TEACHERS' RESPONSES TO TEST: A PRELIMINARY ANALYSIS

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Background:

The atomic theory is an abstract concept, which lies at the heart of modern chemistry. Normally, the theory is treated in a very perfunctory manner in middle school to high school. The envisaged purpose of the training was to provide a historical background to this theory along with its development by Dalton. Since the various laws that lead to the atomic theory required rigorous measurements, there is no attempt to replicate any of the experiments. Instead, the attempt is to get the teacher / student to draw conclusions from the data given.

The development of the atomic theory was covered by getting the teachers to work out quantitative problems related to the laws of conservation of matter, constant proportions and reciprocal proportions. From Dalton's theory, the teachers went on to work out problems related to the law of multiple proportions before going on to the various methods that were used to calculate atomic weights and how these controversies were finally resolved. In the end, the teachers calculated how much hydrogen gas would be evolved from a given amount of zinc on reaction with hydrochloric acid, and verified this experimentally.

An interesting feature was the fact that teachers went through the quantitative exercises with fair degree of patience and diligence. They helped each other and asked questions freely. They enjoyed the experimental verification at the end of the session. However some teachers appeared to have limited exposure to carrying out experiments in chemistry.

In the beginning of the session, we gave a set of questions to the teachers which they answered over the next twenty minutes. This test consisted of questions which we hoped would probe the understanding of the teachers and also the role of the illustrations in text-books in leading to this understanding. The questions have been given below along with an analysis of the answers given by the teachers.

Question 1

Copper and mercury are both metals, with copper a solid at room temperature and mercury a liquid. Also copper is a better conductor of heat and electricity than mercury. Which of the following statements are true for copper and mercury:

a) Atoms of copper are more malleable than atoms of mercury.
b) Mercury atoms are liquid while copper atoms are solid.
c) A copper atom is a better conductor of electricity than a mercury atom.
d) None of the above. Then how do you account for the observed differences?

Analysis

Four teachers did not attempt this question.

Of the eighteen who attempted the question, only eight selected the right option d). Of these, three have not given any reasons for their choice and four have given widely and wildly different reasons for the observed differences. The one answer which is right except for the manner in which it has been expressed (‘As the properties are of elements, *i.e.*, the group of atoms, not of a single particular atom.’) has interestingly been given by a Biology teacher!

Therefore, the correct answer is 1\22.

No particular pattern is seen among the wrong answers except of the fact that no one seems to have rebelled at the idea of a solid but malleable copper **atom** conducting electricity. That is, the teachers selected one or more of the three wrong options with no understanding of what it meant to attribute the given properties to individual atoms. It seems that most teachers think that properties of matter are continuous and atoms have all the properties that we can perceive in their bulk groupings. Is it that the first vivid image all teachers give their students about breaking a brick or a piece of chalk into smaller and smaller pieces till we get a final piece which cannot be broken without losing the ‘brickiness’ or ‘chalkiness’ overshadows what comes later about metallic bonding and the rest?!

It is this image of breaking down that reinforces this notion. You keep breaking down something till you come to an atom. It seems like it is the same thing that you started with. It doesn’t seem to occur to the teachers that there is something wrong with this notion of attributing all the properties of matter that can be observed to the atom.

This also comes because the atom is not built up theoretically from quantitative laws like Dalton did. Instead the simplistic notion of ‘breaking’ down a macroscopic piece down to the atomic level is used and according to one teacher, this is what they have been teaching for years. As a matter of fact, an atom used to be defined as the smallest particle of an element which retains its properties.

Maybe what is needed are some more tests with a different set of questions, some in which the teachers have to articulate their understanding in a more comprehensive manner. Or we need to use interviews where we can continue probing if we find something anomalous.

Question 2

What would be the temperature of an isolated molecule of hydrogen?

Analysis

Eleven (50%!) did not attempt the question at all. They probably felt that the question involved something deeper which they could not guess at.

Only two out of twenty-two teachers got it almost right. One answer is, ‘It is not possible to measure the temperature of an isolated molecule.’ and the other is, ‘Can’t predict and measure.’ But here, too, they thought that the problem was with measurement.

Four say – ‘room temperature’ in greater or lesser detail.
One answer is 0 °C and another is critical temperature.
One answer tries to use PV = nRT and doesn’t get much further than T = PV/nR and another takes a stab at the ‘molecular kinetic theory of gases’ but doesn’t get anywhere (I may be responsible for this since I felt that the teacher was on the right track and thought that a hint would help). One answer – ‘The temperature at which the whole quantity of gas do exist that will be the temperature of individual (isolated) molecule’ – seems to reveal what leads to the muddled thinking about temperature. It is quite clear that they had never thought about this aspect of what is actually being measured when we talk about the temperature of any body.

Temperature is a derived quantity which tells us something about the <u>average</u> energy (kinetic energy, hence velocity) of molecules in bulk, whether this be in solid, liquid or gaseous state. But here it seems to be confused with an intrinsic property that is directly measured (however inaccurately) like the length of a table. Do we ever go into what the level of mercury or alcohol in a thermometer is actually measuring?!

Further testing could probably help clarify matters for us about whether teachers actually know the theory and just don’t think of applying it in this situation or whether the teachers don’t know where temperature comes from at all.

Question 3

Look at the diagram given below (the diagram in question was taken from the current NCERT text-book for class IX and purports to depict ‘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. 1.5)) and answer the following questions:
a) Extract as much information from the given diagram as possible.
b) Compare the change in density from solid to liquid and liquid to gas in this diagram.
c) What is there between the molecules/atoms in the three diagrams.
d) Compare the degree of order in the three states.

Analysis

This question was not worded with sufficient clarity, the teachers seemed to have had a hard time figuring out what answers were expected.

Q. 3. a) had the teachers putting down whatever they knew about solids, liquids and gases and they never got around to taking a critical look at the diagram / figure we had confronted them with.

Q. 3. b) – what we had expected was that they recognise that the decrease in density when a solid changes to a liquid had been greatly exaggerated – the change from solid (crystalline) to liquid is more of a change in orderliness than an increase in inter-particulate spaces. This, for example, explains why the metallic bond survives melting and molten metals have lustre and can conduct electricity. We had expected that the teachers would compute the density difference between the three phases and it would give us an opportunity to discuss the anomaly therein, *viz*., that the difference is greatly exaggerated in case of change form solid to liquid and underrepresented in case of change from liquid to gaseous state.
To take the simple example of water, one mole of water is 18 mL in the liquid state and 22400 mL in the gaseous state (at STP) – the increase in volume is more than a thousand-fold. Another point is that this figure contradicts the common observation that water expands when it freezes to form ice.

We should have clearly asked them to quantify the change in density, i.e., does the diagram show the density increasing tenfold / hundredfold / thousand-fold in going from liquid to gas? What most teachers have baldly stated is that density decreases in the order – solid > liquid > gas.
We could also ask whether such illustrations should be used. Do they cause more confusions or do they help in clarifying what is given in the text?

Q. 3. c) seems to be a good question because it reveals some confusion and some clarity. An ideal answer would be 'nothing' (!). But Aristotle rears his venerable head and most teachers have balked at saying that there is nothing between the molecules / atoms (or particles). Some of the answers are variations of 'intermolecular forces' (seven teachers), 'intermolecular spaces' (six teachers) or both (two teachers). They seem to be clarifying things by adding terms that they think would fit. Our readings of research in Science Education had informed us that most kids think that there is air between the molecules of a gas. Lo and behold! we got this answer from three teachers. A reversion to childhood thinking that air in nothing before we are taught that it has mass and occupies space and hence is matter?! An enigmatic answer given by one teacher was 'atoms' – is this Aristotle's influence or something else?!
Does this confusion tell us something about imperfectly taught theory?

Q. 3. d) also is not helpful in figuring out what teachers think, they have mainly regurgitated text-book statements about order and disorder in solids, liquids and gases. In one case, entropy has been equated with order – the universe would be an interesting place if this were really the case and the second law of thermodynamics were to be worded in the traditional manner itself.

So far, I have not seen any studies in which the teachers' understanding of concepts have been probed. The studies on students and student-teachers show the same kind of confusions that these teachers seem to have. Most studies also administer a multiple-choice paper to a large number of students / student-teachers and follow it up with interviewing a few to explore their understanding further. Maybe we too need to conduct a more rigorous study. Please send your suggestions for this.

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(Original, Unedited version)