Letters to the Editor
Писма до редакцията

TEACHING THE CONSTITUTION OF MATTER

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One of the primary, although often not fully recognized even by teachers, roles of chemistry is its specific effect on pupils' intellectual development. It happens so, as of all sciences only chemistry shows interdependences between the macro-world in which we live and which we perceive with our senses and the micro-world (the world of atoms, ions and molecules). Only chemistry shows the effect of processes occurring in micro-world on the properties of matters and transformations perceived by our senses. At the level of macro-world we can correctly describe the course of all occurring processes without being able to explain them. For this reason while teaching chemistry both descriptions of the surrounding world should be introduced simultaneously. Such a dual description of chemical transformations (perceived with our senses and imagined by our mind) requires, both on the side of teachers and pupils, the almost simultaneous discussion of the phenomena perceived with our senses and explaining the course of their action in the micro-world, i.e. it requires "transmission" from the world of senses to the world of imagination which demands simultaneous use of the concepts of micro and macro-world. The transmission between micro and macro-world in describing and explaining the occurring phenomena is one of the specific features of chemistry and allows pupils to faster develop the ability of abstract thinking.

To be able to properly explain the phenomena occurring at the level of the macro-world from the beginning of the chemistry teaching process, i.e. from the very first lessons, pupils should get acquainted with the constitution of the matter. The constitution of the matter cannot be directly perceived by pupils' senses – they cannot see, hear or touch it. As teaching the constitution of the matter requires abstract thinking, some teachers consider it to be difficult for pupils. Such an assumption is wrong.

The period of formal operations which, according to Piaget, is the final stage of a human's intellectual development, starts at the age of ca. 11-12 years. Formal operations enable pupils' logical reasoning of not only operations on particular subjects but also logical considerations on abstract ideas and hypothetic events (Jurkowski, 1986). Thus, it can be said that a 13 year old pupil has already mastered the ability of logical thinking to the degree which makes thinking processes on abstract objects possible. In order to fully use the intellectual abilities of a pupil, already at this stage of education, it seems advisable to teach of the constitution of the matter at the level of the micro-world based on current scientific views on the constitution of the matter.

However, operations on abstract objects should not be mistaken with abstract representations. If small kids were not able to form abstract representations, how would they treat the world of legends and fairy tales? Therefore, it is possible and even necessary to introduce basic information on the constitution of the matter at early stages of a child's development. It would be very difficult to explain to a child processes such as diffusion, electric conductivity through certain matters or other phenomena he knows from everyday life without first introducing him to the constitution of the matter. It is possible due to the fact that basic, propaedeutical information on the constitution of the matter demands only the use of imagination on the side of a pupil.

At earlier stages of development, some pupils have problems with acquiring certain ideas when given their definitions only. Therefore it seems necessary to work out proper methods of introducing abstract ideas based on carefully selected models. Teaching of the constitution of the matter should lead to the formation, in a pupil's mind, of a proper representation concerning its constitution so that in the course of further teaching of chemistry he could widen and deepen it rather than exchange certain concepts with other, totally different ones as it happens at present. Teaching of the constitution of the matter should lead to the situation in which a pupil, based on his representations, will be able to explain the properties of chemical matters as well as the mechanisms governing the occurring processes.

Despite undisputable progress of studies on the constitution of the matter, its image presented in the process of chemistry teaching, especially on lower levels, remains far behind the current views. It often happens that on particular stages of education different views on the constitution of the matter are presented, usually in their historical sequence. At each time progressing from older to newer theories constitutes a"psychic" barrier which pupils must overcome. Then a cognitive discordance occurs (Festinger, 1957). The creators of the cognitive discordance theory claim that pupils find it harder to acquire knowledge which is inconsistent with their internal belief and tend to forget it faster. Wrong representations formed during the learning process are hard to modify (Maruszewski, 1970); therefore in the teaching process it is necessary to attach importance to the fact that such wrong ideas or cognitive schemes do not form in the pupil's mind. Such a phenomenon is called negative transfer formation. The principles of A.

Jost (1897) are just other arguments favoring the introduction of correct definitions at earliest possible teaching stages. The first of Jost's principles says that with time passing the power of primary association weakens slower. That means that as years go by, a child remembers earliest associations related to a given concept whereas all further associations are forgotten much faster. The second of Jost's principles says that if two associations are equally strong but one is primary (originated earlier) and the other secondary (originated later), any repetition will favor the primary (earlier) association. This principle also indicates the significance of primary associations and definitions related to the concept. Therefore, in our opinion, in the teaching process it is necessary to depart from teaching the constitution of the matter from the "historical" perspective and rather base the teaching process on presenting, from the very beginning, contemporary scientific theories and views on the constitution of the matter, adapting it to the pupils' intellectual development. At the initial phase of teaching, the description of the micro-world should be qualitative and simplified rather than based on mathematical considerations.

Nowadays, teaching of the constitution of the matter starts with atom constitution. Appeals are made to the concepts of Leukippos and his pupil and follower Democritus, however little attention is paid to fully didactic consequences of the historical interpretation of this term. The term „atom" was introduced by ancient Greeks to describe the smallest, indivisible molecule of the matter. Ancient Greeks perceived nature as a continuous movement of material, indivisible and eternal molecules (atoms) which, when combined, formed various bodies. In result of the thorough analysis of the ideas of Leukippos and Democritus, a question arises whether the present understanding of the term "atom" is the same as it used to be in ancient times. It should be mentioned that Leukippos, followed by his pupil Democritus, perceived the term „atom" quite differently from what we define it now. They understood „atom" as the end of the partition of each matter. Therefore, there should be as many kinds of atoms as there are matters. For the ancient, the term „atom" had a much broader sense as, apart from the end of the element's partition, it also meant the ending of the partition of a chemical compound. Ancient term "*atomos*" meant a molecule rather than the „atom" as defined contemporarily.

At later stages of chemical education pupils are presented with the modern atomistic theory of the constitution of the matter, formulated at the beginnings of the 19th century by John Dalton. While being introduced to this theory, pupils are made familiar with its first postulate, namely: *"each matter is formed of permanent and indivisible parts – atoms."* Formulated in such a way, the statement is not true as, for example, water is formed of water molecules (not atoms) and sodium chloride of sodium and chlorine ions.

Basing oneself on the atom as the primary element of the constitution of the matter distorts the pupils' idea of the actual constitution of the micro-world which, in reality, is formed mainly of molecules and ions and only in few cases of atoms (only noble gases are built of atoms solely).

Establishing, at the very beginning of the teaching on the constitution of the matter, the belief that the whole matter is construed of atoms leads to wrong realizations in pupils' minds. In result, a large number of pupils think that water is based of oxygen and hydrogen atoms although it is widely known that H_2O molecules rather than atoms of oxygen and hydrogen are the main elements of water. This realization is wrong as in the process of combining and forming a molecule of a chemical compound atoms change their properties, both physical and chemical ones. While oxygen and hydrogen are active gases, water which is formed in result of reaction between oxygen and hydrogen is a liquid of rather specific properties which do not result from physical and chemical properties of the elements from which it was formed. Similarly, molecules of other chemical compounds have different chemical properties than the atoms they were formed of. On the other hand, the properties of chemical compounds are different from the elements which are made of atoms Similar situation occurs even in case of molecules formed from atoms of the same element. The properties of O_2 oxygen molecule are different from those of ozone O_3 molecules.

Chemical compounds have been treated as "composed of" elements from the turn of the 18^{th} and 19^{th} centuries, the time when chemists, interested mostly in the composition of matters, wanted to find out which matters were elements and which chemical compounds.

Pupils' perception of matters having ionic composition is much worse. Pupils often consider sodium chloride to be composed of either NaCl molecules, atoms of chlorine and sodium or, completely incorrectly, of metal and gas atoms. Only some pupils remember that sodium chloride is composed of cations of sodium and anions of chlorine. The inability to define the type of "elements" which form ionic crystal makes it impossible for pupils to define its physical and chemical properties (such as, for example electric current conductivity by melted sodium chloride or its water solution). Other problems are also difficult to explain. One of these concerns differences between mechanisms responsible for water solubility of saccharose and kitchen salt. Seen from the perspective of the macro-world, both processes look the same but the resulting solutions have different properties (e.g., different electric current conductivities). The knowledge of the constitution of ionic crystal is absolutely necessary to explain this property of water solutions of salt.

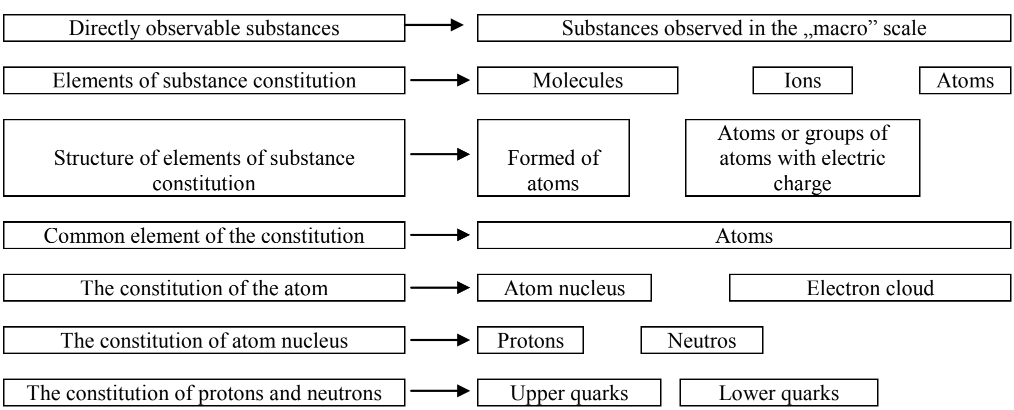
The inability to differentiate between an atom and an ion is a serious mistake. Atoms and ions formed of them differ in many respects, such as electric charge, size, reactivity, properties, etc.

One might get the impression that at early stages of chemistry teaching it is not necessary for pupils to become familiar with the constitution of the matter. However, the lack of this knowledge in many cases leads to the formation of wrong realizations which results, among others, with the occurrence of the negative transfer at later stages of education. In consequence, teaching chemistry at later stages is more time-consuming and demands more effort both from the side of pupils and teachers, bringing poorer effects.

The lack of knowledge concerning the constitution of the matter makes chemistry a purely mnemonic discipline. The inability to define the "elements" (atoms, ions or molecules) which form a given matter causes that a pupil has to learn by heart the properties of each matter he has been introduced to. These include solubility in water, speed of reactions in water solutions and electrical conductivity (both in solid and melted states). Due to such a situation, chemistry, a "logical" science in itself, has become a typically "mnemonic" one.

Our studies show that when teaching pupils of the constitution of the matter it is necessary to mention that the matter consists of three types of molecules: atoms, ions and molecules (Pasko & Nodzynska, 2002). Following that, pupils should be introduced to the atom constitution (atomic nucleus surrounded with electron cloud). The lessons that follow should be devoted to the introduction of the concepts of molecules and ions. Presented in this way, the constitution of the matter can be taught already to 10 year old pupils.

The diagram presented underneath has been prepared for educational purposes and shows, in the simplified way, consecutive stages of teaching the constitution of the matter:



The diagram clearly shows the transfer from macro- to micro-world and its particular, consecutive stages, each of them deepening the constitution of the matter. Seen in this way, matters are formed of molecules or ions and only exceptionally of atoms. It is only molecules and ions which are formed of, i.e. originate, from atoms.

Based on the above diagram, while presenting the scheme of the constitution of the matter we should revise the way in which the knowledge of chemical bonds is introduced. At present it is very chaotic and does not fully reflect the relationship between the constitution of a given matter and its chemical and physical properties. Bonds are discussed by way of reducing the constitution of the matter to the molecule constitution. In result of such an attitude to the problem of chemical bonds, pupils are not taught the right conception of the constitution of the matter and the type of forces combining particular elements of its constitution into one whole. For this reason it seems necessary to distinguish between bonds which occur in molecular constitutions and those typical for ion constitution.

State of aggregation - solid	Ionic bond
	Intermolecular bond
State of aggregation - liquid	Free ions and free molecules of associates

The above scheme shows that ionic and intermolecular bonds are responsible for the solid state of aggregation. Moreover, they are equivalents at the same level of material organization. On the other hand, atomic and atomic polarized bonds occur at a different level of considering the constitution of the matter. They occur inside the molecules and cause that despite the change of the state of aggregation from solid to liquid, molecules remain basically unchanged. In the light of the above statements it seems necessary to revise the so-far structure of connections related to the constitution of the matter. Furthermore, ideas concerning the teaching of the constitution of the matter should be revised too. The attempt to introduce universalism should be given up as in reality it is non-existent on the above-presented levels of the matter organization.

Taught in such a way, pupils will not have knowledge of the constitution of the matter but will also understand it in full.

NOTES

1. Metals are composed of ions immersed in electron gas.

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