MISCONCEPTIONS ABOUT THE ATOMIC THEORY

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While the atomic theory is a fundamental concept in chemistry, the way it is presented in the school textbook can leave students with a superficial understanding and many misconceptions. Do teachers recognise the limitations and challenges of the explanations and illustrations in the textbook?

The atomic theory, while abstract, is at the heart of modern chemistry. Studies show that many middle and high school students may be adept at parroting information on this theory from their textbooks but hold many misconceptions. Often, they are unable to appreciate the nuances of this theory or understand how it relates to other concepts or scientific disciplines. One reason for these challenges is related to the way this theory is presented in school textbooks. Explanations and illustrations in the textbook are often confusing or carry errors. Also, textbooks do not highlight the relevance of this theory to other disciplines and its linkages with other concepts (such as heat and temperature). If taught in a superficial manner, students are unable to apply this idea to explain observed phenomena or engage with problems related to them.

One of the aims of a workshop organized in June 2007 at Eklavya, Indore, was to introduce 22 Grade VIII-X teachers to challenges in the explanations and illustrations related to this theory in the school textbook. The teachers were given a test with three questions, which they answered in approximately twenty minutes. An analysis of their answers to these questions revealed some important insights.

Properties of metals

The first question was: Copper and mercury are both metals. Copper is a solid at room temperature, while mercury is a liquid (see **Fig. 1**). Also, copper is a better conductor of heat and electricity than mercury. Which of the following statements is true for copper and mercury?

a. Atoms of copper are more malleable than atoms of mercury.

b. Mercury atoms are liquids while copper atoms are solids.

c. A copper atom is a better conductor of electricity than a mercury atom.

d. None of the above. Then, how would you account for the differences observed between the two metals?

Of the 18 teachers who answered the question, many selected one or more of the three incorrect options (a, b, and c). Only eight of them selected the correct option (d). Of these, three did not offer reasons for their choice. Four had given widely different reasons. Only one answer could be considered accurate: *"As the properties are of elements, i.e., the group of atoms, not of a single particular atom"*. The teachers who chose the incorrect options seemed to believe that the properties observed in bulk groupings of atoms are found in individual atoms too. In other words, they seemed to think of the atom as the smallest particle of an element that exhibits all the physical and chemical properties of that element.

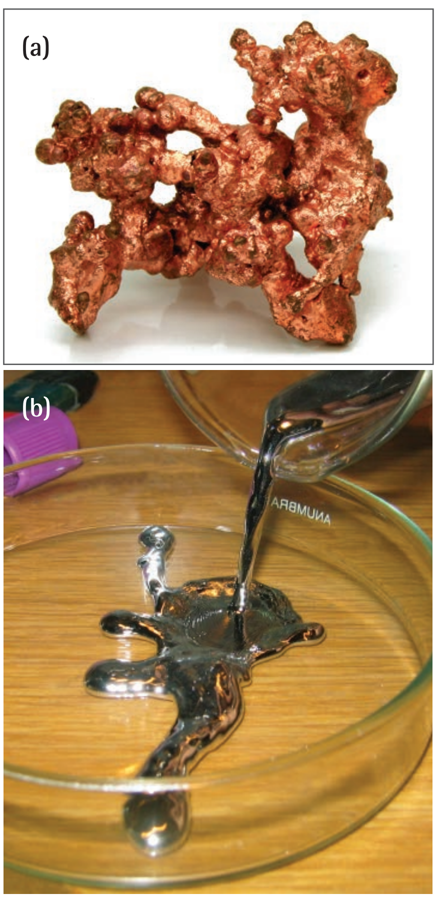

Fig. 1. How are the atoms of copper (a) and mercury (b) different from each other?

(a) Credits: Spinningspark. URL: https://commons.wikimedia.org/wiki/File:NatCopper.jpg. License: CC-BY-SA. (b) Credits: Bionerd. URL: https://commons.wikimedia.org/wiki/File:Pouring_liquid_mercury_bionerd.jpg. License: CC-BY.

What could have led to this misconception? One reason may be related to the most frequent image that teachers use to introduce the concept of atoms to their students. This is of breaking a brick or a piece of chalk into smaller and smaller pieces till one gets a piece that cannot be broken further without losing its 'brickiness' or 'chalkiness'. This vivid image is likely to leave students with the idea that, except for its size, an atom is exactly like the bigger piece it was initially a part of. This idea is so powerful that it seems to overshadow what students and teachers learn at a later stage about metallic bonding and its properties—that this kind of bond not only explains why a metal conducts electricity but also why it is shiny, malleable, etc. Another reason for this misconception may be that, unlike Dalton who formulated the atomic theory, our understanding of atoms is rarely built up theoretically from quantitative laws. Yet another reason may be the compartmentalization of knowledge. This is often strengthened by assessment methods that are not designed to test or probe what children have actually learned about connections between various concepts and the need for coherence between them.

Temperature of a gas

The second question was: What is the temperature of an isolated molecule of hydrogen?

Eleven teachers attempted the question. Four of them stated that the temperature of the hydrogen molecule would be the same as *"room temperature"*. One answer was *"0°C"*, and another was hydrogen's *"critical temperature"*. One of the teachers tried to use the formula: $PV = nRT$, but did not get further than $T = PV/nR$. Another teacher mentioned the *"molecular kinetic theory of gases"*, but did not offer any further explanation. One teacher's answer was: *"The temperature of the individual (isolated) molecule will be the same as the temperature of the whole quantity of gas"*. This reveals one reason for this confused thinking about temperature. Only two of the 22 teachers offered somewhat accurate answers. One of them replied: *"It is not possible to measure the temperature of an isolated molecule"*. The other's answer was: *"Can't predict and measure"*. However, even these answers focused on the problem of measurement.

Many of these teachers were familiar with the kinetic theory of gases. It is likely that they would have been able to solve equations related to this theory with great ease. Yet, none of them seemed to find anything odd about being asked about the temperature of one molecule of hydrogen. They seemed to have ignored the fact that the temperature of a substance (whether it is in solid, liquid, or gaseous state) is a derived quantity that tells us something about the **average** energy (kinetic energy, hence velocity) of molecules in bulk. Their answers seemed to be based on the incorrect belief that temperature is an intrinsic property of individual molecules that is directly measurable (however inaccurately), much like the length of a table.

States of matter

The last question was related to an illustration from the NCERT textbook for Grade IX (see **Fig. 2**). Teachers were asked to study the illustration before answering the following questions:

a. Extract as much information from the given illustration as possible.
b. Compare the change in density of particles during changes in states of matter from solid to liquid and liquid to gas.
c. What do you think exists between the molecules or atoms in the three parts of the diagram?
d. Compare the degree of order in the three states of matter.

The first part (a) was included as an invitation to critically examine as many details of the textbook illustration as

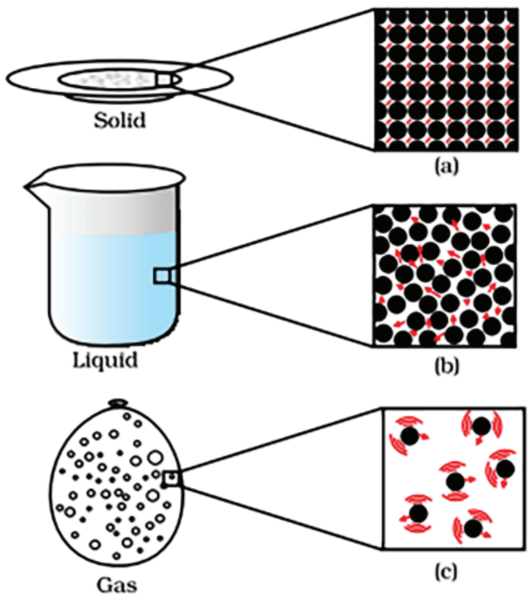

***Fig.1.5:** a, b and c show the magnified schematic pictures of the three states of matter. The motion of the particles can be seen and compared in the three states of matter.*

Fig. 2. **Misleading illustrations in textbooks can influence misconceptions about the nature of matter.** This is one example of such an illustration. It is included in the first chapter 'Matter in our surroundings' of the NCERT science textbook for Grade IX.

possible. None of the teachers accepted the invitation. Instead, they answered this part with whatever they knew about solids, liquids, and gases.

The second part (b) was included to draw attention to two aspects of the illustration:

- The decrease in particle density when a (crystalline) solid changes to a liquid has been greatly exaggerated in the illustration. Thus, the illustration does not reflect the fact that this kind of change in the state of matter involves more a decrease in the degree of order than an increase in interparticle spaces. One example of this is seen in metals, where a decrease in order explains why the metallic bond survives melting as well as why molten metals are lustrous and can conduct electricity.
- The vast decrease in density when a liquid turns into a gas is not adequately represented in the illustration. To take the simple example of water, one mole of water is 18 mL in the liquid state and 22,400 mL in the gaseous state (if we consider that any gas at STP occupies 22.4 L, although this might not be entirely accurate for water). Thus, this change in state can cause more than a thousandfold increase in volume.

Most teachers answered this part by stating that the density of particles decreases in the order of solid > liquid > gas.

The correct answer to the third part (c) would be that there is 'nothing' between the molecules or atoms (or particles). Answers to this question revealed some confusion and some clarity. Three teachers answered it with *"air"*. Interestingly, research in science education suggests that most children believe that molecules of a gas are separated by air. Could this confusion in students be related to imperfectly taught theory? Seven teachers answered it with *"intermolecular forces"*, six teachers with *"intermolecular spaces"*, and two teachers with a combination of both these answers. Is it possible that these teachers used these terms to avoid having to answer this question with 'nothing'?

The fourth part (d) was included to draw attention to one of the most important differences in the particulate nature of the three states of matter. The arrangement of particles (atoms, molecules, or ions) shows a high degree of order in a solid, less order in a liquid, and a state of high disorder in a gas. Thus, the question invited teachers to examine if the textbook illustration clarified that the particles in a solid can only show vibratory motion while those in a liquid or gas can also show translational motion. However, none of the answers touched upon these aspects. Again, teachers answered this question with textbook statements about order and disorder in solids, liquids, and gases.

These answers seemed to suggest that the teachers may not have looked at the illustration carefully or critically enough, or given sufficient thought to the impact of illustrations on reinforcing incorrect concepts among students. It is also possible that a more direct question on the depiction of quantitative changes in density (like, *"Is the density of particles in the gas depicted in the textbook illustration tenfold, hundredfold, or thousandfold that in the liquid?"*) may have elicited more accurate answers.

Parting thoughts

The aim of this short test was to invite teachers to critically examine how the atomic theory is presented in the school textbook. Do the explanations and illustrations in the textbook really serve their purpose to help children understand and apply foundational concepts like the atomic theory to observations in the real world?

The answers to the test seem to suggest that most of the teachers had not engaged with the information in the textbook deeply enough. Also, surprisingly, many of the teachers had the same kinds of misconceptions that studies have shown to be prevalent among middle and high school students. They may have developed these misconceptions as children and have held onto them even as adults. If so, this would counter the common assumption that a pedagogical and assessment approach focused on ensuring that students can memorize textbook statements is sufficient to help them develop an accurate understanding of these statements on their own.

This small study may help teachers reflect more deeply on how they teach the atomic theory. Also, to ask and answer—how does identifying confusion and errors in textbook explanations and illustrations guide their pedagogical and assessment approach?

Key takeaways

- Studies show that many middle and high school students can describe the atomic theory accurately but hold many misconceptions about it.
- Often, students are also unable to appreciate how this theory is related to other concepts or scientific disciplines.
- Some of these challenges may be due to erroneous or confusing explanations and illustrations in school textbooks. These can go unnoticed by teachers.
- Some teachers may also associate the atomic theory with the same kinds of misconceptions that are prevalent among middle and high school students.
- Identifying such misconceptions and engaging more critically with textbook explanations and illustrations could guide teachers in developing pedagogical and assessment approaches that are more effective in helping children understand and apply this theory more accurately.

Notes:

1. This article was first published in Sandarbh, Issue 60, pg. 35-41. This version is restructured and revised for conciseness. URL: https://www.eklavya.in/magazine-activity/sandarbh-magazines/300-sandarbh-from-issue-51-to-60/sandarbh-issue-60/1211-parmanu-sidhant-or-shikshako-ki-bhrantiyan.
2. Source of the image used in the background of the article title: Breaking chalk. Credits: Viktoria Goda, Pexels. URL: https://www.pexels.com/photo/blue-red-and-yellow-chalk-1107495/. License: CC0.

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