Magnet and Pin kit: Connection Symbolic and Submicroscopic Representations of Lewis dot structure and Molecular geometry

Phalakorn Kamkhou\textsuperscript{1,}\textsuperscript{a} and Chokchai Yuenyoung\textsuperscript{2,}\textsuperscript{b}
\textsuperscript{1}Khon Kaen University Demonstration Secondary School (Suksasart), Khon Kaen, Thailand,

\textsuperscript{2}Science Education Program, Faculty of Education, Khon Kaen University, Thailand,

Corresponding author’s e-mail address: \textsuperscript{a}phalka@kku.ac.th \textsuperscript{b}ychok@kku.ac.th

Abstract. This work aims to connect the symbolic and submicroscopic representations of covalent compound’s Lewis dot structure and molecular geometry by using the Magnetic and Pin kit (MP-kit), which was constructed from magnets and pins. The MP-kit was created to facilitate the students. The kit has two sets, the first set, called Magnet set, consists of a 30x30 cm iron plate, an alphabet A with magnet (refer to central atom), 6 alphabets B with magnet (refer to surrounding atom), 18 white circular magnets (refer to valence electron of A), 42 black circular magnets (refer to valence electron of B) and 3 yellow circular magnets (refer to extra electron of molecule, from ion generation). Which was used to create the Lewis dot structure of covalent molecules. The second set, called Pin set, consists of a spherical eraser (refer to central atom), 6 pins (refer to bond and surrounding atom) and 3 droplet pins (refer to lone pair electron of central atom). Which was used to make the molecular geometry of covalent compounds, that predicted by using VSEPR theory. The users can use the Magnet set to create the Lewis dot structure without frequent drawing and rubbing on the papers. The magnets on the plate are moved for anytime when the users know it’s wrong. Moreover, this set can be used to show the number of bond pair electrons, types of bond and number of lone pair electrons on central atom. The Pin set is used to build the 3D molecular structure and specify the bond angles. The kit was used to link the symbolic and submicroscopic representations and encourage the student’s understanding. Finally, the teacher can use the MP-kit to check the student’s misconception, leading to solve problems immediately.

1. Introduction
Gilbert and Treagust presented the types of representation in chemistry for three levels, there are macroscopic, submicroscopic and symbolic. The macroscopic level (or phenomenological type) consists of representations of the empirical properties of matters. These properties are perceptible in chemistry laboratories and in everyday life and are therefore able to be measured. Examples of such properties are mass, density, concentration, pH, temperature and osmotic pressure. The submicroscopic level (or model type), it is usual to produce models built from entities such as atoms, ions, molecules and free radicals, for phenomena described with the macroscopic representation. For
examples, in terms of electron density, shape of atomic and molecular orbitals (including the use of valence electron repulsion theory) and diagrams or graphs. The symbolic level involves the allocation of symbols to represent atoms, whether of one element or of linked groups of several elements; of signs to represent electrical charge; of subscripts to indicate the number of atoms in an individual ion or molecule; of letters to indicate the physical state of the entity (e.g. solid (s), liquid (l), gas (g), aqueous (aq) or other solution). This depiction is then followed by the inclusion of these representations as appropriate within all conventions of chemical and ionic equations, with the use of prefixed coefficients to show the conservation of matter during a reaction. This level of representation also can be used both in respect of the first, the phenomenological representational type, when dealing with bulk quantities of reactants and products in stoichiometric computations, and with a wide range of models of the second type of representation when describing physical changes (e.g. changes of state and dissolution of solutes) and the chemical changes taking place during reactions [1].

Gilbert Lewis formulated that atoms combine in order to achieve a more stable electron configuration. Maximum stability results when an atom is isoelectronic with a noble gas. When atoms interact to form a chemical bond, only their outer regions are in contact. A chemical bond in which two electrons are shared by two non-metal atoms, called covalent bond. The compounds that contain only covalent bonds are called covalent compound. The structures are used to represent covalent compounds are called Lewis dot structures. A Lewis dot structure is a representation of covalent bonding in which shared electron pairs are shown as pairs of dots between two atoms, and lone pairs are shown as pairs of dots on individual atoms. Only valence electrons are shown [2].

Molecular geometry is the three-dimensional arrangement of atoms in a molecule. However, there is a simple procedure that enables us to predict with considerable success the overall geometry of a molecule or ion if we know the number of electrons surrounding a central atom in its Lewis structure. The basis of this approach is the assumption that electron pairs in the valence shell of an atom repel one another. The valence shell is the outermost electron-occupied shell of an atom; it holds the electrons that are usually involved in bonding. In a covalent bond, a pair of electrons, often called the bonding pair, is responsible for holding two atoms together. However, in a polyatomic molecule, where there are two or more bonds between the central atom and the surrounding atoms, the repulsion between electrons in different bonding pairs causes them to remain as far apart as possible. The geometry that the molecule ultimately assumes (as defined by the positions of all the atoms) minimizes the repulsion. This approach to the study of molecular geometry is called the valence-shell electron-pair repulsion (VSEPR) model, because it accounts for the geometric arrangements of electron pairs around a central atom in terms of the electrostatic repulsion between electron pairs. We can predict the geometry of molecules (and ions) in a systematic way. For this purpose, it is convenient to divide molecules into two categories, according to whether or not the central atom has lone pairs. A molecule’s geometry affects its physical and chemical properties, such as melting point, boiling point, density, and the types of reactions it undergoes [2]. If we predict a mistake on a molecular geometry, we will describe their properties error.

For molecules in which the central atom has no lone pairs. If we consider molecules that contain atoms of only two elements, A and B, of which A is the central atom and B is a surrounding atom. These molecules have the general formula ABx, where x is between 2 and 6. Determining the geometry of a molecule is more complicated if the central atom has both lone pairs and bonding pairs. In such molecules there are three types of repulsive forces—those between bonding pairs, those between lone pairs, and those between a bonding pair and a lone pair. We designate molecules with lone pairs as ABxEy, where A is the central atom, B is a surrounding atom, and E is a lone pair on A. Both x and y are integers; x = 2, 3, …, and y = 1, 2, … Thus, the values of x and y indicate the number of surrounding atoms and number of lone pairs on the central atom, respectively [2]. This work aims to construct the Magnet and Pin kit for using as the tool, leading to connect the symbolic and microscopic representations of covalent compound’s Lewis dot structure and molecular geometry [2].
2. Method
The construction of Magnet and Pin kit and their components

The Magnet and Pin kit has two sets, the first set, called Magnet set, Figure 1. (a), consists of a 30 x 30 cm iron plate, an alphabet A with magnet (refer to central atom), 6 alphabets B with magnet (refer to surrounding atom), 18 white circular magnets (refer to valence electron of A), 42 black circular magnets (refer to valence electron of B) and 3 yellow circular magnets (refer to extra electron of molecule, from ion generation). The second set, called Pin set, Figure 1. (b), consists of a spherical eraser (refer to central atom), 6 pins (refer to bond and surrounding atom) and 3 droplet pins (refer to lone pair electron of central atom).

The Magnet set was used to guide the Lewis structure writing for describe the bonding pair electron between atoms and lone pair electron of central atom in covalent molecules. After that, the Pin set was used to construct the molecular geometry, which was predicted by Valence Shell Electron Pair Repulsion theory (VSEPR).

3. Results and Discussion
The Magnet and Pin kit was used to guide the Lewis structure writing, which leads to predict the molecular geometry of covalent compounds and it was used to connect the submicroscopic and symbolic representation.

3.1. The Magnet and Pin kit was used to guide the Lewis structure writing, which leads to predict the molecular geometry of covalent compounds and it was used to connect the submicroscopic and symbolic representation.

3.1.1. Symbolic Representation: Lewis structure and molecular geometry of CO$_3^{2-}$. The molecule of CO$_3^{2-}$ ion consisted of a carbon atom as a central atom, which is rounded by three oxygen atom. It is the covalent compound, resulting from electron sharing between non-metal atoms. Two carbon-to-oxygen bonds are single bonds, involving one electron pair and the third is a double bond, involving two electron pair. Moreover, two extra electrons are accepted into molecule in order to have the electronic structure of a corresponding noble-gas atom. The central Carbon there are no lone pairs of electron. The Lewis dot structure of CO$_3^{2-}$ are shown in Figure 2. (a). Based on Valence Shell Electron Pair Repulsion Theory (VSEPR), the electron clouds of the atoms around the carbon atom will repel each other. As a result, they will be pushed apart giving the CO$_3^{2-}$ molecule a trigonal planar molecular geometry. The CO$_3^{2-}$ bond angle will be about 120 degrees, as shown in Figure 2. (b).
3.1.2. Submicroscopic Representation: The construction of CO$_3^{2-}$ Lewis structure and molecular structure. The CO$_3^{2-}$ molecule consists of a C-atom (4 valence electrons), as a central atom and three O-atom (6 valence electrons), as surrounding atoms. Alphabet A and B refer to C and O-atom, respectively. The Lewis structure was constructed by following steps: (1) put an alphabet A with 4 white magnets on the center of iron plate, (2) place the 3 alphabets B with 6 black magnets around the alphabet A at symmetric position. (3) move a black magnet of each B to pair with white magnet around alphabet A, this step, they are equal to 3 pairs of magnets around A. (4) count the total magnet (black and white) around each alphabet B, they are equal to 7. (5) move a black magnet of B to pair a white magnet of A. (6) count the total magnet around B again, an alphabet B has completely 8 magnets but the other is not. (7) add a yellow magnet for each alphabet B. (8) count the total magnet around B again, an alphabet B has completely 8 magnets. The Lewis structure construction is finished in this step. After that, (9) the molecular structure was constructed by impaling 3 pins on spherical eraser with the widest angle. The angles between each pins are about 120°. This model refers to the geometry of CO$_3^{2-}$ molecule as trigonal planar. The Steps of construction the CO$_3^{2-}$ Lewis dot structure and its molecular geometry are shown in Figure 3.

![Figure 2](image2.png)

**Figure 2.** (a) Lewis dot structure and (b) molecular structure of CO$_3^{2-}$.

![Figure 3](image3.png)

**Figure 3.** The Steps of construction the CO$_3^{2-}$ Lewis dot structure and its molecular geometry

The Conversion of submicroscopic and symbolic representations in construction of Lewis structure and molecular geometry of CO$_3^{2-}$ are presented in Table 1.
Table 1. Conversion of submicroscopic and symbolic representations in construction of Lewis structure and molecular geometry of CO$_3^{2-}$ by Magnet and Pin kit

| Encoding Steps | Explanation of construction | Symbolic Representation |
|---------------|----------------------------|------------------------|
| Step 1        | Put an alphabet A with 4 white magnets on the iron plate | Writing the Lewis structure of a central atom |
| Step 2        | Place the 3 alphabets B with 6 black magnets around the alphabet A at symmetric position | Writing the Lewis structure of surrounding atom and preparation to form bonds |
| Step 3        | Move a black magnet of each B to pair with white magnet around alphabet A, this step, they are equal to 3 pairs of magnets around A | Sharing the electron to form covalent bonds |
| Step 4        | Count the total magnet (black and white) around each alphabet B, they are equal to 7 | Checking the number of electron of surrounding atom following Octet rule |
| Step 5        | Move a black magnet of B to pair a white magnet of A | |
| Step 6        | Count the total magnet around B again, an alphabet B has completely 8 magnets but the other is not | |
| Step 7        | Add a yellow magnet for each alphabet B | Receiving extra electron into molecule for following Octet rule and charge begetting |
| Step 8        | Count the total magnet around B again, an alphabet B has completely 8 magnets | Checking the number of electron of surrounding atom following Octet rule |
| Step 9        | Construct the molecular structure by impaling 3 pins on spherical eraser with the widest angle. The angles between each pins are about 120$^\circ$. This model refers to the geometry of CO$_3^{2-}$ molecule as trigonal planar. | Prediction the molecular geometry following VSEPR |

3.2. The Magnet and Submicroscopic and Symbolic Representation of XeF$_4$ molecule.

3.2.1. Submicroscopic Representation: Lewis structure and molecular geometry of XeF$_4$. The molecule of XeF$_4$ consisted of a xenon atom as a central atom, which is rounded by four fluorine atom. It is the covalent compound, resulting from electron sharing between nonmetal atoms. Four xenon-to-fluorine bonds are single bonds, involving one electron pair. The central xenon there are two lone pairs of electron. The Lewis dot structure of XeF$_4$ are shown in Figure 4. (a). Based on Valence Shell Electron Pair Repulsion Theory (VSEPR), two lone pair electron clouds of the Xe-atom will repulse bond pair electrons, giving the XeF$_4$ molecule a square planar molecular geometry. The angles between Xe and F atoms are 90$^\circ$. Each lone pair electrons are in position of top and bottom of the molecular plane, as shown in Figure 4. (b).
3.2.2. Submicroscopic Representation: The construction of XeF₄ molecular structure. The XeF₄ molecule consists of a Xe-atom (8 valence electrons), as a central atom and four F-atom (7 valence electrons), as surrounding atoms. Alphabet A and B refer to Xe and F-atom, respectively. The Lewis structure was constructed by following step; (1) put an alphabet A with 8 white magnets on the center of iron plate, (2) place the 4 alphabets B with 7 black magnets around the alphabet A at symmetric position. (3) move a black magnet of each B to pair with white magnet around alphabet A, this step, they are equal to 4 pairs of magnets around A. (4) Count the total magnet (black and white) around each alphabet B, they are equal to 8. This step is finished. Then, we have to count the black magnets around A that are not paired with white magnet of B. There are 2 pairs. (5) The molecular structure was constructed by impaling 4 pins and 2 droplet pins on spherical eraser with the widest angle. The angles between each pins are 90°, the angle between two droplet pins is 180° and the angles between pins and droplet pins are 90°. This model refers to the geometry of XeF₄ molecule as square planar. The Steps of construction the XeF₄ Lewis dot structure and its molecular geometry are shown in Figure 5.

![Steps of construction](image)

**Figure 5.** The Steps of construction the XeF₄ Lewis dot structure and its molecular geometry

The Conversion of submicroscopic and symbolic representations in construction of Lewis structure and molecular geometry of XeF₄ are presented in Table 2.

| Encoding Steps | Explanation of construction | Symbolic Representation |
|----------------|-----------------------------|-------------------------|
| Step 1         | put an alphabet A with 8 white magnets on | Writing the Lewis structure of a |
the center of iron plate | central atom
--- | ---
**Step 2** | place the 4 alphabets B with 7 black magnets around the alphabet A at symmetric positon | Writing the Lewis structure of surrounding atom and preparation to form bonds
**Step 3** | move a black magnet of each B to pair with white magnet around alphabet A, this step, they are equal to 4 pairs of magnets around A | Sharing of the electron to form covalent bonds
**Step 4** | Count the total magnet (black and white) around each alphabet B, they are equal to 8. This step is finished. Then, we have to count the black magnets around A that are not paired with white magnet of B. There are 2 pairs | Checking the number of electron of surrounding atom following Octet rule
**Step 5** | Constructed by impaling 4 pins and 2 droplet pins on spherical eraser with the widest angle. The angles between each pins are 90°, the angle between two droplet pins is 180° and the angles between pins and droplet pins are 90°. This model refers to the geometry of XeF₄ molecule as square planar | Prediction the molecular geometry following VSEPR

4. Conclusion
The Magnetic and Pin kit was constructed from magnets and pins. The users can use the Magnet set to create the Lewis dot structure on iron plate without frequent drawing and rubbing on the papers. The magnets on the plate are moved for anytime when the users know it’s wrong. Moreover, this set can be used to show the number of bond pair electrons, types of bond and number of lone pair electrons on central atom. The Pin set, constructed from pin and eraser, is used to build the 3D molecular structure and specify the bond angles. This kit was used to connect the symbolic and submicroscopic representations and encourage the student’s understanding. Finally, the teacher can use it to check the student’s misconception, leading to solve problems immediately.

References
[1] John K Gilbert and David Treagust 2009 Multiple representations in chemical education (Springer)
[2] Raymond Chang 2010 Chemistry (The McGraw-Hill Companies, Inc)