Diagrammatic Representation of Particles of A Chemical Reaction: Tertiary Teachers' and Pre-service Teachers' Views*

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Key words: Diagrammatic representation, conceptual understanding, combustion of magnesium

Abstract
This study identified a number of conceptions about a chemical reaction, namely, the combustion of magnesium in air, perceived by the two groups of teachers in terms of the diagrammatic representations of particles. The sample comprised 88 pre-service chemistry teachers and 10 chemistry university lecturers. Six characteristic conceptions were identified: (A) Formation of intermediate, (B) Formation of free atoms, ions or radicals, (C) Combination of A and B, formation of intermediate and free atoms, ions or radicals, (D) Direct contact between oxygen molecules and magnesium, (E) Formation of closely packed magnesium oxide lattice, and (F) Formation of loosely packed magnesium oxide molecules. The results show that the two groups of teachers have different views about the reaction mechanism of the reaction. The lecturers are in favour of Conception A, using 'intermediate' approach whereas the pre-service teachers in favour of Conception B, using 'free particles' approach. Many pre-service teachers showed Conception F, formation of loosely packed magnesium oxide molecules, which is the scientifically unacceptable concept. Two implications for teaching chemistry are raised: (1) teachers should pay more attention to their conceptions so that they do not transmit any misconceptions to the students, and (2) teachers should also emphasize their teaching at the microscopic level using particles to enhance conceptual understanding.

Introduction
Recent studies reported have shown that while chemistry can be taught at (1) the microscopic level; (2) the macroscopic or sensory level; and (3) the symbolic level, most chemistry courses only concentrate on the symbolic level of chemistry teaching, neglecting the other two aspects (Johnstone, 1990). However, some good teachers may go an extra mile to organize their instructional activities at both macroscopic and symbolic levels, such as demonstrating experiments and conducting practical work to show chemical phenomena (the macroscopic level), and explaining concepts using chemical equations or symbols (the symbolic level). Nevertheless, students may still find it difficult to understand certain chemical concepts. For instance, a typical real-life example of a grade 11 chemistry student, Andrea, being described by Ebenezer and Erickson (1996) as a capable and hardworking student who, at one stage, felt confused in learning ionic equations. The detailed notes which contained the explanations for ionic equations provided by her teacher, and the demonstration on the conductivity of various salts to ionic equations conducted by her teacher, did not seem to help much in her understanding of ionic equations. The following excerpt about Andrea does reflect the predicament of many Chemistry students:

"I'm trying to make sense of all this balancing stuff (i.e., the symbols for the elements, ions, and their respective states), but visually and mentally it is making me dizzy. I just don't understand!"
(Ebenzer & Erickson, 1996, page 182).

The possible explanation for Andrea's confusion can be that her teacher only explained the concept of ionic equations at the symbolic and macroscopic levels. Another possible explanation is that the lessons might have been taught at the three levels, which, however, were inadequately connected. As a result, the information remained compartmentalized in the long-term memory of Andrea.

Gabel (1993) conducted a study to determine whether student's understanding of chemistry would increase if the particulate nature of matter was emphasized in the teaching. The rationale of this study was that if the particle-schemata emphasized during instruction, the macroscopic/sensory and symbolic representations would simultaneously be included as it is not possible to isolate the particle level from them. Two treatment classes and one control class were randomly selected for this study. The treatment classes were provided with 25 additional
worksheets requiring students to link the particulate nature of matter to either physical phenomena and/or chemical symbols. They also had 20 overhead transparencies which portrayed the particulate nature of matter and the teacher therefore had 45 opportunities throughout the year to emphasize particles. The results showed that the treatment classes performed better than the control class not only on the microscopic level, but also on the macroscopic and symbolic levels. This small-scale study therefore seems to indicate that instruction on the particle theory is effective in assisting students to make connections between the three levels of chemistry in which it can be taught and understood.

In the light of the researchers' views and research findings described above and somewhere else, it is suggested that effective chemistry instruction should emphasize at the three levels especially the microscopic level to which many teachers, in general, pay very little attention.

Understanding Chemistry at the Microscopic Level

Many research studies have shown that students were weak in understanding chemistry concepts at a microscopic level (Yarroch, 1985; Nurrenbern & Pickering, 1987; Lythcott, 1990; Sawrey, 1990; Lee, Goh & Chia, 1992). The students generally have difficulties in explaining the nature of materials or changes involved in materials by using ideas about particles of solids, liquids and gases. The few examples given here illustrate the point. The areas of studies include: (1) problem solving in chemistry, (2) balancing chemical equations, (3) chemical changes, and (4) constructivist approach to learning.

(1) Problem solving in chemistry
The replicated studies were conducted by Nurrenbern et al. (1987), Sawrey (1990) and Lee et al. (1993) to investigate whether the students had difficulty in solving chemical problems using some fundamental chemical concepts. The test consisting of traditional problems (The symbolic level) and conceptual questions involving particles (The microscopic level) on stoichiometry and gases was used. Nurrenbern et al. (1987) and Sawrey (1990) administered the test to American students in an introductory chemistry course whereas Lee et al. (1993) administered to two different groups of Singaporean students: one group was first year junior college chemistry students and another group was the pre-service chemistry student teachers. The results of these studies were consistent that students were more able to answer the questions that used symbols and numbers than those depicting particles.

(2) Balancing chemical equations
Yarroch (1985) interviewed fourteen high school chemistry students on how they balanced simple chemical equations. One part of the study investigated the student's representation of the balanced equations with diagrams at the microscopic level. Seven of the twelve students who managed to make diagrams of the equations were not able to construct diagrams (in terms of particles) that were reasonably consistent with the notation of the balanced equations they correctly answered.

In another study, Lythcott (1990) investigated the relationship between chemical knowledge and problem-solving approaches. The study involved high school chemistry students solving problems about mass in chemical reactions. One part of the study asked the students to draw the meaning of a balanced chemical equation in terms of particles (the words 'atom' and 'molecule' were used instead of particles in this study). Of the 13 students who produced correct solutions, eight were not able to represent adequately the balanced chemical equations by drawing of atoms.

(3) Chemical changes
Anderson and other researchers worked on a few studies of students' conception of chemical changes. Anderson (1986) summarized the findings of these studies that chemical changes were conceived in five ways. These are: (i) 'just like that'; (ii) displacement; (iii) modification; (iv) transmutation; and (v) chemical interaction. For the first category, no explanation is given. Displacement means that a substance appears at a given place simply because it has been displaced by some other things. Modification means that what appears to be a new substance is in actual fact that the same substance turns into different appearance. Transmutation means that a given substance is transformed into a new one, for example, iron into carbon. The second, third and fourth were applied by the students both to macroscopic world and to the world of atoms. Only about 20 percent of students gave
responses involving the sense of an interaction between the reactant that characterises the fifth conceptions. The first three categories of conceptions consider a new substance is the result of a separate change in one or more of the original substances. The substances may mix with each other, but the new substances are not formed by chemical rearrangements among atoms. Many students do not see that the matter (in atomic terms) is conserved when new molecular substances are formed.

(4) Constructivist approach to learning
Laverty and McGarvey (1991) designed and evaluated a scheme of work for teaching elements and compounds to 13-14 years old students. The teaching programme incorporated the constructivist teaching sequence of the Children's Learning in Science (CLIS) project and included an opportunity to investigate the students' own ideas, in terms of diagrammatic representations of particles, of two experiments. The two experiments are: (i) the formation of magnesium oxide from combustion of a given mass of magnesium in air, and (ii) the formation of copper oxide from heating copper (II) carbonate.

The teacher demonstrated the two experiments at two different times. The students were divided into small groups to discuss what was happening in terms of particles. They were asked to represent the formation of magnesium oxide and a reaction mechanism for the effect of heat on copper (II) carbonate diagrammatically. Some misconceptions were elicited and these tentative ideas were followed up by the teacher through the use of strategies which provided the students with opportunities whereby they could modify or abandon their existing ideas before adopting the scientifically acceptable ideas on elements and compounds.

The purpose of the study
Learning chemistry in schools is more than just knowing or observing chemical and physical processes or phenomena, and the properties and uses of some chemicals. Recent research has strongly implied that particle model (showing interaction between the atoms and molecules at the microscopic level) should be emphasized in teaching to develop conceptual understanding. Are the teachers confident in teaching chemistry using particle model? What are their particulate perceptions of some chemical changes which are commonly taught in schools? A study of students' microscopic conceptions of two common chemical reactions was undertaken (Laverty and McGarvey, 1991). As an extension of Laverty et al's study, it is interesting to find out how teachers perceive chemical reactions on the same aspect. From a pedagogical point of view, it is thought that a better understanding of teachers particulate conceptions of reactions will provide important insights for teacher trainers and teachers to develop more appropriate instruction and materials for chemistry courses.

This paper will report on a study of two groups of teachers in their perceptions of a chemical reaction, namely, the combustion of magnesium in air, in terms of its diagrammatic representations of particles. One group of teachers were the university chemistry lecturers. Another group of teachers were the pre-service chemistry teachers. The conceptions of the two groups of teachers over the two reactions at the microscopic level were compared. Some implications of the study are also addressed in this paper.

Method
Sample
The sample comprised 88 pre-service chemistry teachers who were enrolled in the one-year Postgraduate-Diploma-in-Education (PGDE) programme from the National Institute of Education and 10 chemistry lecturers from a university in Singapore. The pre-service chemistry teachers (will be called student teachers from here onward) were made up of 3 cohorts who took chemistry teaching method course with the researcher in the academic years of 94/95, 95/96 and 96/97. The numbers of student teachers of the 3 cohorts involved in this study are: 94/95: 28; 95/96: 28; 96/97: 32. These student teachers are science graduate who did chemistry in their first degree study.

Procedure
The chemical experiment, combustion of magnesium in air, was demonstrated to the student teachers by the researcher. The student teachers were then divided into 18 groups of 4-6 student teachers each to discuss the reaction mechanism of the reaction in terms of
particles. They were asked to use circles (O) or shaded circles (( ) etc. to represent particles to show the reaction mechanism taken place on the overhead transparencies. A representative from each group was invited to the front of the class to briefly explain their diagrams after the discussion. The breakdown of the numbers of groups and numbers of student teachers from the different cohorts are summarized in Table 1.

<table>
<thead>
<tr>
<th>Year of Enrollment</th>
<th>No. of Groups</th>
<th>No. of Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>94/95</td>
<td>6</td>
<td>28</td>
</tr>
<tr>
<td>95/96</td>
<td>7</td>
<td>28</td>
</tr>
<tr>
<td>96/97</td>
<td>5</td>
<td>32</td>
</tr>
<tr>
<td>Total</td>
<td>18</td>
<td>88</td>
</tr>
</tbody>
</table>

For the chemistry lecturers, the researcher approached them individually to invite them to use the diagrammatic representations of particles to show their perceptions of the reaction mechanism taken place. Similarly, they were also advised to use circles (O), shaded circles (( ) etc. to represent the different particles in their diagrams. They were given a worksheet where instruction and spaces were provided for their responses. The reaction was not demonstrated to these lecturers because as chemists they are very familiar with the combustion of magnesium in air. The researcher interviewed the lecturers to seek clarification when ambiguous responses arose.

Results

Twenty eight diagrams constructed by 18 groups of student teachers (comprising 88 student teachers) and 10 lecturers were examined in terms of common characteristics shown in the particulate representations of the reaction mechanism. Six characteristic conceptions were identified. They are:

(A) Formation of intermediate;
(B) Formation of free atoms, ions or radicals;
(C) Combination of A and B: Formation of intermediate and free atoms, ions or radicals;
(D) Direct contact between oxygen molecules and magnesium;
(E) Formation of closely packed magnesium oxide lattice; and
(F) Formation of loosely packed magnesium oxide molecules.

A, B, C and D are the conceptions about how the reactant particles interact with each other before magnesium oxide is formed. E and F are the conceptions about the arrangement of the end-product, magnesium oxide molecules, which are either closely or loosely packed. In this section, the meanings of these conceptions are discussed with some examples taken from the subjects' drawings.

(A) Formation of intermediate

Before the formation of magnesium oxide, at the points of contact, oxygen molecules and magnesium atoms of the lattice attract each other and form intermediate as shown below:

```
Mg                           Intermediate (i)
Intermediate (ii)             MgO lattice
```

Figure 1 Diagrammatic Representation of Intermediate

In the intermediate, the attraction between oxygen and magnesium is slowly getting stronger while the attraction between oxygen atoms of the oxygen molecules and between magnesium atoms in the lattice are getting weaker (intermediate shifts from i to ii). The dissociation of oxygen/magnesium bonds are complete when magnesium oxide is formed. The processes of bond breaking and formation are undertaken simultaneously. To illustrate this point, 2 diagrams presented by a
Majority of the lecturers (7 out of 10) shared the same conception of forming intermediate at the transition stage of the reaction. However, it is only 4 out of 18 groups of student teachers (22%) had this conception.

In addition, there are two other ideas which were also revealed in these lecturers' diagrams. Two lecturers (L4 and L5) suggested both nitrogen and oxygen gases taking part in the reaction whereas the rest of the subjects only considered oxygen gas reacting with magnesium. As a result, the final products are the mixture of magnesium oxide and nitride (see Example 1). Furthermore, 2 lecturers (L5 and L9), during the interviews, emphasized the context of energy supply as a determinant of the reaction to be taken place. L9 said that "If the energy is sufficient, MgO will be formed from the intermediate".

(B) Formation of free atoms, ions and radicals

Upon the application of heat, magnesium atoms in the lattice or/oxygen atoms of its molecules vibrate and finally turn into free atoms, ions or radicals. Electrons may be lost, gained or equally divided between atoms in this process. The particles may be formed as followed:

\[
\begin{align*}
0 & \quad 0 \quad (O_{2-}, O_{2+} \text{ (oxygen ions)}) \\
0 & \quad 0 \quad (O^+, O^- \text{ (oxygen ions)}) \\
0 & \quad 0 \quad (O, O \text{ (oxygen radicals)}) \\
0 & \quad 0 \quad (O, O \text{ (oxygen atoms)})
\end{align*}
\]

\[
\begin{align*}
\text{Mg} & \quad (\text{Mg}^{2+} + 2e^-) \\
\text{Mg lattice} & \quad \text{Mg atoms}
\end{align*}
\]

These free particles, then combine and form magnesium oxide. Only 1 (L2) out of 10 lecturers showed this conception whereas 7 out of 18 groups of student teachers (about 39%) had this conception. To illustrate this point, two examples are shown in Appendix, Examples 3 and 4.

Of those who shared this conception, some of them (the lecturer, L2, and 3 groups of student teachers) showed the ionic bonding of magnesium oxide in their diagrams. They either used ionic equations at the symbolic level or circles with "+" and "-" signs in them, or with electrons on the circles (see below).

\[
\begin{align*}
2\text{Mg} & \quad (2\text{Mg}^{2+} + 4e^-) \\
\text{O}_2 & \quad + 4e^- \quad (2\text{O}_{2-})
\end{align*}
\]

\[
\begin{align*}
\text{MgO} & \quad \text{O}_{2-} \\
\text{Mg}^{2+} & \quad \text{O}_{2-}
\end{align*}
\]

Figure 2 Diagrammatic Representation of Ionic Bonding of MgO

(C) Combination of A and B: Formation of intermediate and free atoms, ions or radicals

Of 10 lecturers, one lecturer (L1) considered both intermediate and free particles were possibly produced at the same time as shown below:

Formation of free particles:

\[
\begin{align*}
(i) & \quad 0 \quad 0 \quad (O_{2-}, O_{2+}) \\
(ii) & \quad 0 \quad 0 \quad (O^+, O^-) \\
(iii) & \quad 0 \quad 0 \quad (O, O)
\end{align*}
\]

Formation of intermediate:

\[
\begin{align*}
(iv) & \quad 0 \quad --- \quad 0 \quad (\text{Mg} \quad --- \quad \text{Mg})
\end{align*}
\]

The lecturer suggested that (iii) and (iv) were more likely to occur. Of 18 groups of student teachers, 2 groups also used this combined conception of A and B to explain the reaction undertaken, except that they had different ideas about which reactant broke into free particles.

One group of student teacher (Gp 17) thought that oxygen molecules should be the one which were broken into atoms first before combining
with magnesium. In contrast, the other group (Gp 18) thought that the magnesium atoms should be ionised into magnesium ions prior to joining oxygen molecules to form intermediate then compound later. A diagram is shown in Appendix, Example 5, to illustrate this point.

(D) Direct contact between oxygen molecules and magnesium
One lecturer (L3) and one group of student teacher (Gp 12) considered that the molecules of oxygen sit on or come into contact with magnesium lattice atoms before magnesium oxide or magnesium nitride were formed (see below). How the particles of the reactants interact with each other was not shown in the diagrams. When the researcher interviewed the lecturer (L3), he said "it just happened". The diagram of L3 is shown in Appendix, Example 6, to illustrate this point.

![Mg](Figure 3 Diagrammatic Representation of 'Direct Contact' Conception)

(E) Formation of closely packed magnesium oxide lattice
In the particulate representation of the formation of magnesium oxide, 8 lecturers out of 10 and 8 groups of student teachers (44%) showed explicitly that the end-product of magnesium oxide molecules were arranged in a closely packed order. Some of them also used Conceptions A, B or C to represent the reaction mechanism prior to the formation of end-product (MgO). Two lecturers and 2 groups of student teachers did not show evidence about the arrangement of atoms in the final product. Example 7 is shown in Appendix to illustrate this point.

![MgO](Figure 4 Closely Packed Representation of Magnesium Oxide)

(F) Formation of loosely packed magnesium oxide
In the representation of the end-product, MgO, of 18 groups of student teachers, 8 groups (44%) drew the magnesium oxide molecules in a loosely packed manner. No lecturer showed this conception. To illustrate this point, Example 8 is shown in Appendix.

![MgO](Figure 5 Loosely Packed Representation of Magnesium Oxide Molecules)

In summary, the distribution frequency of the lecturers and student teachers who showed the different conceptions in their diagrammatic representations of the combustion reaction of magnesium in air is shown in Table 2.

<table>
<thead>
<tr>
<th>Char Conception</th>
<th>StuTeachers Groups</th>
<th>Lecturers(Total 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4 (22%)</td>
<td>7 (70%)</td>
</tr>
<tr>
<td>B</td>
<td>7 (39%)</td>
<td>1 (10%)</td>
</tr>
<tr>
<td>C (A &amp; B)</td>
<td>2 (11%)</td>
<td>1 (10%)</td>
</tr>
<tr>
<td>D</td>
<td>1 (6%)</td>
<td>1 (10%)</td>
</tr>
<tr>
<td>E</td>
<td>8 (44%)</td>
<td>8 (80%)</td>
</tr>
<tr>
<td>F</td>
<td>8 (44%)</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>

**Discussion**

The findings of this study show two significant differences between the two groups of teachers in their conceptions of how magnesium and air interact with each other at the microscopic level. The discussion of
the differences in this section is focussed on two aspects, namely, (1) intermediate versus free particles conceptions, and (2) arrangement of particles in magnesium oxide.

(1) Intermediate versus free particles conceptions

Majority of the lecturers (70-80%) hold the intermediate conception (Conception A and C) whereas many student teachers (more than 40%) hold the free particles conception about the reaction of burning magnesium in air. Till todate, there is no report in literature about the reaction mechanism of this reaction in terms of particles. The evidence from this study shows that the theory of ionic bonding does influence the perception of the teachers on how magnesium oxide should be formed. Magnesium oxide is an ionic compound which is taught in secondary schools. The electrons are transferred from magnesium atom to oxygen atom to form magnesium oxide which consists of magnesium and oxide ions (see Figure 6).

Ionic bonding of magnesium oxide
(Textbook information)

Figure 6 Formation of Ionic Bond

The knowledge of the formation of magnesium oxide learned in schools about the transformation of magnesium and oxygen atoms into ions probably attributes to the ideas of Conception B (see Results section).

As reported earlier, one category of thought in this conception is that (i) oxygen molecules and magnesium lattice will turn into atoms upon heating. Another category of thought is that (ii) upon heating oxygen molecules and magnesium lattice atoms will directly turn into positive and negative ions which attract each other and hence form the ionic compound. The idea of forming atoms or ions of Conception B is very unpopular among the lecturers. Nevertheless, a lecturer (L1) who showed Conception C (Combination of A and B) commented during the interview that it was possible that oxygen might be broken into radicals but not so much into atoms and ions in the heating condition. He added that, however, the chance of forming intermediate was higher in this reaction.

In comparison with the study carried out by Laverty et al. (1991), this free particles conception is very similar to their findings that some students of their study (aged 13-14) thought that magnesiums and oxygens broke apart and then mixed to form magnesium oxide whereas some others thought that only magnesium atoms would separate before magnesium oxide formed.

(2) Formation of loosely packed magnesium oxide molecules

From Table 2, it is shown that about 44% of the student teachers who did not arrange the magnesium oxide particles in closely packed manner (Figure 4). It is quite a surprise to find that so many teachers who were science trained and yet did not actively hold correct science concept about the arrangement of particles in solid. The knowledge is obviously very detached or absent from their memories because it was not effectively linked to when needed. These teachers' misconception about solid appeared the same as the students in the study of Laverty et al. (1991) that most of them did not have preconception of closely packed arrangement of magnesium oxide.

Implications

This study identified a number of different conceptions of a chemical reaction about burning magnesium in air, perceived by two groups of teachers (tertiary and pre-service) in terms of the diagrammatic representation of particles. The study, once again, confirms that teachers do have conceptions which are different from those currently accepted by scientists. The study provides insight into the nature of some conceptual difficulties that teachers have. Teachers should always check on and update their conceptions, if necessary, rectify any misconceptions before transmitting them to students. The evidence of this study shows that the student teachers did not have full
understanding of the chemistry concepts. Hence the second implication for teaching chemistry in general is that teachers can emphasize their instruction at the microscopic level in addition to what they have already done in schools. Understanding of chemistry would not be complete if the three levels of teaching, i.e., macroscopic, symbolic and microscopic, as described by Johnstone (1990) are not equally emphasized. The emphasis of three levels of chemistry teaching is the right direction to enhance conceptual understanding.

References


