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ALEXANDER SAVVICH PREDVODITELEV

TO CELEBRATE THE OCCASION OF HIS SEVENTIETH BIRTHDAY

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ALEXANDER SAVVICH PREDVODITELEV, Corresponding Member of the U.S.S.R. Academy of Sciences, was born in a peasant family in the village of Bukrino in Ryazan province. After finishing secondary school he entered the Physicomathematical Faculty of the Moscow University in 1912. On graduating at the University he remained to prepare for professorship. In 1919 he passed the master's examinations and began lecturing on separate topics of optics and molecular physics and working as a senior assistant in the Physical Laboratory at the University.

At the same time, Academician A. P. Lazarev invited him to work at the Research Institute of Physics and Biophysics, and in 1920 he was invited to teach physics at the Moscow Higher Technical College.

Predvoditelev was the first man in the U.S.S.R. to specialize in thermal physics, which he did in 1929. In 1930, he was chosen as professor and appointed as Chief of the Department of Thermal Physics at the Moscow University. He was also acknowledged as a member of the Research Institute of Physics at this University. In the same year Predvoditelev organized a thermophysical laboratory at this Institute.

Predvoditelev is an outstanding scientist who has carried out a set of profound experimental and theoretical investigations in various branches of physics, mechanics, thermal physics, hydrodynamics and physical gas dynamics. Results of his investigations are presented in more than 140 scientific works.

We shall dwell at length on Predvoditelev's investigations into the solution of problems on gaseous, liquid and solid states of a substance, wave processes and hydrodynamics, chemical physics and combustion theory as well as on theoretical physics.

INVESTIGATIONS INTO GASEOUS LIQUID AND SOLID STATES OF A SUBSTANCE [1–14]

In some investigations Predvoditelev suggested an original model of a liquid structure which allowed him to determine a number of laws which gained widespread experimental confirmation.

He considers a liquid to be a quasi-crystal arranged out of tetrahedrons in the same manner as that used by Thomson who made a model of a lightwave carrier out of the same geometrical figures. McCullough used this model as a basis for writing down the prototype of the Maxwell equations.

According to Predvoditelev this model is extremely convenient in elucidating those properties of a liquid which arise from the collective interaction of its molecules. Molecules, or entire complexes of molecules, may be elements of a quasi-crystal structure.

In the course of time, the quasi-crystal structure conditioned by collective interactions of molecules suffers complex periodical changes, i.e. the elements composing it are not in constant and indispensable relation with all the other elements which compose a liquid quasi-crystal. A certain proportion of the liquid molecules is in a wandering state and subjected to statistical gas laws. In colliding with the main elements of a quasi-crystal, these wandering molecules knock out the first ones and replace them. Such a type of molecular collision with molecules subjected to casual wanderings differs in no way from those molecular collisions which are observed in gas systems. But these collisions also maintain a vibrational state on a quasi-crystal.

Thus, in the model described, heat motion is ofcomposed of both casual molecular motion and black-body acoustic radiation of finite amplitude.

If the described state of a substance is subjected to an adiabatic effect, then there will be kept invariable some combination of the following quantities: energy density of heat motion, frequency of black-body acoustic radiation, the number of molecules per volume and thermal molecular velocity. These invariable combinations of the quantities mentioned give the so-called adiabatic invariants.

Using adiabatic invariants, Predvoditelev proved in 1948 that for liquids the following law should hold:

$$\frac{K}{C_p \rho} \sqrt{\left(\frac{M}{\rho}\right)} = f(T). \tag{1}$$

Here K is the heat conductivity coefficient of a substance; C_p is the specific heat of a substance at constant pressure; ρ is the substance density; M is the molecular weight and $f(T)$ is some universal temperature function. Thus, this mathematical group of physical quantities does not depend on the nature of a substance and varies in the same way with temperature for all the substances. It should be noted that many years ago the German investigator Weber came across this combination purely empirically. For a long time the formula given above was referred to as the Weber law with the only difference that the function $f(T)$ was considered constant. This was an error which made the Weber formula inapplicable when it was compared with the accumulating experimental material. When Predvoditelev showed that the function $f(T)$ was not a constant quantity, the above formula was revived.

In connexion with the above-mentioned consideration of the nature of heat motion in liquids, Predvoditelev undertook the task of determining the relation between this motion and thermodynamic temperature. It goes without saying that from the viewpoint expounded the local energy density of heat motion of liquids cannot be the same everywhere. It is of a "hilly" character, the "hillocks" travelling arbitrarily over a space. To Predvoditelev's mind, the thermodynamic temperature is connected, only through certain thermodynamic relations, with the average time or average statistical value of energy density of heat motion of a medium. Having submitted the deviations of the nominal temperature from the thermodynamic one to the laws of random wandering, it appeared to be convenient to estimate the quantity of the above heat "hillocks" by means of these deviations.

Having dealt with the deviations given above with the help of the Smolukhovsky–Markov–Kolmogorov equation, Predvoditelev established another important law regarding the change in the heat conduction coefficient with temperature. This law may be written as follows:

$$K = B\rho^{4/3}. \tag{2}$$

Here B is some constant depending on the nature of a substance. The above formula is valid only for liquids, but Predvoditelev extended it to the whole range of materials, from liquid to gaseous. In this case Predvoditelev's formula is of the following form:

$$K = K_t + B\rho^{4/3}. \tag{3}$$

Here K_t should be calculated according to ordinary formulae of the gas-kinetic theory for a rarefied gas.

Besides the heat conduction coefficient, the viscosity of a liquid is of vital importance as a characteristic of its state. Predvoditelev considers that the solution of this problem is connected with those equations which should describe the motion of a medium creating a black-body acoustic field. Predvoditelev followed Debye's procedure for solving the problem of heat capacity of solids. As is known, Debye submitted the heat motion in solids to ordinary equations of elasticity theory, having restricted the number of degrees of freedom of the elastic continuum by the cube of the atoms in a cubic centimetre. This courageous attempt made by Debye proved to be correct and gave good results, and is still unquestioned to-day.

Predvoditelev's view of the nature of heat motion of liquids is close to Debye's. He tried, therefore, to use hydrodynamics equations, corrected for non-ideal homogeneity, for the description of the heat motion in liquids. This attempt gave good results. He succeeded in establishing the relation between the heat conduction coefficient and the viscosity coefficient. This relation has the following form:

$$K = \epsilon C_v \eta \left(1 - \frac{b}{v}\right). \quad (4)$$

Here ϵ and b are constant. When a specific volume is very large, the multiplier in round brackets becomes unity and the formula converts exactly into the Maxwell formula for gases. The value of the constant b is close to that of the known Van der Waals constant but not equal to it.

Comparing the latter two formulae and eliminating the heat conduction coefficient, Predvoditelev established the following law for viscosity:

$$\eta = \frac{A}{(v - b)v^{1/3}}. \quad (5)$$

Here A is a constant dependent on the nature of a substance. He also generalized this latter formula for liquids and gases. The above generalization leads to such a relation:

$$\eta = \eta_t + \frac{A}{(v - b)v^{1/3}}. \quad (6)$$

η_t should be calculated by the formulae which are given by the gas-kinetic theory for rarefied gases.

To give a more complete idea of Predvoditelev's scientific activity it is important to note that all the relations he obtained have been verified by thorough experiments. His pupils N. B. Vargaftik, L. P. Filippov, Abas-Zade *et al.* confirmed Predvoditelev's laws on various materials and over wide temperature ranges.

Later, on the basis of his general views on the nature of heat-medium motion, Predvoditelev succeeded in framing, in a novel way, the question of how to find a state equation for compressed gases and liquids. He proves that in dense gases and liquids the statistical indications, which are taken as components of heat velocities, cannot be independent as in the Maxwell–Boltzmann theory which, in fact, determines the type of the Maxwell distribution function. He considers that the statistical indications correlate amongst themselves. Limiting himself to the case of isotropic correlation, i.e. considering the correlation coefficients r_{ij} for each pair of components of heat velocities to be equal, Predvoditelev obtains the following general type of the state equation:

$$pv = RT\psi(r)^{-\frac{2}{3}E}. \quad (7)$$

Here the value $\frac{2}{3}E$ is the virial of internal forces; the function $\psi(r)$ is universal and has the following form:

$$\psi(r) = \frac{(1 - r)^{1/2}(1 + r)^2(1 + 2r)^2}{(1 + 3r)^2(1 - 3r)^{3/2}}. \quad (8)$$

The correlation coefficient r proved to be proportional to density, the proportionality factor being dependent on the nature of the substance and practically unchanged with temperature. Predvoditelev successfully verified his state equation on a very extensive virtual material. In his works Predvoditelev lucidly explained numerous experiments of Mikhelson and his co-workers on the measurement of the compressibility factor for gases over a wide range of temperatures and pressures (up to 5000 atm).

Predvoditelev's views on the critical state are interesting. Proceeding from the fact that, on approaching the state line between the liquid and gas, the correlation coefficients for a liquid and its vapour should become equal, and considering the internal energy of each system to be a linear density function, he derives an equation for the state lines between a liquid and vapour in thermodynamic equilibrium. The line of a liquid is of the form:

$$\rho_f = \rho_s \left[1 + A(T) \sqrt{\left(\frac{\mu T_{cr} - T}{\mu T_{cr}}\right)}\right]. \quad (9)$$

The line of a vapour is of the form:

$$\rho_v = \rho_s \left[1 - A(T) \sqrt{\left(\frac{\mu T_{cr} - T}{\mu T_{cr}}\right)}\right]. \quad (10)$$

Only at large distances from a critical point does the density ρ_s differ slightly from the critical density ρ_{cr}.

As to the quantities $A(T)$ and μ, they are definitely related to the difference between a liquid and its vapour as well as to parameters of internal energy. The verification of the formulae obtained from numerous experimental data showed that for each liquid the quantities $A(T)$ and μ remain constant up to 0·2 per cent. Only for transition from one liquid to another does the divergence reach 5 per cent. We may consider that these values are of a universal character and are equal to:

$$A(T) = 2{\cdot}73 \quad \text{and} \quad \mu = 1{\cdot}05.$$

As may be easily seen, the well-known Cailletét–Matias rule follows from the above relation, viz:

$$\frac{\rho_f + \rho_v}{2} = \rho_s. \tag{11}$$

It is interesting to note that the known Hirschfelder equation, for greatly compressed gases and high temperatures, follows as a specific case of the Predvoditelev state equation.

The state equation obtained by Predvoditelev also enables, with the help of the known thermodynamic equality, calculation of that part of the internal energy of a substance which is dependent on density. Such calculations are in a good agreement with experiment. Many other investigators who tried to solve the problem of a substance state equation did not succeed in reaching such a good agreement.

While studying mainly properties of gases and liquids, Predvoditelev paid attention to solids as well. Here, he also obtained some interesting results. Proceeding from wave concepts of molecular heat transfer analogous to those which he developed for liquids, he obtained a very simple formula for the heat conductivity of dielectrics, viz.:

$$K = \frac{cd}{4\pi}\sqrt{\left[\frac{4\pi^3 C_M}{\beta n(n-1)R}\right]}\{\sqrt{[\rho(\lambda + 2\mu)]} + 2\sqrt{(\rho\mu)}\}. \tag{12}$$

Here C is the heat capacity of a substance; C_M is the molecular heat capacity of a substance; ρ is the density; λ and μ are the Lamé coefficients; R is the gas constant; d is the average distance between atoms; β and n are integers dependent on the crystal structure of a substance. In his works Predvoditelev shows how to determine these quantities.

Analysing molecular heat transfer in electrically conducting bodies from just the same viewpoint, Predvoditelev discovered an interesting generalization of the Vierdermann–Frantz law. He found:

$$\frac{K}{\sigma T} = \frac{C_M}{R}\,\frac{(1 + \pi^2)\pi^2}{96}\left(\frac{a}{e}\right)^2. \tag{13}$$

From this formula it is seen that only for high temperatures, when atomic heat capacity reaches its limit equal to 6, does the right-hand side of this equality become the Lorentz expression, viz.:

$$\frac{K}{\sigma T} = 3{\cdot}34\left(\frac{a}{e}\right)^2. \tag{14}$$

INVESTIGATIONS INTO WAVE PROCESSES AND HYDRODYNAMICS [15–22]

Predvoditelev was interested in this branch of science for a long period of time. He concentrated mainly on finding the conditions under which a wave surface might exist. Proceeding from the famous discussion between Frenkel and Poisson and comparing it with the investigations of Hugonio and Hadamard, Predvoditelev developed an extremely plausible general theory of processes propagating as a front. He established a strict definition of wave surfaces, to which all the integral surfaces should be attributed if they may be considered as a geometric location of characteristics determined by Monge. In wave processes, such surfaces separate a region of rest from motion or one motion from another. The existence of such a region requires the observance of special compatibility conditions. In science these conditions were found in two forms: Frenkel–Poisson and Hugonio–Hadamard. Predvoditelev showed that these two formulae were always revealed in those cases when a closed system of differential equations permits the following transformation with respect to the variables:

$$\xi = V(x, y, z) + gt. \tag{15}$$

Integral surfaces, corresponding to a wavefront, are easily singled out with the help of such a transformation. Using the general determination of the compatibility conditions given by Hugonio, this transformation facilitates the derivation of the known Hadamard identities and kinematic conditions. In the course of solving problems on the propagation of acoustic waves in dispersive media, Predvoditelev demonstrated the significance of these conditions. It may be said that the method worked out by Predvoditelev rarely encounters obstacles. Any system of closed differential equations allowing of wave solutions is treated according to Predvoditelev's method so that the dispersion formulae may be easily obtained in their general form without resorting to the integration of a system of equations. Thus, Predvoditelev solved a great variety of concrete problems in the field of physical acoustics. In some of his experimental works he exposed incorrect interpretations of the results obtained, and explained their true nature.

Recently Predvoditelev succeeded in eliminating one defect in the Hadamard algorithm. The Hadamard identity and kinematic conditions are applicable only in those cases when a wave surface in its motion does not suffer deformation. This means that they cannot be used to solve problems on reflection, refraction and diffraction of waves, i.e. in those processes when a front deliberately transforms; for example, the front of an incident ray transforms into that of a reflected ray.

Hadamard derived his identities and kinematic conditions proceeding from the postulate, the essence of which lies in the fact that it is possible to make an entire operation of differentiation on a wave surface. In the case of the deformation of a wave surface, it is obvious that such an operation cannot be fulfilled. Substituting the operation mentioned for the variation operation, Predvoditelev succeeded in generalizing the Hadamard identity and kinematic conditions. The generalized conditions in their application proved to be a powerful tool. With the help of these conditions Predvoditelev made a complete investigation of the reflection and refraction of the so-called shock. He showed that the Mach reflection and refraction was a striking expression of the Hugonio compatability conditions and was the most general law of reflection and refraction. The conditions found for the transformation of a wave front in the Mach reflection and refraction are those from which normal reflection and refraction may easily be reduced as limiting cases. The Mach reflection, as is known, had not been properly explained until the works of Predvoditelev.

Predvoditelev paid much attention to wave processes in which the transformation of a substance took place. Using this general view on the nature of wave processes, he solved a number of problems on the front propagation of combustion and detonation. Using combined processes as an example in such cases when heat propagates in a chemically reacting medium, i.e. heat transfer and kinetics of substance transformation proceed simultaneously, Predvoditelev demonstrated the conditions that should be observed in the formation of a travelling front. In this respect his works possess an independent character as compared with those now accepted in science. The majority of scientists solve this problem as a boundary one. In this direction Predvoditelev's ideas are closely connected with Mikhelson's who did not, however, develop his views.

As a further step, Predvoditelev also explained the nature of detonation by the use of similar reasoning. Not only did he demonstrate that a jet flow might co-exist with shock rupture, as is most frequently observed, but he also showed that in some cases a jet-helical flow might co-exist with a shock rupture and the surface of a shock rupture would rotate around some axis, as is observed in the case of spin detonation.

Predvoditelev also used his own approach to substantiate hydrodynamics equations for a viscous liquid from the viewpoint of the molecular kinetic theory. As is known, the aim here is to use the solutions of the Boltzmann integral differential equation of the first, second and third approximations, depending on the character of a problem. The solutions so found define more exactly ordinary aerodynamics equations by adding higher derivatives to them. This introduces a new problem if they are used specifically, viz. the introduction of the higher derivatives entails an increase in the number of boundary conditions. It is very difficult to predict these conditions for a given case. Thus it would seem that one difficulty gives place only to another, and there is no visible advantage. Predvoditelev's attention was drawn to one peculiarity which is usually observed on application of the usual method. From the molecular kinetic viewpoint, classical aerodynamics equations (according to the way they are obtained) are always valid if apparent transfer velocities of colliding molecules are mutually equal, i.e. if gradients of apparent velocities along the mean free path of the molecules are zero. In some cases this may not happen in a flow of rarefied gas. Consequently, the classical equations become inapplicable.

Using the concept of a physically infinitely small volume, Predvoditelev showed that on going over from a moving discrete medium to an equivalent flow in a continuum it was necessary to change the dimensions of the physically infinite small volume when passing from point to point. By introducing a special parameter similar to volumetric and tangential viscosity, one may take into account this peculiarity of the transition from a discrete medium to the continuum and write generalized aerodynamics equations without introducing the higher derivatives. Considering experimental investigations on acoustic dispersion in rarefied gases, Predvoditelev demonstrated the validity of the considerations given.

INVESTIGATIONS INTO CHEMICAL PHYSICS AND COMBUSTION THEORY [23–49]

Predvoditelev began his scientific career investigating Rayleigh light dispersion in turbid media with particles 1 μ and less. In this work he showed that the general solution for the dispersed light intensity proposed, by the known German theorist Mi in the form of series expansions on spherical harmonics, might be replaced with adequate accuracy by electromagnetic radiation of dipoles and quadrupoles. The conciseness of the formulae obtained considerably facilitated calculations of the dispersed light intensity in turbid media.

A study was undertaken using dispersed light for the concentration determination of one of the components of photochemical polymerization of anthracene in organic solvents which changes into insoluble dianthracene under the influence of ultra-violet light. This method was extremely convenient for investigating the kinetics of this particular photochemical conversion.

Predvoditelev devoted many experimental investigations to photochemical phenomena of organic dyes, mainly of the aniline type. He concentrated his attention in the main on the effect of film-dye thickness on the velocity of material transformations. The film thickness of a dye-stuff seriously influenced the rate of discoloration, and evident periodicity of the process was found, with a period increasing with the film-dye thickness. The periodicity of the process vanished when the film thickness approached 1 μ.

In order to explain the nature of the process described, Predvoditelev investigated the photoelectric properties of films of dyes, since he considered the photoelectric effect to be the primary event in any photochemical reaction. The investigations confirmed his idea. The intensity of photoelectric current was actually found to vary periodically with the film thickness. The periodicity of the phenomenon also vanished when the film thickness approached 1 μ. At one time these investigations roused great interest when it became necessary to explain the nature of the photoelectric effect.

Since dye-stuffs belong to the class of dielectric media, Predvoditelev began experimental investigations of photoelectric properties of dielectric crystals, the crystals being chosen from a class of complex inorganic compounds. These compounds were chosen mainly because, in a spatial structure of a substance, metal atoms capable of loosing electrons are surrounded by a shell of molecules (water, ammonia) which can decelerate electron emissivity. It was consequently possible to evaluate this deceleration by means of the magnitude of photoelectric current and thus to analyse the nature of a molecular field between a metal atom and the structural formations round it.

At the same time Predvoditelev studied the kinetics of disintegration of complex inorganic compounds in vacuum, mainly dehydration of crystalline hydrates, using interesting methods. In these experiments the kinetics of disintegration was studied by the decrease in weight of the substance investigated on a specially designed microbalance and by recording the reactive force of the escaping molecules on a torsion balance. Both instruments were placed into the same vessel with the gas evacuated. Such a simultaneous investigation of the dehydration process allowed Predvoditelev to establish an important law. Kinetic energy of the escaping molecules proved to be exactly equal to the heat of reaction effect calculated per molecule. Numerous complex compounds confirmed this result. Thus, Predvoditelev found a new non-calorimetric method for measuring heat of formation of chemical compounds. These measurements are of interest not only in this respect, but they also explained the rôle of the Maxwell distribution in the flow of molecules which form the reactive force applied to blades of the torsion balance.

In these experiments Predvoditelev also accomplished the easy determination of the progressive separation of water of crystallization; that in itself is of great interest.

Spatial water distribution in crystalline hydrates is frequently in the form of shells and these break down progressively. In his experiments, Predvoditelev investigated the kinetics of such series disintegration in detail and measured separately the heat of formation of each structural shell, an operation which could hardly be done by calorimetric experiments.

In connexion with the solution of some engineering problems, Predvoditelev and his pupils conducted a set of interesting investigations on chemical transformation of a substance in electric discharges at atmospheric pressure. Reactions were considered in a corona discharge of direct and high-frequency current as well as in flame discharges on installations which generated an electromagnetic wave of about 4 m.

In these investigations, resonant transformation of a substance was discovered, and it was thus proved that under suitable conditions the high-frequency discharge was more effective than discharges obtained from constant electric voltage.

He and his pupils thoroughly investigated conversion of a sulphurous gas into sulphuric acid, air nitrogen into nitric acid, and acetylene into butadiene, etc.

Predvoditelev carried out extensive investigations into heterogeneous and homogeneous combustion of solid, liquid and gaseous fuels. For combustion of solid fuels he evolved an entire theory of a process in which he managed to elucidate completely the rôle of natural and forced diffusion of a gas maintaining combustion of solid fuel. His theoretical propositions were well confirmed by numerous experiments which were conducted by his pupils over a long period of time.

He also gave the theory of bedded fuel-combustion. A furnace with liquid slag disposal was designed on the basis of this theory.

For homogeneous combustion, Predvoditelev considered a problem on inflammation of a gaseous fuel in laminar and turbulent flows. He worked out the theory of limiting concentration and that of flame propagation mentioned above.

Latterly he and his pupils were working on the theory of two-phase combustion. In this direction the most interesting results were obtained in his laboratory and experiments of great precision were carried out. Conditions of ignition, formation and motion of a combustion front in two-phase gas mixtures were found out.

A feature of Predvoditelev's work on homogeneous and two-phase combustion is his search for the principles whereby chemical kinetics and the laws of heat propagation could be combined. He proves that in the presence of chemical processes isothermal surfaces satisfying the heat conduction equation acquire the character of wave surfaces. This follows from the fact that each point of an isothermal surface may be considered as a source of the origin of a chemical process. Regarding the process mentioned, Predvoditelev's views bear a strong resemblance to the theory of the origin of secondary waves in optics (the Huygens principle). The above circumstances allowed him to develop a special mathematical apparatus which made it possible to obtain a finite result to practical or theoretical problems, by means of comparatively simple methods.

INVESTIGATIONS INTO THEORETICAL PHYSICS [43–45]

Predvoditelev's investigations on theoretical physics are noted for their great originality. One group of these investigations is connected with the application of the Thomson–Joukovksi method for evaluating the stability of mechanical motions in atomic systems. Thus, in a number of works, Predvoditelev reveals the purely geometric character of "jumps" of electrons in atoms from one orbit to another. He proves that "jumps" are only convenient as a model for plotting a calculation algorithm. This model actually results from the complex motion of electrons over a surface of double curvature. Proceeding from a unified model of the atomic structure, such consideration allowed Predvoditelev to establish a relation between its serial radiation and the Planck radiation.

As is known, in modern statistical physics, statistical systems are based on the so-called quasi-ergodic hypothesis which is still being discussed even now since Maxwell's original work on this problem. Superimposing on statistical systems stability conditions of motion of their elements, Predvoditelev attempted to exclude this hypothesis. The detailed analysis of statistical systems from these positions permitted the author to divide all the systems into two classes. To one class belong statistical systems of Maxwell–Boltzmann and Gibbs, and, to the other, all the statistical systems united by the generalized Schrödinger equation. This generalized equation unites the form of motion of statistical elements, according to the laws of random wandering, with the mode of their mechanical motions, described by the Hamilton characteristic functions. In this case, the generalized Schrödinger equation is characterized by a special modulus of statistical distribution. If this modulus is purely imaginary, we may obtain a quantum system. If this modulus is real, then we may describe such molecular systems in which statistical systems appear in the form taking correlation into account. In the course of its life such a system may degenerate either into a purely mechanical or into a purely statistical system, for example, into the system of Gibbs or Maxwell–Boltzmann. In these works, Predvoditelev also explained what conditions should be observed so that a non-quantum system could transform into a quantum one.

In general, statistical systems may fluctuate. Adhering to his main suppositions, Predvoditelev also made an attempt to explain this aspect.

Predvoditelev did not confine himself to the analysis of systems in which statistical elements possessed constant mass, but he also analysed such statistical systems in which mass depended on velocity, for example, according to the laws of the theory of relativity. In this case he showed that the Dirac statistical systems were not just special cases, but lay within the framework of the generalized Schrödinger equation which might be transformed into four equations of the first order when actually solving problems. Besides the indispensable compatibility conditions discovered by Hugonio–Hadamard for wave processes were observed a remarkable peculiarity of such a concept.

In one of his works, Predvoditelev proves that the Hugonio–Hadamard compatability conditions, expressed in the form of the Hadamard identity and kinematic conditions, are a prototype of an operator method of quantum mechanics.

In addition, according to the very character of the Hugonio–Hadamard compatability conditions, they must contain a mathematical form of the Heisenberg uncertainty principle. In one of his works, Predvoditelev proves this assertion. Thus, the mathematical form of the Heisenberg uncertainty principle is not confined to quantum mechanics, but is in fact a special form of expression of specific qualities of all wave processes.

Applying features of stability of motion to statistical systems according to Thomson–Joukovski, Predvoditelev found a more convenient expression for motion through a function. This expression had the same significance with respect to disturbed motions as the Hamilton characteristic functions had with respect to undisturbed motions.

By means of a number of particular examples taken from atomic physics, Predvoditelev showed the usefulness of his type of equations for disturbed motions.

To characterize Predvoditelev's wide interests in the field of theoretical physics, we may mention his work devoted to the theory of elementary particles. He considers a space filled with a force field in which there exist closed discontinuity surfaces, and he shows that such surfaces will themselves behave like material bodies possessing properties corresponding either to Bose's statistics or to Fermi–Dirac statistics.

If these particles are brought to decay, we may determine their absolute mass from the value of a statistical distribution modulus. Further the author proves that such particles will possess a whole spectrum of masses. The formulae he found, finish up with an extremely great variety of elementary particles. Among this variety there figure proton nuclei, helium, etc. With the help of the relations found, Predvoditelev also determines the dependence between isotropic number T and mass number A. This relation is of the following form:

$$T = 0{\cdot}0136\, A^{3/2}.$$

The above formula completely embraces the Harkinson empirical relation which is as follows:

$$T = \frac{0{\cdot}0073\, A^{5/3}}{1 + 0{\cdot}0073\, A^{2/3}}.$$

Predvoditelev published this work in the form of a discussion.

Recently Predvoditelev has been studying the general properties of a physical space by analysing the entire scientific material accumulated by geometricians and physicists for many centuries. He has come to the conclusion that our cognition is dual. For example, if we assume rectilinear and uniform motion as a basis of mechanics, considering this as a model with which all other motions are compared, then, as Newton showed in his origins, we shall have varied motions of the Euclidean physical space. If, on the other hand, we consider all the motions of material bodies uniform and, proceeding in geodesic lines, we may then end up with a variety of physical spaces instead of motions. The outstanding Norwegian mathematician Sophus Lie showed that both constructions were equivalent. It cannot be therefore asserted which one is correct. As another example, at first sight, well-known experiments on the β-decay of cobalt lead to a concept that our physical space has no minor symmetry. However, a number of investigators showed that it was possible to increase the number of physical properties of a material particle (neutrino) in a similar manner and the space properties will remain in their familiar form. According to the duality principle, it is possible either to increase the number of properties of a physical space by preserving the number of the found properties of material particles, or to increase the number of properties of a material particle by preserving the number of found properties of a physical space. Both views are correct, and our cognition can never escape from the interpretation of the described natural phenomenon in two ways. Such is the interaction between a concious person and the world around. The number of examples of the dualistic principle may be increased many times. Predvoditelev wrote a small monograph on this problem.

Predvoditelev's rôle as an educator of scientific personnel is great. The growth of the scientific personnel of Predvoditelev's school took place under the conditions of a live interaction between theory and practice. His skill in assisting the development of the creative initiative and self-dependence of scientific workers contributed a great deal to the general growth of scientific institutions. In this man, we have a talented educator of scientific specialists, who has trained more than 110 skilled scientific workers among whom there are twenty-five doctors and professors.

It is necessary to note Predvoditelev's great work in the field of methodology and the history of physics, in throwing light on the rôle of Russian scientists in the development of science and in the organization and planning of scientific research work. Predvoditelev took the lead in the publication of *Essays on the Development of Physics in Russia*. He is an author of some papers in this collection.

Between 1937 and 1946, Predvoditelev was director of the Research Physics Institute and Dean of the Physical Faculty at the Moscow State University.

Predvoditelev fulfilled extensive work as Chairman of the University Scientific Technical Board. He was responsible for getting first-class equipment for the new University buildings.

Highly praising Predvoditelev's scientific, teaching and public work, the Soviet Government decorated him with the Order of Lenin, four Orders of the Red Banner of Labour, the Order of the Red Star, and Medals for Valorous Labour in the Great Patriotic War and for Defence of Moscow.

Predvoditelev is an ardent patriot of the

Motherland and gives all his strength and knowledge to the development of Soviet science. Let us wish him great success in his fruitful work and in his varied scientific and academic activity.

MAIN SCIENTIFIC WORKS OF PREDVODITELEV

1. On stability of mechanical motions in atomic physics (O prochnosti mekhanicheskikh dvizhenii v atomoi fizike), *Zh. Eksp. i Teor. Fiz.* **4**, vyp. 1, 43–59 (1934).
2. On the theory of liquid viscosity and molecular association (K teorii vyazkosti zhidkostei i assotsiatsiya molekul), *Zh. Eksp. i Teor. Fiz.* **3**, vyp. 3, 217–229 (1933).
3. Viscosity of liquids and gases from the viewpoint of cyclic motions (Vyazkost' zhidkostei i gazov s tochki zreniya tsiklicheskikh dvizhenii), *Zh. Eksp. i Teor. Fiz.* **3**, vyp. 3, 230–236 (1933).
4. Some invariant quantities in the theory of heat conduction and liquid viscosity (O nekotorykh invariantnykh kolichestvakh v teorii teploprovodnosti i vyazkosti zhidkostei), *Zh. Fiz. Khim.* **22**, No. 3, 339–348 (1948).
5. Some considerations on the operator method of wave mechanics (Nekotorye soobrazheniya ob operatornom metode volnovoi mekhaniki), *Vestnik Mosk. Univ.* No. 2, 57–65 (1949).
6. On molecular heat transfer in liquids (O molekulyarnom teploobmene v zhidkostyakh), *Dokl. Akad. Nauk SSSR, Fiz. Khim.* **72**, No. 2, 323–326 (1950).
7. On the coefficient of heat conduction, viscosity of liquids and compressed gases (O koeffitsiente teploprovodnosti i vyazkosti zhidkostei i szhatykh gazov). Sb. statei, posvyashchennyi pamyati akademika P. P. Lazareva, Izd. Akad. Nank SSSR, 84–112 (1958).
8. On the character of heat motion in liquids I–III (O kharaktere teplovogo dvizheniya v zhidkostyakh I–III), *Inzh. Fiz. Zh.* **4**, No. 6, 3–12 (1961); **4**, No. 7, 4–10 (1961); **4**, No. 8, 3–10 (1961).
9. Über die Abhängigkeit der Flüssigkeitsdichten von der Temperatur, *Zeit. für Physik Bd.* **36**, Hf. 7, 557–562 (1926).
10. Zur Frage der Abhängigkeit der Dichte von der Temperatur, *Zeit. für Physik Bd.* **40**, Hf. 6, 474–476 (1926).
11. Das Maxwellsche Relaxationsgesetz und die innere Reibung der Flüssigkeiten, *Zeit. für Physik Bd.* **49**, Hf. 3/4, 279–294 (1928).
12. The possibility of considering gas systems as calculated sets with correlation attributes. Papers 1, 2, 3, 4, 5 and 6 (O vozmozhnosti rassmotreniya gazovykh sistem, kak schetnykh mnozhestv s korreliruyushchimi priznakami. Stat'i 1, 2, 3, 4, 5 i 6). In press.
13. Heat conduction of electrical conductors (O teploprovodnosti elektroprovodyashchikh tel), *Zh. Eskp. i Teor. Fiz.* **4**, vyp. 8, 838–854 (1934).
14. Heat conduction of solid heat insulators (O teploprovodnosti tverdykh teplovykh izolyatorov), *Zh. Eskp. i Teor. Fiz.* **4**, vyp. 8, 813–837 (1934).
15. Molecular kinetic substantiation of hydrodynamics equations (O molekulyarno-kineticheskom obosnovanii uravnenii gidrodinamiki), *Izv. Akad. Nauk SSSR, Otdel. Tekh. Nauk* No. 4, 545–560 (194
16. Theoretical examination of vibratory movement of the flame front in closed vessels. Trudy 7 Mezhdunarodnogo simpoziuma po goreniyu i vzryvam, 211–214, London (1958).
17. On general properties of discontinuity processes and acoustic phenomena in solid non-uniform bodies (Ob obshchikh svoistvakh razryvnykh protsessov i akusticheskikh yavleniyakh v tverdykh neodnorodnykh telakh). Applications of ultra-acoustics to substance investigation. Proceedings of the 4th conference, 27–45, Moscow (1957).
18. Hydrodynamic non-uniformities in the theory of combustion and explosions (O gidrodinamicheskikh neodnorodnostyakh v teorii goreniya i vzryvov). Gas dynamics and combustion physics. Izd. Akad. Nauk SSSR, 5–44, Moscow (1959).
19. On conditions of regular motion of strong shock ruptures and detonation (Ob usloviyakh regulyarnogo dvizheniya sil'nykh udarnykh razryvov i detonatsii). Physical gas dynamics. Izd. Akad. Nauk SSSR, 5–14, Moscow (1961).
20. On dispersion of transverse and longitudinal waves in liquids in relaxation. Part I (K voprosu o dispersii poperechnykh i prodol'nykh voln v relaksiruyushchikh zhidkostyakh. Chast' I), *Vestnik Mosk. Univ.* Series III, No. 3, 10–18 (1961).
21. On dispersion of acoustic waves in relaxation media. Part II (O dispersii akusticheskikh voln v relaksiruyushchikh sredakh. Chast' II), *Vestnik Mosk. Univ.* Series III, No. 4, 44–52 (1961).
22. Motion of a combustion zone as a hydrodynamic non-uniformity (Dvizhenie zony goreniya kak gidrodinamicheskoi neodnorodnosti). Sb. trudov, posvyashchennyi yubileyu G. M. Krzhizhanovskogo. Izd. Akad. Nauk SSSR, 793–816 (1959).
23. Über den Einfluss des Kristallwassers auf den photoelektrischen Effekt in den Kristallhydraten I., *Zeit. für Physik Bd.* Hf. 1, 60–76 (1927).
24. Über den Einfluss des Kristallwassers auf den Photoeffekt in Kristallhydraten II., *Zeit. für Physik Bd.* **44**, Hf. 3, 207–215 (1927).
25. Über die absoluten Geschwindigkeiten der H_2O-Moleküle, welche bei der Dehydratation von Kristallhydraten herausfliegen, *Zeit. für Physik Bd.* **54**, Hf. 1/2, 159–160 (1929).
26. On one possible method of measuring the heat of formation of chemical compounds capable of disintegrating in vacuum (Ob odnom vozmozhnom metode izmereniya teploty obrazovaniya khimicheskikh soedinenii, mogushchikh raspadat'sya v vakuume), *Zh. Prikl. Fiz.* **5**, 101–114 (1928).
27. The determination of dehydration heat in vacuum on a torsion balance (K voprosu ob opredelenii teploty degidratatsii v vakuume na krutil'nykh vesakh), *Zh. Prikl. Fiz.* **6**, vyp. 3–4, 96–103 (1929).
28. On the theory of the Bunsen flame (K teorii plameni Bunzena), *Zh. Tekh. Fiz.* **5**, vyp. 8, 1484–1487 (1935).
29. On the theory of gas reactions in a high frequency

electric discharge (K teorii gazovykh reaktsii v vysokochastotnom elektricheskom razryade), *Zh. Fiz. Khim.* **6**, vyp. 4, 418–427 (1935).
30. Combustion of a carbon particle in a gas flow (Gorenie ugol'noi chastitsy pri obtekanii ee potokom gaza), *Zh. Tekh. Fiz.* **10**, vyp. 16, 1311–1323 (1940).
31. On the theory of a process of burning-up of a carbon channel (K teorii protsessa vygoraniya ugol'nogo kanala), *Zh. Tekh. Fiz.* **11**, vyp. 10. 893–901 (1941).
32. The effect of solid admixtures on the velocity of flame propagation in fuel gas mixtures (O vliyanii tverdykh primesei na skorost' rasprostraneniya plameni v goryuchikh gazovykh smesyakh), *Zh. Tekh. Fiz.* **7**, vyp. 18–19, 1801–1811 (1937).
33. Combustion of walls of a carbon channel with forced oxygen diffusion (Gorenie stenok ugol'nogo kanala pri vynuzhdennoi diffuzii kisloroda), *Zh. Tekh. Fiz.* **10**, vyp. 13, 1113–1120 (1940).
34. On the kinetics of chemical reactions of solid and gaseous components resulting in the formation of complex compounds (K kinetike khimicheskikh reaktsii tverdoi i gazoobraznoi komponent, vedushchikh k obrazovaniyu kompleksnykh soedinenii), *Zh. Prikl. Fiz.* **3**, vyp. 3, 67–73 (1927).
35. Carbon combustion (Gorenie ugleroda). Izd. Akad. Nauk SSSR, Moscow (1949).
36. On velocities of chemical reactions in turbulent flows (O skorostyakh khimicheskikh reaktsii v potokakh), *Inzh. Fiz. Zh.* Part I, **3**, No. 11, 3–10 (1960); Part II, **4**, No. 1, 14–21 (1961).
37. Flame propagation in two-phase mixtures. Proceeding of the seventh International Symposium on combustion and explosions, London (1958).
38. On the gas formation with carbon combustion in a bed (K voprosu o gazoobrazovanii pri gorenii uglya v sloe), *Izv. Akad. Nauk SSSR* **10**, 1329–1340 (1947).
39. The Arrhenius laws in chemical kinetics of gas reactions (O zakonakh Arreniusa v khimicheskoi kinetike gazovykh reaktsii), *Dokl. Akad. Nauk SSSR. Khim.* **57**, No. 7, 685–688 (1947).
40. The dependence of exhaustion of a catalyst bed on the velocity of gas motion (Zavisimost' istoshcheniya sloya katalizatora ot skorosti dvizheniya gaza), *Dokl. Akad. Nauk SSSR, Fiz. Khim.* **127**, No. 3, 602–605 (1959).
41. The dependence between the concentration of a waste gas and time of adsorbent exhaustion (Zavisimost' mezhdu kontsentratsiei otkhodyashchego gaza i vremenem istoshcheniya adsorbenta), *Dokl, Akad. Nauk SSSR, Fiz. Khim.* **127**, No. 4, 825–827 (1959).
42. On the quasi-equilibrium state of chemical gas systems (O kvaziravnovesnom sostoyanii khimicheskikh gazovykh sistem). Vestnik Mosk. Univ. **10**, 43–57 (1947).
43. On one geometrical interpretation of an atom structure of hydrogen by Rutherford-Bohr (Ob odnoi geometricheskoi interpretatsii stroeniya atoma vodoroda po Rezerfordu-Boru), *J. Russian Fiz. Chem. Soc.*, Physical Part, **61**, vyp. 5, 443–450 (1929).
44. Possible classification of statistical systems (Vozmozhnaya klassifikatsiya statisticheskikh sistem). Vestnik Mosk. Univ. No. 7, 23–42 (1947).
45. Studies on space and time in modern science (Uchenie o prostranstve i vremeni v sovremennoi nauke). *Vestnik istorii i metodologii estestvennykh nauk* No. 3, Izd. Mosk. Univ. (1962).