Journal of Modern Education Review, ISSN 2155-7993, USA
July 2015, Volume 5, No. 7, pp. 686–693
Doi: 10.15341/jmer(2155-7993)/07.05.2015/006

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Conceptions of the First-Year License Students on the Concept "Chemical Bond"

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Abstract: A student not mastering concepts and models related to the concept of chemical bond is not entitled to construct a coherent chemical and procedural knowledge. The objective of this work is to highlight the models that university students, at the beginning of the cycle of the license, associated with this concept and therefore how they represent it. For this, we asked a population of 79 students, studying Chemistry Material Sciences (MSC), to define the concept of chemical bond and two related concepts: the valence and the octet rule, after intense courses on these concepts. Analysis of obtained data showed that this concept is far from to be mastered. The most students remain in declarative knowledge and do not exceed the model of covalent bond. We also found several confusions and amalgams about this concept and those associated, such as octet rule and valence.

Key words: conception, chemical bond, valence, octet rule

1. Introduction

> "Among the concepts that melt chemistry, the chemical bonding plays a central role. It is in some ways the engine around which a science comes alive. It seems indispensable to point that the chemist, often, considered it as a fact of nature, forgetting that it is not nature that produces concepts but the man's spirit".

(Vidal, 1989)

> Chemical bonding, fundamental concept in the heart of the structural base interface of chemistry, allows understanding the mechanisms ensuring the cohesion of the material and thus its description at the microscopic scale. Indeed, it is a base concept of material sciences introduced at secondary school via the model of covalent bonding. Thus we read in the textbook published in Morocco in 2009: "The covalent bond is established through the sharing a pair of electrons between two atoms, each of them participating by one electron".

(Farah et al., 2009)

The deepening of the concept continues at the university where he is one of the basic concepts in science.

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Indeed, among the first lessons taught in the majority of scientific curses at Moroccan university, there is a training module on the chemical bond. The purpose of this module is to explain the different definitions and models related to the concept of the chemical bond and the associated concepts. In fact, like all scientific concepts, the chemical bonding works in relation to other concepts. It is a node in a coherent and organized network consisting of several concepts such as polarity of bonds, valence, and atomic orbital, molecular orbital, the octet rule...The importance of chemical bonding concept is also reflected by the interest manifested by didactic science researchers. Indeed, many studies have shown that this concept is perceived as difficult to teach and even harder to capture because its effective understanding can be hindered by multiple difficulties. For this reason, our goal is to highlight the models that university students, at the beginning of the cycle of license, associate with this concept.

In the first phase of this work, which consists of a literature search, we have attempted to identify various obstacles designs and sources of learning difficulties. Thus, for example:

Secondary school students:

- Have difficulty to go further in the concept of shared electron pair to define the chemical bond (Ünal et al., 2010; Özmen 2004; Taber, 1997).
- Limit the type of bond to two: covalent and ionic bonding. They consider that the metallic bond, hydrogen and Van Der Waals forces are only forces (Robinson, 1998).
- Consider the ionic bond as electrons transfer instead of an attraction of ions resulting from electron transfer (Robinson, 1998).
- Confuse the covalent and ionic bonding (Ünal et al., 2010).
- Think that all the atoms in a molecule should check the octet rule (Coll & Treagust, 2003).
- …

At the high school students' level, learners:

- Ignore the bond between molecules (Taber, 2011; Cokeliz et al., 2008; Cokeliz & Dumon, 2009, 2005).
- Think that the covalent bond is an equal sharing of electron pair (Şenol & Ayhan, 2013; Hazzi et al., 2011; Nahum Levy et al., 2010, 2007).
- Limit the type of bond to two: covalent and ionic (Taber, 2011; Özmen, 2004).
- Make a confusion between ionic and polar covalent bonding (Taber, 2011; Richard, 2008; Cokelez & Dumon, 2009, 2004; Ünal et al., 2006; Özmen, 2004; Coll & Treagust, 2003, 2002).
- Make a confusion between intramolecular and intermolecular bonding (Şenol & Ayhan, 2013; Richard, 2008; Cokeliz, Dumon, 2009; Cokeliz et al., 2008; Özmen 2004). The same results were already identified by Peterson and Treagust (1989), Baker and Millar (2000).
- Believe that covalent bonds are weaker than ionic bonds (Burrows & Reid Mooring, 2014; Özmen, 2004).
- Believe that the intermolecular bonding is stronger than the intramolecular bond (Cokeliz et al., 2008). Similar results have been noted by Goh (Goh et al., 1993).
- …

At the university level, students:

- Have difficulties to conceive stable model other than of Lewis (Hazzi et al., 2011; Nahum Levy et al., 2010, 2007; Taber, 2000).

- Consider that the intermolecular forces are existing forces within a molecule (Treagust & Dhindsa, 2009).
- Make a confusion between ionic and polar covalent bonding (Dhindsa & Treagust, 2014; Burrows & Reid Mooring, 2014).
- Think that all the atoms in a molecule should check the octet rule (Hazzi et al., 2011; Nahum Levy et al., 2010, 2007, Taber, 2001).
- Make a confusion between atomic and molecular orbital (Kaddari, 2005; Taber, 2001).
- Believe that the hydrogen bond is strictly intermolecular (Levy Nahum et al., 2010).
- Believe that the failure of the bond releases energy and its establishment involves an energy gain (Cooper & Klymkowsky, 2013; Ömer Eren, 2010).
- …

The conducted literature search revealed that the related concepts are also sources of difficulties:

- The polarity of a molecule depends on the number of valence electrons of atoms and not on their electronegativity (Pabuccu & Geban, 2006).
- The polarity of a molecule is due to dipoles which are generated by unbounded electrons of an atom (Treagust & Dhindsa, 2009).
- The atoms of a molecule should check the octet rule (Taber, 2001).
- Confusion between atomic orbital and energy level (Taber, 2001).
- The atomic orbital is the trajectory of the electron (Kaddari, 2005; Taber, 2001).
- Confusion between atomic and molecular orbital (Kaddari, 2005; Taber, 2001).
- Difficulties of designing stable models other than the octet rule (Taber, 2001).
- …

So it appears from this study that the difficulties preventing the effective acquisition of the concept of chemical bonding are numerous. The sources of these problems are conceptual confusions, the persistence of Lewis model. In the work presented here, we tried to know how students, in their first academic year, represent the concept of the chemical bond after an intense teaching of this concept.

2. Methodology and Method

To approach the conceptual universe of first-year university students related to chemical bonding concept and associated concepts, we used an approach that consists on “definition study”. The aim is to involve the students in a process of concentration and reflection for a more thoughtful and structured concepts mental image and then to have a better understanding of their conceptual universe (Kaddari, 2005). In addition, the structure of sentences can highlight the logical relationships within the meaning of Schaefer involved during conceptualization (Schaefer, 1994). Note that we are well aware that scientists proceed little by definition because the concepts are not usually ordered in a linear sequence. However a concept, even scientific, has many hierarchical definitions depending on used models, their scopes and fields of action. By this method, we aim also to list concept models that are appropriated by surveyed students. To do this, we asked the students, subjects of our study, to express their definitions of the chemical bond and its associated concepts such as valence and octet rule. The data analysis was performed as follows: we have identified the sub-definitions (formulation having a literal sense) in each proposal (global definition of a student) and we have highlighted the corresponding keyword. After calculating the percentage of keywords on each separate formulation, we conducted a categorization of all formulations and we reported each category corresponding keyword in a table. The survey was conducted among a population of 79 students, enrolled in their first academic year on sciences of chemistry materials, who already followed courses on the chemical bond. The survey was given to students at the beginning of class session and was recovered after a half hour. We also informed the students that the survey is anonymous and is not subject to any assessment.

3. Results

3.1 Study of Chemical Bond Definition

The data consists of 70 copies of 79 students. Nine students, which represent 11.4% of the population surveyed, gave no definition. As we indicated above, the students proposed definitions are fragmented into sub-definitions and grouped in categories characterized by a keyword. Results are shown in Table 1.

Table 1 Sub-definitions of Chemical Bond Concept

Categories	Keyword	Formulations example	% Sub-definitions	% Respondents
I	Connection or relation ship	• Connection (relationship) between two or more atoms (a). • Connection between two or more molecules (b). • Relationship between the chemical elements (particles) (c).	46.4 5.2 8.3	64.3 7.2 11.4
II	Type of connection	• There are two types of bonds σ and Π (a). • There are three types of bonds: covalent, ionic and metallic (b).	15.4 6.2	21.4 8.6
III	Electrons	• The sharing of electrons.	8.3	11.4
IV	Electrostatic Force	• An electrostatic force that binds the atoms or ions.	3.1	4.3
V	Various		7.2	10

In the first category, we gathered all formulations including the term "bond" or the term "relationship" between two entities. These formulations cited by more than 82% of the surveyed population have about 60% of all proposed sub-definitions. In fact, these formulations serve as the introductory definition of the chemical bond; they express the idea of an association between two entities which can be atoms (sub-definition (a)) molecules (sub-definition (b)) or particles (sub-definition (c)). The first reading of the results shows that the defined learning objectives are only partially achieved. Indeed, the percentage of students (64%) who chose the sub-definition (a) remains below expectations. In fact, at this level of the curriculum, it was expected that the concept of the chemical bond is related, in a systematic way, to the combination of two atoms. It should also be noted that a considerable percentage of surveyed students have used the term (relationship) to describe the bond (sub-definitions (a) and (c)) and the terms element or particle instead of the atom or molecule (sub-definition (c)). This high percentage indicates that the problem goes beyond language difficulties generally attributed to Moroccan students. It seems to point more the fact that chemical nomenclature is not well mastered, observation that have already mentioned by other researchers (Taber, 2001). Moreover, less marked conceptual difficulties are reflected by the sub-definition (b), which states that the connection is established between two molecules. In fact, knowing that the surveyed students have not yet studied the concept of intermolecular bonding, this formulation highlights the confusion between atom and molecule already mentioned by other researchers (Harrison & Treagust, 2000; Cokelez & Dumon, 2004a, Taber, 2001; Kaddari, 2005).

In category II, surveyed students have tried to give more details on the concept by explaining the different types of chemical bonding. Then 21% of surveyed students (15.4% of all proposed formulations) argue that there are two types of chemical bond (σ and π) (sub-definition (a)). However, 8.6% of students (6.2% of formulations) assume that the types of chemical bonding are three in number: the covalent, ionic and metallic (sub-definition (b)). This shows that the difference between type and nature of the bonding is not as clear as one can think. It should also be noted, the absence of the concepts of inter-molecular bond, which confirms our initial statement, the atom-molecule confusion, noted in the first category.

In the third category, characterized by the keyword "electrons", the chemical bond is defined as the sharing of two electrons (11.4% of respondents and 8.3% of formulations). These students reduce the definition of the chemical bond in the covalent bond. This can be explained by the fact that it is the first definition of the concept taught in high school and therefore reflects the persistence of pre-acquired models. This result is consistent with our bibliographic data where several researchers (Ünal et al., 2006; Özmen, 2004; Taber, 2001) indicated that the early introduction of the covalent bond, which is a partial approach of the chemical bonding concept, is an obstacle to learning the different models of chemical bonding.

According to the definitions grouped in category IV, 4.3% of students under investigation and representing 3.1% of all proposed formulations, consider that the chemical bond is an electrostatic force that binds the atoms or ions. These students thus refer to ionic bond, to which they limit their definition of the bond.

In the category V, we have listed the formulations cited with insignificant percentages. These are diverse and range from the qualitative description (the bond is established to stabilize the molecule) to the more technical knowledge (the bond is established through the recovery of two atomic orbitals) through metaphors (the bond is a bridge connecting two or more atoms). Note that only one student among 70 referred to the concept of recovery of atomic orbital's, which clearly shows the absence of the quantum model of the bond in the conceptual universe of the surveyed population.

It appears from this study that the majority of students are limited to an introductory definition which is a qualitative description of the chemical bonding concept. This has led in very significant percentages of descriptive formulations compared to all cited formulations and in the high percentage of respondents who proposed these formulations. This statement is also supported by the fact that about only 30% of students have tried to reach the level of procedural knowledge. Indeed, 11.4% have adopted the covalent bond model and 21.4%, who mentioned Π and σ bond types, made reference to the quantum model but with an incoherent way. It seems that despite intense education of the chemical bond, the students did not really understood the conceptual basis of this concept.

3.2 Study of the Valence Definition

The corpus of data reveals 26 of non-responses or 33% of the surveyed population. In Table 2 are grouped the various formulations.

From Table 2, the most prominent response of the definition of the valence is "valence is the boundary layer" (category I). It is cited by 47.2% of respondents and 41.7% of all proposed definitions. This suggests that about half of the surveyed students did not distinguish between the concept of valence and the concept of the valence layer of an atom. Also confusion between the concept of valence and the binding was detected: "valence is a strong bond" (9.4% of respondents and 8.3% of all citations).

Table 2 Sub-definitions of Valence

Categories	Keyword	Formulations example	% Sub-definitions	% Respondents
I	Layer	• The peripheral layer.	41.7	47.2
II	Electron	• Number of unpaired electrons of an atom.	30	34
III	Bond	• The number of single bonds an atom can form. (a) • This is a strong bond. (b)	10 8.3	11.3 9.4
IV	Rare gas	• The tendency of an atom having a configuration of the rare gas.	5	5.7
V	Various		5	5.7

The definitions listed in categories II, III, IV consist of a plurality of more or less correct and distinct definitions:

- "The valence is the number of single electrons of an atom" (34% of respondents, category II).
- "The number of single bonds an atom can form" (11.3% of respondents, category III).
- "The valence is the tendency of an atom to have a noble gas configuration" (5.7% of respondents, category IV).

This diversification can be justified by the large number of different definitions related in the literature references representing the knowledge to be taught on this concept (Pannetier, 1969; Saurd et al., 1981; Didier 1997, Arnaud, 1998; Friedli, 2002). Moreover, the highly significant difference in the percentage of sub-definitions citations of Category I and Category II, III and IV shows that students stop at the general descriptive level of the concept.

In the category V, we gathered all sub-definitions cited with a very low percentage. These sub-definitions are pointing generally conceptual confusions between nucleus and atom "The external level of a nucleus" (3.8% of respondents) and electronegativity and valence "valence is the tendency to give or receive positive or negative charges" (1.9% of respondents).

It appears from this study that the concept of valence is far from being acquired by the surveyed students. Indeed, the very significant difference in the percentage of sub-definitions citation of category I and categories II, III and IV shows that most students stop at a wrong general descriptive level of the concept.

3.3 Study of Octet Rule Definition

The first observation is the increase in the percentage of non-responses (40 of non-responses) so 50% of the surveyed population did not give definitions to the octet rule. The various proposed definitions are listed in Table 3.

Table 3 Sub-definitions of Octet Rule

Categories	Keyword	Formulations example	% Sub-definitions	% Respondents
I	Eight Electrons	• An atom must be surrounded by eight electrons. • An element (substance) must be surrounded by eight electrons. • An energy level must be surrounded by eight electrons.	36.7 3.3 3.3	56.4 5.1 5.1
II	Rare gas	• Atoms tend to have the configuration of rare gas.	38.4	59
III	Various		18.3	28.2

The first category includes various proposals expressing the idea of an entity surrounded by eight electrons. It should be noted that for 56.4% of surveyed students, the entity is equivalent to an atom, for 5.1% the entity seems to be a substance or element and for 5.1% it corresponds to a level of energy. The last two sub-definitions highlight two types of difficulties: language (translated by the indiscriminate use of terms as relation, element, particle) and conceptual (reflected by the third sub-definition which states that the energy level must be surrounded by eight electrons). The energy level is confused with the atom. These difficulties, though they were noted just for a small percentage of students, attracted our attention because firstly there are basic chemistry concepts, and secondly, the population surveyed is in training focused on materials science. We also note that more than half of respondents (59%) have tried to give a supplement to the definition of the octet rule, by indicating that each atom tends to have the configuration of rare gases (category II). 28% of respondents gave a variety of responses such as:

- The tendency of the molecule to have a stable state.
- Each atom must be surrounded by eight single bonds.

In this work, we tried to approach the conceptual universe of the students, at the beginning of the cycle of license, related to the basic concepts in chemistry: chemical bonding and valence octet rule. The purpose was to know, after teaching the basis of the chemical bond, what are the models used and how students represent these concepts and then to have an overview on the achievement of learning objectives. To involve students in a process of reflection, we adopted, as a methodology, the categorization and the structuration of sentences. At the end of this study we have identified several findings: the majority of students are limited to an introductory definition and therefore remain at the declarative level of knowledge. The most appropriated model of the chemical bond is the covalent bond, which may constitute an obstacle to deepen knowledge about the quantum model. However, it seems that the quantum model, which is the primary objective of chemical courses, didn't attract student's attention and even the relationship between this model and chemical bond has not been understood. Also, valence and octet rule are far from to be integrated and acquired. We also identified several confusions related to the concepts atom and molecule. Finally, it should be noted that the obtained results are consistent with those of the literature.

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