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PHYSICAL AND CHEMICAL CHANGE: THE LONG HISTORY OF THE IRON FILINGS AND SULFUR EXPERIMENT

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ABSTRACT

As a part of a doctoral thesis considering the history of teaching physical and chemical change, 641 chemistry/science textbooks have currently been examined. These books are from many different countries and date from the eighteenth century to the present time. The books have described a wide variety of experiments to illustrate the difference between physical and chemical change. This paper will look briefly at these and show that the heating of iron filings and sulfur to form iron II sulfide was and still is a very popular experiment. The paper will then focus on the history of this experiment. Some of the anomalies and wrong conclusions that relate to the experiment will be explored, as will its safety and practicality. A simple experiment that has not been used in textbooks for more than 60 years is described as an alternative to the standard experiment. This will indicate that it is possible to learn from the past.

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INTRODUCTION

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. Older 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 and some of these points have been discussed in an earlier paper (Palmer 1994). However, 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. 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.

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.

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.

Take one textbook as an example (Holmyard 1951, pp.13-15). Holmyard's textbook was chosen because he gives several examples (but not too many) and states clearly whether he considers them to be physical 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 and 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 et al (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.

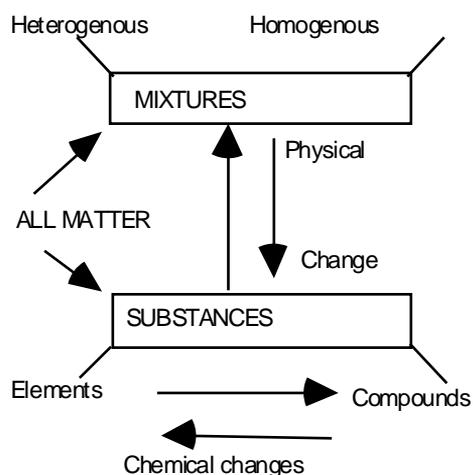
These researchers separately related the theoretical concepts (generally ideas involving micro/representational concepts such as atoms and molecules) to each other in another table. A fairly small number of students was tested with a chemistry test made up of questions involving these concepts. Using the principles of the Gagne 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.

As part of a Ph D thesis in progress I am examining many textbooks to see how they teach physical and chemical change and seeing how this teaching varies according to circumstances. The data is filled in using a system devised for 'Hypercard'. One of the features recorded is 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. If examples that relate to 'everyday life' experience are ignored, and only the changes where the teacher or students are likely to do an experiment are considered, then 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)



Diagrams like the above are moderately common in American textbooks (for example, Brown and 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 and 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 sulfur is not a chemical change but a physical change since a new substance is not formed.* (Freemantle and 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.

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 FeS . It is said to be a good example of a well characterised non-stoichiometric sulfide (Cotton and 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. I have always considered it 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 text books 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.

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 (Fe_2O_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 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 and 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) 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, 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, p.83). Glauber (1604-1688) in his writings explains how sulfuric acid (vitriol) could be

obtained from the naturally occurring iron pyrites/ marcasite (both FeS₂) (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)

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 and 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) 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 is explained by Salzburg (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.

(Crosland, 1971, p.152)

Lowry (p. 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.

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.

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, 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.

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, pp. 1-2) 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 sulfur ...But after the substances have been subjected to chemical action, the most powerful microscope is incompetent to detect either sulphur or iron... Frankland and Japp (1884, p.2)

Frankland 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 text book 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.

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. 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, pp. 130-131; Abbott, pp. 16-17) and also as an example of physical and chemical change (Lugg and Rowney, p.143; Abbott, 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 et al 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 sulfide is formed in the change, but this is incorrectly said to be 'a compound of fixed composition'.

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 sulfide) with gold when they examine a mineral only superficially. (Hunter et al 1983, 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.

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. (ASE 1981, p.24).

There is an alternative to this experiment that I have found in old textbooks (for example, Ostwald 1902, pp. 576-77; 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 sulfur 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 sulfur 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).

At one point Emile 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 Shakhashiri (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.

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