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N M Emanuel Institute of Biochemical Physics as a trinity of chemistry, physics and biology

The Institute of Biochemical Physics of the Russian Academy of Sciences is a scientific enterprise in the system of the Division of Chemistry and Materials Science of the RAS. The Institute's scientific traditions are rooted from the 1930s when the Institute of Chemical Physics of the USSR Academy of Sciences was formed.

The founder of the Institute of Chemical Physics, Nobel Prize winner in chemistry, Academician N N Semenov deeply understood the unified nature of the natural science knowledge, and he developed contemporary areas of physics, chemistry and biology at the Institute. N N Semenov initiated a very large school of thought. Outstanding physicists (Yu B Khariton, Ya B Zeldovich and V V Voevodskii), chemists (V N Kondrat'ev, N M Emanuel and N S Enikolopov) and biologists (L A Piruzyan, I A Rapoport and M A Ostrovsky) worked at the Institute of Chemical Physics. According to N N Semenov, research into basic physicochemical phenomena and the chemistry of important biological processes were to form the basement of the Institute development.

In N N Semenov's opinion, molecularly organized chemical reactions in biosystems are the pitch of perfection of chemical processes. It is necessary to understand the nature of biochemical processes, model them at the chemical level and learn to use them for practical purposes. It is this principle that was taken by Academician A E Shilov as the basis of biomimetics.

N N Semenov believed that chemical kinetics is the heart of chemical physics. The Department of Kinetics of Chemical and Biological Processes headed by Academician N M Emanuel was actively progressing at the Institute of Chemical Physics. The interests of the Department were rather broad and comprised studies of elementary chemical reactions, liquid-phase oxidation reactions, magnetic phenomena in chemistry, polymer chemistry, photochemistry, the chemistry of drug agents, study of the nature of cancer, photobiology and radiobiology and molecular genetics.

'Kinetics as a science of the laws and mechanisms of development of various processes in nature finds almost infinite prospects for theoretical investigations and practical applications in biology' — this is how Academician N M Emanuel stated his scientific credo in 1966.

In 1994, the N M Emanuel Institute of Biochemical Physics was established on the basis of the Department of Kinetics of Chemical and Biological Processes and the Department of Electronics of Organic Materials. Later, the Institute of the Chemistry of Foodstuffs created on the basis of ideas and development works of Academician A N Nesmeyanov and his staff was merged to the Institute of Biochemical Physics.

Historically, the following departments were formed at the Institute of Biochemical Physics:

— Department of kinetics of chemical and biological processes (professor E B Burlakova);

— Department of biocatalysis and physical chemistry of bioprocesses (Corresponding Member of the RAS S D Varfolomeev);

— Department of photochemistry and photobiology (Academician M A Ostrovsky);

— Department of biological and chemical physics of polymers (professor G E Zaikov);

— Department of the chemistry of foodstuffs and biotechnology (Ph.D., Chemistry, I G Plashchina);

— Department of new methods of biochemical physics and materials science (Professor A A Kuznetsov);

— Department of the electronics of organic materials and nanostructures (Doctor of Physics and Mathematics, V Ya Krivnov).

The formula for success in the modem science is the use of high-information and high-productivity research methods. This is particularly important for the studies of complex chemical and biochemical processes. In recent years, the Institute has in some respect completed the formation of basic methodical centres provided with advanced equipment. The Centre for magnetic spectroscopy (Professor A L Kovarski) has modern NMR and EPR spectrometers. Unique equipment suitable for analysis of diverse substances ranging from small molecules to proteins and nucleic acids is concentrated at the Centre for mass spectrometry of biomacromolecules (Professor E N Nikolaev). The formation of the Centre for X-ray diffraction analysis (Ph.D., Chemistry, A V Krivandin) is being completed. Optical spectroscopy methods rely on the use of high-resolution microscopes and a confocal microscope. Unique acoustic microscopes that visualize the image in a hypersonic field are being developed at the Institute (Ph.D., Physics and Mathematics, V M Levin). Atomic force microscopy is a traditional technique in the priority research.

The Institute has its own vivarium, which allows for performing animal experiments.

This inventory of powerful physicochemical methods is aimed at solving key problems, namely, studies of the physics and chemistry of reactions in complex molecularly organized systems, design of new compounds and materials, elaboration of the grounds for novel practically important processes.

Theoretical investigation methods hold an important place in the advancement of research at the Institute of Biochemical Physics and chemical physics as a whole. The theoretical works, which are mainly concentrated at the Department of the electronics of organic materials and nanostructures (it was founded and headed for many years by Corresponding Member of the RAS A A Ovchinnikov) often provide the basis for experimental research. The world priority theoretical investigations of Professor L A Chernozatonskii (Laboratoty for acoustic spectroscopy) performed in the 1990s and in the early 2000s defined the today progress of many areas of nanophysics and nanotechnology, studies of physical and physicochemical properties of nanoclusters and nanocomposite materials. A large series of studies on the dynamics and thermodynamics of nonlinear systems was performed by Doctor of Physics and Mathematics G A Vinogradov. Unique theoretical results on the long-range energy and charge transfer in biopolymer systems have been obtained in recent years. The possibilities of performing a large amount of computations on supercomputers that appeared in the last decades opened up new prospects in the research of complex biochemical processes by quantum mechanics and quantum chemistry techniques. The computational research carried out at the Laboratory for computer modelling of biomolecules and nanomaterials (Professor A V Nemukhin) clarified quite a few issues concerning the nature of high efficiency and specificity of enzymatic catalysis.

Oxidation processes in biosystems, in particular in the human body, constitute the subject of intensive research carried out at the Institute under the direction of Professor E B Burlakova. Studies of these processes revealed subtle mechanisms of regulation of biochemical reactions and gave rise to the field of knowledge that can be conventionally called 'antioxidants' and has a very broad scope of application. A number of pharmaceutical drugs of general therapeutic action have been developed, have successfully passed clinical trials and are produced on an industrial scale (the sales volume of the Mexidol drug developed under the supervision of Corresponding Member of the RAS K M Dyumaev and Professor L D Smirnov reaches 1 billion roubles per year). The new phenomenon discovered by E B Burlakova related to the use of low and ultralow doses is now being actively studied experimentally. Research into the mechanisms of photochemical reactions (Professor V A Kuzmin) resulted in the discovery of new photochemical mechanisms. This provides the possibility of creating a strategic basis of new photochemical techniques for modern biochemistry and molecular biology. Advanced photochemical investigations are performed at the Institute by several research groups at the Laboratory for photo- and chemiluminescent processes (Doctor of Chemistry A V Trofimov) and Laboratory for photonics of chemical and biological nanosized systems (Doctor of Chemistry P P Levin).

In recent years, renewable energy studies initiated by Academician N N Semenov in the 1970s have considerably advanced at the Institute. The key lines of research are associated with the development of the chemical grounds for the production of biofuels, development of new effective methods for direct conversion of solar energy to electric energy (Laboratory for solar converters headed by Doctor of Physics and Mathematics O I Shevaleevskii) and development of new-generation electric energy storage systems.

A large set of studies dealing with renewable feedstock (biomass) conversion to energy commodities of various chemical natures have been performed at the Institute. The methane (biogas) production process using biocatalytic systems was studied in detail, the intermediates were identified, the kinetic schemes for the process were developed, the mathematical models suitable for process intensification and optimization were designed, and new equipment solutions were proposed.

Depolymerization of biopolymers to give soluble carbohydrates under catalytic or enzymatic mechanochemical treatment of biomass in different modes was investigated. A basically new process for oxidative depolymerization of biomass that allows for transition of the solid phase of any biopolymer into solution was developed. The fundamentals of new-generation biotechnological processes that are catalyzed by cryoimmobilized microbial cells and give fuel bioalcohols (bioethanol, biobutanols) were devised. New synthetic engine fuels were prepared from biomass by the chemical modification of carbohydrates and polyols. Bioketals were synthesized from carbohydrates and glycerol and tested as engine fuel components.

Pyrolysis processes were investigated for various sorts of biomass, including lignin, to give bio-oil. The pyrolysis products were studied in detail to determine their composition, caloric value and environmental characteristics. New in principle solutions were invented for performing flash pyrolysis in induced electromagnetic fields, which can be employed to convert various types of lignocellulose materials and polymers to bio-oil (synthetic oil).

In recent years, substantial progress has been observed in the development of new high-capacity and high-power electric energy storage systems as supercapacitors.

The exploration of the biological and chemical physics of polymers, especially concerning the destruction, ageing and stabilization aspects, are traditional for the Institute. Lately, the interest in the biodegradable polymers and in the polymers obtained by condensation of natural amino acids arose at the Institute. The modern polymer chemistry requires a basically new raw material base and new strategic solutions. It is of principal importance to devise new strategies and techniques for the production of polymer materials from renewable feedstock. The Institute's pursue along this line includes the design of composite materials with biodegradable additives (Doctor of Chemistry A A Popov) and new materials obtained by polycondensation of natural amino acids (Doctor of Chemistry V M Goldberg). Ready accessibility and functional diversity of natural amino acid monomers provides the possibility of developing new synthetic functionalized polymers with a wide variety of properties.

The specific class of biopolymers that form the basis of human nutrition is the subject of research of the Department of the chemistry of foodstuffs. This is a highly demanded area with high potential of commercialization.

The trinity of sciences is the basic benefit of the Institute of Biochemical Physics. The biological research performed at the Institute relies on the solid basement composed of modern physics and chemistry. The works performed by Academician M A Ostrovsky in the field of physicochemical grounds of photoreception represent a vivid example of science triumvirate. The molecular physiology of vision reception created and developed in the works of Academician M A Ostrovsky, President of the I P Pavlov All-Russian Society of Physiologists, arrives at a new level and acquires quite a new meaning due to the use of extremely complex set of advanced physical methods for the analysis. The recent works on the femtosecond spectroscopy of rhodopsin created a new view on the primary visual reception processes and revealed unusual interactions of the protein matrix with the visual chromophore.

Traditionally, since N N Semenov's time, molecular-genetic studies have attracted considerable attention at the Institute. The Laboratory for chemical mutagenesis was founded by Corresponding Member of the USSR Academy of Sciences I A Rapoport in 1965. The works of this laboratory laid the foundation and developed the views of the chemical mutageneses. The genetic procedures based on modern physicochemical research techniques have arrived at a new stage of development. Mapping of the genomes of many organisms, including humans, and the potent informational support of this research give rise to a qualitatively new stage of experimental and theoretical works. The Institute was an organizer and an active participant of the IUPAC project called Post-genomic chemistry, the fundamental research program of the Presidium of the RAS 'Human molecular polymorphism' and the project 'Post-genomic studies and technologies'. The experimental basis for these works is the modern approach relying on the mass spectrometry of biomacromolecules (Centre for mass spectrometry of biomacromolecules, Professor E N Nikolaev), which allows for detailed analysis of the human genetic material (Laboratory for post-genomic molecular-genetic studies, Professor V V Nosikov).

The reviews that constitute this issue of the journal reflect to a large extent the studies performed at the Institute. It is clear that one issue is unable to introduce to any full extent the whole range of research activity of the Institute staff. Nevertheless, I believe that it represents the style and the spirit of the research that combines chemistry, physics and biology and is performed at the Institute of Biochemical Physics over the whole range from profound theoretical investigations to elegant experimental works.

Director of the Institute,
Corresponding Member of the RAS
S D Varfolomeev