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Instructional Misconceptions in Acid-Base Equilibria: An Analysis from a History and Philosophy of Science Perspective

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Abstract. The implications of history and philosophy of chemistry are explored in the context of chemical models. Models and modeling provide the context through which epistemological aspects of chemistry can be promoted. In this work, the development of ideas and models about acids and bases (with emphasis on the Arrhenius, the Brønsted–Lowry, and the Lewis models) are presented. In addition, misconceptions (alternative and instructional ones) on acid-base (ionic) equilibria are examined from the history and philosophy of science perspective. The relation between the development of the models and students' misconceptions are investigated. Finally, the hypothesis that history and philosophy could help educators anticipate students' misconceptions is examined.

Key words: instructional misconceptions, acid-base chemistry, acid-base equilibria, ionic equilibria; history of chemistry, philosophy of chemistry, models for acids and bases

1. Introduction

Students' concepts are a major area of science education research. Mental representations of concepts which is at variance with currently held scientific theory are termed *misconceptions* (Kesidou & Duit 1993; Lewis & Linn 1994), and are distinguished into two kinds: (a) *alternative* or *experiential* or *intuitive* or *native conceptions* and (b) *instructional misconceptions* (Skelly & Hall 1993; Nakiboglu 2003). In this paper, we use the term misconceptions without discriminating between alternative and instructional misconceptions. In numerous areas of chemistry, misconceptions have been identified and in the literature there exist specific documented misconceptions. Acid-base chemistry has received some attention too. An important component of acid-base chemistry is the (ionic) equilibrium concept.

In a review of students' chemistry misconceptions, Griffiths (1994) identified fifteen misconceptions relating to acid and bases. Five of them are relevant to acid-base equilibria: 'more hydrogen gas is displaced from a strong acid because the strong acid contains more hydrogen bonds than a weak acid'; 'all acids are

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strong and powerful'; 'strong acids have a higher pH than do weak acids'; 'neutralization always results in a neutral solution'; 'because a salt contains neither hydrogen nor a hydroxyl group, its solution cannot contain hydronium nor hydroxide ions'. According to Schmidt (1991), the term 'neutralization' acts as a hidden persuader', leading to the misconception that the product of 'neutralization' is a neutral solution'.

In a similar review, Garnett et al. (1995) listed just five misconceptions. The first is identical to the first mentioned above, while the others are: 'a weak acid cannot perform as well as a strong acid'; and 'pH is a measure of acidity but not of basicity'. The authors refer specifically to the various models of acid-base behavior; thus, younger high-school students operate with the Arrhenius model, while older high-school and university students operate with both the Arrhenius and the Brønsted–Lowry models. Carr (1984) stated that the textbook treatment of these models is often confused, and this results in misconceptions with some students. Finally, in their review, Garnett et al. considered that clearly there is need for more work in this area, and predicted a number of areas and issues where misconceptions are likely: confusion between acid-base strength and concentration, the hydrolysis of salts, the selection and the role of indicators in acid-base titrations, the difference between equivalence and end points, and the amphoteric properties of some substances.

Following the above directive, we undertook to investigate further the misconceptions on the subject of acid-base equilibria among twelfth-grade Greek high school students (Demerouti 2002). In this work, we will treat part of our findings from the history and philosophy of science (HPS) perspective. It is pertinent at this point to mention that in a study on students' reasoning of incomplete chemical conversions and also of chemical equilibrium, Van Driel et al. (1998) emphasized the role of the historical development of these concepts. The study revealed similarities and differences between students' reasoning and that of 19th-century scientists. It is remarkable that most of the students reasoned in macroscopic terms, but only few related the observed phenomena to their corpuscular conceptions.

2. Rationale: The Role of History and Philosophy of Chemistry in Chemistry Education

Rodriguez and Niaz (2002) have shown that the importance of history and philosophy of science (HPS) has been recognized since the 1920s. "Chemist-historians" such as Kopp, Thomson, Berthelot, Ostwald, and Idhle have maintained a long tradition of interest in history of chemistry (Russell 1985). In the United States, suggestions for including the history of chemistry in chemistry teaching can be traced back to the 1930s (Jaffe 1938; Oppe 1936; Sammis 1932). In addition, history of science has captured the interest of some chemists and found a way into the curriculum (Akeroyd 1984; Ellis 1989; Kauffman 1989; Herron 1997). On the other hand, Brush (1978) has argued that the ahistorical nature of chemical