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THE HISTORICAL DEVELOPMENT OF THE WORDS "DISSOCIATION" AND "IONIZATION" IN CHEMISTRY

O DESENVOLVIMENTO HISTÓRICO DAS PALAVRAS "DISSOCIAÇÃO" E "IONIZAÇÃO" NA QUÍMICA

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ABSTRACT: The words "dissociation" and "ionization" are sources of misconceptions in chemistry teaching, mainly in the subjects of acids and bases, chemical equilibrium and solutions. In the present article, the historical development of the two words was analyzed. Ever since the ending of the 19th century, with the studies of Berthelot, Arrhenius and Ostwald, until the middle of the 20th century, the general use of these words was made independently, with no clear differentiation between them, in some cases being used interchangeably. This idea was changed with the introduction of new atomic models by Thomson, Rutherford and Bohr, other conceptions of acids and bases, as proposed by Lewis, and research with gases and solutions. With the first recommendations of the International Union of Pure and Applied Chemistry (IUPAC) in the sixties and Herron's questionnaire in the seventies, the first formal differentiations between "dissociation" and "ionization" started to emerge. Driscoll proposed using the words based on whether ions already existed in the structure of the chemical entity and could be separated. In the nineties, IUPAC defined the two words formally, and their definitions were not mutually exclusive. A few years later, Schultz and Adams proposed a differentiation based on whether the chemical species interacted with water (e.g., solvation) or reacted with water (e.g., producing hydronium). Currently, IUPAC recommendations, academic publications and textbooks use the words in an irregular manner, perpetuating the difficulties in chemistry when "dissociation" and "ionization" phenomena are taught.

KEY WORDS: Chemistry education. History of science. Language in classroom. Terminology.

RESUMO: Os termos "dissociação" e "ionização" são fontes de misconceptions no ensino de química, principalmente nos assuntos de ácidos e bases, equilíbrio químico e soluções. No presente artigo, o desenvolvimento histórico das duas palavras foi analisado. Do final do século XIX, com os trabalhos de Berthelot, Arrhenius e Ostwald, até a metade do século XX, o uso geral dessa terminologia era feito de maneira independente, não havendo clara diferenciação entre as palavras e, em alguns casos, usadas como sinônimos. Essa ideia foi sendo alterada com a proposição de novos modelos atômicos por Thomson, Rutherford e Bohr, outras concepções de ácidos e bases, como por Lewis, e pesquisas com gases e soluções. Com as primeiras recomendações da *International Union of Pure and Applied Chemistry* (IUPAC) nos anos sessenta e os questionamentos de Herron nos anos setenta, as primeiras ideias de diferenciação entre "dissociação" e "ionização" passaram a surgir. Driscoll passou a usar os termos com base na existência ou não de íons para serem separados na estrutura da entidade química em questão. Nos anos noventa, a IUPAC define as palavras formalmente, não sendo suas definições mutualmente excludentes. Alguns anos depois, Schultz e Adams propuseram a diferenciação baseada na interação da espécie química com a água (ex. solvatação) ou na reação com água (ex. formando hidrônio). Até os dias atuais, as recomendações da

IUPAC, as publicações acadêmicas e os livros-texto usam as palavras de maneira irregular, perpetuando as dificuldades no ensino de química quando “dissociação” e “ionização” são empregadas.

PALAVRAS-CHAVE: Ensino de Química. História da ciência. Linguagem em sala de aula. Terminologia.

Introduction

Chemistry has its own nomenclature, which is something inseparable from science itself. To learn this discipline in High School, the student must also learn to master a wide array of new words. Among these words that must be learned by the student are "dissociation" and "ionization", which are nominalizations used for chemical processes. These kinds of words require a high level of knowledge to be completely understood, since they are abstract nouns that represent complex phenomena and processes (Quílez, 2019).

From an etymological point of view, the origin of the two words is known. *Dissociation* is the nominalization of *dissociate*, which comes from the junction of the prefix *dis* with *associate*. The word *associate*, in turn, comes from the Latin *associāre*, which is derived from the Latin word *socius*. *Socius* means fellow, companion or mate, giving the word a meaning of junction or union. However, the presence of the prefix *dis* brings the concept of opposition to the prefixed word, thus giving *dissociate* a meaning of having no connection (Quílez, 2019; Partridge, 2006, Wedgwood & Atkinson, 1872; Cambridge, 2008).

The word *ionization*, in turn, comes from the nominalization of *ionize*, which is derived from the word *ion*. This word was created by Michael Faraday, after William Whewell's suggestion, to refer to anions and cations simultaneously. This suggestion came to Michael Faraday in a letter sent in May, 1834, in which William Whewell suggested several terms that he considered more correct to denote components and processes of the electrolysis studies carried out by Faraday. In this case, the word *ion* was suggested based on the word *iōn*, which is the participle present in the neutral form of *ienai*, which means to go (Quílez, 2019; Partridge, 2006; James, 1993).

In Chemistry, however, the etymological definition of any word is not enough for scientific learning, and it is necessary for the student to understand all of the abstraction involved in the phenomena that these words represent. This causes Chemistry teachers to act as a language teacher in the classroom - the scientific language - teaching words about which there is often no consensus in the literature, as in the case of the processes of "dissociation" and "ionization", which still produce learning difficulties to students (Quílez, 2019; Quilez-Pardo, 2016).

The discussion about these words is not new in the literature. J. Dudley Herron, in 1977 and 1978, had already carried out research with this kind of focus, asking whether Chemistry is an exact science or not (Herron, 1977; Herron, 1978). Later, in 1997, Emeric Schultz revived the discussion again with an article (Schultz, 1997). However, the discussion has not been pursued and explored recently, and these two words are still seen as terminological obstacles for Chemistry students in current years (Quílez, 2019).

In view of the points presented, this article proposes to deepen and elucidate the forgotten discussion on the words “dissociation” and “ionization”, since it is still necessary (Quílez, 2019). For this, a historical approach of the use of the words “dissociation” and “ionization” and its discussion in Chemical Education was carried out, from the elaboration of the Theory of Electrolytic Dissociation by Svante Arrhenius to the present day, bringing forth the International Union of Pure and Applied Chemistry (IUPAC) to the discussion. Through its recommendations, this institution is recognized worldwide as an authority on chemical nomenclature and terminology (Hibbert; Minkkinen; Faber & Wise, 2009), which was neither analyzed by J. Dudley Herron nor Emeric Schultz in their studies.

Timeline

1884 – 1913: The theory of electrolytic dissociation of Arrhenius, the ionization of sodium chloride and the dissociation of acetic acid

The historical approach begins in the transition from the 19th to the 20th century. At that time, ions were already known, due to the research conducted by Michael Faraday in the early 19th century (Partridge, 2006). However, the conception of the atom was a far cry from the understanding that we currently have.

Svante Arrhenius defended his doctoral thesis in 1884, which was written in French. He explored the electrical conductivity of different substances in water. At no point in his thesis did Arrhenius use the term "ionization", although the term "dissociation" had been used frequently by the author to refer to the separation of salts when they were dissolved in water, including saying that water is responsible for dissociating these substances (Arrhenius, 1884). Arrhenius relied on the terminology used by Berthelot in 1879, which determined dissociation as a process by which substances break down into smaller ones (Berthelot, 1879).

In 1888, Von W. Ostwald published his work in German, which discussed what would come to be known as Ostwald's Dilution Law, using the term "dissociation" to refer to the process which the organic substances he studied were subjected to when they were diluted in water (Stock, 1997; Ostwald, 1888a; Ostwald, 1888b; Ostwald, 1888c; Ostwald, 1888d). It is necessary to make a brief contextualization about the knowledge of the composition of matter and the atomic models at the time, since they interfered in how scientific knowledge was presented in such historical moment (Kurniawan & Firman, 2018). Up to the defense of Arrhenius' thesis in 1884, the atomic model proposed in 1808 by John Dalton in his work "A New System of Chemical Philosophy" was presenting difficulties in its acceptance, due to the electrical phenomena discovered by the investigations of Michael Faraday in 1832 (who was responsible for the creation of the term ion) (Kurniawan & Firman, 2018). An interesting point for the discussion is that Dalton, in his work, did not use the term "dissociation" to refer to the separation of two atoms, but instead used "decomposition", even when he presented the idea of his atomic model, stating that atoms are indecomposable (Dalton, 1808a; Dalton, 1808b).

J. J. Thomson, in 1904, based on his studies on cathode rays carried out in 1887, proposed his atomic model. However, he did not mention the terms "dissociation" and "ionization", only proposing a model that predicted positive and negative charges in the atom (Kurniawan & Firman, 2018; Thomson, 1904). In the same year, Ernest Rutherford also published his book "Radio-activity", which brought, among other topics, a chapter on the electrical properties of gases, carrying out experiments similar to those of Michael Faraday. However, instead of applying a potential difference in an electrolyte solution, gases were used. This chapter was written before Thomson's publication of "Conduction of Electricity Through Gases", which dealt with the same subject. Interestingly, Rutherford used the word "ionization" to refer to the phenomenon, with the following addendum on the word "ion" made in a footnote in the book (Partridge, 1872; Rutherford, 2004):

> The word ion has now been generally adopted in the literature of the subject. In using this word, it is not assumed that the ions in gases are the same as the correspondent ions in the electrolysis solutions (Rutherford, 2004, p. 31).

In 1911, Rutherford published the article from his famous experiment involving a gold plate, which was fundamental to his atomic model, that predicted that the negative charges (electrons) were orbiting free around the atom, which had a large empty space. In this regard, he cited Thomson's work and explained what the flaws of his atomic model were (Rutherford, 2012). In 1912, Arrhenius, already awarded with the Nobel Prize for Chemistry since 1903 (Kauffman, 1990), published in the Journal of the American Chemical Society, after an invitation to edit the journal, an article in English where he commented on the Electrolytic Dissociation. However, Arrhenius here stated that sodium chloride undergoes an ionization process when it is dissolved in water, generating a different sodium from metallic sodium (Arrhenius, 1912).

In a quick reading of the article, this passage may go unnoticed in relation to its historical significance. At that time, Arrhenius was using the word “ionization” to explain his theory, responding indirectly to what Rutherford had written in his footnote in “Radio-activity”, where he had not assumed that the ions of ionized gases were the same as ions produced in an electrolyte solution. In addition, Arrhenius continued to use the term “dissociation” with the idea of separating one substance into others, including sodium chloride and acetic acid, stating that the latter undergoes dissociation when dissolved in water (Rutherford, 2004; Arrhenius, 1912). Until then, the word "dissociation" meant the separation of a structure, and the word "ionization" was presented simply as the formation of ions, not being mutually exclusive words. In the following year, 1913, when Niels Bohr proposed the atomic model that would come to be known as the Rutherford-Bohr atomic model, these two terms continued to be used in the same manner (Kurniawan & Firman, 2018; Bohr, 1913).

1914 – 1945: research from World War One to World War Two

This period is about the First and Second World Wars, from the years 1914 to 1918 and 1939 to 1945, respectively. The number of scientific publications had decreased from 1911 to 1918, a period related to the First World War, but it increased in the interwar period until 1937, years before the beginning of the Second World War. This phenomenon indicates that, to analyze any subject historically in these periods, one must take into account the political-military scenario of the time (Cornwell, 2004; Gingras, 2010; Barrett & Barrett, 1957).

The war scenario was also present when analyzing the journal’s countries. Germany had its physics newspaper publications significantly reduced during the beginning of World War Two until the end of it. When comparing with the United Kingdom and the USA, which had similar numbers in previous years, it is clear that they kept more frequent publications, rather than Germany (Gingras, 2010). In the case of Chemistry and Chemical Engineering, there was an increase in the number of publications in English in that period, followed by publications in German (Barrett & Barrett, 1957).

In the year 1914, two articles became relevant to this discussion. The first interesting case came from the article published by F. P. Worley, in 1914, severely criticizing Arrhenius' Electrolytic Dissociation Theory, called “The Decline of the Hypothesis of Ionic Dissociation”, where he called, in a pejorative tone, the ideas of Arrhenius “hypothesis” and “doctrine”. Although he had criticized the author, Worley used the terminology of "dissociation" and "ionization" in a similar way to what was advocated by Arrhenius (Worley, 1914). The second interesting case came from the article published by J. Kendall, also in 1914, in which he proposed an amendment to Ostwald’s Dilution Law, stating that the dissociation of a molecule from a substance does not happen spontaneously, but due to the impact of the solvent in the molecule. However, he continued to use the term “dissociation” with the meaning of separation in a structure and “ionization” as an ion formation (Kendall, 1914).

In general, when analyzing publications from 1914 to 1945 in English, one sees the use of words in a similar way to that used by Arrhenius and Rutherford, where "dissociation" means the separation of a structure and "ionization" means the formation of an ion (Worley, 1914; Kendall, 1914; Sheard, 1914; Dempster, 1916; Hughes, 1924; Smyth, 1925; Menzel, 1933; Neuberger, 1937; Bleakney; Walker & Smith, 1937; Kusch; Hustrulid & Tate, 1937; Westheimer & Shookhoff, 1939; Baughan, 1939; Hagstrum & Tate, 1941; Stevenson & Hipple Jr, 1942; Hipple & Stevenson, 1943; McCullough & Eckerson, 1945). When publications in German in the same period are analyzed, the same is perceived (Rümelin, 1914; Günther-Schulze, 1922; Becker, 1923; Kondratjeff & Semenoff, 1924; Lukirsky & Ptizyn, 1931; Kilde, 1936; Möglich, Riewe & Rompe, 1939; Jusuf, 1942).

Finally, it is worth mentioning two events between the limbo of the two wars. The first one that occurred was the foundation of the International Union of Pure and Applied Chemistry (IUPAC) by the union of chemists from the academic and industrial fields, motivated by the concerns that touched the chemical communication with regard to the nomenclature, terminology, standards and tabulated values used in chemistry, such as physical-chemical constants and atomic masses (Hibbert et al., 2009; Noyes & Thompson, 1960). The second event took place in 1923, with the publication of "Valence and the Structure of Atoms and Molecules" by Gilbert N. Lewis, where, among other things, he presented his concept of acids and bases, which depended now on donating and receiving electron pairs. In his work, Lewis continued to use the word "dissociation" only for the separation of a structure and "ionization" for the formation of an ion, both of which were often used throughout the text and could be considered as synonyms (Lewis, 1923).

1960 – 1974: The first IUPAC recommendations

From 1960 onwards, IUPAC published, through Pure and Applied Chemistry, technical reports, recommendations, symbols, lectures, conferences, symposia and workshops sponsored by IUPAC (International Union of Pure and Applied Chemistry, n.d.). When analyzing the 1960 period, it is noted that these publications generally used "dissociation" as the separation of structures and "ionization" as the formation of ions, which are not mutually exclusive or hierarchical (Kortüm; Vogel & Andrussow, 1960; Fells, 1962; Feitknecht & Schindler, 1963; Perrin, 1969; Marcus, 1969; McGlashan, 1970).

In 1960, tables with chemical equilibrium constants were published for the dissociation of organic acids in water, using the term "dissociation" again in a similar way to the one that Arrhenius used, while the word "ionization" did not even appear (Kortüm; Vogel & Andrussow, 1960). In 1963, tables of solubility constants of oxides, hydroxides and metallic salts in aqueous solution were published, in which neither the "dissociation" nor the "ionization" words were used (Feitknecht & Schindler, 1963). In 1969, recommendations and symbols of chemical equilibria in solution were published, which used the term "ionization" for the equilibrium constant of the self-ionization of water, without mentioning the term "dissociation" in the text (Marcus, 1969).

1975 – 1979: J. Dudley Herron's research

During the years 1975 to 1979, J. Dudley Herron published a series of works, in which he discussed the use of words and concepts in chemistry. In 1975, in the Journal of Chemical Education, J. Dudley Herron published an article called "What is Oxidation?", in which the author started a discussion about the care that must be taken when defining certain terms. He defended the idea that there is no pedagogical plausible reason for the simplification of oxidation and reduction phenomena to the mere loss or gain of electrons. Herron also pointed out that this could bring problems and misconceptions to the student, causing difficulties in learning (Herron, 1975).

In December 1977, Herron began other research through the Journal of Chemical Education, in which he wondered whether chemists used certain terms carefully or not. For this, he proposed a quiz with 9 chemical reactions, asking the respondents if the term that best represented each of the processes was "ionization", "dissociation" or another word. The willing respondents had to respond by letter, also identifying their background in chemistry. The result of this research quiz was published in June, 1978, and showed that there is no consensus on the definition of the word "ionization" among the chemists participating in that research, just as there is no consensus in chemistry textbooks. Herron's research included High School teachers, graduate students, university faculty, undergraduate students, chemists, and secondary school teachers (Herron, 1977; Herron, 1978).

For Herron, this was a problem, as it was a sign that teachers did not use the words "ionization" and "dissociation" distinctively in teaching, in addition to not explaining the meaning of those words in the context of the class in which they were teaching. This made the use of these words confusing to the student, a fact that could even produce more epistemological problems when the student came across the same terms being used in another context, such as, for example, by another teacher in higher education classes (Herron, 1978).

In the following month, D. R. Driscoll responded to Herron's work, making his considerations about the definitions of the words "dissociation" and "ionization", in addition to "hydrolysis", "reduction" and "oxidation". For Driscoll, ionization involved the formation of ions, which could not be originally in the structure of the substance, emphasizing that the dissolution of NaCl in water was not an ionization process, but a dissociation, which he defines as the separation of molecules in particles already present in the structure (Driscoll, 1978). The statement that the dissolution of NaCl in water was not an ionization process did not meet Arrhenius' own definition, as seen previously (Arrhenius, 1912).

In addition to the attempt to define the words "ionization" and "dissociation", Driscoll also presented a Venn diagram with the words "dissociation", "ionization", "oxidation", "reduction" and "hydrolysis", trying to exemplify with chemical equations some combinations of them, as well as reactions that should be classified by just one of these words. Driscoll questioned whether there could be a hydrolysis that was not a dissociation, or also an ionization that was not a dissociation, reduction or oxidation. Therefore, Driscoll questioned how far they should be going and what the limits were when defining a term for chemistry students, before learning became counterproductive (Driscoll, 1978).

In 1979, Herron published an article called “Hey, Watch Your Language!”, in which he once again discussed and emphasized the care that the teacher must take with the terms during teaching. Herron exemplified the dissolution of HCl in water, saying that it is dissociated to form hydrogen ions. He stressed that it must be said that the dissolution produces hydrogen ions, and not that it produces hydrogen from water, since one could mistake “hydrogen” for H_2 or H, while the teacher would like to refer to H^+. The author also said that HCl, when dissolved in water, undergoes both an ionization, since it forms ions, and a dissociation, since the molecule separates. Herron treated these two phenomena as simultaneous and said that, if treated as non-simultaneous or mutually exclusive phenomena, it could cause difficulties in the student's learning (Herron, 1979).

1994: IUPAC’s manifestation on dissociation and ionization

In 1994, IUPAC finally commented on what would be its recommendation for the definitions of "ionization" and "dissociation", through the "Glossary of Terms Used in Physical Organic Chemistry", prepared for publication by P. Muller (Muller, 1994).

Hence, “dissociation” was defined as:

> (1) The separation of a molecular entity into two or more *molecular* entities (or any similar separation within a polyatomic molecular entity). Examples include *unimolecular heterolysis* and *homolysis*, and the separation of the constituents of an *ion pair* into free ions. (2) The separation of the constituents of any aggregate of molecular entities. In both senses, dissociation is the reverse of *association* (Muller, 1994, p. 1007).

While “molecular entity” was understood as:

> Any constitutionally or isotopically distinct *atom, molecule,* ion*, ion pair, radical, radical ion complex*, conformer etc., identifiable as a separately distinguishable entity. Molecular entity is used in this glossary as a general term for singular entities, irrespective of their nature, while chemical species stands for sets or ensembles of molecular entities. Note that the name of a compound may refer to the respective molecular entity or to the chemical species, e.g., methane, may mean a single molecule of CH_4 (molecular entity) or a molar amount, specified or not (chemical species), participating in a reaction. The degree of precision necessary to describe a molecular entity depends on the context. For example, "hydrogen molecule" is an adequate definition of a certain molecular entity for some purposes, whereas for others it is necessary to distinguish the electronic state and/or vibrational state and/or nuclear spin, etc. of the hydrogen molecule (Muller, 1994, p. 1142).

"Ionization" was defined as:

> The generation of one or more ions. It may occur, e.g., by loss of an electron from a neutral *molecular entity*, by the *unimolecular heterolysis* of such an entity into two or more ions, or by a heterolytic substitution reaction involving neutral molecules, such as.
>
> $$CH_3CO_2H + H_2O \rightarrow H_3O^+ + CH_3CO_2^-$$
>
> $$Ph_3CCl + AlCl_3 \rightarrow Ph_3C^+ + AlCl_4^- \text{ (electrophile assisted)}$$
>
> $$Ph_3CCl \rightarrow Ph_3C^+Cl^- \text{ (ion pair, in benzene)}$$
>
> The loss of an electron from a singly, doubly, etc. charged cation is called second, third, etc. ionization. This terminology is used especially in mass spectroscopy (Muller, 1994, p. 1127).

Their definitions do not consider the words "dissociation" and "ionization" as synonyms, mutually exclusive or hierarchical. For example, the third equation above, which refers to the ion pair in benzene, can be both an ionization and a dissociation, showing that the terms are not exclusive. On the other hand, the last example of an atom losing an electron to form a cation is an ionization, but cannot be considered a dissociation, seeing as an electron is not a molecular entity. Thus, IUPAC's definitions in 1994 were similar to the form used by Arrhenius, Rutherford and all others analyzed so far in the present work, the only exception being the definition proposed by Driscoll (1978).

1997 - 1998: the work of Emeric Schultz

In 1997, Emeric Schultz published an article in the Journal of Chemical Education called "Ionization or Dissociation?", in which there was a resumption of the discussion on the meaning of these two concepts, although he did not consider past work. Schultz reviewed several higher-level academic books on the definition of the two words, discovering that there is no consensus in the literature and, in his conclusions, defended the idea that there needed to be a clearer distinction between the two processes in textbooks and in classrooms. Schultz criticized authors who used the concepts in a similar way and, in his personal opinion, believed that using the term "ionization" was more suitable for a substance that reacts with water during its dissolution (such as, for example, a weak acid). Consequently, an acid-base neutralization could be called deionization. Dissociation, in turn, would be a general form for all other common reactions in water, such as precipitation of salts or solvation (Schultz, 1997).

To argue his ideas, Schultz (1997) did not comment on IUPAC's recommendations from previous years, which did not agree to his proposals, nor did he take into consideration past research on the topic. The author mentioned Chemistry as being a language, and because of that, the use of the word "dissociation" could cause confusion because of its everyday meaning. Schultz emphasized that "to dissociate" would be to separate what is associated, giving a connotation that one would be separating the components that already existed in a given chemical species. According to Schultz, the components of HF are neither H^+ nor F^-, and the word "dissociation" is insufficient to describe the phenomenon. This connotation had not been considered by IUPAC in 1994, whose definition of "dissociation" did not consider the components of the initial molecular entity. In a period of just three years, there was a disagreement between Schultz's ideas and IUPAC's recommendations.

Schultz said that Arrhenius' theory of acids and bases presupposed the presence of water, and that using the term "dissociation" for this is, in his view, disturbing. The author said that the word "dissociation" was adequate in the past to describe species in aqueous solution and, at the date of his work, it was no longer sufficient, although this is, admittedly, an assumption of his own (Schultz, 1997).

In the following year, David L. Adams commented in the journal about Schultz's work, congratulating him for finally raising this discussion, while also proposing a general definition of "ionization" and "dissociation", and another specific definition for aqueous solutions, where ionization would be a chemical transformation involving H_3O^+, OH^- or both. Dissociation would then be a change involving the separation of a substance without the formation of H_3O^+ or OH^- (Adams, 1998). Although the author used the adverb "finally" to congratulate Schultz, a historical survey showed that this discussion had already been raised by Herron in the late seventies, which apparently was not considered by Adams (Herron, 1977).

2000 - Today: The studies on teaching acids and bases

Nowadays, the discussion about the definitions of the terms "dissociation" and "ionization" in the teaching of chemistry has been revived a few times, although not as directly as in the works of Herron, Schultz and Adams (Herron, 1977; Schultz, 1997; Adams, 1998). The two terms are still problematic today in the teaching of solutions, chemical equilibrium, and acids and bases. In recent years, several articles in the field of education have identified these epistemological problems, as well as the irregular use of terms by teachers and textbooks, although they did not focus down the problem on the two words specifically (Quílez, 2019; Kousathana; Demerouti & Tsaparlis, 2005; Furió-Más; Calatayud & Bárcenas, 2007).

In 2004, Gouveia and Valladares sought to verify the prior knowledge of Chemistry of High School students through concept maps, in which one of the subjects was acids and bases. At first, one of the students had difficulties to differentiate "dissociation" from "ionization". Since that research had a verification approach, the students had already had contact with the subject, and this differentiation was a learning problem that the authors aimed to improve through the use of concept maps. In the teaching of solutions, the difficulty also appeared. In 2007, an investigative laboratory approach was used by Tien, Teichert and Rickey. Students from research universities, undergraduate institutions and community college had to describe and draw in advance what they thought would happen in the dissolution of sodium chloride and sugar in water, subsequently carrying out the experiment and reviewing their ideas. Although the authors encountered more serious errors in their research, one of the students was not able to differentiate "ionization" from "dissociation", as had already been observed in previous research (Gouveia & Valadares, 2004; Tien; Teichert & Rickey, 2007).

In 2005, Kousathana, Demerouti and Tsaparlis carried out a questionnaire with High School students, based on previous research that revealed the biggest epistemological problems in the subject of acids and bases. The authors presented a historical approach to how Chemistry had evolved in the classification of acids and bases since Lavoisier, Arrhenius, Brønsted-Lowry and Lewis, to then compare to the students' conceptions. In one of the questions, it was noticed that there was difficulty from part of the students to differentiate between “dissociation” and “ionization”, as in the previous cases. To the authors, there is a clear difference between the terms, and their definitions were similar to the ideas of Schultz and Adams, in addition to mentioning the fact that textbooks used the words as synonyms (Kousathana; Demerouti & Tsaparlis, 2005).

Two years later, Furió-Más, Calatayud e Bárcenas published a study in which they applied several questionnaires to High School students as well as interviews, in order to verify students' knowledge about dissociation, atoms, ions, ionic and covalent substances, and the conductivity of solutions. In this study, the authors showed that students did not differentiate “ionic dissociation” from “ionization”, and most of them used the Arrhenius concepts for acids and bases, stating, for example, that the hydroxyl of methanol is ionized in aqueous solution. According to the authors, the terms are different, and they were used according to the definitions of Schultz and Adams (Furió-Más; Calatayud & Bárcenas, 2007).

More directly, Ekiz, Bektas, Tuysuz, Uzuntiryaki, Kutucu, and Tarkin revived the discussion of the meaning of “ionization” and “dissolution” in 2011, evaluating the understanding of future Chemistry teachers. This was done by means of a questionnaire similar to that of Herron, as well as by the analysis of representative drawings of the phenomena. The authors treated the words "dissolution" and "dissociation" as synonyms, and claimed that the future teachers were unable to distinguish between "ionization" and "dissolution" and represent them by means of illustrations (Ekiz; Bektas; Tuysuz; Uzuntiryaki; Kutucu & Tarkin, 2011)

Although Herron initiated the questioning about the definition of the two words in 1977 through his questionnaire, being answered by Driscoll in 1978, with IUPAC defining the terms in 1994, Schultz making his inquiry in 1997 and Adams proposing broader definitions in 1998, it is observed that there are still epistemological problems arising from the irregular use of the two terms. In one of the most recent mentions of the difficulty generated by the two words, Quílez published a paper in which he categorized several terminological sources that make it difficult to learn chemistry. The author highlighted “ionization” in the category of “poor or incorrect definitions given by textbooks and teachers”, citing several of the authors already mentioned here. According to Quílez, textbooks aggravate students' difficulties when they make their definitions and explanations very vaguely or are unable to establish connections with other concepts that were already learned by the student (Quílez, 2019).

According to the author, students are not always able to express their understanding of chemistry through oral and written communication. Teachers, who would be tasked with solving this difficulty, are not always prepared to address the linguistic aspect and to teach the scientific language. Through the categorization of the chemical terminology that generates these problems, Quílez aimed to assist teachers in training to deal with this obstacle, in addition to expanding research and studies with this kind of focus, which, although had already existed for a long time, have not been discussed very often recently (Quílez, 2019).

Based on the most recent reports, it is evident that the terms "dissociation" and "ionization" are still sources of epistemological problems in chemistry, mainly in the teaching of solutions, chemical equilibrium and acids and bases. In addition, there is no consensus between the historical use of terms, academic publications, textbooks and in IUPAC’s recommendations, which remain unchanged to this day with regards to the two words (International Union of Pure and Applied Chemistry, n.d.). We emphasize that, with IUPAC being currently the leading authority in chemistry nomenclature, researchers, teachers and writers should abide by their guidelines and recommendations, which can be easily be read in IUPAC’s Gold Book website. Several definitions for other words are also available, in an attempt to standardize and solve misconceptions in the language of chemistry.

Final Considerations

Bearing in mind all of the aspects presented, it is possible to state that, historically, the use of the term “dissociation” was subsequent to the use of the word “decomposition”, which was used by Dalton to refer to the separation of atoms when he presented his atomic model in 1808. The author also cited the term “indecomposable”. In 1834, when studying electrical phenomena, Faraday established the term "ion", but "ionization" did not become a common word for many years.

Later, in 1884, Arrhenius used “dissociation” to refer to the separation of salts dissolved in water, while Ostwald, in 1888, used the same word to describe the dissolution of organic substances. Although in 1904 Thomson did not use both words to propose his atomic model, Rutherford, in the same year, used the term "ionization" to refer to the formation of ions in gases. With the proposition of Rutherford’s atomic model in 1911, Arrhenius used the word "ionization" in the following year, when referring, unlike Rutherford, to the dissolution of sodium chloride in water. From that moment on, in several other research on solutions and gases, the terms were used in an irregular manner. In 1923, Lewis used the term “dissociation” for the separation of chemical entities and “ionization” for the formation of ions, a usage that was common throughout the first half of the 20th century.

In the sixties, IUPAC published its first recommendations, in which the two words have similar meanings to those used by Arrhenius, thus, the words were not mutually exclusive or hierarchical. In the seventies, the first evident appearance of the problematization of the irregular use of "dissociation" and "ionization" occurred in Herron's publications, which also used the terms as IUPAC recommended. During this period, Driscoll responded to Herron with a new perspective, stating that "dissociation" already assumed the existence of ions in the structure before they were even separated.

In 1994, IUPAC formally defined the two terms, maintaining its understanding that they were independent and not hierarchical terms. Later, in 1997, Schultz problematized the two words based on the irregularity of textbooks, adopting a point of view analogous to that of Driscoll. Like Adams, who responded shortly afterwards, Schultz proposed that "dissociation" should be used in cases of interaction with water, while "ionization" should be used in cases of a reaction, with the production of hydronium, for instance. To this day, there are irregularities in the definitions and use of those terms, and they are still sources of epistemological problems in chemistry.

Future research could benefit from exploring once again the questions elaborated by Herron and Schultz, after many years of this debate having been proposed. Nowadays, are textbooks still broad in their definitions and use of both words? Are they in accordance to IUPAC’s recommendations? Is the historic approach being considered in teaching? What do chemists and chemistry teachers gain in naming chemical reactions “dissociations” and “ionizations”? These questions, once enlightened and further discussed, may assist in avoiding misconceptions related to both terms, helping solidify the language of chemistry.

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