Lower-secondary introductory chemistry course: a novel approach based on science-education theories, with emphasis on the macroscopic approach and the delayed meaningful teaching of the concepts of molecule and atom

Georgios Tsaparlis, Dimitrios Kolioulis, and Eleni Pappa

Chemistry Education Research and Practice, 2010, Volume **11**, Issue No. 2

SUPPLEMENTARY MATERIAL

PART 1. Excerpt from the lesson "*The concept of molecule in solids and liquids*".

PART 2. Excerpt from the lesson "*The concept of atom*".

PART 3: An example lesson: *Lesson 10, "Chemical reactions in aqueous solutions"*.

PART 1. Excerpt from the lesson *"The concept of molecule in solids and liquids."*

The molecules of different substances are different

Experiment 4

Take two identical beakers (each, say, of 100 mL capacity), and fill one entirely with beans and the other with rice. Shake each beaker so that they settle completely. Supposing that we empty the contents of the two beakers into a third empty beaker of double capacity (200 mL), followed by shaking this beaker again so that the grains in it settle. Could you make a prediction about the resulting total volume of beans and rice together?

Then, perform this experiment by emptying the contents of the two beakers into a much larger vessel and shaking it well. Following that, empty the content of the larger vessel back into the original two beakers by first filling one beaker completely (after shaking the content), and then transfer the remaining mixture of grains into the second beaker and also shake that well. What do you observe? Is the second beaker full? Has anything changed after the shaking?

……………………………………………………………………

We observe that after shaking, while no grains of either kind are lost, the final volume is less than the sum of the volumes in the two beakers. How do you explain it?

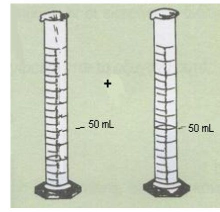
……………………………………………………………………………………………

……………………………………………………………………………………………

The grains of beans and of rice do not have the same size, they have different sizes – the two materials are different.

There is empty space between the molecules of a liquid substance

Experiment 5



water alcohol

Take two measuring cylinders, and place 50 mL pure water (purified, that is, distilled or deionised water) in one of them, and 50 mL pure alcohol in the other. Following that, transfer the content of the two cylinders into a 100 mL measuring cylinder, and shake the mixture well. What do you observe? Has anything changed after the mixing? What is the final volume of the mixture? How could you explain it?

……………………………………………………………………………………………

……………………………………………………………………………………………

There is **empty space** between the particles (the **molecules**) of a liquid substance

We observe that while none of either of the two liquids was lost, the final volume is not 100 mL (as we would have expected), but 96 mL.

Use the findings from the previous experiment with the grains of beans and rice to give an explanation to the result of this experiment. (You should make a hypothesis about the sizes of the particles of water and of alcohol: do they have the same size or could they be different?)

……………………………………………………………………………………………

……………………………………………………………………………………………

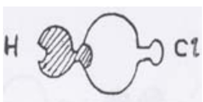
PART 2. Excerpt from the lesson *"The concept of atom"*.

Experiment 6

Take two identical pairs of plastic balls, with each pair consisting of two balls of different colour and size, joined one to the other in some way. Separate the two pairs into balls of the same colour and size. What do you think could be the relevance of this exercise?

……………………………………………………………………..…………………………………...

…………………………………………………………………….………………………..………..



Each pair of the joined balls represents a hydrogen chloride molecule, with one ball (the smaller) representing hydrogen and the other representing chlorine.

Hydrogen chloride is a composite substance (a chemical compound), consisting of the element hydrogen and of the element chlorine. The simplest case would be that the hydrogen chloride molecule consists of one unit (1 'molecule') of hydrogen and one unit (1 'molecule') of chlorine. In this way, we have decomposed the two hydrogen chloride molecules into two 'molecules' of hydrogen and two 'molecules' of chlorine.

Experiment 7

Take the balls of the same colour and size and join them, making again pairs of plastic balls, with each pair consisting of two balls of different colour and size. What do you see?

……………………...……………..…………………………………………………………………………

…………………………………………………..…………………………………………………………...

If we accept Avodagro's hypothesis, we conclude that the outcome of our experiment (the construction of two hydrogen chloride molecules from two 'molecules' of hydrogen and two 'molecules' of chlorine) does not agree with Gay–Lussac's experiment. Therefore, either Avodagro's hypothesis is wrong or the models we have used to represent the molecules are not valid.

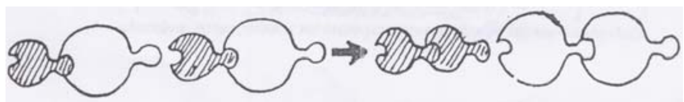
Experiment 8

Take two pairs of balls of different colour and size, joined one to the other, and make again two pairs of balls, each pair of the same colour and size (that is, this time modify the procedure you followed for Experiment 7). This time, you will assume that Avogadro's hypothesis is valid. What is your conclusion in this case?

………..……………………………

……

We conclude that each of the hydrogen and chlorine molecules is 'double', each consisting of two identical parts.



Take into account

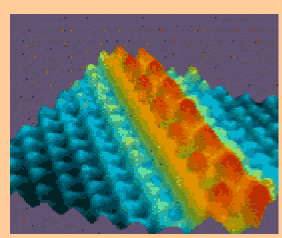
We should not think that molecules or atoms are solid balls. Also do not think that the molecules of a solid substance are solid, or of a liquid substance are liquid, or of a gaseous substance are gaseous. The balls we use to represent molecules or atoms are what we call **models** of molecules / **models** of atoms.

"*There was no doubt that atoms could explain some puzzling features of the world. But in truth they were merely one man's daydream. Atoms, if they really existed, were far too small to be perceived directly by the senses. How then would it ever be possible to establish their reality? Fortunately, there was a way. The trick was to assume that atoms existed, then deduce a logical consequence of this assumption for the everyday world. If the consequence matched reality, then the idea of atoms was given a boost. If it did not, then it was time to look for a better idea*".

Chown, M. (2001)
The magic furnace: The search for the origin of atoms
N. Y: Oxford University Press

Chemistry and technology: "We see atoms"

A modern experimental technique called scanning tunneling microcopy (STM) offers evidence for the existence of atoms. This technique reveals that the surface of a solid material consists of 'hills' (the atoms), among which there exist 'valleys' (empty spaces among the atoms). The scanning of the surface of the solid is carried out in a way similar to the way a blind man walks the road ahead by scanning with a stick: as he/she moves, he/she moves the stick continually to the left and to the right, hitting at the same time with the stick the ground.



Source of picture (STM image) on this page:

http://inventors.about.com/library/inventors/blstm.htm (accessed: 14 April 2010).

PART 3: An example lesson

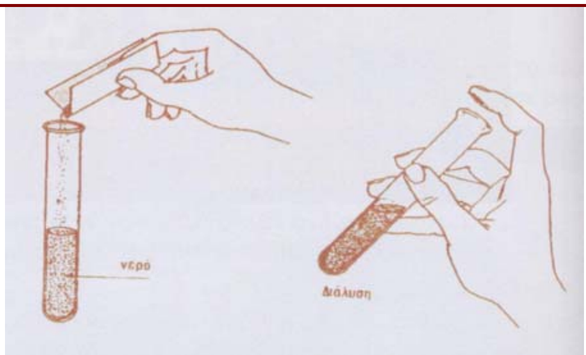
Lesson 10

CHEMICAL REACTIONS IN AQUEOUS SOLUTIONS
The role that water can play in chemical reactions

In the previous lesson we studied the chemical reaction between two solid substances that resulted in the formation of two new substances, one of which had an intense yellow colour. * *We also found that while the two starting solid substances were soluble in water, the yellow solid was insoluble in water. In this lesson, we will check if the same reaction could take place not directly between the solid substances, but between their aqueous solutions.*

Experiment 1

In two test tubes place a small quantity of deionised water. In one of the tubes dissolve a small quantity of one solid substance, and in the other test tube dissolve a small quantity of the other solid substance. Then, pour some of one solution into the other, and take a note of your observation. Allow the tube in which the chemical reaction took place to stand for some time.



It is apparent that the same chemical reaction that we observed taking place in the previous lesson took place again. At the bottom of the tube, we see a solid material, which is called a **precipitate**. This is the new yellow substance that was formed in the reaction. Above the solid substance, there is a liquid. Inside the tube therefore we have a ………………. mixture.

Question 1

How could we separate the insoluble yellow solid from the liquid?

....
....………...……………………..……

* The reaction studied is that between potassium iodide, KI, and lead nitrate, $Pb(NO_3)_2$, leading to the formation of insoluble lead iodide PbI_2.

Recall that we can separate the components of a mixture by pouring out the liquid or even better with filtration. It is apparent that the new substance that was formed, the *precipitate*, is the one left on the filter. The *filtrate* is a homogeneous mixture (solution)
(DO NOT THROW AWAY THE FILTRATE).

Question 2

Can we recover from the filtrate the pure (deionised) water that we used at the start? If yes, how?(IF YOU CARRY OUT AN EXPERIMENT, USE ONLY PART OF THE FILTRATE, AND KEEP THE REST.)
....
....
....

Reactant / Product

Aqueous solutions help the reacting substances to come into contact one with another

Water = solvent

Apparently the *filtrate* consists of the water we used to make the two solutions, in which remained, in dissolved form, the second soluble substance that was formed in the reaction (the second **product** of the reaction), plus the starting substances (the **reactants**) that might not have reacted.

We conclude:

❖ *The water has not changed, has not taken part in the chemical reaction. However, the reaction took place quickly and easily by simply mixing the two solutions. Therefore, water has just contributed to the easy and fast contact of the reacting substances (the* ***reactants****) with each other. Water was the* ***solvent*** *with which we made the aqueous solutions, which reacted easily and quickly one with another. For this reason, in chemistry we very often carry out the chemical reactions in aqueous solutions*

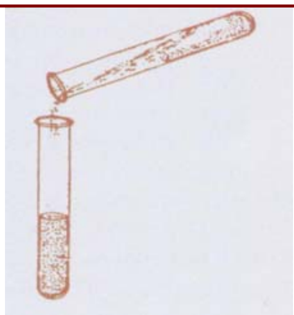
Take into account

There are cases where water is not just the solvent, but it takes part itself as a reactant. On the other hand, in many cases, water is produced as a product of a reaction.

Source of picture on this page: *School Science Review*

Experiment 2

To part of the *filtrate* add now some of one of the initial solutions. If no change is observed, add some of the other initial solution to another sample of the filtrate. Make a note of your observations and conclusions.
....
....
....



In the filtrate, one of the two initial substances (reactants) was left unreacted. The case might be that by mixing different quantities of the two solutions, after the reaction, the other initial substance would have remained unreacted.

Take into account

In higher grades, you will study further chemical reactions. You will find out then that if we mix the right amounts (which in higher grades you will be able to calculate yourself), the above reaction (and many others) will lead to the formation of new substances, while none of the initial substances (reactants) would remain (that is, the reactants would disappear).

A question that might come to your mind is this: '*Supposing that we have mixed the right amounts of substances that correspond to the complete reaction: are in every reaction all reactants used up? Or could a reaction stop before all reactants are used up?*"

Experiments show that *for many reactions the latter is the case, that is, we have formation of one or more new substances, but at the same time the reactant or the reactants are not used up completely*.

Finally, you should take into account that when we mix some substances, a chemical reaction does not necessarily take place. Also, that some chemical reactions need proper conditions in order that they take place, for instance, they may need heating.

Take into account

Food is preserved for longer if we add to it various natural or artificial substances, which are called **preservatives**. How can we keep cod for a long time? How can we keep fruit? In what medium do we keep olives and some types of cheese (such as feta cheese)?

The aqueous solution of cooking salt, which is about 10% by mass in salt (that is, we add about 10 g of salt to 100 g or 100 cm^3 water) is called *brine*, and is used as a preservative liquid.

Boiled fruit can be preserved in *syrup*. *Do you know how we can make syrup?*

THE LESSON IN QUESTIONS

1. What is the reason that very often we carry out chemical reactions using aqueous solutions of the reacting substances?
2. What is the role of water in reactions that take place in an aqueous solution? Does water take part in the reaction?
3. What do we call the *reactants* and what the *products* in a chemical reaction?
4. Suppose we mix two clear, colorless aqueous solutions (two *homogeneous mixtures*), and as a result a chemical reaction takes place, with formation of a coloured precipitate. What do we mean by the term *precipitate*? Is the new mixture that resulted from the chemical reaction a *homogeneous* or *heterogeneous mixture*?
5. How could we take away (separate) the new substance that was formed (that is, the precipitate?)
6. Can it be that no reactant is left in a chemical reaction? When does this happen?
7. Can it be that part of a reactant is left in a chemical reaction? When does this happen?
8. Can it be that some quantities of ALL REACTANTS remain at the end of a chemical reaction? (In other words, NONE OF THE REACTANTS disappears completely.)
9. Do chemical reactions take place whenever we mix two or more substances?
10. Can it be that for a chemical reaction to take place, it is necessary to use different conditions, for instance raise the temperature?

Know more, think, and find out why

1. Do you know that living organisms contain a large amount of water? (For instance, the human body is 70% water.) Taking into account that from the biological point of view, the phenomenon of life consists in a very large number of chemical reactions that take place inside the organism (these are called **biochemical reactions**), discuss in class the role of water in the creation of life on earth.

2. Explain why dried fruit (currants, figs, apricots, plums, etc.) can be kept for a long time. The same about salted nuts (peanuts, almonds, etc.)

3. Temperature plays an important role in the preservation, but also in the spoiling of food. Could you mention ways in which we can maintain food by controlling the temperature of the food?

4. Justify why on the labels of many foods (and also of medicines) the following is written: KEEP IN A DRY AND COOL PLACE.