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The Philosophical Requirements to Explain Chemical Change in the Academic Laboratory

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ABSTRACT

Element and mass conservation are integral to the understanding of chemical change. This essay argues that these two conservation claims are not adequately explained by the usual chemical syntheses which students perform in the academic laboratory. The syntheses considered involve the formation of a binary compound from two reacting elements. This type of synthesis is regarded as significant because it is the basis for more complex examples of chemical change. Within this context, element and mass conservation are explained by two different philosophical arguments. Element conservation in a compound is explained by first, the formation of the compound followed by the decomposition of that compound into the initial elements. Mass conservation is explained by quantifying both the reacting elements and compound. For various reasons, many compounds synthesized from elements cannot readily decompose to the elements and/or be completely quantified and therefore, do not adequately justify the conservation claims. Of a sample of 16 chemistry lab manuals that contain this type of synthesis, only one synthesis supports element and mass conservation. The chemicals involved, zinc, iodine and zinc iodide, enable the construction of sound and preferred arguments that could help promote conceptual change of students' misconceptions in this subject area.

INTRODUCTION

Within the context of chemical change, two important conceptual areas are element conservation (reacting elements are conserved in a compound) and mass conservation (the Law of Conservation of Mass). Within the last 10 years, educational researchers have found that before and even after instruction, students' understanding of chemical change and the associated conceptions of mass and element conservation are often different from the preferred scientific meanings (Hesse & Anderson, 1992; Lythcott, 1990; Basili, 1989; De Vos & Verdonk, 1987; Anderson, 1986; Driver, Guesne & Tiberghien, 1985). This phenomenon suggests two possible causes: 1) that some instructional strategies, intended to promote conceptual change in the mind of the learner, are not effective, and 2) that element and mass conservation, which are often examined in the beginning of the school year and sometimes only in passing, are more difficult for students to learn then commonly thought. This essay will address these causes by describing in detail two philosophical arguments that teachers could use to promote conceptual change during instruction and that could enable this difficult subject area to be clarified and integrated into a meaningful whole.

An instructional strategy that has potential to foster conceptual change involves, in part, students discussing what they know in the form of arguments (Duschl, 1990; Martin, 1985). In the past, consideration for the premises of an argument was recommended as one of seven goals of science by the Educational Policies Commission in Education and the Spirit of Science. Drawing attention to the importance of arguments is for good reason. The creation of sound arguments can explain important scientific conclusions such as laws and theories and make them intelligible. According to contemporary conceptual change theory, intelligibility is one of four necessary conditions which learners should undergo to accommodate new knowledge (Strike & Posner, 1985). Finally, the strategy of allowing students to create arguments is in keeping with a constructivist theory of learning which stresses the importance of a learner's prior knowledge in the construction of new knowledge (Wheatley, 1991; von Glasersfeld, 1984; Resnick, 1983).

The 2 philosophical arguments described in this essay center on element conservation and mass conservation, respectively. Discussions of the philosophical requirements that explain and justify each conservation claim are also presented. These arguments are followed by an examination of chemistry laboratory manuals that contain syntheses of binary compounds from the elements. It will be evident that many of these syntheses which introductory chemistry students perform do not adequately support element and mass conservation. One synthesis that has been documented and supports both claims is the reaction between zinc and iodine to produce zinc iodide. This essay ends by drawing implications for teachers concerning these arguments and the choice of syntheses used to elucidate chemical change.

THE CONTEXT OF CHEMICAL CHANGE AND ITS SIGNIFICANCE

Chemical change is "a change in which one or more kinds of matter are transformed into a new kind of matter or several new kinds of matter" (Ebbing, 1987, p. 30-31). Due to the generality of this definition, investigating chemical change can involve many different conceptual areas of chemistry such as equilibrium, redox, radioactivity, photochemistry, etc. This essay discusses a fundamental aspect of chemical change, that is, the reaction between two elements to form one compound. This reaction is regarded as fundamental because, 1) the bedrock of understanding chemical changes rests on a classification of substances into elements and compounds, and 2) this type of reaction is the basis for more complex examples of chemical change. With regard first to classification, elements are classified on the macroscopic level as the simplest substances that cannot be broken down by physical or chemical means. Elements are ordered exclusively in the Periodic Table to demonstrate specific relationships between one another. This, in part, allows predictions concerning the combination of elements into compounds. Secondly, it is the combination of elements and compounds into other compounds that is the basis for the diversity of substances found in the world. Therefore, to understand the most basic example of chemical change is to know that two elements combine to form one binary compound.

The formation of a compound from its elements is called a synthesis reaction. Synthesis of compounds from elements, moreover, is governed by a quantitative or stoichiometric relationship between the reacting quantities of elements and the quantity of the compound produced. Two laws that define this stoichiometric relationship are the Law of Constant Composition or Definite Proportions and the Law of the Conservation of Mass. The Law of Constant Composition, which is one of the first laws of chemical change to be described historically (Leceister, 1971), states that "a pure compound, whatever its source, always contains definite or constant proportions of the elements by mass" (Ebbing, 1987, p. 33). The Law of the Conservation of Mass describes the phenomenon "that mass [of reacting substances] remains constant during a chemical change" (Ebbing, 1987, p. 3). While the Law of Conservation of Mass explicitly deals with mass, it assumes that the reacting chemicals which form a compound are conserved and make up the compound (this will be referred to as element conservation). It is out of these two laws and this assumption that the Atomic Theory of Matter developed. This theory supports the concept of stoichiometry and allows empirical formulas and balanced chemical equations to be written.

Given that element conservation is a necessary part of the Atomic Theory of Matter, a critical assumption of the Law of Conservation of Mass, and is fundamental to the origins of understanding chemical change phenomena, and given that Law of the Conservation of Mass is fundamental to the understanding of stoichiometry, it is imperative that phenomena from which such understanding can be generated be available to chemistry teachers and students. The simplicity of reacting 2 elements to form a compound and its historical importance (Lavosier illustrated the Law of Conservation of Mass by reacting the elements mercury and oxygen; Ebbing, 1987) suggest that these specific types of matter may allow students to effectively construct this crucial, complex and fundamental knowledge.

THE CONTEXT OF LEARNING

Chemical change is presented to students in different contexts. These include reading, lectures, demonstrations performed by teachers, cooperative learning, team teaching, computer aided instruction, just to name a few. This essay focuses on activities which students perform in a laboratory context. Since the 19th century, student interaction with physical materials in the laboratory has been regarded as an important aspect of science education in United States (DeBoer, 1991). Recently, there has been a reaffirmation of the science laboratory as a place for students to learn about science (Gardner, 1990; Hegarty-Hazel, 1990). Science educators have recognized that the importance of experimental work for learners is to promote conceptual understanding, scientific inquiry, technical skills, motivation and positive attitudes, and to make explicit an empirical basis for scientific knowledge (Solomon, 1980; Boud, Dunn & Hegarty-Hazel, 1986; American Association for the Advancement of Science, 1990; College Entrance Examination Board, 1990).

Students working in a laboratory often use commercial laboratory manuals to conduct experiments. For a variety of reasons (safety, cost, availability, etc.) many syntheses of a compound from two elements are not performed by introductory chemistry students. Only a handful, listed in Table 1, can be found in first year college chemistry laboratory manuals. Most of these syntheses have been used by teachers for many years and can be found repeatedly in different manuals (see Table 2 for support). One reason for their widespread use is their simplicity. These syntheses do not require sophisticated equipment, the addition of numerous reagents to prepare the elements for reaction, nor involve the formation of a hydrated compound.

Table 1: Common Syntheses of Binary Compounds

Element	Element	Compound	Formula
Magnesium	Oxygen	Magnesium oxide	MgO
Copper	Oxygen	Copper (I) oxide	Cu_2O
		Copper (II) oxide	CuO
Tin	Oxygen	Tin (II) oxide	SnO
		Tin (IV) oxide	SnO_2
Copper	Sulfur	Copper (I) sulfide	Cu_2S
		Copper (II) sulfide	CuS
Magnesium	Sulfur	Magnesium sulfide	MgS
Lead	Sulfur	Lead sulfide	PbS
Nickel	Sulfur	Nickel sulfide	NiS
Antimony	Iodine	Antimony triiodide	SbI_3
Zinc	Iodine	Zinc iodide	ZnI_2

In all of the above syntheses, the procedure and purpose outlined in the laboratory manuals are essentially the same. The procedures call for measuring the mass of the elements when possible, reacting the elements, measuring the mass of the compound, and showing that the physical and chemical properties of the compound are different from the reacting elements. The purposes of the reactions are to generate empirical formulas and balanced equations via quantitative analysis. The empirical formula describes the types of elements present in the compound and the ratios of the different atoms that make up those elements. Two arguments will now be presented which involve the above syntheses. The first argument (A) concerns element conservation while the second argument discusses mass conservation (B). Each argument assumes prior conceptual knowledge such as the concepts element, compound, conservation, etc.

ARGUMENT A: ELEMENT CONSERVATION

One important purpose of the scientific enterprise is to generate knowledge claims which are justifiable. To justify a claim or a hypothesis is to exhibit the claim as a conclusion by way of premises, premises being initial statements made prior to the conclusion. Taken together, the premises and conclusion act as the structure of an argument. A sound or appropriate argument is one in which 1) the premises are justified, and 2) there is an appropriate connection between premises and between the premises and the conclusion (Giere, 1984). Below is an argument generated from a hypothetical laboratory activity involving the synthesis of a compound from two different elements.

Argument A-1

Premise #1: 2 elements (X and Y) react to form compound Z.

Premise #2: Compound Z has different physical and chemical properties than the elements X and Y.

Conclusion: Compound Z consists of elements X and Y.

The first premise involves the synthesis while the second premise involves testing the product and finding that indeed a substance is formed which is different from the reactants. Premise #1 and #2 are justifiable in that they can be related to "reality," that is, the experimental findings in the laboratory. The statement underneath the premises is the conclusion dealing with element conservation. This conclusion can be thought of as essential knowledge of chemical change that, as teachers, we want our students to learn. Examining the premises, it is evident that the links between premises #1 and #2 and the conclusion are not appropriate. Just because 2 elements react with each other, it does not necessitate that the 2 elements are contained or conserved in the compound. With these premises, one cannot point to experimental evidence from the hypothetical laboratory activity to show that the compound consists of the elements X and Y. While the 2 premises are justifiable, the links between the premises and the conclusion are not, and therefore, the argument is unsound.

If these premises are the only ones students have available to them, what conclusions could students possibly make? Will they construct a conservation conclusion based solely on these premises? According to Andersson's work on how students explain chemical reactions, students are prone to harbor a range of explanations From his own research and from studies of other researchers (Andersson, 1986), he has grouped students' explanations of the appearance and disappearance of chemicals during chemical reactions into 5 different categories. By doing this, he synthesized much of the work that was previously completed on this topic (Champagne, Halbwachs & Meheut, 1984; Andersson and Renstrom, 1981; Shollum, 1982; Pfundt, 1982; Meheut, Saltiel & Tiberghien, 1983; Andersson and Renstrom, 1983a, 1983b). These studies for the most part involved learners, 11 and 17 years old, who's verbal and written responses were recorded prior to and after instruction. The 5 different categories of explanations involved 1) not being able to give an explanation, 2) that the reactants are hidden behind the product, 3) that the reactants are still present in the product but in a modified form (ie: change of physical state), and 4) that the reactants are irreversibly changed in the product (ie: elements are no longer there). Even after instruction, few students mentioned the last and only correct category: 5) that elements and their atoms are still present in the compound and that their interactions and arrangements create a substance with new physical and chemical properties (Andersson, 1986). As the above argument (A-1) is written, the four ascientific explanations which Andersson described could not be refuted or at least challenged. This is due to the lack of clear links between the premises, which are based on the students' experimental findings in the laboratory, and the conclusion concerning element conservation. In order to support the conclusion that elements are conserved in compound Z, a premise must be added which is connected to the other premises and is appropriately connected to the conclusion. The recommended premise concerns reversing the synthesis reaction. By incorporating a third premise, the argument seen below is much stronger.

Argument A-2

Premise #1: 2 elements (X and Y) react to form compound Z.

Premise #2: Compound Z has different physical and chemical properties than the elements X and Y.

Premise #3: Compound Z decomposes into the elements X and Y.

Conclusion: Compound Z consists of elements X and Y.

One can conclude that compound Z consists of elements X and Y, that elements are conserved in a compound, based on the relationship between premise #1 and premise #3. Premise #1 and #3 have in common the elements X and Y. In premise #1, the elements X and Y can be viewed as the input (before synthesis), while in premise #3 the same elements can be considered as the output (after decomposition). The correspondence between input and output (by physical and chemical tests) supports the conclusion that the same elements must be contained in a state after the input and before the output. Since an examination of the compound in order to observe the elements is impossible without destroying the compound, conclusions are based on evidence observed before the formation of the compound and after the compound decomposes. Lying between the synthesis and decomposition, the compound cannot indicate anything about the presence of elements X and Y on the macroscopic level. It is the evidence gleamed before synthesis and after the decomposition that is compared and extended to determine the nature of the compound itself. It is because of this that the conclusion of argument A-2 can never really be justified; it is an inference that is strengthened by the inclusion of premise #3. While both arguments can not be justified in a strict sense, argument A-2 is preferred because it includes additional inferential information that could be used to argue against the 4 ascientific ideas which Andersson has mentioned.

The third premise in argument A-2 is justifiable since it occurs experimentally in the laboratory. For example, water can be decomposed by electrolysis to the elements that formed it, hydrogen and oxygen. While other substances might be more difficult to decompose in the laboratory and require specific pressure and temperature conditions, it has been pointed out that it is theoretically possible to reverse any reaction given sufficient energy (Cambell, 1980). Finally the conservation conclusion and its premises can be generalized to compounds other than compound Z.

ARGUMENT B: MASS CONSERVATION

As previously mentioned, the purpose of many syntheses of a compound from elements, as described in laboratory manuals, is to generate empirical formulas and balanced chemical equations. These expressions are meaningless without the assumption of a crucial law: The Law of Conservation of Mass. Without this law, the ratios between reacting elements in a compound would never be constant and consequently, the Law of Constant Composition would not be valid. Also, a new balanced equation would need to be written every time a reaction trial was conducted. Therefore, it is this crucial information that underpins the justification of an empirical formula and balanced equation. Mass conservation can be demonstrated by knowing the masses of the two elements (limiting and excess) <u>and</u> the mass of the compound. The word "and" is underscored for good reason. If for example, the mass of one element (ie: the excess reactant) is not known, then the following hypothetical argument can not be justified.

Argument B-1

Premise #1: Mass of reacting Element X is 1 gram.

Premise #2: Mass of reacting Element Y cannot be readily measured.

Premise #3: Mass of Compound Z is 3 grams.

Conclusion: Mass of Elements X +Y is equal to the mass of Compound Z.

The conclusion, which refers to mass conservation, is not justified because the mass of element Y is not known. One may know what Y should equal in order to make the conclusion valid, but what Y actually equals is not known. Since no appropriate link exists between premise #2 and the conclusion, the argument is not internally consistent.

A sound argument can be easily constructed if premise #2 is changed to "Mass of reacting Element Y is 2 grams." Now, when 2 grams of element X is added to 1 gram of element Y, the sum is equal to 3 grams of reacting elements. This mass of 3 grams is equal to the mass of the 3 grams of compound Z. Knowing the initial and excess masses of element Y enables premise #2, the mass of element Y which reacted, to be calculated. With the change in premise #2 and the addition of the other premises, the links from premises to conclusion are appropriate and therefore, the argument is sound. It is only by the quantification of both elements and the compound that mass conservation can be adequately understood.

In the context of the synthesis of a one compound from two elements, two important conclusions have been stated. The conclusion in argument A, that reacting elements are conserved in a compound, is sound if:

- The synthesis of the compound from elements is followed by its decomposition into the same elements.

Secondly, the conclusion in argument B, that mass is conserved in a chemical reaction, is justified only if:

- The masses of both elements and the compound are known.

ANALYSIS OF LABORATORY MANUALS

At this point, the question that must be asked is: Do these philosophical requirements exist in the laboratory syntheses which students perform in introductory chemistry courses? By examining Table 2, where U.S. laboratory manuals from 1971 to the present are ordered by year, the answer is not very encouraging. Analysis of 16 different first-year college chemistry laboratory manuals that contained the synthesis of one compound from two elements (28 manuals were sampled) showed that no decomposition reaction was included in the respective experiments. Moreover, in all but two of the manuals surveyed, does a synthesis exist where the mass of the two elements and compound are measured.

Table 2: Syntheses of Compounds in U.S. Laboratory Manuals

Name, Authors & Year of Laboratory Manual	Type of Synthesis	Decomposition	Masses known for Elements & Compound
1. Experiments for College Chemistry (Goldwhite & Moynihan, 1971)	Ni + S	No	No
2. Experimental General Chemistry (Lippincott, Meek & Verhoek, 1974)	Cu + S	No	No
3. Chemistry in the Laboratory (Alexander & Steffel, 1976)	Cu + S	No	No
4. Experiments in General Chemistry (Drago & Brown, 1977)	Cu + S	No	No
5. Laboratory Manual for General Chemistry Principles and Structure (Beran & Brady, 1978)	Cu + S Pb + S Ni + S	No No No	No No No
6. General Chemistry in the Laboratory (Sollimo, 1980)	$Mg + O_2$	No	No
7. Laboratory Manual for Fundamentals of Chemistry (Beran, 1984)	$Mg + O_2$ Cu + S Pb + S Ni + S	No No No No	No No No No
8. Basic Laboratory Studies in College Chemistry (Hered, 1984)	$Mg + O_2$ Cu + S	No No	No No
9. Chemical Principles in the Laboratory (Bryan & Boikess, 1985)	Cu + S Mg + S Pb + S Sn + S	No No No No	No No No No
10. General Chemistry Laboratory Manual (Puerschner, 1985)	$Mg + O_2$	No	No

11. Chemistry: A First Laboratory Course (Kroschwitz, Winokur & Petrin, 1987)	$Sn + O_2$	No	No
12. General Chemistry in Laboratory (Roberts, Hollenberg & Postma, 1987)	$Zn + I_2$	No	Yes
13. Modern Experiments for Introductory Chemistry (Neidig & Stratton, 1989)	$Sb + I_2$	No	Yes
14. Third Ed. Experiments in General Chemistry (Wentworth, 1990)	$Mg + O_2$	No	No
15. Laboratory Experiments for Fifth Ed. Chemistry the Central Science (Nelson & Kemp, 1991)	$Cu + S$ $Cu + O_2$	No No	No No
16. Barnard College General Laboratory Manual (King, 1992)	$Cu + S$	No	No

It is understandable that a decomposition activity following the synthesis of a compound is absent in most of these laboratory manuals. The metallic sulfides produced when the metal copper, iron, lead, tin, magnesium or nickel reacts with sulfur can not be readily decomposed into their elements with equipment usually available to introductory chemistry students (ie: electrolysis with a small battery or with heat). This is also true for metallic oxides produced when magnesium, tin or copper reacts with oxygen. Antimony triiodide, produced from the reaction between antimony and iodine, decomposes not to the elements, but to SbOI when placed in water (Windolz, 1983). The only compound in the list that can readily undergo decomposition to the elements is zinc iodide (Walker, 1980). Unfortunately, the synthesis of zinc iodide from zinc and iodine as described by Roberts, Hollenberg and Postma (#12 in Table 2) is not followed by a decomposition activity. While electrolysis and heat are two methods to recover the elements, the addition of specific reagents can also be utilized as in the copper cycle (Umans & De Vos, 1982). This latter method is not preferred because it is more convoluted and entails having students believe that the elements are not contained or hiding in the reagents or do not spontaneously change into the elements (these involve #2 and #4 in Andersson's list of ascientific explanations).

With regard to mass conservation, only two manuals enable students to measure the masses of both the elements and the compound. In the syntheses involving sulfur, it is the mass of the excess sulfur that can not be quantified. This is because these syntheses require heat to react. Heat vaporizes sulfur (bp = 445^{o}C) which reacts with hydrogen and oxygen in the air to form hydrogen sulfide and sulfur dioxide gases (Windholz, 1983). In the syntheses involving oxygen, it is the excess oxygen that cannot be quantified. This is because these procedures call for heating magnesium, tin or copper with oxygen from the air. By using the air as a source of oxygen in these reactions, a quantification problem arises. There is no easy way to quantify the initial mass of oxygen and the excess oxygen left over once the reaction is complete. Therefore, the amount of oxygen actually reacted cannot be calculated. Oxygen tanks or syringes were not mentioned in any of the manuals most likely due to the higher cost the activity would incur. Only in the synthesis of zinc iodide and antimony iodide can both the two elements (limiting and excess) and the compound be quantified. Within the uncertainty of the balance being used, this allows the mass conservation claim to be justified in the form of a sound argument.

IMPLICATIONS FOR TEACHERS

Currently, many science educators and associations have advocated the addition of philosophy into the science curriculum. Proposals for school science reform in this area are found in the British National Science Curriculum (National Curriculum Council, 1988), in U.S. Project 2001 (American Association for the Advancement of Science, 1989) and in The Liberal Art of Science (American Association for the Advancement of Science, 1990). Additionally, a book on this very subject entitled History, Philosophy and Science Teaching has been published (Matthews, 1991). One way for teachers to participate in this type of educational reform, is to incorporate philosophical arguments into their lessons such as the two presented in this essay. The advantages for teachers for using these arguments are many. First and in a general sense, using arguments in the classroom can demonstrate that science can be understood as a process of justifying knowledge (Duschl, 1990). In this way, the strengths and weaknesses of the constituent parts can become apparent. In the long run, this could help students clarify complex subject matter, evaluate discourse and explain phenomena in scientific terms (Martin, 1885). Secondly, constructing arguments counteracts the tendency to stress “final form science” (Duschl, 1990, p. 69), that is, teaching only facts and conclusions without including the rationality, underlying assumptions and supporting evidence (Duschl, 1990). By omitting this important information, “final form science” can lead to a decontextualized and therefore, inaccurate view of science. Thirdly, and more specifically, arguments A and B can make element and mass conservation intelligible and therefore, can be used in part to promote conceptual change in learners. Intelligibility is created by constructing the specific premises and discussing thier relationship to the arguments' conclusions Fourthly, both arguments A and B can be extended to involve other important concepts involving chemical change. For instance, if students understand the concept of atoms, then the structure of argument A-2 can be used to support atom conservation. Knowing that the atoms of the elements are conserved in a compound begs the question: why are the physical and chemical properties of the compound different from that of the reacting elements? A discussion of electron interaction and atom geometry during bonding of the elements can take place. These additional concepts are also crucial to understanding chemical change. In a similar fashion, the structure of argument B-2 could support the Law of the Conservation of Energy. After an examination of the relationship between energy and mass, the ultimate unification of mass and energy conservation laws could ensue.

When a teacher wants his or her students to learn about chemical change in the laboratory, along with other important decisions, the teacher has to choose materials that will help students construct this information. The teacher has at least 2 choices- either choosing a variety of chemical experiments for students to do, each of which elucidates different aspects of chemical change such as the Law of Constant Composition, empirical formulas, element and mass conservation, bonding between atoms, etc., or choosing only one experiment, such as the zinc iodide synthesis, which can elucidate the same breadth of information. In the first choice, for example, the teacher can perform a copper sulfide synthesis to generate an empirical formula and balanced equation, and then introduce other activities that allow students to construct element and mass conservation. Demonstrating element conservation could involve the decomposition of compounds that have not been synthesized or the use of other reagents to recover elements. One activity to demonstrate mass conservation might involve weighing chemicals in a sealed vessel before and after a reaction and comparing masses. The availability of these other activities could explain why the authors of the manuals sampled in Table 2 included the syntheses they did- other experiments could be used to support these conservation claims. In other words, the syntheses were not chosen with the purpose of teaching element and mass conservation, but rather, were only used to demonstrate empirical formulas and balanced equations. The second choice a teacher could make is to use an experiment that can generate an empirical formula, a balanced equation, etc. as well as support element and mass conservation. This latter choice has some advantages over the first choice. Using one experiment would decrease the cognitive complexity of learning because knowledge about new experiments which involve new chemicals, new procedures, new observations, etc. would not have to be accomodated into a learner's cognition. Already taxed by many difficult concepts, further information found in additional experiments could obscure the signal the teacher wants to convey (Johnstone, 1984). Reliance on a single experiment would also integrate and unify the arguments being constructed, which in turn could promote a greater understanding of chemical change. Using other experiments creates a more convoluted or at least more complex argument since rational links must be created between experiments. Lastly, this choice makes sence on a practical level. Time needed for preparation, cleanup, and disposal can be greatly reduced when a teacher has only a few materials to be concerned with. For these reasons it is argued that using only one experiment in this context is preferable to using many different ones to promote understanding of chemical change. Of the type of syntheses listed in Table 2, it is believed that zinc and iodine are best suited to demonstrate chemical change and argue for element and mass conservation. Research pertaining to the synthesis and decomposition of zinc iodide is currently being conducted by the author and specific activities that describe these reactions will be made available to teachers in the near future. In the endnotes of this essay is a brief discussion of these two reactions.

CONCLUSION

A fundamental example of chemical change is the synthesis of a binary compound from 2 elements. This type of synthesis is usually performed by introductory chemistry students to produce an empirical formula and balanced equation. Unfortunately, many of these type of syntheses found in laboratory manuals do not allow students to construct 2 crucial ideas: element and mass conservation. It is believed that the quantitative synthesis of zinc iodide and the decomposition of this compound back into the elements allow for the construction of sound philosophical arguments in support of these conservation claims. While a combination of other activities separate from a synthesis could possibly be used to allow students to construct this knowledge, it is the above chemicals that allow integration of this knowledge into a meaningful whole. These chemicals and the construction of the conservation arguments in part could clarify the complex nature of chemical change and enable accommodation of this knowledge in the mind of the learner.

ENDNOTES

The Synthesis and Decomposition of Zinc Iodide

2 grams of iodine is reacted with 2 grams of zinc in the presence of water to produce a solution of zinc cations and iodide anions. The equation is:

$$Zn(s) + I_2(s) + H_2O(l) \text{ ----> } Zn^{2+}(aq) + I^-(aq) + H_2O(l)$$

The subsequent evaporation of the water produces the ionic compound, zinc iodide (s). The mass of this compound along with the excess zinc can be determined. The equation is:

$$Zn^{2+}(aq) + I^-(aq) + H_2O(l) \text{ ----> } ZnI_2(s) + H_2O(g)$$

When two wires that are connected to a 9-volt battery, are placed into an aqueous solution of zinc iodide, zinc cations gain electrons forming elemental zinc at one end of the wire and iodide anions lose electrons to form aqueous iodine at the other end. This experimental technique is called electrolysis and is used to recover the element zinc. The net equation is:

$$Zn^{2+}(aq) + 2\ I^-(aq) \text{ -----> } Zn(s) + I_2(aq)$$

When a large test tube containing the ionic compound, zinc iodide, is heated over a flame, iodine vapor is produced. This vapor can solidify on the outside surface of a cold test tube that is placed inside the mouth of the large test tube. The zinc reacts with oxygen in the air to produce zinc oxide. The decomposition reaction of zinc iodide allows iodine to be recovered. The equations are:

$$2\ ZnI_2(s) + O_2 + \text{heat} \text{ ----> } 2\ ZnO(s) + 2\ I_2(g)$$

$$I_2(g) \text{ ----> } I_2(s)$$

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