An analyses of multiple representation about intermolecular forces

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Abstract. Intermolecular forces (IMFs) is an abstract concept. Therefore, to understand this concept requires understanding of concepts from various chemical representations. This study aims to analyze the topic of IMFs in term of three representation of chemistry such as: macroscopic, submicroscopic, and symbolic. This study use descriptive method involving document analyses including 5 general chemistry textbooks. The result of this study present various ways of explaining the IMFs concept in three different levels of representation. All chemical representations presented in those chemistry textbooks are dedicated to provide comprehensive explanations about the concept of IMFs. This kind of study is essential for formulating a concept correctly which can avoid the raise of students’ misconceptions. Furthermore the results of this study will be beneficial for further study about developing an effective strategy to teach the topic of IMFs to the students.

1. Introduction
Chemistry is one of the most important science and has been regarded as a difficult subject for students by teachers, researchers, and educators because most of the topics in chemistry are abstract and many of the terminology in chemistry were used in everyday language but have different meanings [1]. One of them is the concept of Intermolecular forces (IMFs). Students have difficulty in visualizing the submicroscopic representation of how interactions between molecules can occur [2]. Based on the analysis of teacher interviews, students assume that there is only 1 molecule of H₂O in water so that the interaction between the particles occurs only on the interaction between H atoms with O atom in H₂O molecule. This understanding can lead to misconceptions if the teacher does not overcome the alternative concept of the student, such as; IMFs occurs in the molecules [3,4,5]; IMFs are stronger than chemical bonds [2,6]; IMFs is causes a chemical reaction [2,7,8]. Besides, students also have difficulty in internalizing the three levels of chemical representation as a whole, such as: macroscopic (physical structure), submicroscopic (particulate structure) and symbolic (symbol of chemical notation) [9]. The lack of students’ understanding about chemical representation leads to the confusion in students' understanding of chemistry [10]. In addition, most of the teaching of chemistry focuses only on one level of representation alone and rarely helps students to build bridges to master the three levels of chemical representation [11]. Thus, students tend to be at the macroscopic level and have difficulties in visualizing and interpreting molecular and
symbolic representations [12]. Therefore, to reduce the alternative conception that can lead to misconceptions, the concepts need to be studied and selected from various levels of chemical representation. This study will analyze the concept of IMFs from various chemical representations based on five general chemistry textbooks that are widely used in chemistry lessons. The aim is to formulate a concept correctly which can avoid the raise of students’ misconceptions.

2. Method
This study used descriptive method including document analysis which analyzed the concept in IMFs topic from five general chemistry textbooks. The concept analyses was based on 3 levels of representation such as; macroscopic, submicroscopic, and symbolic. Textbooks which have been analyzed are Zumdhal, S.S., Zumdhal S H [13] Chang R., and Overby J [14] Silberberg, M.S [15] Brown L S and Holme T A [16] Whitten K W, Davis R E, Pack M L, and Stanley G G [17] and randomly symbolized such as; textbook I, II, III, IV, V.

3. Result and discussion
The result of the analysis of 3 levels of about the concept in IMFs topic from all textbooks are presented in table 1.

| Content                | Textbook I | Textbook II | Textbook III | Textbook IV | Textbook V |
|------------------------|------------|-------------|--------------|-------------|------------|
|                        | M  | S   | Sym | M  | S   | Sym | M  | S   | Sym | M  | S   | Sym |
| Intermolecular Forces  | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   |
| Ion-dipole forces      | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   |
| Dipole-dipole forces   | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   |
| Ion-induced dipole     | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   |
| Dipole-induced dipole  | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   |
| London dispersion      | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   |
| Hydrogen bond          | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   | ✓  | ✓   | ✓   |

*M: macroscopic, S: Submicroscopic, Sym: Symbolic

In general, the above contents are covered by the textbooks which analyzed, although not all of them presented in those textbook. However, there are 3 concept that are not covered in textbooks III, IV, and V that are concept of ion-dipole forces, ion-induced dipole, and dipole-induced dipole. This is because some books assume that the concept of IMFs is a force between molecules not ions so that the concept of ion-dipole force, ions-induced dipole forces not include the IMFs. Meanwhile some other books assume that the force between molecules includes the force between the particles so that the ion-dipole forces and ion-induced dipoles including IMFs.

The basic concept of IMFs is found in all textbooks. Textbook I present the macroscopic representation of IMFs concept is the phenomenon of water that has different phases which influenced by the interaction between water particles. This interaction is due to the electrostatic forces between the water particles to create the phase properties and also the phase changes. For more details, the interaction between particles can be explained in the submicroscopic levels that energy kinetic of particles affects the phase change. Beside, to provide a clear picture of the interactions between particles, the symbolic representations as seen in figure 1 can be used to show the process of phase changing H₂O(g) → H₂O(s) at a temperature of 130°C to -40°C. the diagram show that the phase changing process of water could be depicted in 5 steps that are; gaseous water cools, gaseous water condenses, liquid water cools, liquid water freezes, solid water cools. The symbolic representation of the above levels clearly shows the differences in the interactions of the molecules in each stage and the graph exactly right because the explanation with the picture can avoid the
students’ misconception about IMFs occur in molecules. Furthermore, to discuss the difference between IMFs and chemical bonding requires symbolic representation of the atomic representation of H atom and O atom in the H$_2$O molecule.

In the other side, textbook II and IV explain the macroscopic representation of IMFs based on the fact that it takes greater energy to break the H-O bond in 1 mol of water molecule than to evaporate 1 mol of H$_2$O at its boiling point which also provided the description in the symbolic representation of how the breaking of IMFs and chemical bonding occur in H$_2$O molecules. The other way, textbook III and V present the IMFs concept based on macroscopic representation is giving the data about density of water in all states such as; solid, liquid, and gas.

Regarding the concept about ion-dipole, textbooks I and II present the macroscopic representation on ion-dipole concept through the solubility of NaCl in water known as a hydration process where the ions are surrounded by water molecules which arranged in certain circumstances. The submicroscopic representation about ion-dipole force explain of how the ion-dipole forces interaction can occur on NaCl solution in water. Ion-dipole forces is the force involved between the ions (Na$^+$, Cl$^-$) and the polar molecule (H$_2$O). The molecular description of the symbolic representation can be seen in figure 2.
Figure 2. The symbolic representation of ion-dipole force (a) Textbook I (b) Textbook II.

Figure 2 shows how ions can interact with dipoles. When salt is dissolved in water, Na\(^+\) and Cl\(^-\) ions will be separated from each other. In the solution, each Na\(^+\) ion will be surrounded by a number of water molecules that direct its negative end toward the cation according to the above description. However, the symbolic representation shown in textbooks I and II only describes the Na\(^+\) ions but not the Cl\(^-\) ions. It would be better if the Cl\(^-\) ions were also illustrated so that students could imagine the interaction between Cl\(^-\) ions with the H\(_2\)O molecule which directs the positive end.

Furthermore, textbook I present the macroscopic representation of dipole-dipole concept can be described by a graph of boiling point difference based on molecular structure and dipole moment. While the submicroscopic representation can be explain about how the dipole-dipole forces occur on polar molecules. Molecules with a dipole moment can attract each other electrostatically so that the positive and negative charge points are close together. The greater the dipole moment, the stronger the dipole-dipole forces. For symbolic representation can be seen in figure 3 which shows the different dipole-dipole interactions between two molecules and between more than 2 molecules in the condensed state. A more complex diagram can be seen in figure 3b which presented that the dipole-dipole interactions not only occur by the attraction forces but also produced by the repulsive forces between molecules that have the same type of charges. In addition, the dipole-dipole interaction in figure 3b occurs in the liquid phase because the irregular interactions caused by the kinetic energy between the particles are larger than figure 3a.

Figure 3. The symbolic representation of dipole-dipole forces (a) interact of 2 molecules (b) interact more than 2 molecules.

In the concept of the ion- induced dipole, Textbook I present the phenomenon at the macroscopic level is binding of Fe\(^{2+}\) ion with O\(_2\) which present in hemoglobin. This interaction can be explained with submicroscopic representation based on the polarization that occurs when ion charges distort the electron
cloud from nearby non-polar molecules. The symbolic representation can be seen in figure 4 which shows how the interactions of ion-induced dipole occur. Figure 4a present the interaction of ion-induced dipole which is shown in the presence of dotted lines while the induced dipole is indicated by the arrows with a dotted circle that directs its arrow toward to the more electronegative charge. Meanwhile, Figure 4b is unclear showing how interactions occur of ion-induced dipole forces.

![Figure 4. The symbolic representation of ion-induced dipole forces (a) Textbook I (b) Textbook II.](image)

Meanwhile, the concept about dipole-induced dipole were presented in textbooks I, II, III. Based on textbook I, the macroscopic representation is presented in the solubility of oxygen in water. These phenomenon can be explain through the submicroscopic representation that the interaction of dipole-induced dipoles is based on polarization that occurs when the polar molecule (H₂O) distorts the cloud of electrons from nearby non-polar molecules (O₂). The following representation of the symbolic representation of dipole-induced dipole force from textbook I, II, and III can be seen in figure 5 which shows a symbolic representation of how the dipole-induced dipole interaction occurs. Among all of the symbolic representation presented in figure 5, figure 5a shows the most obvious dipole-induced dipole interaction. In Figure 5a the interaction is illustrated by the dotted line and the induced dipole is indicated by an arrow with a dotted circle that directs its arrow toward to more electronegative charge. While the diagram in 5b and 5c are not apparently clear in depicting the interaction between dipole-induced dipole although the diagram in 5c has introduced a sign of relativity positive and negative.

![Figure 5. The symbolic representation of dipole-induced dipole forces (a) Textbook I (b) Textbook II (c) Textbook III.](image)

The other topic which include in the coverage of IMFs topic is London dispersion. Textbook I, II and IV present the macroscopic representation on London dispersion forces is a phenomenon of non polar substances which can melt and solidify such as; Ar, He, N₂. These interaction can explain through the submicroscopic representation of how non-polar substances can have an induced dipole and then induced dipoles in the other substances to form interactions between one substances with another. Similar with these phenomenon, textbook III also present with different examples such as polymers (polyethylene) that can form solids due to the interactions between molecules. On the other hand, textbook IV present the analogize of London dispersion forces with Velcro. Each hook and loop in Velcro represents a very weak interaction but if everything is put together, it will create a very strong total pull force. Likewise, the London dispersion forces starts from one molecule that has an induced dipole which then induces its neighboring molecule so that its interaction gets stronger and can cause a gas to melt and solidify. The symbolic representations of the London dispersion forces can be seen in figure 6. Figure (6a) shows two non-polar atoms are adjacent
to each other; (6b) there is a temporary moment dipole due to the uneven tendency of the electrons location; (6c) dipole moment induces its neighboring dipole resulting in mutual interaction of attraction causing a gas to melt and solidify.

![Image of London dispersion forces]

Figure 6. The symbolic representation of London dispersion forces based on Textbook I.

The last concept that covered in the topic of IMFs is Hydrogen bonding. Textbook I, II, IV and V present the macroscopic representation of hydrogen bonding concept is the phenomenon of boiling point deviations in H₂O, HF, and HNO₃ based on molar masses depicted by graphs. Typically, the boiling point of a series of similar compounds containing elements in the same period increases with increasing molar mass. However, the hydride compounds of the 5A, 6A, and 7A elements do not follow these trends. These phenomenon can be explained by the submicroscopic representation of how hydrogen bonding can occur. The deviation is due to the hydrogen bond that occurs between the electronegative H atoms of one molecule with the highly electronegative atom F, O, N in the other molecule. In the other way, textbook III explain the macroscopic representation of hydrogen bonding concept based on phenomenon of the role of hydrogen bonding in connecting two single chains of DNA into a double helix. The representation of symbolic representations on hydrogen bonds can be seen in Figure 7 which shows that hydrogen bonding presents not only in water but also in alcohol. This representation may help explain to students that alcohol also has an electropositive H atom which allows for the occurrence of hydrogen bonds.

![Image of hydrogen bonds]

(a) (b)

Figure 7. Hydrogen bond on (a) water molecules (b) alcohol.

4. Conclusion
Based on the results of analysis of chemical representation from various textbook found that there are various ways to explain the concept of IMFs so that teachers need to select those concepts from the macroscopic, submicroscopic and symbolic representation aspects that will be applied in the learning.
Submitting these concepts in different ways can also be used as a consideration for determining effective strategies for teaching IMFs to students.

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