ISSN 1070-3632, Russian Journal of General Chemistry, 2013, Vol. 83, No. 6, pp. 1204–1211. © Pleiades Publishing, Ltd., 2013.
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On Chemistry and Teaching Chemistry at School. Report at the I All-Russian Congress of Chemistry Teachers

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Received April 24, 2011

Abstract—A brief historical background of the formation of chemistry and the development of modern science is given. A role of chemical knowledge in the student's personal development is emphasized. Particular attention is paid to the interaction of Lomonosov Moscow State University with schools (school subject competitions, schools for training teachers etc.). A brief analysis of current reforms in the sphere of science and education is given.

DOI: 10.1134/S107036321306039X

Let me welcome the participants of the First All-Russian Congress of Chemistry Teachers, who are gathered in this hall today.

In this hall there are more than seven hundred teachers from seventy eight regions of Russia, specialists in pedagogy and methods of teaching chemistry, and heads of various educational institutions. Professors and teachers of higher educational institutions, as well as representatives of the education authorities and the business community take part in the work of this congress. In one word, everybody who is sincerely interested in successful development of Russian natural science education and can do a lot to achieve this goal is here today. We are also happy to welcome our colleagues from the CIS countries, namely, from Azerbaijan, Belarus, Ukraine, Moldova, and Kazakhstan.

Moscow University has revived a tradition to hold congresses of teachers. The congresses of mathematics, informatics, physics, biology, and geography teachers, which have taken place earlier, have demonstrated the unity of secondary and higher education in understanding the challenges facing the Russian educational system and their willingness to join efforts to address them. I have no doubts that similar unity will be demonstrated by the participants of the congress of chemistry teachers, who will discuss the pressing problems of their professional activities. Year 2012 has just started; therefore, we can consider it our conclusion of the Year of Chemistry declared by UNESCO.

Every second a countless number of chemical reactions take place in the world around us. A person inhales and reactions of oxidation of organic compounds start happening in the human body. A person exhales and carbon dioxide is emitted into the air and is later absorbed by plants, which will start forming carbohydrates. Some reactions can be observed directly, for example, motor fuel combustion, blood coagulation etc. However, the majority of chemical processes remain invisible; but it is these reactions that determine the properties of the surrounding world. And today chemists know quite a lot about it; not only can they understand but also control transformations of substances.

The chemical science has passed its way of development together with the mankind. Even the primitive man, who used water and fire to cook food, acquired the first elementary "chemical skills."

The emergence of chemistry, like all the other natural sciences, was caused primarily by practical needs. People continuously accumulated data about different chemical processes (combustion, dissolution etc.) and widely used them. Smelting of metals, production of dyes and cosmetics, glass and construction materials (bricks), baking of bread, and wine-making are processes from a much longer list of the oldest areas of chemical knowledge application. The prerequisites for chemistry to become an independent academic discipline were formed in the XVII and the first half of the XVIII centuries when mechanics, physics and astronomy achieved spectacular successes and the first "support blocks" started to form the foundation of the chemical science.

The phlogiston theory, which can be called the first chemical theory, emerged at the turn of the XVII—XVIII centuries. Almost the entire XVIII century it held the minds of the overwhelming majority of researchers until its fallacy was proved.

A decisive contribution to the development of chemistry was made by Mikhail Vasil'evich Lomonosov, the tercentenary of whose birth was widely celebrated last year.

At the time of Lomonosov chemistry was interpreted as an art to describe properties of various substances and methods for their extraction and purification. Neither the research methods, nor the ways to describe chemical transformations, nor the style of thinking of the chemists of that time satisfied Lomonosov; therefore, he moved away from the old approach and outlined a large-scale program of transformation of the art of chemistry into the science of chemistry.

In 1751 at a public meeting of the Academy of Sciences Lomonosov spoke his famous "Word of The Benefits of Chemistry," in which he expressed his views on the objectives and importance of chemistry for the chemical production industry. What Lomonosov planned to accomplish was really ambitious in terms of the underlying path-breaking idea, as he wanted to turn chemistry into a science; he also was the first to define such a new area of chemical knowledge as physical chemistry.

In 1756 in a chemical laboratory Lomonosov carried out a series of experiments on calcination of metals, which he described as follows, "…the experiments were carried out in tightly sealed glass containers in order to investigate whether there is a weight gain resulting from heating alone; as a result of the experiments it was found out that the opinion of good Robert Boyle was false as without letting in outside air the weight of the burned metal remained the same…." Thus, by this experiment Lomonosov did not only disproved the phlogiston theory, but he also provided a specific example of application of the general law of conservation, proving the constancy of the total mass of the substance in the course of chemical transformations, and discovered the principal law of chemistry, i.e. the law of conservation of mass.

Thus, Lomonosov was the first in Russia, like later Lavoisier in France, to completely turn chemistry into a strict, quantitative science.

Unlike modern science with narrow specialization according to professional areas, namely, chemistry, physics, biology etc., in Lomonosov's time there was only natural history, which in essence was a combination of interdisciplinarity (almost as we understand it today) and innovation and application developments. As one of the most talented scientists of his time, Lomonosov was quite successful in development of fundamentals and prototypes of different materials represented by artificially produced substances with practically important properties. This interdisciplinary area of materials science is now rapidly developing.

One of the cornerstones of Lomonosov's research works and simultaneously the fundamental basis of modern chemistry was, of course, an improved form of "corpuscular philosophy," combining the basic concepts of physics and chemistry on the basis of atomic and molecular ideas. Such Lomonosov's outstanding achievement as the discovery of the law of conservation of energy, which is now known as the first law of thermodynamics, is also associated with this aspect of his work. Lomonosov stated that, "...All changes taking place in the nature are of such a character that as much as is taken from one body is added to another..."

The beginning of the XIX century was marked by the development of the basic principles of chemical atomism due to the works of John Dalton and Jacob Berzelius. It is characteristic that the first ever International Chemistry Congress in Karlsruhe (1860) was dedicated exactly to problems of the atomic and molecular theory.

During the entire XIX century the formation of inorganic, analytical, organic, and physical chemistry as independent areas of this science continued. In this period new achievements in chemistry were associated with such names as Gustav Kirchhoff, Wilhelm Ostwald, Germain Henri Hess, Marcellin Berthelot, van't Hoff, Svante Arrhenius, Josiah Gibbs, and others.

The successes of the XIX century chemistry were related to the fact that it was based on the atomic and molecular theory. However, by the end of the century it lost the opportunity for further development, as nothing was known about the structure of the atom. Chemistry had to find a new point of support. Another revolution was awaiting it. And this revolution really came; moreover, it turned out to be associated with revolutionary discoveries in natural science in general and, first of all, in physics. These discoveries included X-rays and the phenomenon of radioactivity, as well as evidence of the existence of the electron as the smallest material particle with a negative electric charge.

It turned out that the atom was a complex system consisting of a nucleus and several electrons surrounding it in a certain manner. However, atoms "do not last forever," i.e. in the process of radioactive decay atoms of one element can turn into atoms of another. D.I. Mendeleev discovered the Periodic Law, which made it possible to see all chemical elements in their interconnection and to predict the properties of yet unknown elements. Due to the Periodic Law, the search in the area of study of the structure of matter, in chemistry, physics, geochemistry, cosmochemistry, and astrophysics, became well-directed.

The necessity to solve complex and diverse tasks facing such branches of modern chemistry as chemical materials science, chemical energy engineering, and chemistry of living things causes the necessity to solve the physical problems of chemistry and the appearance of a new area, namely, physics of chemical processes. The logic of the relationship between these two sciences was expressed by the great physicist R. Feynman with a phrase, which at first glance seemed paradoxical, "Chemistry is the most complicated physics, which physicists have given to chemists."

The history of chemistry in Moscow University, originating from Lomonosov, is the history of formation and development of major scientific schools, the first of which was the school of V.V. Markovnikov. He carried out very important works in the field of organic chemistry and the first systematic studies on chemistry of oil. These research works were continued by N. D. Zelinskii, who formed a new area of science, namely, organic catalysis, and established famous schools of organic chemists, petrochemists, and catalytic chemists in Moscow University. These schools were represented by such outstanding scientists as academicians A.N. Nesmeyanov, S.S. Nametkin, B.A. Kazanskii, A.A. Balandin, and professor A.F. Plate.

Academician A.N. Nesmeyanov, during whose rectorship the complex of the University buildings was constructed, was the author of fundamental works in the field of organoelemental chemistry and a number of important original works in organic and theoretical chemistry, as well as works on manufacturing of synthetic food products. Academicians O.A. Reutov and N.K. Kochetkov were among his students.

At the turn of the XIX and XX centuries the first physicochemical schools were formed in Moscow University by academician I.A. Kablukov and professor V.F. Luginin, the founder of Russia's first thermochemical laboratory.

Large inorganic chemistry schools were established by academicians N.S. Kurnakov, V.I. Spitsyn, and A.V. Novoselova, a school of analytical chemistry was created by academician I.P. Alimarin, a school of polymer chemistry was founded by academician V.A. Kargin, and a school of protein and nucleic acid chemistry was established by M.A. Prokof'ev. The years when M.A. Prokof'ev served as a minister were the time of rise of our educational system.

Moscow University and Russian natural science in general can be proud of the works carried out by academician N.N. Semenov, the founder of the theory of branched chain reactions, combustion, and explosions, and a winner of the Nobel Prize in Chemistry.

The XX century was a century of scientific and technological revolution resulting in a tremendous leap in the development of civilization. Chemistry was among the sciences that experienced a particularly high acceleration. In this situation it is important that, as said by Harold Kroto, a winner of the Nobel Prize in Chemistry (the 1996 Prize for discovering fullerene), "No one has done as much for the well-being of the mankind as chemists."

Lomonosov is the author of the following significant words, "Chemistry stretches its arms deep into human affairs." In our time these words have become even more relevant due to development of such advanced areas of science and technology as biotechnology, medicine, nanotechnology, and space exploration. Chemical processes form the basis of many high technologies, determining the place of modern countries on the international arena.

The outstanding achievements of modern chemistry testify to its development in different areas, including at the intersection of sciences. A list of such achievements which is far from complete is given below.

Discovery of new forms of carbon existence, i.e. fullerene, carbon nanotubes, and graphene, in a narrow sense means progress in chemistry of simple compounds; in a wider sense it is renaissance of classical inorganic chemistry.

Such a new area of chemistry as supramolecular chemistry is developing.

Scientists of Moscow University are working to create so-called "smart polymers," which are macromolecular systems that can modify their properties according to changes in external conditions. For example, when injected into an oil well they automatically block water layers, at the same time, letting oil freely come to the surface.

The mechanism of protein production as a result of actions of ribosomes, biological nanomachines, has been also discovered.

"Green chemistry" involves principled orientation towards the development of as environmentally friendly technologies as possible, as well as technologies based on renewable sources of raw materials.

Successful development of chemistry requires modern infrastructure. Within the framework of the Program of development of Moscow University expensive world-class scientific equipment, making it possible to drastically improve the quality of research works, has been purchased.

Russian education, both higher and secondary, has been working under conditions of reformation for a long time already. Each level of education has its own reforms. One of the key moments for higher educational institutions was transition to two-level education, which for the majority, in fact, means a reduction in the period of study, leading to a decrease in the level of training. Under conditions of modern economy, which is called a knowledge-based economy for a reason, the quality of education should not fall.

The challenges of the time require training of competitive world-class specialists, high quality professionals. It applies to chemistry as much as it applies to many other disciplines. Poorly trained chemists who do not know their subject are simply a danger for the society; outstanding chemists are worth their weight in gold; this profession is one of those that are in the highest demand. Chemistry is an extremely complicated experimental science, more precisely, a complex of naturally linked chemical disciplines. Therefore, it is simply impossible to teach inorganic, physical, analytical, organic, and quantum chemistry to students within 3–4 years, i.e. within the framework of the bachelor program. It is exactly the case when the quality of education makes all the difference. That is why we are struggling to preserve our traditional system of chemistry education, which is known in the country and in the world, despite all the "Bologna" transformations.

For more than two years Moscow University has been living in compliance with the Federal Law, specifying its special status, including the right of the University to follow the educational standards independently defined by the University and to issue diplomas of its own. We have taken advantage of this right given to us in order to implement the unique intellectual, human resource, and infrastructural potential of the University to the fullest extent possible and to train highly qualified professionals meeting the demands of the modern labor market.

At present, chemistry is one of the few strategically important specialties included into the list of the Ministry of Education and Science, suggesting the preservation of a five-year education period. Moreover, the educational standards developed by Moscow University suggest six years of studying chemistry under the specialist program, or the so-called integrated master program. Important features of these standards are a significant number of general university cycle disciplines, which makes it possible to use the opportunities of classical university education to the best advantage, and a great diversity of specializations, including interdisciplinary areas.

In Moscow University chemistry is given a very important place; it is studied and taught in all the richness of its subject content. You can judge for yourself. We have three faculties, which are the Faculty of Chemistry, the Faculty of Materials Science, and the newly established Faculty of Fundamental Physical and Chemical Engineering, which is designed to strengthen the technological component of classical university education. At each of these faculties chemistry is the queen of sciences; at the same time, each of them has its own interdisciplinary subject area.

Apart from that, there is A.N. Belozersky Institute of Physicochemical Biology in Moscow University; this institute carries out interdisciplinary pioneering research works. Another institute in the structure of the University is Human Research Institute, uniting scientists in natural sciences and humanities, where chemistry is also essential.

Addressing an audience of teachers, I would like to recall Lomonosov's words that University without Gymnasium is like a ploughed field without seeds. From the very beginning, starting from two Moscow University gymnasiums we care about the seeds for our field, i.e. about talented young people.

Several years ago Moscow University initiated the organization of school subject competitions, which today have become an integral part of the Russian educational system.

Moscow University organizes seven such competitions, the largest of which are "Lomonosov" and "Pokori Vorob'evy Gory!" (Conquer the Sparrow Hills!) multidisciplinary competitions. Last year school children competing in the field of chemistry accounted for 3% and 8% of the total number of participants, respectively. I think these figures could have been higher. There is something to think about in this connection.

I would like to pay special attention to the International Mendeleev Chemistry Competition for School Children, which is a unique phenomenon in the field of intellectual competitions among school children. Owing to the Faculty of Chemistry of Moscow State University it was possible to preserve and enhance the traditions of the former All-Union Competition in this very subject. After the breakup of the Soviet Union school children from the former Republics of the Soviet Union started taking part in this competition. It was the first time when school children from Bulgaria, Romania, and Macedonia took part in the 38th Mendeleev Competition in 2004.

The next, 46th Mendeleev Chemistry Competition will take place in Astana, the capital of Kazakhstan, at the end of this April; representatives from 16 countries have applied to participate in the competition. The Mendeleev Competition winners and prize-winners are admitted into the first year of study at any higher educational institution specializing in chemistry without any entrance examinations.

In general, approximately one in four first-year students admitted to the Faculty of Chemistry of Moscow State University for the last two years are winners of different Federal competitions. Their level of knowledge is higher than the average level in their course, let alone their fellow students admitted to the University within the framework of the traditional scheme.

The learning outcomes of such competition winners fully confirm the validity of this strategy attracting gifted school graduates into the leading higher educational institutions of the country.

Since the seeds for the ploughed field mentioned by Lomonosov are prepared at school, it is natural that the University has to interact with schools in such a wide and active manner as possible. Moscow State University implements a whole range of activities which we call the "Moscow State University for Schools" Program. This program includes organization of school subject competitions, "summer" and "winter" schools for advanced training of teachers, and development of school textbooks and manuals for entrants to higher educational institutions. All these activities are important forms of interaction between the University and secondary schools, which have already become traditional; moreover, all these traditional forms are successfully put into practice by the Faculty of Chemistry.

There is another initiative that I would like to make a special reference to. The Faculty of Chemistry together with the Karusel' (Carousel) research and education central television channel for children and youth have developed a cycle of 12 television lectures in chemistry for teachers, school children, and applicants to higher educational institutions. This cycle of lectures is warmly received by school children and fellow teachers. The teachers will have an opportunity to get acquainted with the lectures of this cycle during the corresponding sections.

Speaking about the University interaction with secondary schools, we cannot but dwell on school educational standards, which are in the focus of the reforms, affecting our secondary school.

Unfortunately, there is little reason for optimism. Within the framework of school education, the new educational standards do not reflect the role that has to be played by this discipline in training of school children. We often meet school graduates who are unable to read and write in a proper "chemical language." And it is not schools that are to blame but approaches to school education that are embodied in the new school educational standards.

Now I would like to say a few words about specialized schools. Differentiated education in senior school years is undoubtedly necessary. However, the number of specialized schools has to be relatively small and they have to differ from usual general education schools not by their name but by their strong teaching staff and excellent material base. The curricula of such schools must necessarily envisage a possibility to switch from one specialization to another or to transfer from a specialized to a general school in case of necessity.

Integration of natural science disciplines is a very important direction of school education development. Of course, it is necessary to develop understanding among senior school students that the nature is one whole, whereas physics, chemistry, and biology look at it from different angles. However, efficient implementation of this idea requires development of a brief summarizing (conclusive!) course, but not elimination of these disciplines as independent school subjects. It is clear that the countrywide introduction of such a new school subject as “Natural History” requires the corresponding curriculum, textbooks, and properly trained teaching personnel. There is neither a proper curriculum, nor quality textbooks, nor teachers with encyclopedic knowledge yet.

There are not very many people with an inclination for music, painting, or literature, who are eager to study deeply and learn the secrets of excellence. There is no enormous competition among unmusical people willing to enter the Conservatory of Music. Maybe, it should be admitted that not everyone should study natural sciences. Maybe, we should give up teaching biology, chemistry, and physics to school children, replacing them with natural history, as all today’s discoveries take place at the intersection of sciences. However, it should be emphasized that it is the intersection of fundamental sciences, which physics, biology, and chemistry are. Every school subject with the corresponding name has its own clearly defined, historically established goals, contributing to the development of the school children’s natural science worldview; whereas natural history is a good subject to summarize the obtained knowledge. What is more, the problem of training natural history teachers has not been solved by now and most probably it is impossible to solve because there are very few people combining encyclopedic knowledge with teaching skills. It can be demonstrating using the following example. The authors of the natural history textbook for the tenth grade describe self-organization processes at a high scientific level and in a quite comprehensible manner. The colorfully illustrated pages of the textbook speak about “open thermodynamic systems,” “attractors,” “oscillation processes,” and “non-linear kinetic equations”… What level of knowledge in physics, mathematics, and chemistry should school children have to understand the given material? What basic education should natural history teachers have? They need fundamental knowledge in all the components, i.e. biology, physics, and chemistry; only in this case the natural history course will naturally summarize the previously studied material. It requires a special, very high level of training of natural history teachers.

Yes, it is true that we have many talented children who demonstrate enthusiasm for chemistry and great knowledge at school chemistry competitions. At the same time, unfortunately, it should be admitted that the average level of knowledge among school graduates applying to faculties of chemistry or to higher educational institutions specializing in chemistry is declining steadily.

It can be illustrated by the following example. One of the works submitted by a participant of the correspondence stage of Lomonosov-2012 Chemistry Competition contained a thoroughly performed calculation of the volume of a certain gaseous substance at normal conditions. And what do you think about what gaseous substance was chosen? I doubt you can guess it was sodium chloride!

This sad phenomenon has several reasons. One of them is that schools abandoned the practice to conduct experimental laboratory works, which happened as long ago as the beginning of the 1990s. At present, the situation is that more than 5000 Russian schools out of the total number of 66.000 (approximately 70% of which are located in rural areas) have no special chemistry classrooms.

Meanwhile, the new standards make a great emphasis on school children’s project activities. Within the framework of collaboration with schools the University chemists have proposed a hundred interesting natural science subjects for school children’s research projects, which can be used by any school in Russia (they can be found at www.nanometer.ru). None of these works can be implemented without good knowledge of chemistry!

However, multiple repetition of the idea of senior school children performing individual projects cannot but raise such questions as, for example, why is it individual but not joint (team) projects? Where to find tutors to supervise such educational research works or projects? To what extent are individual projects necessary in the modern school system, as in scientific reality more and more works are conducted by research teams? In particular, all scientific discoveries of recent years have been made by research teams headed by prominent scientists.

To study chemistry is necessary not only for those who are planning to apply it in their future professional activity (Can school children's life plans be so well defined at all? Do these plans not change in the majority of cases under the influence of various factors?). To study chemistry is important not only for future specialists in chemistry. It plays an important role in comprehensive development of the personality and intellectual and creative abilities, including memory training, learning logic, mastering the ability to establish cause-and-effect relationships, and model building. It is chemistry with its multiplicity of chemical reactions and means of influence on the system that occupies a special place among natural sciences in terms of development of intellectual abilities.

It can happen that a person will never face chemical problems in his or her professional activities; however, a purely utilitarian approach (will need/will never need) is not applicable in this case. Chemistry gives knowledge that ensures life safety. For example, chemistry says that people must not smoke near a filling station because gasoline tends to evaporate, forming explosive mixtures with air.

Chemistry does not forgive even minor mistakes. In this respect it is close to mathematics. Both in chemistry and in mathematics if you make even one small mistake in the formula or equation, it can cause catastrophic consequences, in a literal sense. It applies to launching spacecrafts, large-scale production plants, and the complicated chemistry of our body. A vivid example is the activities of Alfred Nobel, the inventor of dynamite. It is known that at that time the immaturity of the chemical technology for production of this explosive material resulted in a series of explosions at the factories belonging to his family and the death of his younger brother, which greatly contributed to the appearance of the Alfred Nobel's will establishing the very fund of the Nobel Prize.

Unfortunately, in our society the attitude to chemistry among non-specialists is still very specific, as if, as it used to be thought, it were some sort of black magic. People often say about things they do not understand that it is "some chemistry." Below I will yet describe one positive and, maybe, even instructive case. One day a crew from a Central TV channel came to Moscow University to very quickly (as journalists often do) make a few beautiful shots of chemical experiments for a TV program on innovative activities in the Russian Federation. In general, it was a series of usual experiments conducted by our post-graduate students and staff members. However, instead of the initially planned half an hour of "very quick" shooting, the whole TV crew could not tear themselves away from the experiments for as long as three hours and asked for more. And, most importantly, a fashion model girl in a white overall, who was very far from any science at all and whose job was to pose with test tubes, left the room very happy and excited like a small child who has seen a miracle, saying, "Now I understand that chemistry is nice and beautiful; I wish they did not only make us write all these income-prehensible equations but showed us some experiments as well."

By the way, last year the University chemists conducted a series of open lectures under the title "Secrets of the World of Materials," consisting of not only colorful experiments for school children but, of course, of chemical reactions equations and all the explanations. We were very glad that the large chemistry auditorium was full of appreciative listeners (mostly, school children) who kept quiet during the experiments and stayed after the lecture was over to discuss their impressions and small discoveries with the teachers of Moscow State University. It is a very good initiative demonstrating that chemistry is needed both by school children and teachers despite any recent developments and the strangely small number of hours allocated to this school subject in the new educational standards.

To what extent changes in chemistry as a science should be reflected in the school chemistry course? Or, in more general terms: to what extent should the school chemistry course correspond to the level of modern science development? The answer to this question is far from obvious. In any case, the science is developing faster than any school curricula and textbooks can change and it is impossible in principle to catch up with it. In this situation, in the pursuit of "modernity" it is possible to lose understanding of the science fundamentals, which the school course is intended to explain. All these questions arise in connection with possible update of the content of chemistry education and it is joint efforts of scientists, professors, and teachers that are required to solve these questions in the optimal way.

Judging by the expressed interest and the intensive program, our professional community feels a need for such meetings. Therefore, it would be a good idea to hold such congresses on a regular basis. And in the intervals between them, works on the development of chemistry education in the country and on the coordination of efforts of school and university chemists could be carried out by the non-governmental organization we propose, namely, Chemistry Teachers and Professors Association, which would unite our entire corporation, its school and university wings.

In an information society, under conditions of a knowledge-based economy, the role of chemistry increases immeasurably. Correspondingly, there is an increase in the responsibility of the teacher, who faces a challenging task. The University understands and shares this responsibility with schools. And the objective of our congress is to progress in understanding of what we should do together to successfully solve our professional tasks, adequately meeting the challenges of the time and the current demands of the society and the state. We need to know how to find a talent, to help it reveal itself to the full measure, to train intelligent and knowledgeable, creative and purpose-driven, curious, and hard-working.

I wish fruitful work to our congress and I would like to wish all chemistry teachers talented students and new pedagogical achievements!