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## **DO WE HAVE TO INTRODUCE HISTORY AND PHILOSOPHY OF SCIENCE OR IS IT ALREADY 'INSIDE' CHEMISTRY?**

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**ABSTRACT:** The main objective of this article is to review literature in order to show how history and philosophy of science (HPS) is already 'inside' chemistry and we do not have to wait or ask for its inclusion in the curriculum. Examples are provided from the topics of atomic structure, kinetic theory, covalent bond, and the law of multiple proportion, to illustrate how an HPS perspective can facilitate students' conceptual understanding. [*Chem. Educ. Res. Pract. Eur.*: 2001, 2, 159-164]

**KEY WORDS:** *history and philosophy of science; atomic structure; kinetic theory; covalent bond; law of multiple proportions; conceptual understanding*

### **INTRODUCTION**

Recent literature in science education has recognized the importance of history and philosophy of science, HPS (Abd-El-Khalick & Lederman, 2000; Duschl, 1994; Matthews, 1994; 2000; Monk & Osborne, 1997; Moore, 1998; Niaz, 2001a; Niaz & Rodríguez, 2000). In addition, many researchers and teachers are working towards the inclusion of HPS in the science curriculum and textbooks. On the other hand, Bevilacqua and Bordoni (1998) innovators of Pavia Project Physics have stated: "We are not interested in adding the history of physics to teaching physics, as an optional subject: the history of physics is 'inside' physics" (p. 451). Similarly, Matthews (1998) has argued that philosophy is not far below the surface in any science classroom, as most textbooks and classroom discussions deal among others, with concepts, such as law, theory, model, explanation, cause, hypothesis, confirmation, observation, evidence, and idealization (p. 168). The main objective of this article is to review literature in order to show how HPS is already 'inside' chemistry textbooks and we do not have to wait or ask for its inclusion in the curriculum. Examples are provided to show that if we want our students to have conceptual understanding of scientific progress and practice, then we must go beyond regurgitation of experimental details.

### **ATOMIC STRUCTURE**

#### **Cathode ray experiment**

In the case of Thomson's cathode ray experiments, determination of the mass-to-charge (m/e) relation played an important part. It would be interesting to analyze as to how freshman students and general chemistry textbooks understand and interpret this aspect of Thomson's work. Blanco and Niaz (1998) asked freshman students the following question:

Why did Thomson determine mass-to-charge ( $m/e$ ) relation? Very few students could provide a satisfactory response and many responded: a) Cathode rays were deflected when subjected to electric and magnetic fields; b) To obtain a value for the relation ( $m/e$ ); c) To verify that the electron was extremely small, etc. Now let us see how Thomson himself described as to why he decided to determine the relation ( $m/e$ ): “I can see no escape from the conclusion that they are charges of negative electricity carried by particles of matter. The question next arises, What are these particles? Are they atoms, or molecules, or matter in a still finer state of subdivision? To throw some light on this point, I have made a series of measurements of the ratio of the mass of these particles to the charge carried by it” (Thomson, 1897, p. 302). Later in the article, Thomson clearly visualized that the determination of relation ( $m/e$ ) would help him to identify cathode ray particles as ions or a universal charged particle. One would expect that a HPS perspective would emphasize the role of alternative hypotheses (cathode rays as ions or universal charged particles) in the interpretation of Thomson’s experimental findings. At this stage it would be interesting to see how general chemistry textbooks present this aspect of Thomson’s work. Niaz (1998) has reported that of the 23 textbooks (all published in the U.S.) analyzed, only two described satisfactorily that Thomson decided to measure mass-to-charge relation to identify cathode rays as ions (if the ratio for different gases was not constant) or as a universal charged particle (constant ratio for all gases).

### **Alpha particle experiment**

Rutherford’s alpha particle scattering experiments are presented in sufficient detail in most general chemistry textbooks. Most textbooks, however, ignore that Rutherford had the experimental data as early as June 1909 (Geiger & Marsden, 1909), to postulate his model of the nuclear atom. It is interesting to note that Rutherford announced his nuclear model of the atom in March 1911. What happened between June 1909 and March 1911 is important not only for historians and philosophers, but also for science educators. Soon after Geiger and Marsden (1909) published their results, Thomson and colleagues started working on the scattering of alpha particles in their own laboratory. Although results from both laboratories were similar, interpretations of Thomson and Rutherford were entirely different. Thomson propounded the hypothesis of ‘compound scattering’, according to which a large angle deflection of an alpha particle resulted from successive collisions between the alpha particle and the positive charges distributed throughout the atom. Rutherford, in contrast, propounded the hypothesis of ‘single scattering’, according to which a large angle deflection resulted from a single collision between the alpha particle and the massive positive charge in the nucleus. The rivalry between Rutherford’s hypothesis of single scattering based on a single encounter and Thomson’s hypothesis of compound scattering, led to a bitter dispute between the proponents of the two hypotheses. At one stage, Rutherford even charged Crowther (1910), a colleague of Thomson, to have ‘fudged’ the data in order to provide support for Thomson’s model of the atom (Wilson, 1983, pp. 300-301). From a HPS perspective, the important point is that such rivalries based on alternative interpretations of the data have been found quite frequently in the history of science (Lakatos, 1970). Niaz (1998) has reported that of the 23 general chemistry textbooks analyzed, none mentioned this rivalry between Thomson and Rutherford.

### **Oil drop experiment**

The oil drop experiment was crucial for providing confirmation of the elementary electrical charge. Although, most textbooks consider it to be a classic experiment, it is

difficult to perform even today. Most science educators ignore the fact that the acceptance of the elementary electrical charge was preceded by a bitter dispute between R.A. Millikan and F. Ehrenhaft, that lasted for many years (1910-25). Both Millikan and Ehrenhaft obtained very similar experimental results and yet Millikan was led to formulate the elementary electrical charge (electrons) and Ehrenhaft to fractional charges (sub-electrons). Holton (1978) has presented a detailed reconstruction of the research methodologies of Millikan and Ehrenhaft. Ehrenhaft followed the traditional scientific method (as presented by most textbooks) by allowing his theory to be dictated by experimental data. Millikan, on the other hand, was guided by the presuppositions (Holton, 1978) /hard core (Lakatos, 1970) of his theoretical framework. Interestingly, Holton's (1978) examination of Millikan's hand-written notebooks revealed that in the preparation of the article (Millikan, 1913), 59% of the drops were discarded as they did not provide support for Millikan's hypothesis of the elementary electrical charge. Science educators can ask students to memorize the details of Millikan's classic experiment or to discuss as to the warrant which allowed him to discard data. The latter discussion can certainly be more revealing and stimulating for students. Niaz (2000a) has reported that of the 31 general chemistry textbooks (all published in the U.S.) analyzed, none mentioned the Millikan-Ehrenhaft controversy. Implications of this episode in the history of science are important. On the one hand, textbooks pontificate about the use of the scientific method and yet the role of Ehrenhaft (who followed the scientific method strictly) has been ignored and forgotten.

### KINETIC THEORY

An important aspect of scientific progress is that many research programs are based on inconsistent foundations and yet as science educators we ignore the difficulties faced by scientists as they grapple with complex issues. For example, Bohr's (1913) postulation of the 'quantum of action' was considered to be based on an inconsistent foundation not only by philosophers of science but also by many contemporaries of Bohr (Holton, 1986; Lakatos, 1970).

Maxwell's (1860) seminal paper on the kinetic theory is another example of a research program progressing on inconsistent foundations. It was based on 'strict mechanical principles' derived from Newtonian mechanics and yet at least two of Maxwell's simplifying assumptions (referring to the movement of particles and the consequent generation of pressure) were in contradiction with Newton's hypothesis explaining the gas laws based on repulsive forces between particles. Newton provided one of the first explanations of Boyle's law in his *Principia* (1687) in the following terms: "If a gas is composed of particles that exert repulsive forces on their neighbors, the magnitude of force being inversely as the distance, then the pressure will be inversely as the volume" (Brush, 1976, p. 13). Apparently, due to Newton's vast authority, Maxwell even in his 1875 paper, 'On the dynamical evidence of the molecular constitution of bodies' reiterated that Newtonian principles were applicable to unobservable parts of bodies (cf. Achinstein, 1987, p. 418). Brush (1976) has pointed out the contradiction explicitly: "... Newton's laws of mechanics were ultimately the basis of the kinetic theory of gases, though this theory had to compete with the repulsive theory attributed to Newton" (p. 14). Niaz (2000b) has reported that of the 22 textbooks (all published in the U.S.) analyzed, none mentioned the inconsistent nature of Maxwell's presentation of the kinetic theory.

## ORIGIN OF THE COVALENT BOND

A reconstruction of the origin of the covalent bond enables us to understand how the sharing of electrons (covalent bond) had to compete with the transfer of electrons (ionic bond), considered to be the dominant paradigm until about 1920. Formation of the ionic bond leads to a lowering of energy (stabilization) because of electrostatic attraction between ions of opposite charge. In this context, how can we explain the lowering of energy when two electrons are shared to form a covalent bond? Apparently, the approach of two electrons having the same charge should produce repulsive forces and hence produce destabilization. Thus it is not surprising that when first proposed the idea of a covalent bond was considered to be ‘absurd’ and ‘bizarre.’ Lewis (1916) and colleagues were among the first chemists to support the rival theory (hypothesis/idea) of covalent bonding by the postulation of a model based on the cubic atom. According to Kohler (1971), who has presented a detailed account of the origin of Lewis’s ideas: “When it was first proposed, Lewis’s theory was completely out of tune with established belief. For nearly 20 years it had been almost universally believed that all bonds were formed by the complete transfer of *one* electron from one atom to another.... From the standpoint of the polar theory the idea that two negative electrons could attract each other or that two atoms could share electrons was absurd” (p. 344). Later the quantum theory provided further support to the theory of sharing electrons when Pauli (1925) introduced his exclusion principle. It is plausible to suggest that a classroom presentation of the origin of the covalent bond, based on its rivalry with the ionic bond can facilitate conceptual understanding. Niaz (2001b) has reported that of the 27 general chemistry textbooks (all published in the U.S.) only one made a simple mention that sharing of electrons (covalent bond) had to compete with the transfer of electrons (ionic bond).

## LAW OF MULTIPLE PROPORTIONS, DALTON AND GAY-LUSSAC

In the early 19<sup>th</sup> century philosophers popularized the positivist version that Dalton was led to his atomic theory and the law of multiple proportions by the discovery of Gay-Lussac’s law of combining volumes, based on empirical data (Rocke, 1978). According to Pauling (1964): “The discovery of the law of simple multiple proportions was the first great success of Dalton’s atomic theory. This law was not induced from experimental results, but was derived from the theory, and then tested by experiments” (p. 26). It is interesting to observe that Pauling’s historical perspective was presented in a general chemistry textbook. Niaz (2001c) has reported that of the 27 general chemistry textbooks (all published in the U.S.) analyzed, none explained that Dalton’s atomic theory explained Gay-Lussac’s law of combining volumes.

## CONCLUSION

This article shows that various topics of the general chemistry program, at both the high school and freshman level can be presented within a history and philosophy of science perspective. In the case of atomic structure, experimental details of the cathode ray, alpha particle and the oil drop experiments do not suffice to present to the students, a glimpse of the efforts, struggles and vicissitudes in the lives of the scientists. Furthermore, it shows that although experimental details are important, the theoretical rationale in which the experiment is conducted, is even more important. A historical reconstruction of the origin of the kinetic

theory shows how scientific theories, at times progress on inconsistent foundations. Origin of the covalent bond shows the rivalry and competition between alternative approaches to bond formation. Finally, a historical perspective based on the law of multiple proportions shows that scientific progress does not necessarily follow the sequence: experimental details, laws and then theories. According to Brush (1978): "... as soon as we start to look at how chemical theories developed and how they were related to experiments, you discover that the conventional wisdom about the empirical nature of chemistry is wrong. The history of chemistry cannot be used to indoctrinate students in Baconian methods" (p. 290). It is concluded that history and philosophy of science is already 'inside' chemistry and this perspective can facilitate students' conceptual understanding.

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