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Design and physicochemical studies of advanced materials at the Saint Petersburg State University

The foundations of the science of materials were laid down by fundamental discoveries in physical chemistry made by M V Lomonosov — an outstanding scientist and educator, rector of the Saint Petersburg Academic University. In 1752 – 1753, M V Lomonosov delivered the first course of lectures in physical chemistry, which was later presented in his publications 'Introduction to True Physical Chemistry' and 'Principles of Physical Chemistry Needed for Youngsters who Wish to Advance in It'. The results of M V Lomonosov's unique research were reflected in a new trend of the 'science of glass' and in the publication in 1763 of the first Russian study book dealing with the grounds of metallurgy or ore mining. Today, it is difficult to conceive a modern laboratory for investigation of materials without instruments the key principles of which were first proposed and implemented by M V Lomonosov, in particular, without a viscometer, devices for vacuum filtration and determination of hardness, gas pressure indicator, pyrometer and other devices. M V Lomonosov's extensive scientific heritage remains relevant even in the present time of advanced technology. Academician S I Vavilov, who headed the Russian Academy of Sciences for six years, noted, 'It is only now, two centuries later, that one can completely embrace and properly appreciate all that was done by this amazing knight of science. His achievements in physics, chemistry, astronomy, instrument-making, geology, geography, linguistics and history would have been worthy of a whole Academy.'

Since 1868, the division of inorganic chemistry of the first faculty of chemistry at the Saint Petersburg University was headed by D I Mendeleev, whose scientific contribution to the development of modern materials science can hardly be overestimated. The Periodic Law discovered by D I Mendeleev in 1869 was not only a highly important event of the 19th century but still remains the most dramatic event in the history of chemistry, as was stated by the American Chemical Society (ASC) in 2013 when the ASC Chemical Breakthrough Award was presented to the Saint Petersburg State University. In the opinion of Academician Yu D Tretyakov, as regards the development of advanced materials, 'stagnant zones have virtually disappeared from the Periodic Table, and almost all elements are actively used in novel materials', furthermore 'transition from chemical elements to materials is extremely sophisticated and cannot be solved even by combinatorial chemistry techniques, because a multitude of combinations of chemical elements is possible. For example, only for elements that have stable isotopes, there are more than 7×10^{23} combinations'.

It should be emphasized that among the very broad spectrum of scientific research, D I Mendeleev paid a lot of attention to the development of domestic technologies for the manufacture of materials and food products. Starting from 1861, D I Mendeleev translated the Wagner's encyclopedia of technology and made numerous supplements to it. For example, the fourth issue of Wagner's technology contains an original article dealing with glass production.

D I Mendeleev noted that '... most of all, four subjects made my name: Periodic Law, study of the elasticity of gases, understanding of solutions as associations and the Principles of Chemistry'. These fundamental discoveries are still of prime importance for the modern materials science. 'The Principles of Chemistry' published in 1868 – 1971 have run through thirteen editions in Russia and still remain a reference book for scientists. Academician A A Baikov, the first Dean of the Faculty of Chemistry of the Leningrad State University in 1934 – 1939 and later Director of the Institute of Metallurgy of the Academy and the founder of the Russian school of metal science and metallurgy, wrote about his meeting with D I Mendeleev, being aware that author was much engaged in investigations of alloys, proposed to write some notes to be included in the 'Principles of Chemistry'. Our conversation was mainly devoted to alloys and started with Mendeleev's words: 'In alloy studies, I see many remarkable aspects'. A A Baikov fulfilled his task and paid keen attention to his words. In the 'Principles of Chemistry', D I Mendeleev noted: 'One can hope that the periodicity principles noticed by Baikov would prove to be generally applicable upon thorough investigation of diverse alloys and that the tight connection between physicomechanical relationships and general chemical phenomena would be consolidated in this way from a new side.'

A A Baikov's studies of the phase transformations in metals and alloys and high-carbon phases in steels and evidence for the existence of austenite in steels he obtained are the milestones in the development of modern materials science.

A distinctive feature of the scientific schools created at the Faculty of Chemistry (currently Institute of Chemistry) of the Saint Petersburg State University (SPbSU) is always combination of experimental physicochemical approaches to studies of materials and theoretical substantiation of the obtained results. For this reason, the scientific schools currently existing at the SPbSU Institute of Chemistry that are engaged in the synthesis and studies of advanced materials are subject to profound traditions and occupy leading positions not only in Russia but also in the world. Preserving these traditions, since 2006, the Chemistry, Physics and Mechanics of Materials have been taught as a major at the SPbSU Institute of Chemistry in the two key sections: Functional Materials and Nanomaterials and Chemical Thermodynamics of Materials.

This issue of the Russian Chemical Reviews, which continues the publication of reviews devoted to the 85-year anniversary of the Institute of Chemistry of the Saint

Petersburg State University (2015, **84**, Nos 6 and 10), deals with the topical problems of the modern materials science. The reviews introduced for your consideration cover the key lines of physicochemical studies of advanced materials (nanomaterials, high-temperature oxide materials, thin films, coatings and polymers) carried out now.

The issue starts with the fundamental review by Academician A I Rusanov — the leader of Russian thermodynamics. The review introduces a new thermodynamic potential, which underlies the most general theory of the strength of materials. A I Rusanov's fundamental research is concerned with the statistical theory of surface layers, physicochemical hydrodynamics of capillary systems, thermodynamics of solid surfaces and mechanochemistry and was awarded the USSR State Prize, D I Mendeleev Prize of the RAS, P A Rebinder Prize of the RAS, and D I Mendeleev Gold Medal of the RAS. Among A I Rusanov's state awards, noteworthy is the Certificate of Merit of RF President received in 2015.

The review of V V Kondratiev, V V Malev and S N Eliseeva 'Composite electrode materials based on conducting polymers loaded with metal nanostructures' gives a systematic discussion of the methods of synthesis of metal–polymer composite materials and characteristics of the electrochemical behaviour of these composites. A large portion of the review is devoted to analysis of the model views on the mechanisms of charge transfer in the rechargeable films of conducting polymers developed to date and description of the kinetics of electrochemical processes at inhomogeneous metal–polymer electrodes. The original scheme of electrode processes on a composite film with indicated location of electrochemical reactions involving external redox species proposed by the authors is the hallmark of this issue. The studies carried out in the recent decades at the SPbSU Department of Electrochemistry are aimed at the development of preparation methods of energy storing and catalytically active materials, investigation of the charge transfer mechanism in these materials and utilization of the unique properties of these materials for the design of electrochemical current sources, fuel elements and sensors. Since its foundation in 1940, the Department of Electrochemistry has made headway from kinetic and mechanistic studies of metal dissolution and deposition to the production of new nanostructured materials for electrochemical power engineering. Materials science aspects have always been present in these investigations and have become especially pronounced in the last decades.

The review that introduces the scientific school of I V Murin and colleagues K N Semenov, N A Charykov V N Postnov and V V Sharoyko summarizes the available data on various types of phase equilibria in the systems containing light fullerenes. The paper gives a discussion of experimental options for separation of fullerene mixtures, development of bioactive phases and application of fillerenes as nanomodifiers. This is only one of the numerous examples of scientific achievements of the staff of the Department of Solid State Chemistry headed by I V Murin, which are related to the synthesis and investigations of solid-phase materials in the bulk and nanostructured states with specified functional properties.

The vaporization processes and thermodynamic properties of ultra high-temperature ceramics, materials for nuclear power engineering, coatings, glasses and molten slags at high temperatures are discussed in the review of Corresponding Member of the RAS V L Stolyarova, who was the first to apply high-temperature mass spectrometry to study oxide systems and materials. Currently this line of research is being developed by V L Stolyarova and colleagues at the Department of General and Inorganic Chemistry, thus carrying on the traditions of scientific schools of Academician M M Shulz and G A Semenov.

The transport properties of membrane materials, which are widely used in the development of power- and resource-saving environmentally safe processes, are considered in the review of A Yu Pulyalina, G A Polotskaya and A M Toikka. The research along this like is successfully carried out under A M Toikka's supervision at the Department of Chemical Thermodynamics and Kinetics. The review of I A Rodionov and I A Zvereva devoted to the prospects for the use of perovskite-like oxides in photocatalysis illustrates the wide scope of physicochemical studies of advanced materials carried out at the Department.

The considerable amount of scientific problems solved by the Department of Analytical Chemistry, which carries on the traditions of the N A Menshutkin, D P Konovalov, A E Favorsky, V E Tishchenko and Yu V Morachevsky scientific schools, includes issues related to analysis of materials. These studies carried out at the Department are supervised by L N Moskvin, who repeatedly received state awards, including the Prize of RF Government, Red Banner and Alexander Nevsky Orders, as well as the V G Khlopin Prize of the RAS. L N Moskvin's scientific school presents two reviews. The first one (written by V N Postnov, O V Rodinkov, L N Moskvin, A G Novikov, A S Bugaichenko and O A Krokhina) discuss the prospects of application of various nanomaterials in sorption and chromatographic processes. The second review (written by A A Ganeev, A R Gubal, S V Potapov, N N Agafonova and V M Nemets) gives a detailed account of the unique capabilities of mass spectrometry for direct elemental and isotope analysis of solid-state materials such as films, coatings and polymers.

The authors of the reviews and the issue editor are hoping that the physicochemical investigations of materials carried out at the SPbSU Institute of Chemistry would be of interest for a broad circle of specialists.

Issue Editor
Corresponding Member of the RAS,
V L Stolyarova