Science Education International
32(4), 308-310
https://doi.org/10.33828/sei.v32.i4.5

ORIGINAL ARTICLE

Teachers' Misconception Concerning Valence and Valency in Chemistry

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ABSTRACT

A study on the misconceptions developed or held by teachers related to the two terms valence and valency was undertaken. A total of 48 teachers (26 males and 22 females) teaching the chemistry component of science subject to 14–16-year-old students, in 48 schools affiliated to one district, were randomly selected for the study by taking one teacher from each school. One session was devoted for administering the questionnaire among the teachers and second session (with a gap of 1 day) was for addressing the teacher's misconceptions. From the analysis of the responses, it was found that the two terms although they have the same meaning were misconceived as having different meanings. Due to this, a misleading relationship between the two terms was discovered. Even the highest numerical value of valence was misconceived. The possible reasons for these misconceptions were identified. A simple, brief, and precise description of the concepts was presented to remove the misconceptions of the teachers.

KEY WORDS: combining capacity; bonds; electrons

BACKGROUND HISTORY

In 1852, Edward Frankland proposed that an element has a definite capacity or power to combine with other elements. This chemical meaning of combining power of element was derived from German "Valenz" which has its etymology from Late Latin "Valentia" (capacity and power). The English words valency and valence were also formed from the same Latin word. Hence, the two terms valency and valence became common usage for this concept. However, American and Canadian chemists prefer to use the word valence over valency.

To quantify the capacity of combining, an operational definition of valence was given which states that valence is equal to the number of hydrogen atoms or number of chlorine atoms with which one atom of the element combines. A broader definition of valence adopted by IUPAC in 1994 is: "The maximum number of univalent atoms that may combine with an atom of the element under consideration, or with a fragment, or for which an atom of this element can be substituted" (McNaught and Wilkinson, 1994. p. 1175). Since the electrons of the outermost shell (in some cases penultimate shell also, as in transition elements) are involved in the chemical combining of elements. This definition of valence is based on the classical definition of the words valence or valency.

Following the development of the Lewis theory of bonding, which postulates that it is the electrons which are involved in bond formation, another definition by Lewis (1923) based on electron was given which is: Valence is the number of electrons gained, lost, or shared by the atom of an element with the atom of another element so as to complete the octet.

Hence, the concept of valency has been correlated with the number of bonds and also to oxidation states. However, the evolution of this concept has led to some ambiguity and misleading descriptions in some cases. Some of the workers have highlighted this. In a study done to identify the influence of chemistry textbooks in the process of teaching and learning of concepts, particularly of chemical valency by Tejada et al. (2015), it was observed that the concept of valence in the textbooks was introduced to students in an incomplete and static form. In another study by Smith (2005), it has been observed that some authors equate valency with oxidation number while others seem to use valence, covalence, and oxidation number as interchangeable terms for main groups chemistry. Parkin (2006) has explained that valence, oxidation number, and formal charge are fundamentally different concepts.

However, the author during his interaction with Indian chemistry teachers in different training programs observed totally different conceptions of teachers about the terms valency and valence in chemistry. This has prompted the author to carry out an empirical study to find out the misconceptions, identify possible causes, and present a lucid explanation to remove the misconceptions.

Objectives

The objectives are as follows:

1. To find out teachers' misconceptions about valence and valency in chemistry
2. To analyze the background of the reasons behind the misconceptions

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3. To remove the teachers' misconceptions by presenting a simple and precise description of the terms.

METHODOLOGY

A total of 48 teachers (26 males and 22 females) teaching the chemistry component of science subject to 14–16-year-old students in 48 schools affiliated to one board (Central Board of Secondary Education, New Delhi, India) were randomly selected for the study by taking one teacher from each school. The average of their teaching experience was 12.6 years. Teachers were informed that their responses will be used for research study only and their identity will not be disclosed. The teachers had gladly volunteered to act as respondents. These teachers were attending a training program of 5 days duration.

The following questionnaire was administered among the selected teachers by visits to their schools or by requesting the teachers when they were attending training programs to write their responses. A panel of experts was used to establish the validity and reliability of the questionnaire. The panel included a team of ten experts from the field of chemistry and actively engaged in teaching and research related to chemistry education. The experts had opined that the questionnaire was valid and reliable.

1. What is the meaning of the word valency in chemistry?
2. What is the meaning of the word valence in chemistry?
3. Are there any differences between valency and valence? Explain your answer
4. What would be the valences or valencies for chlorine having a $3s^2 3p^5$ electronic configuration? Write the method you followed
5. Can the valence or valency be more than four? Give answers for both the terms, with reasons.

The responses of the teachers were analyzed. The responses carrying nearly the same meaning were joined together for interpretation purposes. The analysis and interpretation were done by the investigator only.

On the basis of misconceptions, confusion, and ambiguities observed, a simple and precise description was prepared and presented to the teachers to remove their misconceptions, in the second session organized with a gap of 1 day after the first session. During the presentation, some doubts raised by the teachers were addressed on the spot. The description developed was also sent to the school of teachers who had not attended the training program, with the request to send their observations by post.

RESULTS AND DISCUSSION

The analysis of the responses of the question No.1 showed that 42 teachers had given the classical definition of valency which states, "Valency is equal to the number of hydrogen atoms with which an atom of the element combines." Four teachers had added "or number of chlorine atoms" and two had added, "or double the number of oxygen atoms in the definition."

In the case of question No. 2, all the teachers had described that the term is used for the electrons present in the outermost shell and named that as the valence shell.

For question 3, the responses indicated that all the teachers had repeated the same meaning as given in questions 1 and 2. However, besides this, six teachers had, also written that valency of an element is decided by the number of valence electrons taking part in bond formation.

In case of question 4, the analysis showed that all the 48 teachers had given the valency of chlorine as one on the basis of transfer or sharing of electrons for having eight electrons in outermost shell and valence on the basis of electrons present in outermost shell.

In response to question 5, 42 teachers stated that valency cannot exceed four. However, six teachers responded that in some cases valence can exceed four also.

It is clear from the responses given by the teachers for the five questions that the teachers considered valency and valence to have different meanings. They assigned the term valency only to the classical definition and thus correlated the concept of valence with the number of electrons present in the outermost shell. They considered these electrons as valence electrons and the outermost shell as valence shell. This is due to the reason that the background of the terms valence and valency has not been described in chemical textbooks. The most of the books describe the number of electrons presents in the outermost shell as valence electrons and the number of valence electrons in the atom of an element decides the valency of the element (Kheterpal and Dhawan, 2014 and Singh and Kaur, 2015). This description also creates misconceptions among the teachers. At one point only, the book by Singh and Kaur (2015) states that valency is known as valence also, but in establishing the relationship between valency and valence, confusion is created by the authors. Another misconception is that valency cannot exceed four. This is because at lower level that is for the student of 14–16 years of age, teachers discuss bonding for the lower atomic number elements by applying the electronic theory of valency (the term has been used in most of the books while discussing the bonding theory developed by Lewis and Kossel). With the passage of time, teachers might have forgotten that in the case of some elements, the valence shell is expanded as in case of PCl_5 and SF_6.

A simple and precise description of the valence and related concepts was developed which is:

The words valency and valence have been derived from Latin "Valentia" with the meaning power, strength, or capacity. In chemistry, these two terms were used for combining capacity of the element for the theory propagated by Frankland (1852) for this concept. However, in British English, the word valency is used for this concept while in American English the word valence is used.

It is to be noted that valency is not restricted to the classical definition of the concept. For that, valence also can be used. Even, IUPAC (McNaught and Wilkinson, 1994) while defining

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the concept has used valence (given in IUPAC, Gold Book on page number 1175) which is based on the classical definition of the concept.

The Encyclopedia Britannica (2011) states that the word valence is also spelt as valency. The 1889 edition of Oxford English dictionary mentions; valence as another term for the word valency in chemistry but points out valency is used in British English (Simpson and Weiner, 1889). In chemistry literature, the terms valency electrons or valency shell also have been used in texts by Bhatnagar (1999). Therefore, both terms can be interchangeably used whether it is for classical definition of the concept or definition based on the number of electrons present in the outermost shell of the atom of an element. It is to be noted that all electrons present in the outermost shell of an atom can decide the valency or valence of the element. For example, chlorine can have valence or valency as one or seven depending on what other atoms they bond with and on the experimental conditions. In a simple way, valence or valency will be equal to the number of valence or valency electrons of one element forming a bond by sharing or transfer of electrons with another element. In other words, valency or valence can be used to indicate the number of covalent bonds formed by an atom in a compound or the charge on a monoatomic or polyatomic ion.

However, there are exceptions, for example, hydrogen has one valence electron. Therefore, it should form one bond by donating its electron to an atom of another element (ionic bond) or by sharing its electron with one electron of another element (covalent bond). However, hydrogen can form bonds with more than one atom in a molecule. For example, it forms three-center two-electron bonds in the electron-deficient diborane (B_2H_6) as shown in Figure 1.

In the representative elements of the second period, one s-orbital and three p-orbitals are available. Therefore, the maximum transfer or sharing of electrons between two elements cannot be more than four to complete the octet. Due to this situation, these elements cannot have valence or valency more than four. However, heavier representative elements in period 3 and subsequent periods have vacant d-orbitals in the outermost shell which can be used for covalent bonding and hence, expand their valence.

Due to some ambiguity in the definition of the valency or valence, the term oxidation state is now generally preferred.

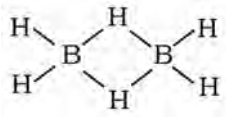

Figure 1: Structure of the diborane molecule

The oxidation state of the atom of an element is equal to the number of valence electrons it has gained or lost. It can be positive as well as negative. For example, H can have an oxidation state of +1 as in HCl and −1 as in NaH.

The description presented by the investigator in the second session of the program was appreciated by the teachers. The teachers to whom the description was sent by post had also given positive observations.

Implication of the Study

The present study clearly shows that the teachers are having misconceptions concerning valency. They also have a misleading understanding of the relationship between "valency" and "valence" and about the maximum valence. If the simple narrative of the concept as described here is used, then misconceptions can easily be removed.

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