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Multiple Representations Analysis of Chemical Bonding Concepts in General Chemistry Books

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Abstract.
This research aimed to analyze the use of the concept of the three levels of chemical representation in eight general chemistry books. It was qualitative research with an evaluative descriptive design. The concepts analyzed included the concepts of ionic, covalent, and metallic bonds. The analysis focused on two main criteria: the use of macroscopic, sub-microscopic, and symbolic levels of representation and the relationship between the three levels. The results of the analysis showed that in the concept of ionic bonding, there were pictures of some salts or reactions for the formation of ionic compounds from their elements at the macroscopic level, explanations at the sub-microscopic level, and models of the arrangement of ions in the ionic crystal lattice for the symbolic level. In the concept of covalent bonds, there were images of gasses or covalent compounds at the macroscopic level, explanations at the sub-microscopic level, and models of electron density shifts at the symbolic level. In the concept of metallic bonds, there were pictures of some metals at the macroscopic level, explanations at the sub-microscopic level, and electron cloud models at the symbolic level. The relationship between the levels of representation was found in five of the eight general chemistry books analyzed. General chemistry books present the relationship between the three levels of representation in images that include energy level diagrams, atomic or ionic arrangement models, reaction equations, and explanations of the molecular level.

Keywords: concept, chemical representation, general chemistry, books

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1. INTRODUCTION

Chemistry is still one of the subjects that are considered difficult by students. Several previous studies have revealed that chemical concepts involving three levels of representation make chemistry difficult for students to understand. The difficulty of students in studying chemistry lies in the inability to understand the intrinsic nature of a subject [1].

Effective chemistry learning must cover three levels of chemical representation (chemistry triangle), namely macro, sub-micro, and symbolic. At the macro level, chemistry is studied at the factual level or something that can be observed with the senses. The sub-micro level describes macro phenomena at the atomic, molecular, or ion level and the symbolic level includes symbols, formulas, equations, chemical calculations, and graphs or schematics. Chemical phenomena must be explained using all three levels of chemical representation. No one aspect or level is superior or major than another [1]. According to Talanquer (2011), the chemistry learning process must involve three basic knowledge of relevant chemistry. First, experience as knowledge in the form of an overview of chemical substances and chemical processes obtained directly (through the senses) or using instruments. Second, the model includes descriptive theoretical models that have been developed by experts to predict various properties of systems in chemistry. Third, visualization which includes chemical symbols or formulas, particulate images, mathematical equations, graphs, and so on that are used to visually represent the core components of the theoretical model [2].

The difficulty of students in studying chemistry resulted in the emergence of misconceptions in students. One of the chemical concepts that are difficult for students to understand is the concept of chemical bonds. When students study the concept of chemical bonds students are asked to understand various phenomena in everyday life in all three levels of representation. The three levels of representation that students must understand are the macroscopic level which will relate to the physical properties of substances, the sub-microscopic level which will relate to the properties of substances at the molecular level, and the symbolic level to represent the characteristics of substances in the form of symbols, equations, or schemes. The three types of chemical bonds that students study are ionic bonds, covalent bonds, and metallic bonds. The results of previous studies revealed that students still have misconceptions about the material of ionic bonds, covalent bonds, and the concept of metallic bonds, especially at the sub-microscopic level [3–7]. The use of appropriate chemical representations in the learning process can reduce students' misconceptions and help students understand chemical concepts as a whole.

General chemistry books as the main teaching materials for teachers in the chemistry learning process should be able to provide appropriate chemical representations for chemical concepts. The results of previous studies reveal that general chemistry books use different models or representational images to explain chemical concepts [8, 9]. Chemical representations in the form of written explanations or text and pictures used in general chemistry books are often adapted and quoted in school chemistry books.

Analysis of chemical representations in general chemistry books is an attempt to evaluate the use of chemical representations in general chemistry books, especially for the concept of chemical bonds.

In this study, we analyze the use of the three levels of chemical representation for the concept of chemical bonds in general chemistry books. The main concepts of chemical bonds that analyzed in multiple representations are the concepts of ionic bonds, covalent bonds, and metallic bonds. The three types of chemical bonds analyzed for their chemical representation at the macroscopic, sub-microscopic, and symbolic levels. The results of this study can be used by the teacher as a reference when choosing a general chemistry book that will be used to teach the concept of chemical bonds to students. In addition, the results of this analysis can be used as a teacher's consideration in choosing an appropriate chemical representation for the concept of chemical bonds and also as a reference for future researchers who want to develop teaching materials or chemical evaluation tools by involving all three levels of chemical representation.

2. RESEARCH METHOD

This research is qualitative research with an evaluative descriptive design. The method used includes document analysis, namely general chemistry books. Evaluative descriptive research design is research conducted with two main stages, namely evaluating a subject with certain criteria and followed by describing the results of the evaluation so that the quality or feasibility of the subject being analyzed is known [10]. Eight general chemistry books were analyzed using multiple chemical representations for the concept of chemical bonds. The three concepts of chemical bonds analyzed include ionic bonds, covalent bonds, and metallic bonds. The analysis carried out focuses on two main criteria, namely the use of macroscopic, sub-microscopic, and symbolic levels of representation and the linkage of the three levels of chemical representation. Furthermore, the results of the analysis and evaluation of multi-representational chemistry textbooks are described so that it is known that textbooks provide multiple-representation chemistry to explain the concepts of chemical bonds. Eight books were analyzed in this study; [11–16]. To simplify the analysis process, each book is coded into book A to book H.

Table 1: List of books analyzed.

Book code	Book identity (author, title, year of publication)
Book A	Neil D. Jespersen, James E. Brady; Chemistry: the molecular nature of matter – 6^{th} ed. (2012)
Book B	Kenneth W. Whitten, Raymond E. Davis, M. Larry Peck, George G. Stanley. Chemistry, 10^{th} Edition (2014)
Book C	Raymond Chang, Chemistry. - 10^{th} ed. (2010)
Book D	Martin S. Silberberg. Chemistry: the molecular nature of matter and change - 5^{th} ed (2018)
Book E	Nivaldo J Tro. Introductory Chemistry Essentials 5^{th} ed. (2017)
Book F	Darrell D. Ebbing, Steven D. Gammon. General Chemistry, Eleventh Edition (2017)
Book G	Theodore L. Brown, et al. d Chemistry: The Central Science, 15^{th} Edition (2022)
Book H	Petrucci, Ralph H, et al. General chemistry: principles and modern applications Eleventh edition. (2017)

3. RESULT AND DISCUSSION

The results of the analysis are described in tabular form. Table 2 to Table 4 describe the use of chemical representations and linkages between levels in general chemistry books for the concepts of ionic bonds, covalent bonds, and metal bonds. Furthermore, in Table 5, there is a general summary of what chemical representations are generally used in general chemistry books in explaining the concept of chemical bonds.

The concept of ionic bonding is explained by using the three levels of chemical representation in several general chemistry books. General chemistry books generally display experimental pictures of reactions for the formation of ionic compounds such as NaCl to represent phenomena that occur at the macroscopic level. The linkage of the three levels of chemical representation is found in five of the eight general chemistry books that have been analyzed. The linkage of the three levels of chemical representation is shown in the form of schematics and drawings, accompanied by explanations for the sub-microscopic level, and a model of the arrangement of atoms or ions in a crystal. The concepts of covalent bonds and metallic bonds are also explained using all three levels of chemical representation. However, some general chemistry books do not provide a chemical representation for the sub-microscopic level, especially for the concept of metallic bonds. The relationship between the three levels of chemical representation is only found in some general chemistry books. In Table 5, the chemical representations commonly used in general chemistry books are analyzed to explain the concepts of ionic and metallic bonds and covalent bonds.

Table 2: Results of analysis of the use of three levels of chemical representation on the concept of ionic bonds.

Chemistry book	Chemical representation level			Chemical representation level link
	Macroscopic	sub-microscopic	Symbolic	
Book A	Experimental picture of the formation of NaCl	Explanation of the process of forming NaCl crystals at the molecular level, the reaction steps to form ionic compounds.	Schematic or diagram of the formation of NaCl Model the arrangement of ions in a crystal lattice	An experimental picture of the formation of NaCl in a reaction flask with a model of the arrangement of atoms or ions in a crystal and a molecular-level explanation for the picture
Book B	Pictures of some ionic compounds in a beaker Li Metal Cutting	The molecular-level explanation for the formation of several ionic compounds such as LiO_2, NaCl, and CaO.	Lewis formula for Li_2O Schematic of energy changes for the formation of NaCl	-
Book C	Experimental video for the formation of MgO and NaCl Discourse about the benefits of ionic compounds	Written explanation of changes that occur in metals or gases that form ionic compounds such as; LiF, Li_2O, CaO, and Mg_3N_2.	The reaction equation for the formation of LiF Animated video of the formation of NaF Born-Haber cycle of the formation of LiF	-
Book D	Experimental picture of the formation of NaBr	Explanation of the molecular level of LiF formation, electron transfer process, and energy release. Written explanation for the formation of MgO	LiF electron transfer equation, Schematics of several compounds and types of bonds, Ionic arrangement model	The Born-Haber cycle of LiF formation is accompanied by a reaction equation, atomic or ionic model, and an explanation of the sub-microscopic level for the cycle
Book E	Image of metallic Na, chlorine gas, and salt NaCl	The written explanation is that in the formation of ionic compounds, when metals and non-metals bond, electron transfer occurs, and there is an electrostatic attraction.	Lewis structure for the formation of KCl	The image contains an explanation of the NaCl formation process, a sub-microscopic model, and a macroscopic image of the NaCl formation reaction.
Book F	NaCl mineral crystal	Written explanation of the process of change at the molecular level that occurs during the formation of NaCl compounds.	Crystal lattice model and arrangement of NaCl ions. Equation of electron transfer with Lewis structure for the formation of sodium ions and chloride ions.	Experimental picture of sodium and chlorine reaction with ionic arrangement model and explanation of sub-micro level. Discourse on the role of salt solution in the industry as well as an explanation of macro and sub-micro levels.

Table 2: Continued.

Chemistry book	Chemical representation level			Chemical representation level link
Book G	Gypsum Crystal Picture	Explanation that in general ionic bonds are formed between metals and nonmetals. Described the process of formation of NaCl.	An illustration of an experiment for making NaCl NaCl crystal lattice model	Macro image of NaCl salt with lattice crystal model for the formation of NaCl compounds with an explanation of the molecular level
Book H	Type of salt (written)	The explanation that ionic compounds are formed from positive and negative ions joined by electrostatic attraction.	Crystal lattice models & equations	-

4. CONCLUSION

General chemistry books generally use NaCl compounds as examples for ionic compounds in everyday life. Several general chemistry books display experimental pictures of the formation of ionic compounds as macroscopic representations. At the sub-microscopic level there is an explanation of the concept of ionic bond formation at the molecular level and the use of reaction equations with Lewis structures; the Born-Haber scheme or cycle; and the model of the arrangement of ions in the crystal lattice as a representation of the symbolic level. The concept of metallic bonds is also explained with chemical representations, but only five books mention examples of metals in everyday life as representations of the macroscopic level. Most of the books explain the concept of metallic bonding with the electron cloud or ocean model at the sub-microscopic level and at the symbolic level, an image is presented for the described electron ocean or cloud model. The concept of covalent bonds at the macroscopic level is represented by mentioning some examples of compounds or substances that are covalently bonded. Explanation of the concept of covalent bonds by using the concept of electron density shift and the balance of attractive and repulsive forces at the sub-microscopic level. In addition, a model that represents the shift in electron density for the concept of covalent bonds is also used, the difference in electron attraction for the concept of polar covalent bonds, and the use of Lewis structures to show the sharing of electrons at a symbolic level. The link between the levels of chemical representation of the three concepts was found in five of the eight books analyzed. The linkage of the three levels of representation is shown in schematic drawings, cycles or curves of bond or compound formation, atomic or ionic arrangement models (ionic bonds), electron shift models (covalent bonds), and sub-microscopic

Table 3: Results of analysis of the use of three levels of chemical representation on the concept of covalent bonds.

Chemistry book	Chemical representation level			Chemical representation level link
	Macroscopic	sub-microscopic	Symbolic	
Book A	Natural phenomena related to ozone (O_3)	Explanation of the concept of forming polar covalent and covalent bonds, modeling electron density shifts, and the balance of attractive and repulsive forces.	Electron density shift models, bond formation curves, and Lewis structures.	-
Book B		Explanation of the concept of sharing electrons and differences in electronegativity (polar covalent).	Electron density shift model, bond formation curve, Lewis structure, and electrostatic potential map model.	-
Book C	Mentioned several types of compounds that are covalently bonded.	An explanation with the concept of sharing an electron pair as an example is using the H_2 molecule. Equal and unequal division to distinguish the type of bond polarity.	Lewis structure and electrostatic potential map model.	-
Book D		Explanation using the concept of electron density shift and electronegativity difference (polar/nonpolar).	-	The H_2 molecule formation curve is accompanied by an electron density shift model and an explanation of the sub-microscopic level.
Book E		Explanation using the concept of sharing electrons between non-metal and non-metal atoms	Lewis structure	-
Book F		Explanation of the process of forming covalent bonds in the H_2 molecule.	-	The H_2 molecule formation curve is accompanied by a model of the distance between atoms and an explanation at the molecular level.
Book G	Molecular Man statue photo Mentioned substances that are covalently bonded	Explanation with the concept of sharing electrons according to Lewis. The forces of attraction and repulsion and their relationship to electron density.	Schematic of the relationship of attraction, repulsion and distribution of electrons; Lewis structures, and electrostatic potential map models.	Image of glass filled with water, water molecule model, and molecular level explanation.
Book H	-	The concept of sharing electrons.	Lewis structures, and electrostatic potential map models.	-

Table 4: Results of analysis of the use of three levels of chemical representation on the concept of metal bonds.

Book chemistry	Chemical representation level			Chemical representation level link
	Macroscopic	sub-microscopic	Symbolic	
Book A	Mentioned some examples of metals in everyday life and their physical properties	Explanation with the electron cloud model, namely positive ions surrounded by electrons that can move freely.	Electron sea model picture of metal crystal.	-
Book B	Picture of some tools made of metal	The explanation that metallic bonds are the result of attraction between positively charged metal ions and moving electrons, which are delocalized throughout the crystal.	-	-
Book C	Aluminum recycling discourse	The explanation that in metals there are delocalized electrons and positive metal ions immersed in the sea of electrons.	Electron sea model.	-
Book D	-	Written explanation regarding the existence of electron clouds and electron delocalization in metals (using the electron sea model)	Metal crystal lattice model; a sea of flowing electrons and positive metal ions	-
Book E	-	Explanation using the cloud model or the sea of electrons surrounding metal ions.	Electron sea model.	-
Book F	-	The explanation using the electron delocalization model (electron sea).	-	-
Book G	Picture of gold layer and copper wire Some types of other metals and their physical properties	Written explanation using electron delocalization model or electron sea.	Nitinol alloy illustrations Electron sea model and metal crystal lattice model drawing	Image of a glass filled with water, a spoon filled with salt. An explanation of the sub-micro-level model of the electron sea for metallic bonding in a spoon and a model for the arrangement of metal ions in a crystal lattice.
Book H	Mentioned several types of metals and their physical properties	The explanation that in metals there is a network of positive ions that are submerged in a sea of electrons.	-	-

Table 5: Commonly used chemical representations for the concept of chemical bonds.

Chemical Bond Concept	Chemical Representation Level			Chemical Representation Level Link
	Macroscopic	Sub-microscopic	Symbolic	
Ionic Bond	Five books show pictures of experiments for the manufacture of ionic compounds. Four books cite NaCl as an example of an ionic compound and three books give an example of another ionic compound.	Explanation of the process of formation of ionic compounds, the formation of atoms; ion formation/electron transfer; bond formation (electrostatic forces between ions).	The scheme or the Born-Haber cycle for the formation of ionic compounds, reaction equations with Lewis structures, and models of the arrangement of ions in an ionic crystal lattice.	The Born-Haber cycle for the formation of ionic compounds is accompanied by an explanation of the molecular level and a model of the arrangement of atoms or ions.
Covalent Bond	Only two books show discourse accompanied by pictures when explaining the concept of covalent bonds and one book mentions examples of covalently bonded substances.	Explanation using the electron density shift model, the balance of attractive and repulsive forces, and the concept of sharing electrons.	Model of electron density shift in the H_2 molecule, H_2 formation curve, Lewis structure, and electrostatic potential map.	H_2 formation curve, with the explanation at the molecular level and electron density shift model.
Metal Bond	Mention some examples of equipment made of metal or some examples of metal.	Explanation with the cloud or sea of electrons model	Model cloud or sea of electrons.	Metal pictures, metal crystal lattice models with a sea of electrons, and molecular level explanations.

level explanations for each step. The results of this study can be used by further researchers as consideration for developing teaching materials or evaluation tools that are oriented to multi-representation of chemistry and as considerations for educators in using multiple representations in the process of learning the concept of chemical bonds.

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