lead tetra-ethyl in petrol can leave children intellectually damaged, when they breathe in these very small particles containing poisonous lead compounds. This is a major problem for children in the crowded cities of the third world, but not really for Darwin. However, in remote rural areas of the Northern Territory petrol sniffing is a major problem and the availability of leaded petrol makes bad medical problems many times worse as the lead in the leaded fuel stays in the sniffer's metabolism.

Natural gas is available in Central Australia and this powers our local power station, making it one of the more environmentally friendly power stations in Australia. This happened more by luck than judgement, as the Channel Island power station was built at a deep water location to allow the import of coal. The decision to use gas was made while the power station was actually being constructed. To provide a given amount of energy natural gas produces less carbon dioxide than coal does. There is currently the strong possibility that gas from the Timor sea gas fields may be brought onshore.



The NT really lacks major manufacturing industries, so many of the issues that might relate to chemical change may seem minor. Finally the archetypal chemical change of fire which Aboriginal people have used for thousands of years to control the landscape has become a hotly debated subject.

#### *10.4.6 Case study: Physical and chemical change caused by fire in the Northern Territory and the public understanding of science*

The archetypal chemical change is fire. Fire has been a theme of this study, considered an element by early Greek scientists and accepted by scientists as an element until medieval times. Fire was thought of as a process during which phlogiston was removed as metals, for example, were changed to calx for the greater part of the eighteenth century. Lavoisier provided the basis for a modern view that fire is oxidation, yet this concept took at least 30 years to be widely accepted. Even today science educationalists, such as Ross (see Chapter 6), argue that general public understanding of the nature of fire (combustion) is not properly understood as there is little comprehension that two substances (the fuel and oxygen) are involved. Children's and perhaps adult's understanding of the nature of fire is still generally poor, with perhaps only about 20% of 15 year old students in Britain understanding that fire is a chemical change (Donnelly & Welford, 1988). More recently (2002) many of my external student-teachers set up small scale projects to test whether students of primary school age understood the difference between living and non-living objects and fire was one of the examples commonly provided. A considerable proportion of these primary students thought that fire was living. It can be concluded that even in the developed world there is much work to be done in the public understanding of science.

In Australia, the Aboriginal people have used fire for thousands of years to control the landscape and the Aboriginal use of fire has become a hotly debated subject with a wide variety of views possible. A book *The Future Eaters* (1998) by Tim Flannery was produced as a TV series. (www7). Flannery's theories relate the Aboriginal use of fire to the demise of the megafauna of Australia, to providing a better way of controlling the land and its flora and fauna than European practices over the past 200 years, and to be worth researching to use for future control of the Australian environment. These theories are not agreed upon, but there does appear

to be an acceptance that there is still a lot of learning to be done to find appropriate fire regimes for Australia. It may well be that we have to learn about some aspects of fire control from our indigenous population. Because uncontrolled fires cause so much destruction and becomes a very emotional issue, there are a variety of solutions promoted. Research papers provide the evidence around which many different hypotheses are built. Examples can be found in several articles (Wayne, 1984; Vines, 1987; Vines, 1988; Schulmeister, 1994; Kohen, 1995; Flannery, 1998; Langton, 1998).

The NT Department of Business, Industry and Resource Development says that

Traditional Aboriginals used fire for hunting to flush out their prey. They created fire to make areas accessible for walking, to encourage a green pick for native animals and to stimulate growth of bush food plants such as *Solanum* species (bush tomato). Fire was also actively used for signalling and spiritual reasons. Aboriginals still use fire as a means of hunting, and as a regime for managing their native pastures. (www8)

In the end, there are many fascinating hypotheses about how we should use fire to provide solutions to the fire-prone nature of Australia.

#### *10.4.7 Comment on the case studies: Physical and chemical change and the public understanding of science*

I have briefly attempted to relate the public understanding of science, the concept of physical and chemical change and Northern Australian scientific issues together. I conclude that there is much work to be done to assist the general public in understanding science; it would also assist this aim if scientific journalists knew more about what children understood whilst at school: they should try to include more information in news stories to make the issues more comprehensible to the general public.

## 10.5 Chapter by chapter conclusions

### 10.5.1 Conclusion in Chapter 1

The research question in Chapter 1 was 'What is my personal experience of physical and chemical change?' My biography was presented explaining at different stages of my life the personal relevance of the phrase, physical and chemical change, in the expectation that this would make formal definitions and explanations more meaningful. Apart from my own biography, I paid some attention to the autobiography by Oliver Sachs, who had an amazing insight into the concepts of physical and chemical change aided by uncles who assisted him in physics and chemistry, respectively. The research methodology indicated the special value of triangulation for a wide-ranging thesis such as this. The chapter illustrated the major research methods used in the study and it also started to examine the meaning of the words 'physical and chemical change'. The title of the thesis "A study of teaching and learning about the paradoxical concept of physical and chemical change" was de-constructed to clarify its meaning.

### 10.5.2 Conclusion in Chapter 2

The research question in Chapter 2 was 'Does the concept of the physical and chemical change exist as a scientific explanation in the early history of chemistry?' The aim of this chapter was to try to give an overview of what chemistry and chemical change are. Sources used to plot a history of physical and chemical change were identified. I have used a large number of histories of chemistry. Indeed those interested in the history of science are fortunate in the range and variety of books available. Most are quite lengthy books, but the history of understanding the nature of matter is virtually the history of chemistry. Thus Chapter 2 consists of the first part of an historical description of humanity's quest to find out of what base materials matter is made. From the earliest recorded history to about 1750, chemistry's history is outlined indicating those who to some extent contributed towards the development of a concept of chemical change and providing some biography where appropriate. The major theoretical ideas during that period were the Aristotelean four element theory and its modifications by Paracelsus and others and Stahl's phlogiston theory. It is probably safe to say that the concept of the

physical and chemical change did not exist as a scientific explanation in the early history of chemistry, though some glimmerings of the modern conception are visible.

### *10.5.3 Conclusion in Chapter 3*

The research question in Chapter 3 was 'When does the concept of the physical and chemical change take shape as a scientific explanation?' Lavoisier was the first person to create a modern understanding of the concept of chemical change. Lavoisier did use the contrasting pair, physical and chemical as far back as 1774. He was also the first person to write a textbook that would be easily comprehensible today and was the first textbook writer to clarify the language so that the concept of chemical change would be easier to understand. Lavoisier is the central figure of the brief history, but I also emphasise his educational views as well as his brilliant chemistry. The chapter continues with a well-known list of chemists/physicists each of whom adds to the certainty of a concept of physical and chemical change. Misunderstandings about the nature of heat and elements seemed particularly apt discussion points, but the 1860 Karlsruhe Congress could be considered a time when the concept of chemical and physical change was largely clarified. The history does venture into the 20<sup>th</sup> Century to consider hydrogen bonding. The science of chemical and physical change is clear at this time, but the last section of the chapter considers paradoxes created.

### *10.5.4 Conclusion in Chapter 4*

The research question in Chapter 4 was 'What part do textbook writers, educationalists and teachers play in the historical development of a concept of physical and chemical change?' This study is about education as well as science and Chapter 4 follows a less well known road of considering the role played by those who wrote school textbooks to make sure that what was discovered in the laboratory was passed on to the succeeding generation in the classrooms. I have found room here for many who are not famous, but whose life stories and achievements are absolutely fascinating. In particular women have played a much larger part in making the science discovered by the great scientists clear to the children at school level. My heroes were Youmans, Cooley, Armstrong and Freund

and I have enjoyed the real research involved in finding out about the lives of each of them and how each was involved in clarifying the concept of chemical and physical change. The answer to the research question is that textbook writers, educationalists and teachers have played a major role in the historical development of a concept of physical and chemical change and in clarifying the concept for future generations.

#### *10.5.5 Conclusion in Chapter 5*

The research question in Chapter 5 was 'What is the debate about the distinction between physical and chemical change been over the past 200 years and how has this debate changed with the increased understanding of chemical processes?' This chapter started with a study of the Encyclopaedia Britannica looking under the entry 'chemistry' for the terms 'physical and chemical change' in all the editions between 1700 - 1950 or their equivalents showed the terms not to be used much. Of those writing for the Encyclopaedia Britannica the term 'chemical change' was perhaps most frequently used by H. E. Armstrong. Further searches were carried out. In the first of these, some 19 alternative words for chemical change were found and referenced in the literature. It was asserted that this multiplicity of words indicating the same concept was a cause of confusion to tyro chemists. In a second search, a variety of dictionaries were searched for definitions of physical and chemical change. It was found that the definitions of the terms together were quite infrequent in dictionaries. A further search was the use of categorisation into contrasting pairs as a means of learning, which is quite common in chemistry. Then different models for clarifying the understanding of physical and chemical change were examined. Then the arguments from open debates from academic journals about physical and chemical change were analysed. Finally, research evidence from curricula and assessment tasks were examined briefly to show where the concept of physical and chemical change is today. The overall conclusion that I reached from the discrepant results of Chapter 5 is that physical and chemical change was considered a fairly important idea in schools, but might not be thought very important in the outside world.

### *10.5.6 Conclusion in Chapter 6*

The research question in Chapter 6 was 'What does science education research say about children's/students' learning of physical and chemical change?' Chapter 6 attempts to summarise the vast amount of educational research that exists on physical and chemical change concentrating in the main on constructivist projects of the last 25 years. Alternative conceptions research on physical and chemical change often fails to define what the scientific knowledge is with which the children's knowledge is being compared. Some research is inconsistent in this regard having changing definitions of 'physical and chemical change'. There are a whole variety of inconsistencies when comparing the work of different researchers. Some early research indicated that children younger than about 12 years old were unable to understand the concept of 'physical and chemical change'. More recent research is equivocal and research which spans large age ranges is particularly suspect if it does not indicate that what an 8 year old should be expected to know about physical and chemical change is likely to be different from what a 16 year old should be expected to know about physical and chemical change. The research into physical and chemical change varied widely in aim and style, so there were no grand overarching theories, only individual caveats about details of the methodology.

### *10.5.7 Conclusion in Chapter 7*

The two research questions in Chapter 7 were 'Is there any discernible trend in the way that textbooks deal with physical and chemical change and has this altered over the last two hundred years?' and 'Did textbook authors who wrote both chemistry and physics (natural philosophy) textbooks introduce the concept of physical and chemical change into their natural philosophy/physics texts more frequently than those authors who only wrote physics textbooks?'

In Chapter 7 there were two projects relating to science textbooks each using different methods to investigate the pedagogic influence that the textbook has had on the teaching of physical and chemical change over time in the United Kingdom, USA, Australia and elsewhere. The first project was to examine as wide a range of textbooks as possible to see how they wrote about physical and chemical change. A means of recording the information from the survey of textbooks using Macintosh

Hypercard has been devised and this records some 26 pieces of information about the way in which each textbook deals with the topic of physical and chemical change. Typical cards may be seen as Appendix 6 with 527 textbooks recorded on this hypercard stack. The textbook has been one major influence on teaching physical and chemical change. The hypercard stack is thus a major source of information about the teaching of physical and chemical change in different countries and eras.

The second project was to consider the textbooks of nineteenth century textbook writers who had written both physics/natural philosophy texts and chemistry texts as it was hypothesised that writers who had written books in both areas would be most likely to treat the topic of physical and chemical change in their physics texts. This is certainly true and the method did help to show that LeRoy Cooley was the first to use the topic of physical and chemical change as a first introductory chapter in his chemistry textbook. Cooley was concerned to make science more understandable to school students and this was a strategy that he chose.

#### *10.5.8 Conclusion in Chapter 8*

There were two research questions in Chapter 8 which were as follows: 'What can we learn about student alternative conceptions relating to concept of physical and chemical change from student manuals (1890-1950)?' and 'What can we learn from the history of the experiments using iron and sulfur to illustrate the differentiated concept of physical and chemical change?'

Chapter 8 provides two studies that relate practical work to physical and chemical change. Firstly the practical manual during the period 1890-1950 was studied to look at student writing within the manuals to find evidence of student ideas of physical and chemical change historically. Secondly a variety of historical approaches were used to look at the changes that can take place between iron and sulfur as the most common example used to illustrate physical and chemical change. The answer to the first research question is that some of the alternative views held by student's today were also held by students in about 1900, showing that student alternative views are consistent historically as well as geographically. The methodology suffers from problems in that it takes quite a large number of manuals to produce very few

results, yet I believe this, limited though it is, to be an extension of our knowledge about student alternative conceptions.

The answer to the second research question in this chapter is to note that a practical example of iron combining with sulfur is chosen most frequently as a practical exemplar of chemical change in spite of this being a non-stoichiometric (Berthollide) reaction. It is also quite a difficult experiment to perform well in practice even as a demonstration, and it is dangerous in practice if performed by students as there are a variety of hazards, mainly the accidental ignition of sulfur producing sulfur dioxide. It is paradoxical that the much safer experiment which is easier to perform using almost identical materials, which was used by Fabre, is now forgotten.

#### *10.5.9 Conclusion in Chapter 9*

The research question in Chapter 9 was 'Is there a divergence of views between scientists and science educators over the science of physical and chemical change?' The research aim in Chapter 9 was to discover more about physical and chemical change from a variety of points of view, including the point of view of the practising scientist, the university lecturer, the teacher educator, the historian of science, the primary teacher and the secondary teacher. This was carried out using a questionnaire to ascertain their opinions about the teaching of physical and chemical change. Some respondents were interviewed using the same questionnaire and some authors of science/chemistry textbooks were included in the sample to explain how and if they dealt with physical and chemical change in their texts.

#### *10.5.10 Conclusion in Chapter 10*

The research question in Chapter 10 was 'Is an understanding of physical and chemical change any use to the ordinary person?' In Chapter 10 the relationship of physical and chemical change was considered briefly in respect of both the www and the public understanding of science. Some case studies were considered. Overall, I consider that science teachers, science educationalists and science journalists all have a responsibility for helping the general public understand science better. Generally understanding that there is a difference between physical and chemical change would be helpful.



## 10.6 Limitations of the study

Although this study has covered large areas that relate to the teaching and learning of physical and chemical change, there are aspects which remain uncovered. For example, I have not carried out any direct classroom research involving actual students, though I have analysed a number of research projects carried out by other researchers.

I have asked a variety of science educators from different countries about their views of the teaching of physical and chemical change. The numbers replying were not large (80 altogether) and it is difficult to be sure that the views expressed were representative in any way of the views of science educators generally or that they were typical of educators in their country of residence.

The majority of the study has been historical and I have used a wide range of materials to ensure historical accuracy, but as not all books have been read, it is not possible to be certain that some particular historical aspect of the development of the concept may not have been omitted.

Assessment of student's understanding of physical and chemical change has not been given sufficient attention. The place of the concept of physical and chemical change in science curricula world-wide should have been discussed more thoroughly.

Overall, there is room for further research into the teaching and learning of physical and chemical change over the whole age range, but research should be more specific about the understandings that children of a given age should have of physical and chemical change.

Finally, the conclusions of each chapter are summarised. Overall conclusions for the thesis are reached from a consideration of the chapter summaries.

## 10.7 Final conclusion

It is difficult to evaluate the main points to come out of this thesis. These will have been mentioned in the previous chapter summaries. The main aspects of the thesis are, in fact, personal. I have been involved with the thesis for more than 10 years and trying to find the answers to the problems involved has changed my thinking and my own aims in life. The research has encouraged me to become increasingly interested in the history of science, particularly the history of chemistry and old science textbooks. This has occurred even though the history of science is not my teaching area. Research on this study has changed how I spend my time and money. Perhaps the resultant of this intense interest is that I have become clearer about the goals of the thesis over the past few years. I will try to explain what these goals are.

I started by claiming that I would use a number of methodologies and that I expected that their results obtained would point in similar directions (triangulation). The summaries of each chapter indeed show that the different methods used give similar conclusions.

The thesis provides a good set of factual materials giving:

- A history of who discovered different aspects of physical and chemical change- when, where and how.
- A history of who wrote textbooks including different aspects of physical and chemical change - when, where and how.
- Information about changing teaching methodologies for teaching different aspects of physical and chemical change - when, where and how.
- Information about the practical teaching aspects of physical and chemical change (particularly in respect of the reaction between iron and sulfur) - when, where and how.
- Information from the *Encyclopaedia Britannica* (each edition) about the changing definition of physical and chemical change.
- Information from dictionaries about the definition of physical and chemical change.
- Information about changing research methodologies for understanding student learning of physical and chemical change- when, where and how.

- Some anecdotes and stories about physical and chemical change.
- Some biographies and autobiographies of those connected in some way with physical and chemical change.
- Information from student manuals about student understandings/ alternative conceptions of physical and chemical change historically-when, where and how.
- Information from an international questionnaire about teacher/ educationalists views on the teaching of physical and chemical change.
- Information about the public understanding of science with regard to physical and chemical change.

The basic question to be asked after studying the pros and cons of teaching physical and chemical change for 10 years is: How would I now advise an inquirer to whether physical and chemical change should be taught or scrapped?

I hope any information provided will be useful for future researchers. However, a thesis is not just a collection of information. It has to answer the research questions originally set and I believe this has been done. Perhaps too a study like this can answer some questions not originally asked and perhaps more courageously indicate the questions to which no definite answers can be given.

Firstly, following any particular definition of physical and chemical change logically and consistently will lead to contradictions. This is the element of paradox that lies at the root of any concept of physical and chemical change. In the study, I have worked at removing the paradox but it remains stubbornly there. It is due to a number of factors, but mainly these.

- Physics and chemistry are closely aligned sciences but separate and different, but not completely, and there are a few parts of physical science that equally belong to physics and chemistry. The word physical means relating to physics: the word chemical means relating to chemistry. Words used as contrasting pairs need to contrast absolutely. There will thus always be elements of paradox.

- Physical and chemical change is used to describe both macroscopic worlds and sub-microscopic worlds (the worlds of atoms, ions and molecules). These worlds differ greatly. For example, in the way in which we could describe the properties of a small piece of copper and the way in which we could describe the properties of an atom of copper. The piece of copper is a lovely salmon pink: the atom of copper has no colour.

These difficulties lead to confusion and have led to many calls to scrap teaching physical and chemical change. I now believe that physical and chemical change should be taught in schools – certainly in elementary schools – in a broad simplified way with large scale examples in mind. I think we should embrace and rejoice in the flexibility and breadth of the definition. Being able to use and understand the words physical and chemical is a useful skill which should be possessed by all pupils and all adults. Throughout the student's science education we should add examples. Eventually we should explain the difficulties of the comparatively loose definitions similar to those loose definitions of metals and non-metals or conductors and non-conductors. Students should not be asked questions where there is an element of uncertainty about whether a particular reaction is a physical or a chemical change, unless the teacher is prepared to accept either answer backed by good reasoning.

For those who advise on curriculum reform or write new curricula, I would advise caution when considering the oft made call not to include the concept of physical and chemical change as a necessary part of school science curricula. It is clear that chemistry can be taught without using the concept of physical and chemical change. However the thesis provides evidence that a balance of advantage is obtained by teaching the concept of physical and chemical change with a variety of examples in a variety of contexts.

Finally I hope that others (teachers educators) may be able to use the ideas and information in this study to think about the issues involved or simply as a source of materials to help their students enjoy the study of chemistry.

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## **APPENDIX 1**

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**Note: For privacy reasons Appendix 1 (p. 384-386) has not been reproduced.**

**(Co-ordinator, ADT Program (Bibliographic Services), Curtin University of Technology, 07/01/2004)**

## APPENDIX 2

### Editions of Encyclopaedia Britannica (Chapter 5)

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1771 First edition. Edited W. Smellie *Encyclopaedia Britannica: or a Dictionary of Arts and sciences compiled upon a new plan in which the different sciences and Arts are digested into distinct treatises or systems and the various technical terms are explained as they occur in the order of the alphabet.* (3 Volumes). Edinburgh: A. Bell & C. Macfarquhar.

1778-83 Second edition. *Encyclopaedia Britannica* (10 Volumes) (Editor unstated). Edinburgh: J. Balfour & Co.

1793 Third edition. *Encyclopaedia Britannica* (18 Volumes) (Volumes 1-12 edited by C. Macfarquhar) (Volumes 13-18 edited by G. Gleig). Edinburgh: J. Balfour & Co.

1810 Fourth edition. *Encyclopaedia Britannica* (20 Volumes) (edited by J. Millar). Edinburgh: A. Bell.

1817 Fifth edition. *Encyclopaedia Britannica* (20 Volumes) (edited by J. Millar). Edinburgh: A. Constable & Co.

1823 Sixth edition. *Encyclopaedia Britannica* (20 Volumes) (edited by J. Millar). Edinburgh: A. Constable & Co.

1842 Seventh edition. *Encyclopaedia Britannica* (21 Volumes) (edited by M. Napier). Edinburgh: A. Constable & Co.

1853-60 Eighth edition. *Encyclopaedia Britannica* (21 Volumes) (edited by T. S. Traill). Edinburgh: A. & C. Black.

1875-89 Ninth edition. *Encyclopaedia Britannica* (21 Volumes + index) (edited by T. Baynes & William Robertson Smith). Edinburgh: A. & C. Black.

1902-1903 Tenth edition. *Encyclopaedia Britannica* (Ninth edition + eleven supplementary volumes). The new volumes of the *Encyclopaedia Britannica* constituting with the existing volumes of the ninth edition, the tenth edition of that work and also supplying a new distinctive and independent library of reference dealing with recent events and developments. Edinburgh & London: Adam & Charles Black.

1910-1911 *Encyclopaedia Britannica* (29 Volumes) A dictionary of arts, sciences, literature and general information. New York: Encyclopaedia Britannica Ltd.

1922 Twelfth edition. *Encyclopaedia Britannica*. The new volumes constituting with the twenty-nine volumes of the eleventh edition, the twelfth edition of that work and also supplying a new distinctive and independent library of reference dealing with events and developments of the period 1910- 1921 inclusive. London & New York: The Encyclopaedia Britannica Company Ltd.

1926 Thirteenth edition. *Encyclopaedia Britannica* A dictionary of arts, sciences, literature and general information. The three new supplementary volumes constituting with the volumes of the latest standard edition, the thirteenth edition. London & New York: The Encyclopaedia Britannica Company Ltd.

1929 Fourteenth edition. *Encyclopaedia Britannica*- A new survey of universal knowledge. London & New York: The Encyclopaedia Britannica Company Ltd.

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### APPENDIX 3

The use of the terms "chemical change" and "physical change", synonyms and related concepts in various reference works over time  
(Chapter 5)

Dictionary	Affinity	Cohesion	Chemical Change	Physical Change	Comment
Diderot and D'Alembert, 1772, pp.408-420 SCIENCE/ ART FRANCE/ SWISS	No	No	No	No	This dictionary discusses the differences between physics and chemistry at length.
Anon, 1807 SCIENCE/ ART UK	Yes	Yes	No	No	Affinity discussed at length.
Ure, 1821 CHEMISTRY UK	Yes. Under chemical attraction	Yes	No	No	2 volumes bound as one.
Vauquelin, 1830  CHEMISTRY FRANCE	Yes. Under attraction	Yes. Under attraction	Yes. As chemical phenomena	Yes. As physical phenomena	ATTRACTION is the basis of all physical phenomena" and all chemical phenomena. Large. 1350 pages
Brand, 1844 SCIENCE/ ART UK/USA Edn	Yes. In detail	Yes	No	No	
Rodwell, 1871 SCIENCE UK	Yes. In detail	Yes	No	No	
Rossiter, 1879 SCIENCE UK	Yes	Yes	Yes as chemical under chemical combination.	Yes as physical under physical geography = physiography.	
Buchanan, 1884  SCIENCE/ ART UK	Yes. In detail	Yes. Brief.	Yes*	No	Physical as opposed to chemical as in the physical properties of minerals. Single volume with short entries- 700 pages.
Burt, 1884	No	No	In explaining Chemistry, the expressions action, force and change are all used.	No	
Markun, 1927 SCIENCE USA	No	Yes	No	No	Very small book -50 pages.
Flood, 1961 GENERAL REFERENCE UK	No	No	No	No	220 pages
Hechtlinger, and Abbott, 1961 SCIENCE UK	Yes	Yes	Yes	Yes	A wide variety of short definitions
Marks, 1967 PHYSICAL SCIENCE USA	No	Yes	No. Chemical bond defined.	No	Small book- 230 pages

Collocott, 1971* SCIENCE UK	Yes. Chemistry	Yes Physics	No	No but see physical change under physical chemistry	Large reference of about 1000 pages
Daintith, 1976 SCIENCE UK	No	No	No, but under chemical reaction	Yes	330 pages
Flood et al, 1978	Yes	No	No	No	410 pages
Daintith, 1981 PHYSICS UK	No	No	No, but under chemical reaction	Yes	220 pages
Godman, 1981	No	Yes	Both physical change and chemical change together	Both physical change and chemical change together	200 pages
Kerrod, 1983 SCIENCE UK	No	Yes	No, but chemical compound defined.	No.	250 pages
Godman and Denney, 1985 CHEMISTRY USA	Yes	No	Yes	Yes	Related topics together under heading physical properties and chemical properties See "Labile"
Stone, 1985	No	No	No	No	190 pages
Sharpe, 1987 CHEMISTRY UK	Yes	No	No	No	430 pages
Pitt, 1988 PHYSICS UK	No	No	No	No	430 pages
Uvarov and Isaacs 1988 SCIENCE UK	Yes	No	Yes	Yes	460 pages
Room, 1988 GENERAL REFERENCE UK	No	No	No	No	290 pages
Emiliani, 1987 SCIENCE USA/ UK	No	No	No	No	360 pages
Schneider, & Schneider, 1990 SCIENCE UK	No	No	Yes under physical chemistry	Yes under physical chemistry	325 pages
Isaacs, Daintith, & Martin, 1991 SCIENCE UK	Yes	No	No	No	390 pages
Verma, 1991 SCIENCE AUSTRALIA	No	Yes	No but under chemical reaction	No	240 pages
Walker, 1991* SCIENCE UK	Yes. Chemistry	Yes Physics	No	No but see physical change under physical chemistry	Large reference of about 1000pages
McGraw-Hill, 1992	No	Yes	No but chemical bonding	No	20 volumes.
Morris, 1992	Yes and many related terms	Yes now has specialised meanings in geology, botany, computing as well as physics	Yes under chemical reaction	Yes, but given as a chemical term	Massive 2400 pages.

Lewis, 1993 CHEMISTRY USA	Yes	Yes.	Yes. In detail - includes physical change, chemical change and physio-chemical change	No- except under chemical change.	Huge reference work.
Hempel and Hawley 1994	No	No	No	No	1200 pages
Lafferty, & Rowe, 1994 SCIENCE USA	Yes	Yes.	Yes	Yes.	Large reference of about 680 pages.
Walker, 1995* SCIENCE UK	Yes. Chemistry	Yes Physics	No.	No but see physical change under physical chemistry	Large reference of about 1000pages
Considine & Considine, 1995	No	No	No	No	Massive - two volumes 1800 pages EACH
Daintith, 1996 CHEMISTRY UK	Only as affinity chromatography	Yes. Very brief	No. Chemical combination defined.	No but physical properties are mentioned under physical chemistry	530 pages
McKeever, 1997	No	Yes	Physical change and chemical change in encyclopedia and indexed. Not in glossary.	Physical change and chemical change in encyclopedia	A cross between a text -book and an encyclopedia
Lindley, and Moore, 1998 SCIENCE USA	Yes	Yes	yes and also chemical weathering	Mentioned as physical phenomena under physical chemistry	Physical weathering mentioned under weathering as opposed to chemical weathering
Isaacs, Daintith, & Martin, 1999	No	Yes	The expressions bond, reaction, combination are all used, but not chemical change. But physics is said to be about changes other than chemical change	No but see physical property under physical chemistry	850 pages
Hunt, 1999	No	No	No, but chemical equations mentioned	Physical properties mentioned	300pages

\* These different dictionaries seen very similar (Different imprints- same content).

### References to the reference works from the previous table used to look up terms chemical change and physical change and related concepts.

Anon (1807). *The new encyclopaedia or universal dictionary of arts and sciences, in which the different sciences and arts are digested into the forms of distinct treatises or systems, including the latest discoveries and improvements....* London: Vernon, Hood and Sharpe and Thomas Ostell.

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Buchanan, W. M. (1884) *The dictionary of science and technical terms used in philosophy, literature, professions, commerce, arts and trade.* London: George Bell and Sons.

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- Lindley, D. & Harvey Moore, T. (Editors) (1998). *Webster's new world dictionary of science*. New York: Macmillan.
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- Rodwell, G. F. (1871). *A dictionary of science; comprising astronomy, chemistry, dynamics, etc.; preceded by an essay on the history of the physical sciences* (The Haydn series). London: E. Moxon, Son, and Co..
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## APPENDIX 4

### An Individual Science Autobiography (Chapter 6)

#### AN INDIVIDUAL SCIENCE AUTOBIOGRAPHY

##### ASSIGNMENT A (No grades or marks given)

Please try to give a very full answer (about 2-3 typed pages or equivalent) to the detailed request below to be available in a week from now.

Please also include your recollections of any science lesson that either encouraged you to do science or nearly put you off altogether. Was it the content of the lesson or the personality of the teacher that influenced you more?

##### Looking Through the Lens of Science

When you look at your education through the lens of "science", what do you see? Did you have much of it? Did you like it? Did you ever even think about it? A science autobiography is a personal description of your experience with science, or out of school, through teachers, friends, parents, museums, magazines, and other sources.

Frequently, we bring preconceived ideas and beliefs to our science learning and teaching experiences. These are formed by our direct experiences with science, the people we meet who work in science, and the publicity science receives. Please think about your own personal experience with school science, scientists, science in the media, and science teachers. It doesn't matter how limited or extensive your experiences are, only that you describe them.

Relate your earliest memories of school science and your reactions. Write about your experiences with school science up to the present, explaining what you think the study of science involves. What have you grown up to believe about the scientists themselves? Who are they, and what do they do? Be as candid as possible. This writing-and-thinking exercise will be your first step toward school science *teaching!*

Idea from :- Koch, J. 1990 The Science Autobiography, *Science & Children*, Nov / Dec, Vol 28, No 3, pp 42-43.

The whole paper can be downloaded from URL. (accessed 15/6/01)

<http://info.mq.edu.au/Educ/atea/palmerw.htm>



## APPENDIX 5

### Examples Of Science Through Biography (Chapter 6)

#### QUOTE 1: WARTIME SECONDARY TEACHING (CHEMISTRY)

I was coping with physics and chemistry well enough while Mr Ryan was still teaching them. But Mr Ryan was due for retirement, an event which was hastened by an accident in the laboratory. He was showing how careful you had to be when handling potassium in the presence of water. Certainly, you had to be more careful than he was. The school's entire supply of potassium ignited at once. Wreathed by dense smoke and lit by garish flames, the stunned Mr Ryan looked like a superannuated Greek God in receipt of bad news. The smoke enveloped us all. Windows being thrown open, it jetted into what passed for a playground, where it hung around like some sinister leftover from a battle on the Somme. Shocked, scorched and gassed, Mr Ryan was carried away, never to return. (James, 1980).

#### QUOTE 3: PRIMARY SCIENCE IN AUSTRALIA

Once a week we were given a lesson called "Science". I liked this lesson because then we were allowed to stand round the table and you could push and shove and have fun.

Mr Tucker opened the cupboard containing some glass tubes, a spirit lamp, a bottle of mercury and a leather disc with a piece of string attached to the centre. He placed these things on the table and said, "Today we are concerned with the weight of air which is fourteen pounds to the square inch".

This didn't make sense to me but the fact that I was standing beside Maggie Mulligan made me wish to shine, so I proffered the information that my father had told me the fuller you are with air the lighter you are and you couldn't sink in the river. I thought this had some bearing on the subject but Mr Tucker slowly put the piece of leather back on the table then looked at me with his eyes, so that I could not face him and said through his teeth, "Marshall, I would have you know that we are not interested in your father or in any observation made by your father even if such observations proclaim the stupidity of his son. Would you please attend to the lesson".

He then wet the leather disc and pressed it on the desk and none of us could pull it off except Maggie Mulligan who ripped the guts out of it with one yank and proved air didn't weigh anything.

She told me when she was wheeling me home that what I said was right and that air weighed nothing. (Marshall, 1979)

#### QUOTE 4: A SCIENCE TEACHER'S RECOLLECTIONS

The only chemical event that I can recall from my preparatory school days was when Miss Aird (I think that was her name) gave us a piece of coke and some copper sulphate to take home. We were to dissolve the copper sulphate in water and suspend the coke in it from a piece of cotton. After a day or two beautiful blue crystals began to appear on the surface of the coke. This so impressed me that I am sure it gave rise to a lifelong interest in crystals.

(Van Praagh, 1988)

#### QUOTE 8: A CHEMIST'S REVENGE

A friend of mine, who taught chemistry under Jones (*A secondary school headmaster*) for years, used to get his own back in an original way. Jones was rather asthmatic. Whenever a large class of 30 or so would be preparing irritating gases (such as chlorine) in the laboratory, my friend would let the process go on until the place was saturated. He would then go to the

end of the long laboratory farthest from the door and send a message to the head master that he wished to speak to him. But Jones never managed to go farther than half way, for by that time he could not breathe, and had to go out again. (Jones, 1943)

QUOTE 10: THE BEGINNINGS OF SCIENCE FOR A RESEARCH SCIENTIST (FEMALE)

Just before all that took place I came across Chemistry for the first time. I went for a lesson or two while they were searching for a small PNEU governess' class where science was introduced, one science at a time in each of the terms. I was present for the beginning of Chemistry, growing crystals - copper sulphate and alum and was immediately captured. (Hodgkin, 1988)

QUOTE 12: THE GENIUS OF JAMES MAXWELL

The Scottish schoolmaster, Will Dalglish, was just about at the end of his tether in the country estate of Glenlair one day in 1840. He stood looking out through a window, across the moors and blue-hazed mountains of northern Scotland. But, at that moment, he had no eye for rustic beauty. On a blackboard, he had written a simple English sentence for the pale-faced, straw-haired boy he was tutoring. "Surely," he said, his voice dripping with sarcasm, "You know which of those words is a verb?"

"Nae," replied nine-year-old Jamie Clerk Maxwell.

"How about three times two?"

"I dinna ken that, either," said Jamie. "But wad ye look at this?" He rummaged in a cupboard for a box of tops, which he had painted in stripes of different colours. As the tops spun, the colours appeared to mingle and change - a simple scientific fact today, but a startling, unknown wonder 150 years ago.

Dalglish stared but couldn't explain the phenomenon, so he shrugged it off.

Young Maxwell then brought out a machine, which he had designed himself. An ingenious arrangement of mirrors revolved and the reflections in them appeared to move. "Is that nae wonderful?" he asked.

"It's nonsense," said Dalglish. "You're playing with toys. I'm trying to teach you something real."

The truth was that Jamie Maxwell's 'toys' were far beyond the teacher's ken. Though built by a child, they would one day be recognised as scientific marvels and the boy himself as Scotland's greatest scientific brain. (Anon, 1991)

QUOTE 13: A STUDENT'S MEMORIES OF MALAK, DARWIN.

In celebration of Malak School's Tenth Anniversary, the Editorial Committee interviewed members of the school community, past and present. They felt that everyone has vivid memories of their school life. Sometimes they are funny, sometimes sad, but everyone experiences them. Here is one of the contributions that they thought readers would enjoy.

'Something humorous that happened at Malak which I remember vividly was when my science teacher Mr Preswell attempted a science experiment about suction. He poured water into a large beaker till it was half full. He then covered the beaker with a piece of cardboard and turned it upside down. Amazingly the cardboard stayed suspended. To show how well this worked he held the beaker above his head but at the precise moment the cardboard gave way and the water gushed over Mr Preswell. He was saturated. My class couldn't stop laughing. (Godfrey, 1991) Student 1981-1986.

#### QUOTE 15: CHEMISTRY AT COURT

Received from S. Wayne Mascarella (By E - Mail)

"During a lecture by Justus Liebig before a selected audience in Munich he exhibited the strikingly beautiful combustion of carbon bisulfide in nitric oxide. The delight of the onlookers led him to repeat the demonstration. This time, to the great horror of all present, there was a terrific explosion, the flask was shattered into bits. Queen Therese, Prince-regent Luitpold, and Liebig himself were seriously wounded by the flying glass. The accident would have been fatal for Liebig if his snuff box had not prevented a large splinter of glass from penetrating his femoral artery."  
(Winderlich, 1950)

#### QUOTE 31: MEMORIES OF A BIOCHEMIST 1 (W. A. ENGELHARDT)

Perhaps the first signs of my inclination towards a scientific profession became perceptible at a fairly early stage. It so happened that during primary school my classmates, fond of giving nicknames, as probably all boys in the world do, honoured me with the title "Wolodya-Outcheny," which means scientist, Wolodya being the diminutive of Wladimir. This probably was due to my liking for playing around with all kinds of simple apparatus electric bells, primitive toys—and gadgets such as those that show the attraction of light objects to a rubbed haircomb or glass-rod, etc. I even recollect my first "invention:" a small test tube with a light bead of elder-marrow in it and two wires attached to the ends of the tube. I declared that this apparatus could serve as a "cunny-scope," showing the degree of cunning of a person, according to the displacement of the bead when the wires were applied to definite parts of the body. Needless to say that the effect was produced by dexterously rubbing one end of the tube with a piece of silk cloth by which the "apparatus" was held. Thus I started my scientific career as a quack. I hope that my later behaviour has amended this regrettable qualification.

The next landmark of my career was in the field of chemistry, in which I became interested in college. As every beginner I was attracted by the handling of explosive materials. Nitrogen iodide was the object of choice, for when dry it explodes when even slightly touched. I carried a piece, damp and therefore safe, the size of a wheat-corn, to enlighten my classmates. But I dropped the damned stuff near the teacher's pulpit during the lesson on orthodox religion. At the very end of the lesson, the boy in charge of pronouncing the closing prayer stepped on the ill-fated piece, producing no harm but great noise.

It was a period when attempts on the life of tzars and members of the royal family were fashionable, so the priest who gave us the lesson rushed out of the classroom to the headmaster's study shouting: "an attempt has been made on my life . . ."

Engelhardt, W. A. 1990

#### QUOTE 56: AN INDELIBLE MEMORY OF AN EXOTHERMIC REACTION

And F. J. Moorhouse remembers the following:

Teacher: "Now, boys, we are about to demonstrate an exothermic reaction." (Writes on blackboard.)

Boys: "Yes, sir."

Teacher "We take a piece of calcium hydroxide in a pair of tongs and hold it over a bunsen burner until it glows. We then leave it to cool." (Boys do as they're told, then scribble notes while the substance cools.)

Teacher: "We now have calcium oxide. Put a largish piece in the palm of your hand and allow water to drip from the tap onto it" (Boys do so.)

Teacher: "This is called . . ."

Boys: "Aaaaagh!"

Teacher: "... an exothermic reaction. If any of you had kept the piece of material in your hands, you would have seen the reconstituted calcium hydroxide." The resulting blister lasted several days, Moorhouse says, leaving the boys with an indelible memory of what an exothermic reaction was.  
(Feedback 1995)

## APPENDIX 6

### Hypercard example (Chapter 7)

## Bibliography 4 Card 3

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Author:

Date:  Publisher:

Book:  Country of Pub:

	Page	No of lines	Name used	Example	Sep/Tog
Physical	2-3	--	Physical change	Melting wax	<input type="checkbox"/>
Chemical	2-3	--	Chemical	Burning candle wax	<input checked="" type="checkbox"/>

	Text on Phys	Rev	Energy	Wt loss	Atom/Mole
	<input type="text" value="QUOTE: Most raw materials consist of"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	<input type="text" value="NEW SUBSTANCE"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Area of Science:  level:

## APPENDIX 7

### Listing of 527 Hypercard cards were used in the initial analysis (Chapter 7)

1. Accum, F. C. (1824). *An explanatory dictionary of chemical and philosophical apparatus and instruments*. London: Thomas Boys. (U.K.)
2. Addicoat, R. R. (1967). *Basic chemistry and physics*. Melbourne: Hall's Book Store Pty Ltd Australia. (Australia)
3. Ainley, D., Lazonby, J. N. & Masson, A. J. (1987). *Chemistry in today's world* (2nd edition). London: Bell and Hyman Ltd. (U.K.)
4. Alder Wright, C. R. (1891). *The threshold of science*. London: Charles Griffin and Company. (U.K.)
5. Allan, A.D., Page, J.A., Bonneyman, K. R. & Talesnick, I. (1967). *Chemistry: an introductory study*. Toronto, Canada: W.G. Gage Ltd. (Canada)
6. Allan, E. R. & Harris, J. H. (1978). *'H' Grade chemistry: essential facts and theory*. London: Edward Arnold (Publishers) Ltd. (U.K.)
7. Ander, P. and Sonessa, A. J. (1965). *Principles of chemistry: An introduction to theoretical concepts*. New York: The Macmillan Company. (U.S.A.)
8. Anderson, C. B., Ford, P. C. & Kennedy, J. H. (1973). *Chemistry: principles and applications*. Lexington, Massachusetts: D. Heath and Co. (U.S.A.)
9. Anderson, J. H. (1886) *The public school chemistry, being at once a syllabus for the master and an abstract for the boy*. London: Cassell & Co. (U.K.)
10. Anderton, J.D. (editor) (1981). *Fundamental science* (Book 1). Melbourne: Longman Cheshire. (Australia)
11. Anderton, J. D., Garnett, P. J., Liddelow, W. R., Lowe, R. K. and Manno, I. J. (1985). *Foundations of chemistry*. Melbourne: Longman Cheshire. (U.K.)
12. Andrade, E. N. de C. & Huxley, J. (1934). *Simple science*. Oxford: Basil Blackwell. (U.K.)
13. Andrews, D. H. & Kokes, R. J. (1965). *Fundamental chemistry*. New York: John Wiley & Sons, Inc. (U.S.A.)
14. Andrews, D.H. (1974). *Chemistry: a humanistic view*. New York and London: McGraw -Hill Book Co. (U.S.A.)
15. Anon (1944). *Chemistry for intermediate classes*. Sydney and London: Angus and Robertson. (Australia)
16. Anon 1964 *Chemical systems* (CBA Project). St Louis, New York, etc.: McGraw-Hill Book Co. (Webster Division). (U.S.A.)
17. Anon. (1932). *Chemistry of intermediate classes*. Sydney and London: Angus and Robertson. (Australia)
18. Anstee, S. A., MacMahon, C. F., Passmore, B. V. & Poulter, R. S. (1964). *Science through experiment* (Year 1). Brisbane: The Jacaranda Press. (Australia)
19. Ardley, N. (1984). *Simple chemistry*. London: Franklin Watts Ltd. (U.K.)
20. Arkless, S. M., Davies, N., Evans, D. E. J. and Hambleton, D. I. (1976). *Combined science worksheets* (Year 2). Exeter: Wheaton. (U.K.)
21. Arnold, C. (translated by Mandel, J. A.) (1904) *A compendium of chemistry*. New York and London: John Wiley and Sons. (U.S.A.)
22. Ashcroft, K. (1974). *Action chemistry*. Agincourt, Canada: The Book Society of Canada Ltd. (Canada)
23. Atherton, M. A. and Lawrence, J. K. (1986). *Chemistry for the Caribbean: A CXC course*. London: John Murray. (West Indies).
24. Atkins, P. W. (1989). *General chemistry*. New York: Scientific American Book. (U.S.A.)
25. Atkinson, A. 1974 (3rd Ed.) *Certificate chemistry*. London: Longman Group Ltd. (U.K.)
26. Attfield, J. (1898). *Chemistry: general, medical and pharmaceutical including a manual*. London: Gurney and Jackson. (U.K.)
27. Attfield, J. (1898). *Chemistry: general, medical and pharmaceutical including the chemistry of the British Pharmacopoeia*. London: John Van Voorst. (U.K.)
28. Aveling, E. (1889). *Mechanics and experimental science*. London: Chapman and Hall Limited. (U.K.)
29. Bailar, J. C., Moeller, T., Kleinberg, J., Guss, C. O., Castellion, M. E. & Metz, C. (1987). *Chemistry*. San Diego: Harcourt, Brace Jovanovich and its subsidiary Academic Press. (U.S.A.)

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31. Bailey, G.H. & Briggs, W. (1896). *The tutorial chemistry - part 1: non-metals*. London: University Correspondence College Press. (U.K.).
32. Bailey, G. P., Dombroski, J. W., Dombroski, P. J., & Fielding, A. J. (1966). *Science and man: Form I*. Sydney and Brisbane: William Brooks & Co Ltd.(Australia).
33. Bailey, J. and Seddon, T. (1987). *The young scientist's guide to the physical world*. Oxford: Oxford University Press. (U.K.).
34. Bajah, S. T. & Godman, A. (1984). *Chemistry: a new certificate approach* (IUPAC edition). Harlow, Essex: Heinemann. (Nigeria).
35. Baker, J. (1838) *An epitome of chemistry in a course of seventeen lectures, illustrated by a series of 500 experiments*. London: W. Harrison. (U.K.).
36. Baker, J. J. W. & Allen, G. E. (1965). *Matter, energy and life*. Reading, Massachusetts: Addison-Wesley Publishing Co. (U.S.A.)
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## APPENDIX 8

### Summary of the results of studies, providing common alternative conceptions held by students in recent years about physical and chemical change (Chapter 8)

**STUDY 1** Anderson & Renstrom (1982). In this experiment steel wool was burned whilst on a balance. The researchers asked 593 pupils to describe what they had seen. The answers were a mixture of observations and explanations. Anderson and Renstrom (1982) divide the material into five categories which are : no explanation: expressions indicating that the steel wool became lighter: explanations of a physical nature: explanations of a chemical nature: other. This is a limited set of criteria, but is comparatively simple.

**STUDY 2** Schollum (1982) notes the following misconceptions about chemical change in his study (Quoted Anderson, 1984)

- The conglomerate conception. All the substances that react collect together like needles to a magnet
- The conception of "favourable circumstances" (or Bear in a cave). The products of chemical reactions have been there all the time, though hidden, but when conditions are right they appear.
- Magic: Anything can happen in chemistry

**STUDY 3** Briggs & Holding (1986) (Quoted from Griffiths, 1994.) noted that the students' ideas were often difficult to assess as they had not been asked specifically to provide their reasoning. However, the following unacceptable ideas were noted:

- Mass is not conserved in a chemical reaction.
- Melting is evidence of a chemical change.
- Expansion of a substance on heating is evidence of a chemical change
- Change of colour is evidence of a chemical change.
- Change in the form a substance is evidence of a chemical change.
- When elements combine to form a particular compound, they may do so in different proportions.

**STUDY 4** Hesse & Anderson (1992) Three 'misconceptions' were inferred from the discussion in a paper (Quoted from Griffiths, 1994.)

- Conservation of matter applies to solids and liquids, but may be ignored for gaseous reactants and products.
- It is not necessary to compare the combined mass of all reactants with that of all products when considering conservation of matter.
- The characteristics which represent a change as physical are also appropriate when considering chemical change.

**STUDY 5** Anderson (1991) and Pfundt (1981) in separate papers came to the following conclusions about common misconceptions on physical and chemical change (Quoted Driver et al, p.86 1994.).

- no conception other than 'it just happens like that: matter just disappears: when petrol is used as a fuel 'it just vanishes';
- product materials, though unseen, must somehow be contained in the starting materials (for example, some think that the water which results from the distillation of wood must already have existed as such in wood);
- the product material is just a modified form of the starting material: 'as the alcohol burns it turns into alcohol vapour';
- the starting material undergoes transmutation to the product material: 'the steel wool that burnt has turned into carbon';

starting materials interact and form a different product: 'oxygen reacts with copper and forms copper oxide'.

**STUDY 6** Griffiths (1994) examined a number of the earlier papers and put together the conclusions that they had reached. The resultant is the following list of 18 misconceptions relating to physical and chemical change.

1. Changes involving natural phenomena are physical, while changes involving artificial phenomena are chemical.
2. When matter changes in appearance a chemical change is involved.
3. When one substance is added to another any observed change is chemical, whereas if only one substance is involved any observed change is physical.
4. Changes which can be reversed are physical changes, whereas changes which cannot be reversed are chemical changes.
5. Conservation of matter applies to solids and liquids, but may be ignored for gaseous reactants and products.
6. It is not necessary to compare the combined mass of all reactants with that of all products when considering conservation of matter.
7. The characteristics which represent a change as physical are also appropriate when considering chemical change.
8. Mass is not conserved in a chemical reaction.
9. Melting is evidence of a chemical change.
10. Expansion of a substance on heating is evidence of a chemical change.
11. Change in the form of a substance is evidence of a chemical change.
12. Change of colour is evidence of a chemical change.
13. When elements combine to form a particular compound they may do so in different proportions.
14. Matter may be destroyed in a chemical reaction.
15. Substances can change their properties, and still retain their identity.
16. Boiling and dissolving are chemical changes.
17. Reaction products are hidden in a substance, and emerge when conditions are right.
18. Reactions can occur by magic ...anything can happen once chemicals set each other off.

**REFERENCES FOR SUMMARIES ABOVE.**

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## APPENDIX 9

Practical Laboratory manuals collected, displayed in chronological order, including the names of students who owned them  
(Chapter 8)

### Chemistry

1. 1817 Henry, W. *The elements of experimental chemistry to which are added notes by John Redman Coxe* (Fourth American from the seventh London edition). Philadelphia: James Webster.
2. 1869 Odling, W. *A course of practical chemistry, arranged for the use of medical student* (fourth edition). London: Longmans, Green and Co.
3. 1878 Appleton, J. H. *The Young Chemist: a book of laboratory work for beginners*. Philadelphia.
4. 1885 Ripper, W. *Practical chemistry with notes and questions on theoretical chemistry adapted to the revised syllabus of the Science and Art Department for the elementary stage of inorganic chemistry*. London: Wm. Ibister, Limited.
5. 1886 French, N. *Experiment blanks for a short course in elementary chemistry* (Student: Anon 1). Boston: M. T. Rodgers & Co. (photocopy).
6. 1887 (1E 1871) Stockhardt, J. A. & Heaton, C. W. *Experimental chemistry: A handbook for the study of the science by simple experiments*. London : George Bell & Sons.
7. 1893 Coleman, J. B. & Addyman, F. T. *Practical agricultural chemistry for elementary students*. London: Longmans, Green & Co.
8. 1896 Stevens, F. L. *The Columbus chemistry note book*, (Columbus North High School, copyright by F.L. Stevens, 1895). (Student: Carrie Southard, Junior at Columbus North High School, Columbus, Ohio in 1896).
9. 1896a Williams, R. P. *Laboratory manual of general chemistry* (Student Alta Lemmon). Boston: Ginn & Company, Publishers.
10. 1896b Williams, R. P. *Laboratory manual of inorganic chemistry* (Student Eric Austin). Boston: Ginn & Company, Publishers.
11. 1902 Dennis, L. M. & Clark, F. W. *Laboratory manual to accompany Clark and Dennis's elementary chemistry* (Student Ralph C. Zindel). New York, Cincinnati, Chicago: American Book Company.
12. 1902 Dennis, L. M. & Clark, F. W. *Laboratory manual to accompany Clark and Dennis's elementary chemistry* (Student A. B. Nilliv). New York, Cincinnati, Chicago: American Book Company.
13. 1902 Hessler, J. C. & Smith, A. L. *Essentials of chemistry* (with laboratory manual). Boston: Benj. H. Sanborn & Co.
14. 1903 Tilden, W. A. *Practical chemistry: the principles of qualitative analysis*. London: Longmans, Green & Co.
15. 1905 Remsen, I. *A laboratory manual containing directions for a course of experiments in general chemistry, systematically arranged to accompany the author's "Elements of chemistry"* (Student: Alex W. Spears). New York: Henry Holt & Co.
16. 1910 Roe, J. N. *Practical chemistry* (Student: Anon 1). Valparaiso: M.E. Bogarte Book Co..



- 17 1912 Blanchard, J. M. *Household chemistry for girls: a laboratory guide*. New York: Allyn and Bacon.
- 18 1913-1914- *Junior chemistry* (Notes by student: Lillian Abra Rhodes)
- 19 1915 McPherson, W & Henderson, W. E. *Laboratory manual arranged to accompany "A Course In General Chemistry"* (First edition). New York: Ginn and Company.
- 20 1916 Morgan, W. C. & Lyman, J. A. *A laboratory manual in chemistry*. New York: The MacMillan Company.
- 21 1916 Newell, L. C. *Laboratory manual of inorganic chemistry for colleges*. Boston, Mass: D.C. Heath & Co.
- 22 1917 Brownlee, R. B., Fuller, R. W., Hancock, W. J., Sohon, M. D. & Whitsit, J. *Laboratory exercises to accompany "First Principles of Chemistry"* (Student: Mary Kagled) New York: Allyn & Bacon.
- 23 1917 Brownlee, R. B., Fuller, R. W., Hancock, W. J., Sohon, M. D. & Whitsit, J. *Laboratory exercises to accompany "First Principles of Chemistry"* (Student: Ronald Elden Williamson) New York: Allyn & Bacon.
- 24 1918 Hale, W. J. *A laboratory manual of general chemistry*. New York: The MacMillan Company.
- 25 1920?? (n.d.) Rudman, R. E. *A manual of home science*. Auckland, New Zealand: Whitcombe & Tombs Limited.
- 26 1921 Brownlee, R. B., Fuller, R. W., Hancock, W. J., Sohon, M. D. & Whitsit, J. *Laboratory exercises to accompany "First Principles of Chemistry"* (Student: Virginia Nutman) New York: Allyn & Bacon.\*
- 27 1921 Brownlee, R. B., Fuller, R. W., Hancock, W. J., Sohon, M. D. & Whitsit, J. *Laboratory exercises to accompany "Elementary Principles of Chemistry"* (Student: C. C. Wilson) (Ring bound sheets) New York: Allyn & Bacon.
- 28 1921 Jones, Mary, E. *A laboratory study of household chemistry*. New York: Allyn and Bacon.
- 29 1921 McPherson, W. & Henderson, W. E. *Laboratory manual arranged to accompany the second edition of "A Course in General Chemistry"* (Student: E. S. George). Boston, Mass: Ginn & Co.
- 30 1922 Holmes, H. N. *Laboratory manual of general chemistry* (Student: J. C. Watkins). New York: The Macmillan Company.
- 31 1928 Brinkley, S. R., & Kelsey E. B. *Laboratory manual: arranged to accompany "Principles of General Chemistry"*. New York: The Macmillan Company.
- 32 1928 Walton, J. H. & Krauskopf, F. C. *A laboratory manual of general chemistry* (Student: Anthony Hellman). Menasha, Wisconsin: Collegiate Press, George Banta Publishing.
- 33 1929 Kendall, J. *A laboratory outline of Smith's college chemistry* (Revised edition) (Student: John F. Higginson). New York: The Century Co..\*
- 34 1932 Rosenholtz, J. L. *Applied chemistry for nurses with laboratory experiments* (Student: Anna L. Ficerchia). Philadelphia and London: W. B. Saunders Company.\*
- 35 1934 Bennett, H. *Practical Everyday Chemistry*. New York: The Chemical Publishing Co. of New York.\*

- 36 1935 Bigelow, H. E. & Morehouse, F. G. *Dominion chemistry manual to accompany Dominion High School chemistry*. Toronto: The Macmillan Company of Canada Limited.
- 37 1932 Richardson, K. B. & Scarlett, A. S. *A laboratory manual of general chemistry* (larger edition, revised) (Student: Sara Twigg).. New York: Henry Holt & Co.\*
- 38 1936 Black, N. H. *New laboratory experiments in practical chemistry to accompany Black and Conant's "New Practical Chemistry"* (Student: Francis Brown). New York: The Macmillan Company.\*
- 39 1942 Davidheiser, L. Y.(Editor) *Lionel Chem-lab manual of experiments*. New York: The Lionel Corporation.

#### **Physics, geology and general science**

- 1 1923 Brown, S. E. *Experimental science- I Physics*. Cambridge: at the University Press.\*
- 2 1943 White, M. W., Manning, K. V., Weber, R. L. and Cornett, R. O. *Practical Physics*. New York and London: McGraw-Hill Book Company.\*
- 3 1964, Tyler, F., *A laboratory manual of physics*. London :Edward Arnold.
- 4 1969 Brice, J. C. & Levin, H. L. *Laboratory studies in earth history* (Student: G. Tompkins). Dubuque, Iowa. Wm. C Brown Company Publishers.\*
- 5 1921 Elhuff, L. *New laboratory manual: a book of projects for general science*. New York: D. C. Heath & Co., Publishers.
- 6 1922 McKay, H. *Easy experiments in elementary science*. London: Oxford University Press.

The last six laboratory manuals on physics, geology and general science were included to see if there were any general observations linking these books to the chemistry laboratory manuals, but no strong relationships were observed.

## APPENDIX 10

### A preliminary analysis of some chemical laboratory manuals (Chapter 8)

Manual number or notes	Date	Level School/ University	Percentage written	Expt on P/CC included and written	Expt on mixt/ comp include- ed/ written	Further analysis possible
1 *	1817	Univrsty	0%	No	No	No
2*	1869	Univrsty #	0%	No	No	No
3*	1878	School	0%	No	Yes	No
4 *	1885	School	20% Advnd	No	Yes (Defn)	No
5 Notes +	1886	School	60%	No. chemical action there	No Yes	Yes
6 *	1887	Univrsty	0%	No		No
7 *	1893	School #	0%	No	No	No
8- Notes +	1896	School	100%	Yes Yes	Yes Yes	Yes
9 +	1896	School	30%	Yes Yes	Yes Yes	Yes
10 +	1896	School	80%	Yes Yes	Yes No	Yes
11 +	1902	School	25%	Yes Yes	Yes Yes	Yes
12 +	1902	School	60%	Yes Yes	Yes Yes	Yes
13 -	1902	School	0%	No	No	No
14	1903	Univrsty	0%	No	No	No
15 +	1905	School	0%	Yes No	Yes No	No
16+	1910	School	40%	Yes Yes	Yes Y	Yes
17 #	1912	School	2%	Yes No	No	No
18 Notes	1915	School	100%	- Yes	- Yes	Yes
19+	1916	School	20%	Yes No	Yes No	No
20	1916	School	2%	Yes No	Yes No	No
21	1916	School	0%	No	No	No
22 +	1917	School	40%	Yes Yes	No	Yes
23 +	1917	School	20%	Yes Yes	No	Yes
24	1918	Schl/ Uni	10%	No	No	No
25	1920	School	2%	Yes-No	No	No
26 +	1921	School	10%	Yes Yes	No	Yes
27 +	1921	School	30%	Yes Yes	No	Yes
28 #	1921	School	0%	Yes No	No	No
29 +	1921	School	10%	Yes Yes	Yes No	Yes
30 +	1922	School	10%	Yes No	Yes No	No
31 +	1928	School	0%	Yes No	Yes No	No
32	1928	School	30%	No	Yes Yes	Yes
33+	1929	Schl/ Uni	30%	No No	Yes No	No
34 # + -	1932	Schl/ Uni	10%	No No	Yes Yes	Yes
35+	1932	School	5%	Yes No	No	No
36~	1935	School	0%	No	No	No
37	1935	School	2%	Yes No	Yes No	No
38	1936	School	0%	No	Yes No	No
39	1942	School	0%	Yes No	Yes No	No

Advnd= Written notes on advanced work. # = Special groups e.g. medical/ household/ agricultural/ girls.

• = Practical and theoretical chemistry mixed together.

• + = Manual constructed with blank pages or spaces for answers.

= Book constructed with text book and laboratory manual as a single book.

~ = Reference work.

## APPENDIX 11A

Table of misconceptions: physical and chemical changes  
(Chapter 8)

Manual number	Student name	Observation	Explanation physical	Explanation chemical	Other
5	Anon 1	None	-	-	-
8	Carrie Southard	Correct observations	Correct applies defn	Correct applies defn	-
9	Alta Lemmon	Correct observations	Does not apply defn	Correct applies defn; Errors	-
10	Eric Austin	Correct observations	Applied defn incorrectly	Applied defn incorrectly	
11	Ralph C. Zindel	Correct observations	Correct applies defn	Correct applies defn but error	Four expts here. One is dubious
12	A. B. Nilliv	Correct observations	Correct applies defn	Correct applies defn	Four expts here. One is dubious
16	Anon 2	Correct observations	Correct applies defn	Correct applies defn	Two expts here.
18	Lillian Abra Rhodes	Correct observations	Correct applies defn	Correct applies defn	Three expts here.
22	Mary Kagled	Correct observations	NA	Correct applies defn	
23	Ronald Elden Williamson	Correct observations	NA	Correct applies defn	
26	Virginia Nutman	Mainly correct observations	Omitted	Omitted	
27	C. C. Wilson	Correct observations	NA	Correct applies defn	
29	E. S. George	None	-	-	
32	Anthony Hellman	None	-	-	
34	Anna L Ficerchia	Expt 3 Correct observations. Expt 3 Wrong observations.	Does not apply defn	Does not apply defn	

## APPENDIX 11B

Table of misconceptions: mixtures and compounds  
(Chapter 8)

Manual number	Student name	Observation	Explanation mixture	Explanation compound	Other
5	Anon 1	Correct observations	Correct Applies defn	Corect applies defn	-
8	Carrie Southard	Correct observations	Correct Applies defn	Misconception apparent	-
9	Alta Lemmon	Correct observations	Not asked to explain. error	chemical change	-
11	Ralph C. Zindel	Correct observations	Question really on	chemical change	
12	A. B. Nilliv	Correct observations	Question really on	chemical change	
16	Anon 2	p.15 Correct observations	No conclusion	No conclusion	
18	Lillian Abra Rhodes	Correct observations	Correct Applies defn	Corect applies defn	
32	Anthony Hellman	Correct observations	Correct Applies defn	Corect applies defn	
34	Anna L Ficerchia	Mainly Correct observations	Correct Applies defn	Very muddled Misconception apparent	

## APPENDIX 12

### The questionnaire (Chapter 9)

#### PHYSICAL AND CHEMICAL CHANGE: AN INFORMATION SHEET

This sheet and the questions that follow is for colleagues who are:-

University academics who are lecturing in University Science /Engineering Faculties in chemistry, physics or other science disciplines.

Science educators who are lecturing in University Faculties of Education or Teachers' Colleges.

Science teachers who are teaching primary or secondary science.

Historians of Science/ Chemistry

Authors of science text books.

Or Scientists who combine more than one of the above roles

Those being interviewed are people, who have expert knowledge in all or part of this area.

#### INTRODUCTION

This information sheet is intended to provide the reader with background information without attempting to influence respondents. I intend to ask respondents questions verbally and record the answers. Alternatively where distance prevents this approach, I will simply ask colleagues to reply in the form of a letter on those areas that interest them. This method should provide significant information in the form of opinion, anecdote and fact about the concept of “physical and chemical change”, which is a small part of the science curriculum. Prior to conducting this interview, I have already carried out research in the area; so in the interviews I will try using supplementary questions to keep the interviews from retracing old ground.

Questions relate to opinion, experience and anecdote. Question topics relate to the areas entitled General, History, Personal History, Definition, Teaching, Broader aspects about teaching, Section for textbook authors.

The questions are completely open ended, so if you have other information about “physical and chemical change” that I have not asked, please feel free to include the point in the discussion or the letter to express your views. I will feel free to use views expressed as a part of my thesis and to summarise and categorise such views in groupings. However the data is qualitative rather than quantitative, so I do not expect to come to specific conclusions, rather I expect there to be a range of views, which should indicate what professional opinion is on the topic.

I will nonetheless be interested in some overall view of whether the concept of physical and chemical change has a future in the teaching of science or whether it should be abandoned without further delay. I am also seeking a personal reflective and even anecdotal style of response as I believe that my thesis relates to factors additional to pure science. Whether responding by interview or letter please feel free not to answer questions in a whole area or individual questions.

#### INFORMATION ABOUT PHYSICAL AND CHEMICAL CHANGE.: SECTION A. A COMPARISON OF PHYSICAL AND CHEMICAL CHANGES - A TRADITIONAL WAY OF TEACHING.

The table below may have formed the basis of a typical introductory lesson in chemistry some years ago. The teacher would have put the heading “physical and chemical change” on the black-board and would have completed the table as follows:

PHYSICAL CHANGE	CHEMICAL CHANGE
No substance formed or destroyed	Substances changed-new substances formed
No change in weight	Change in weight
Reverse change easy	Reverse change difficult
No energy produced although energy may be changed from one form to another	Energy in the form of light or heat may be given out as a result of chemical change

The pupils would have copied down the heading and the table. The teacher may well have boiled some water, melted some ice, or torn up some paper into little pieces, as examples of physical change. As examples of chemical change the teacher may have burnt some paper, struck a match, heated iron filings and sulphur, or ignited some magnesium. Each of the criteria would be carefully looked at, with a more thorough teacher actually weighing the products and reactants of each reaction. There might well have been some class discussion to elicit further examples. The teacher would have given more explanation, which might be summarised on the board as further notes. The teacher would round off by setting some examples from the textbook and return to the staffroom satisfied that the pupils had received a thorough grounding in the important concept of physical and chemical change. I will ask for comments on this approach.

#### SECTION B. AN OPINION ABOUT PHYSICAL AND CHEMICAL CHANGE

The reaction of a practicing chemist from the United Kingdom (Satchell, 1982) when he learnt that his son was being taught in the way described above was to write the following.

"My son recently showed me his O - level chemistry textbook. He finds some of its introductory statements and definitions confusing. The book certainly surprised me. The early sections contain statements that are woolly or wrong by present day standards; indeed, wrong in terms of facts given later in the book. Some difficulties arise because the authors introduce chemistry by distinguishing between chemical and physical processes..... It is only after these topics have been covered that sections dealing with atoms and molecules are given. ....

.....Another example of needless early inaccuracy concerns the distinctions made between physical and chemical changes. For chemical changes we learn that:

- (i) A new kind of matter is always formed.
- (ii) the change is not easily reversed.
- (iii) a large heat change is usual.
- (iv) the products have different masses from the reactants.

The opposite situations are said to apply to physical changes. These criteria do not bear serious examination! Why bother with them in books at this level? The properties of substances and the various processes relevant to Chemistry can be fully treated without labelling them physical and chemical."

Satchell's complaints aroused considerable controversy and convinced me that there is interesting and worthwhile information to be obtained from the views of people who use chemistry differently in their daily lives such as those currently being surveyed.

In searching through science/chemical journals I have found about 3 other instances of very strong opinions being expressed about physical and chemical change. This makes me believe that there are reasons other than scientific reasons for the use of the concept of "physical and chemical change"

#### REFERENCES

Satchell, D.P.N. (1982). Beginning O- Level chemistry, Chemistry in Britain, March, p.161

#### SECTION C. ALTERNATIVE HYPOTHESES

(This section will be needed in answering question 10)

I put forward four possible alternative hypotheses to explain the longevity of the concept. 'Physical and chemical change' may have remained in school science/chemistry curricula because:

(1) The concept is a remainder of an 'Aristotelian' theory of matter, kept by the natural conservatism of scientists.

(2) The opposition of 'physical and chemical change' in textbooks is a pedagogical device, so that it is easier for students to learn related concepts.

(3) The concept is often illustrated by a number of exciting and interesting experiments that appeal to those teachers who see themselves as being practically orientated.

(4) The concept is a device used by chemists to define the boundary between chemistry and physics to the advantage of chemistry, so that young people will tend to choose chemistry as a subject to study rather than physics.

#### SECTION D. EXPLANATION OF MACRO/MICRO PHENOMENA

(This section relates to question 32)

The problem was stated by the authors of the Chemical Bond Approach Project (CBA, 1964) who carefully explain how the different opinions, that people express on this topic, can be reconciled.

"In chemical change the reactants and products contain the same atoms but differ in the pattern in which the atoms are arranged. The definition of a chemical change in terms of atomic theory differs from the earlier operational definition of chemical change in terms of observable properties.

Such a conceptual definition tells you what to think about rather than what to do. Chemical change may thus be given either an operational or a conceptual definition. These two definitions suggest that changes in properties are associated with changes in arrangement of atoms. It is important to note that the two kinds of definitions will sometimes refer to a given change in the same way and sometimes not. When liquid water changed to steam, the operational definition labelled this as a physical rather than a chemical change. Comparison of the arrangement of the molecules in liquid water suggests that at least this physical change does not differ in principle from the changes ordinarily called chemical."

#### REFERENCE.

CBA (1964). Chemical systems (Chemical Bond Approach Project), St Louis, McGraw-Hill Book Company.



## INTERVIEW PROTOCOL OR BASIS FOR WRITTEN RESPONSE

STATE the name of the person being interviewed, the time and date and place

### GENERAL QUESTIONS

1. What is your highest qualification ?
2. Are you a trained teacher?
3. Where do or did you work?
4. Which broad area of chemistry/physics/other is your main teaching and research area? eg inorganic chemistry.
5. Would you class yourself as an experimental or a theoretical scientist(in as far as these broad definitions are meaningful)?
6. If you are a science educator, which of the sciences are most interested in teaching?

### HISTORY SECTION

7. Would you associate the name of any particular scientist with the concept of physical and chemical change in the same sort of way that you might associate Darwin's name with evolutionary theory?
8. (i) Are you broadly sympathetic with the idea of using historical material in the teaching of school chemistry?(ii) Or should teachers concentrate on teaching the facts and principles of chemistry divorced from their historical context?
9. Do you have any view about the gradual change in the usage of the words "cohesion and chemical affinity" in the first half of the nineteenth century gradually changing to the words "physical and chemical change" in the latter part of the nineteenth century. Views about reasons for this change, people or events that may have influenced the change or precise timing would be helpful. My research is currently showing differences between France, UK, and USA. I would be interested in comments.
10. Do you consider that any of the four hypotheses (Section C in the information sheet) account for either the origins or the longevity of the concept of "physical and chemical change"?

### PERSONAL HISTORY: LOOKING BACK WHILST YOU WERE A STUDENT AT SCHOOL.

I realise that your own school days may be some time ago, but I feel that taken over a large group of people, details of personal experience can give valuable insights into what parts of school science, if any, influence people's lives

11. Looking back on your own school science generally can you recount the most memorable lesson that you remember? (It may have been humorous/sad/ enjoyable/exciting etc).
12. Can you recollect the topic of physical and chemical change being taught at school for the first time? Please give an account of your recollections. In particular can you remember any lesson about physical and chemical change that was humorous, sad, enjoyable or exciting
13. Can you remember if any particular teacher or scientific topic interested you enough to help you decide to choose science as a career.
14. Do you think that the concept the topic of physical and chemical change is of any value in thinking about the major world issues that relate to science generally and to chemistry, in particular? Issues like greenhouse effect, lead in petrol, the ozone layer etc). Please give an account of how you believe that the concept of physical and chemical change has influenced your thinking?

### CLARIFICATION OF THE DEFINITION OF PHYSICAL AND CHEMICAL CHANGE

15. In your view is the definition of physical and chemical change (as indicated in the first part of the paper) a clear definition scientifically? If your answer is NO, please indicate how you would improve the definition of physical and chemical change.

16. Let us now look at the stated criteria as found in school textbooks for physical and chemical change as shown in Table 1, and consider them one at a time. Are there scientific, logical/practical or pedagogic problems with each part of the definition?

17. Can you summarise the scientific, logical / practical or pedagogic problems with the joint definitions of physical and chemical change taken as a whole?

18. Can you give any practical examples of changes that cause difficulties in the classification of physical and chemical change?

19. Do you consider it necessary to oppose the words "physical and chemical" in contexts other than "physical and chemical" change? eg "physical and chemical" properties in chemistry or "physical and chemical" weathering in geology. If so, how would you define "physical and chemical" without using the concept of physical and chemical change.

#### THE TEACHING OF PHYSICAL AND CHEMICAL CHANGE IN SCHOOLS

20. Do you think that the topic of physical and chemical change should be taught in schools at all? If you think that the topic of physical and chemical change should be taught in schools, at what grade levels should it be taught?

21. If you think that the topic of physical and chemical change should be taught in schools, please indicate how you think it might be taught ?

22. Should the way that physical and chemical change is taught in schools be in line with the idea of a spiral curriculum? (That means teaching important curriculum topics more than once at increasingly sophisticated levels of understanding)

23. I do not think that anyone suggests that teaching chemical reactions and change of state should be eliminated from the curriculum. Some people do object to physical and chemical change being taught in opposition to one another as in the table on p.2? Do you consider that these topics should be taught separately, perhaps giving examples of chemical reactions in one part of the syllabus and an explanation of change of state in another part of the syllabus or that they should be taught in opposition to each other?

24. From your experience, do you think that students generally find the concept of physical and chemical change easy or difficult to understand?

25. If students are taught the topic of physical and chemical change in a fairly traditional way, do you think that they should be able to categorise changes into those that are physical changes and those that are chemical changes with a reasonable degree of accuracy? Is it a useful skill for them to have? Are there any particular changes that give you consider might give students difficulty in categorising correctly?

26. In the science/ chemistry curriculum at a school what related topics should be taught before physical and chemical change and what topics should be taught after physical and chemical change?

27. Should students do any practical work themselves when they are taught about physical and chemical change? If so please mention some suitable experiments.

28. Should students observe any demonstrations when they are taught about physical and chemical change? If so please suggest some demonstrations.

29. Do you know of any films, slides, videos or other teaching aids that are relevant when students are taught about physical and chemical change? If so please give details.

30 Do you think that the teaching of physical and chemical change should be related to any particular relevant application, everyday use or ethical problem? If so please give details.

31. Satchell (1982) made some comments about the teaching of physical and chemical change at a junior secondary level. Do you agree/ disagree with Satchell? Why?  
"These criteria do not bear serious examination! Why bother with them in books at this level? The properties of substances and the various processes relevant to Chemistry can be fully treated without labelling them physical and chemical."

32. Sometimes we consider matter in terms of its 'bulk properties' (a macro scale approach), whereas on other occasions we consider matter in terms of the individual atoms or molecules (a micro scale approach) that make it up. When we consider changes on a macro scale we may consider them to be one sort of change; when we consider them on a micro scale we may consider them to be another sort of change. ( A fuller explanation in Section D of the information sheet)

Do you have any further comment on this explanation?

#### MORE PEDAGOGY AND BOUNDARIES BETWEEN PHYSICS AND CHEMISTRY

I was able to find evidence that some researchers who interpret their data as stating that the concept of physical and chemical change should not be taught to children below the age of eleven and I was able to find evidence contrary evidence that the first UK National curriculum recommends that the concept of physical and chemical change should be taught to children at about the age of six years.

32. What are your views as to the age when students should be taught the concept of physical and chemical change and why?

33 An objection to teaching physical and chemical change has been that it would interfere with students understanding of thermodynamics at a later stage. this view was expressed by Nyhom & Halliwell in the planning of Nuffield Chemistry. Do you agree or disagree with this view?

34 Do you consider that in boundaries between the separate sciences (and in this instance the boundary between chemistry and physics) should be clearly spelt out to students at a junior high school level. Alternatively do you feel that this hinders the integration of the sciences?

35 Do you consider that teaching the concept of physical and chemical change helps to clarify the boundary between chemistry and physics?

36 In your view, is one of the reasons that chemists and physicists continue teaching the concept of physical and chemical change is that they believe that it helps to clarify the boundary between chemistry and physics for junior high school students?

37. In your view is one of the reasons that chemists, in particular, continue teaching the concept of physical and chemical change to junior high school students is that they believe that it is an interesting and exciting area and that it will attract students to do chemistry later?

#### SECTION FOR TEXT BOOK AUTHORS ONLY (THIS MEANS YOU ARE THE AUTHOR OR PART AUTHOR OF A SCIENCE / PHYSICAL SCIENCE / CHEMISTRY TEXT BOOK).

38 Please complete this section for one named text book that you authored/ co-authored.

39 Did you include a section on physical / chemical change in your text book?

40. In your book, are physical and chemical change taught in opposition to one another as in the table on p.2? Or are the topics taught separately, perhaps giving examples of chemical reaction in one part of the book and an explanation of change of state in another part of the book?

41 Do you have any comments about writing the section on physical and chemical change, perhaps on the choice of examples of each, the position in the book of this section, the length of the section, the choice of definition of physical and chemical change for this section or any other aspect of writing about physical and chemical change?

THAT IS ALL! THANK YOU FOR YOUR HELP!

## **APPENDIX 13**

List of respondents (in alphabetical order)

**Note: For privacy reasons Appendix 13 (p. 429) has not been reproduced.**

**(Co-ordinator, ADT Program (Bibliographic Services), Curtin University of  
Technology, 07/01/2004)**

## APPENDIX 14

### List of questionnaires returned (in order of being processed) (Chapter 9)

#1	Written	Male	PNG	Teacher/sec	Chem
#2	Written	Male	UK	T/Trainer	Physics
#3	By e-mail	Male	Taiwan	T/Trainer	Chem
#4	Written	Male	UK	T/Trainer	Chem
#5	Written	Male	UK	University	Hist/Chem
#6	Written	Male	UK/ Wales	Teacher/sec	Chem
#7	Written	Male	UK	T/Trainer	Chem
#8	Written	Male	Aust/NSW	T/Trainer	Chem
#9	Tpd intrvw	Male	UK/Scotlnd	T/Trainer	Chem
#10	By e-mail	Male	USA	University	Chem
#11	By e-mail	Male	USA	University	Chem
#12	By e-mail	Male	USA	University	Chem
#13	By e-mail	Male	USA	University	Chem
#14	By e-mail	Male	USA	Teacher/sec	Chem
#15	By e-mail	Male	USA	Teacher/sec	Chem
#16	By e-mail	Male	Canada	University	Hist/chem
#17	On disc	Female	Aust/NT	Uni & primary	Science
#18	By e-mail	Male	UK	T/Trainer	Physics
#19	By e-mail	Male	UK	T/Trainer	Chem
#20	e-mail&typ	Female	USA	Teacher/prim	Bio/phys
#21	By e-mail	Male	USA	Teacher/sec	Phys/Chem
#22	On disc	Male	Aust/NT	Teacher/sec	Geol/Chem
#23	Typed	Male	UK	T/Trainer	Phys/sci ed
#24	Typed	Male	USA	University	Hist chem
#25	Written	Male	UK	Teacher/sec	Chem
#26	By e-mail	Male	NZ	University	Che/pharm
#27	By e-mail	Female	UK	Uni/prim sci	Bio
#28	Written	Male	UK	Teacher/sec	Hist/chem
#29	Written	Male	Aust/NT	Teacher/sec	Che/admin
#30	By e-mail	Female	USA	University	Chem
#31	By e-mail	Male	USA	University	Chem
#32	By e-mail	Female	Aust/QU	T/Trainer/Prim	Chem
#33	By e-mail	Male	USA	University	B-che/B-phy
#34	By e-mail	Male	Mexico	University	Phys chem
#35	Typed	Male	UK	Admin/ex teach	Chem/ISci
#36	Tape	Male	USA	Community Col	Chem
#37	Typed	Male	USA	Liberal Arts Col	Chem
#38	By e-mail	Male	Aust/QU	University	Chem
#39	By e-mail	Male	USA	University	Organ chem
#40	By fax	Male	Aust/NSW	Uni/Hist/rtd	Chem/Ind
#41	By e-mail	Male	Aust/SA	T/Trainer/	Sci/Geology
#42	By e-mail	Male	Aust/NSW	T/Trainer/prim	Sci/Chem
#43	By e-mail	Male	Russia	University	Phys chem
#44	By e-mail	Male	Aust/NSW	T/Trainer/sec	Sci/Chem
#45	By e-mail	Male	Botswana	Teacher	Sci/Chem
#46	By e-mail	Male	USA	University	Gen/phys che
#47	By e-mail	Female	Norway	T.Train/sec	Chemistry
#48	Typed	Male	Aust/VIC	University	Chem
#49	By e-mail	Male	Czeck Rep	University	Resrch/che

#50	By e-mail	Male	Aust/VIC	Industry	Chem/infor
#51	By e-mail	Male	Russia	University	Resrch/che
#52	By e-mail	Male	USA	University	Gen/phy che
#53	By e-mail	Male	Aust/VIC	University	Chem
#54	By e-mail	Male	Argentina	Teacher/sec	Chem
#55	By e-mail	Female	Aust/NSW	University	Gen/Chem
#56	Typed	Female	Aust/NT	Teacher/sec	Che/Bio/Phy
#57	By e-mail	Male	Jamaica	University	Chem
#58	By e-mail	Male	Germany	Teacher/sec	Biology/Chem
#59	By e-mail	Female	Canada	University College	Gen/Chem
#60	Written	Male	Aust/WA	T/Trainer	Chemistry
#61	Tpd intrvw	Male	Aust/SA	T/Trainer	Chem
#62	Written	Female	Aust/WA	Teacher/research	Chem
#63	Tpd intrvw	Male	Aust/WA	University	Chem
#64	Faxed/hand	Female	NZ	T Trainer/prim	Chem
#65	By e-mail	Male	USA	University	Gen Chem
#66	By e-mail	Male	USA	University	Chem Ed
#67	Fax/typed	Male	Aust/Q	Teacher	Chem
#68	E-mail	Female	USA P/Rico	University	Gen Chem
#69	Written	Female	Norway	Teacher	Chem
#70	Disc	Female	Aust/NT	Teacher	Int Sci
#71	Typed	Male	Solomon I	Teacher/Curr	Chem/Phys
#72	E-Mail/atach	Male	Nethlands	Researcher	Chem Ed
#73	Written	Male	NZ	University	Chem Ed
#74	E-mail	Female	Brazil	University	Chem Ed
#75	Typed	Male	W. Samoa	Curric Dev sec	Chem/Bio
#76	E-Mail	Female	S. Africa	Teacher Tr	Phys Edn
#77	E-Mail	Male	Thailand	University	Chem
#78	Written	Male	Aust/NT	Govt/Ind	Chem
#79	Disc	Male	Aust/NT	University	Chem/Ab Ed
#80	E-Mail/atach	Male	Hong Kong	University	Chem/PhD

## APPENDIX 15

### Countries from which completed questionnaires were received

Argentina	1	
Australia	23	
Botswana	1	
Brazil	1	FINAL ALL UK 13 = 16.3%
Canada	2	FINAL ALL USA 20 = 25%
Czech Republic	1	FINAL AUSTRALIA 23 = 28.8%
Germany	1	FINAL ALL OTHERS 24 = 30%
Hong Kong	1	
Jamaica	1	MALE/FEMALE 66/14 = 82.5%/ 17.5%
Mexico	1	
Netherlands	1	PROFESSION
New Zealand	3	(These totals are only approximate)
Norway	2	Teaching 22/80 = 28%
Papua New Guinea	1	Teacher education 21/80 = 26%
Russia	2	University lecturers pure science 33/80 = 41%
Solomon Islands	1	Others (industry/ research)4/80 =5%
South Africa	1	
Taiwan	1	
Thailand	1	SUBJECT
UK	11	Very largely chemistry with physicists/
UK (Scotland)	1	historians of science being the biggest
UK(Wales)	1	subgroups at 5% or less each.
USA	19	
USA (Puerto Rico)	1	
Western Samoa	1	
* = incomplete		

## **APPENDIX 16**

Core ideas in science by Hazen and Trefil

**Note: For copyright reasons Appendix 16 (p. 433) has not been reproduced.**

**(Co-ordinator, ADT Program (Bibliographic Services), Curtin University of  
Technology, 07/01/2004)**



## **APPENDIX 17**

E-MAIL from Brian Salter-Duke, Honorary Fellow in Chemistry, NT University

**Note: For privacy reasons Appendix 17 (p. 434) has not been reproduced.**

**(Co-ordinator, ADT Program (Bibliographic Services), Curtin University of  
Technology, 07/01/2004)**