PERSONALIA

Yakov Borisovich Zel'dovich (on his sixtieth birthday)

S. S. Gershteĭn, I. I. Gurevich, V. S. Imshennik, I. D. Novikov, B. M. Pontecorvo, and R. Z. Sagdeev

Usp. Fiz. Nauk 112, 533–540 (March 1974)

Academician Yakov Borisovich Zel'dovich celebrates his sixtieth birthday on March 8, 1974. This date marked yet another anniversary. Forty years ago, Zel'dovich published his first theoretical paper, which was devoted to the theory of adsorption on an inhomogeneous surface and opened a new field of chemical physics. Today there is hardly an area of physics or its related sciences that has not benefited by the remarkable efforts of Zel'dovich and his numerous students.

The breadth of Zel'dovich's scientific interests is nothing short of immense. It is difficult to imagine how one man could have accomplished and continued to accomplish so much. The noted English physicist and mathematician Hawking was only half joking when he wrote Zel'dovich after a visit with him that "I now know that, unlike Bourbaki, you are a real man and not the collective title for a whole group."

Zel'dovich began his scientific work as an experimental physicist. This influences his later creative career. It would be difficult to find a theoretical physicist with Zel'dovich's sensitivity and appreciation of the modern experiment and technology and industry. His activity was always closely tied in with experimentation and kept in perfect step with the experimentors (whose ranks, incidentally, also include many of his students). He was repeatedly called upon to direct large teams of theoreticians, experimentors, and engineers charged with the solution of various important scientific and engineering problems.

Zel'dovich has to his credit many original proposals for the design of various experiments, and often he himself, his status as a major theoretician notwithstanding, becomes involved with his characteristic energy and enthusiasm in experiments whose purpose is to shed light on problems that arouse his interest (as was the case, for example, in the experiments performed at Moscow State University in the search for quarks).

Zel'dovich's rare scientific intuition is an object of admiration. His attention is immediately attracted to the "hottest" problems that present themselves in the development of science and (a most important point) are accessible to solution at its present level. This has resulted in a surprising range of variation of the focus of Zel'dovich's scientific interests over the entire course of his career, from problems of chemical physics, combustion, gas dynamics, and fluid dynamics to problems of nuclear physics, elementary-particle physics, gravitation, astrophysics, and cosmology. As a rule, problems that Zel'dovidh has taken up have soon thereafter been at the center of attention of world science and fundamental results, in the acquisition of many of which Zel'dovich has a hand, have been obtained in them.

All those who know Zel'dovich are invariably struck by the speed with which he can "get into" a field of research that is totally new to him. It happens that Zel'dovich has begun, quite recently, to study a new problem; just a little while ago, to the amusement of the expert, he was putting "naive" questions and talking and arguing with anyone who would listen, usually young people; then "all of a sudden," he begins to publish papers in the new field—papers that solve important problems hitherto overlooked by the experts, pose new and original problems that reveal new relationships and indicate ways to experimental solution of the problem. Zel'dovich himself has never made a secret of his ability to familiarize himself quickly with a new scientific field. His advice: "The best way to study a new field is to pose and solve a problem in it." But the real secret is how Zel'dovich manages to find so many highly interesting problems. L. D. Landau often said that, except for Fermi, he did not know a single physicist with Zel'dovich's wealth of new ideas. To amplify this, we might say that it is also difficult to find a scientist as eager to share his wealth of ideas with others. It is just as difficult to find a man who welcomes new ideas with Zel'dovich's enthusiasm. There are very many people, theoreticians, experimentors, and engineers alike, who will remain eternally grateful to Zel'dovich for his help in nurturing their ideas and bringing them to fruition. It is therefore not surprising that Zel'dovich has always been surrounded by many students from the very start of his scientific career. Observing once again that Zel'dovich's interests have often shifted to totally new fields of science, we cannot fail to note that he has left, in all of the fields in which he had occasion to work, scientific schools that have successfully developed trends of investigation that he originated. Here Zel'dovich "interacts" continuously with his former students, keeping abreast of their work and rendering invaluable aid in the form of his remarks and criticisms. Here it must be said that Zel'dovich does not, as a rule, lose touch with his former areas of research, but returns again and again to them, bringing in new ideas and results obtained in the field in which he is most interested at the particular time. This is what inspires Zel'dovich's brilliant papers in the most promising trends, on the "borders" between different sciences – cosmology and elementary-particle physics, chemical kinetics and fluid dynamics, nuclear and molecular physics.

Almost everyone who works with Zel'dovich is impressed by his ability to foresee the final result of a step-by-step calculation or estimate even before it is completed. This is explained by Zel'dovich's exceptionally clear thinking and his ability to penetrate deep into the very essence of the problem under consideration. These qualities have helped Zel'dovich arrive at correct estimates for extremely complex phenomena that do not admit of rigorous calculations. We know of no one who compares with him in this respect.

The striving for clarity and simplicity is one of the characteristic features of Zel'dovich's scientific style. He is the foe of all scientific dillettantism and unnecessary confusion of a problem. In his papers, the mathematical formalism, of which he is absolute master, is always adequate to the problem at hand and aids in reducing it to its physical essentials. His physicist's intuition has often helped Zel'dovich to solve extremely complex mathematical problems and find methods unknown to mathematical specialists. Zel'dovich's mastery of the choice of mathematical tools and his skills in adapting them to specific physical phenomena have borne fruit in his original and highly popular mathematical textbooks. The businesslike and scientific style of Zel'dovich's work is inseparable from his fine spiritual qualities: simplicity, democratism, a loathing for gossip and idleness, his patience in explaining a problem, his high human compassion.

It would be quite impossible to present a condensed list of Zel'dovich's results and ideas in all their enormous variety, the more so since they are to be found not only in papers published in his name, but also in many papers by his students and colleagues. With no attempt at completeness or logical sequence, we cite below the best-known and most productive results of Zel'dovich's many years of activity. Being unable to present a detailed bibliography of Zel'dovich's works, we shall make only occasional references as necessary.

Combustion, detonation, shock waves, and high-temperature hydrodynamic phenomena. Today a great many of Zel'dovich's fundamental results and productive ideas are fundamental in the broad field of the physics of combustion processes, detonation, shock waves, and high-temperature hydrodynamic phenomena. All of these achievements of Zel'dovich and his scientific school, like his earliest cycle of studies in chemical kinetics, are well known and have been set forth in detail in a whole series of books and monographs in whose preparation he assisted.

Zel'dovich's investigations in the physics of combustion and detonation have become classics. His study of combustion processes – the most important subdivision of macroscopic chemical kinetics – inspired such classical papers as those on flame-propagation regimes and the relation between propagation velocity and the characteristics of the combustible mixture, on flame stability, on the ignition of a mixture by an incandescent surface, on the induction regime of combustion, etc. Zel'dovich laid the physical foundations for the internal ballistics of solid rocket engines. This extensive cycle of studies in combustion theory (its experimental verification and technical applications) took form in close collaboration with his many students and successors and especially with his close friend and colleague David Al'bertovich Frank-Kamenetskiĭ, who was a co-author of the article in this journal[1] (with Ya. A. Smorodinskiĭ) marking Zel'dovich's fiftieth birthday. In that article, the reader will find a thorough analysis of Zel'dovich's scientific activity in chemical kinetics, combustion, detonation, and shock waves, which we shall only touch upon here. The importance and stature of these studies of Zel'dovich have been enhanced even further during the pase decade. Moreover, despite the shift of his interest to new areas in physics, Zel'dovich has continued to be active in this trend, generating a whole series of new and interesting papers.

A study of the front structure of a plane stationary blast wave made it possible to explain the various regimes and limits of detonation. The well-known Chapman-Jouguet rule that the speed of sound equals the velocity of the matter with respect to the blast-wave front received a natural interpretation in Zel'dovich's papers. Everyone will be familiar with his elegant solution of the spherical blast-wave problem and his important contribution to the theory of spinning detonation. Zel'dovich's results on the front structure of strong shock waves with consideration of radiative energy transfer were of fundamental importance [2]. Radiative energy transfer becomes the basic factor determining the width of the front when the shock-wave amplitude is sufficiently high, and radiative transfer therefore becomes the basic mechanism of energy dissipation within the shock front. Zel'dovich noted that this problem must be solved with consideration of the finite range of the photons, i.e., on the basis of the radiation transfer equation. Here he laid the groundwork for later research (jointly with Yu. P. Raĭzer) on the luminosity of shock waves propagating in various media, including solids. A closely related subject was treated in Zel'dovich's paper (written jointly with A. S. Kompaneets and Raĭzer) on the cooling wave, in which the radiation-matter interaction again becomes the basic factor. The problem was actually reduced to the stationary problem of the front structure of a cooling wave, in which, in contrast to the preceding problem of shock-wave front structure, the radiant energy flux can escape unhindered to infinity. These papers give a noteworthy representation of the stationary regimes that are so important in physical applications. For example, the cooling-wave problem was applied successfully to explain the emission of the fireballs formed by powerful explosions in air. There is no question that Zel'dovich's paper on the short shock [3] has come to be a major milestone in the development of the hydrodynamic theory. In response to a brief pressure pulse applied to the surface of a medium, a self-similar motion with highly interesting properties arises in it. In the corresponding self-similar solution, Zel'dovich correctly describes the motion in the vicinity of the shock front propagating into the medium in spite of the paradox inherent in the infinite value of the total energy. Zel'dovich's paper on the short shock is highly impressive for the uncommon lucidity with which the resulting solution is physically analyzed. His elegant paper on the propagation of heat in the case of nonlinear thermal conductivity on instantaneous release of a certain thermal energy is of great importance in its own right [4]. Later [5], in an analysis of the short-shock solution and other self-similar solutions for thermal and hydrodynamic phenomena, Zel'dovich formulated (with G. I. Barenblatt) a succinct system of views as to their physical content as intermediate asymptotic solutions of the complete problem. At the same time, the existing self-similar solutions were classified as two essentially different types, in the first of which the self-similar variable can be found from dimensional considerations, while in the second it can only be determined from the existence conditions of the intermediate asymptotic solutions on the whole. Combined with numerical methods of analysis, the search for self-similar solutions have now become one of the principal pathways for quantitative development of complex physical and engineering problems. The extent of Zel'dovich's conceptual contribution to scientific progress in this direction is perfectly clear.

Zel'dovich's elaboration of approximate methods for solution of non-one-dimensional hydrodynamic problems led him to propose a number of efficient methods that, along with those of foreign authors, have been used extensively to solve problems of shock-wave propagation in inhomogeneous media and to investigate the stability of various hydrodynamic flows.

Nor can we overlook the fact that Zel'dovich has shown a steady interest in the cumulation of hydrodynamic flows and made an extremely important contribution to the solution of this problem.[6]

Nuclear power. The foundations of reactor physics and nuclear power engineering were laid in a cycle of papers produced by Zel'dovich and Yu. B. Khariton in 1939–1940. These papers gave the first treatment of the fast-neutron chain raction and investigated the drift of neutrons over the fission threshold due to scattering. Subsequently, the theory of the homogeneous thermal-neutron reactor was formulated, the multiplication constant was obtained for this system, and a theory of resonant absorption of neutrons by U^{238} nuclei was elaborated. The kinetics of the reactor were discussed, and the fundamental importance of delayed neutrons in regulating the work of the reactor was pointed out.

Zel'dovich's activity as one of the close collaborators of I. V. Kurchatov was of outstanding importance for practical achievement of the chain reaction (see, for example, the book "I. V. Kurchatov" by I. N. Golovin).

Nuclear physics. Zel'dovich predicted a whole series of highly interesting phenomena in the field of nuclear physics. In 1953, he pointed to the possibility of meson catalysis of nuclear reactions in cold hydrogen [7]. (This phenomenon was observed experimentally in 1956.) Zel'dovich developed a detailed theory [8] of the process of μ-catalysis and phenomena related to it (a theory that has been confirmed by numerous experiments).

In 1957, Zel'dovich showed that nuclear reactions that superheat matter begin to take place rapidly (as a result of subbarrier transition) in cold hydrogen that has been compressed to a density on the order of 0.7 $\times 10^5$ g/cm^3. This is a highly important consideration for astrophysics, since it establishes the limit to which cold hydrogen can be compressed: according to Zel'dovich's calculations, cold hydrogen with a mass of about $0.75 M_\odot$ under compression by gravitational forces will be transformed into a hot star in less than 10^8 years.

In 1959, Zel'dovich offered an original method for the trapping of neutrons based on the fact that ultracold neutrons experience total internal reflection at all angles of incidence on matter with a positive scattering length. This method was realized experimentally at the JINR by F. L. Shapiro and his co-workers in 1968. It offers unique opportunities for study of the properties of the neutron.

Zel'dovich predicted the possible existence of nuclei with a large neutron excess. One of these nuclei–He^8–was discovered in the JINR laboratory of Nuclear Problems in agreement with this prediction. (That this discovery is nontrivial is obvious, since the nuclei He^5 and He^7 do not exist.)

Elementary-particle physics. The problems of elementary-particle physics have attracted Zel'dovich's attention since 1952–1953. In the paper [9], he succinctly formulated the law of baryon conservation and introduced the concept of the baryon charge on the basis of generalization of a number of experimental facts. This paper (together with a slightly earlier paper of Wigner) played an important role in establishing this fundamental law of nature.

Zel'dovich also formulated the concept of lepton number and the law of lepton conservation [10]. (This was also done independently by G. Marx.) He noted the possibility that the electron and the muon have opposite values of the lepton number. He proposed this scheme in order to forbid the process $\mu \to e + \gamma$, which does not occur in nature. Now, after the discovery of the two types of neutrinos–electronic and muonic–, this scheme (which has also been treated by Mahmud and Konopinski) is the most "economical" one that has been proposed to explain the difference between these two particle types.

The physics of weak interactions has proven to be one of the most interesting problems around since the late 40's and early 50's. The discovery of pion and muon decays and μ-capture raised the question of a common nature of the forces causing these phenomena and those causing the β-decay of nuclei. In his attack on this problem, Zel'dovich first sought methods for experimental determination of the β-decay law and establishment of the universal nature of weak interactions. For example, he was the first to propose that the polarization of particles be measured in β-decay with the object of determining the relative signs of the variants of the interaction [11]. A few years later, polarization measurements had become one of the basic experimental methods for the study of weak interactions.

In 1954, Zel'dovich predicted a new phenomenon–the β-decay of charged pions. His method of treating this phenomenon is, in a sense, characteristic of Zel'dovich's scientific style. Beginning with the composite model of the pion proposed by Fermi and Yang, Zel'dovich observes that, in virtue of isotopic invariance, the wave functions of the nucleon and the antinucleon are the same in charged and neutral pions. Hence the matrix element of the $\pi^\pm \to \pi^0$ transition, which determines the probability of the process, should be the same as in the case of transition between mirror nuclei with isotope spin $T = 1$, i.e., it should be independent of the model. This conclusion played a decisive role in a latter paper of Zel'dovich, which established the fundamental property of the vector variant of weak interactions that is now known as the law of vector-current conservation[12].

Zel'dovich noted that when the β-decay of pions is taken into account, the cloud of virtual pions surrounding the nucleons should not affect the vector constant of the β-decay (in much the same way as it does not change the electrical charge on strongly interacting particles). We should note that at that time, it was believed on the basis of experimental data that the β-interaction constitutes a combination of scalar and tensor variants. The fact that this remarkable property of the vector variant did not escape Zel'dovich further attests to his astonishing intuition. It is also interesting that he undertook his study of the effects of virtual pions on β-decay of nucleons with the purpose of comparing this process with muon decay and determining the change in the ratio of the Gamow-Teller and Fermi variants of the β-decay (on the assumption that this ratio equals unity in the absence of strong interactions). It was this type of program that was followed later when it was established that weak interactions represent a combination of vector and axial-vector variants. The law of vector-current conservation is one of the fundamental and general premises of the modern theory of weak interactions. It has also had significant influence on the theory of strong interactions, serving as an example for the construction of PCAC theory, the algebra of currents, and vector dominance.

Even this brief recital of results obtained by Zel'dovich indicates that he has made a fundamental contribution to the physics of weak interactions. He pointed out the existence of new electromagnetic characteristics of the particles that form on violation of parity (including the so-called anapole moment); he has studied the influence of weak interactions on the electromagnetic properties of particles (jointly with A. M. Perelomov), and was the first to draw attention to the existence of the neutrino charge form factor [13] and to note that the decay probability of the short-lived neutral K_S^0 meson should be equal in order of magnitude to the mass difference between the short-lived and long-lived mesons[14]. Zel'dovich's work was of decisive importance in experimental verification of the universal law of weak interactions and for establishment of the relative signs of the vector and axial-vector variants in the elementary process of muon capture by the proton in hydrogen [15].

At the present time, when the possibility of creating a unified theory of weak and electromagnetic interactions and the neutral-current problem are being widely discussed, it should be noted that one of the first papers in this trend was written by Zel'dovich back in 1959[16,17]. In particular, he observed in [17] that the assumption that weak and electromagnetic interactions are of the same nature results in the conclusion that the mass of the intermediate boson (M_W) should be of the order of 30 GeV; then the order of magnitude of the muon mass is $m_\mu \sim \alpha M_W$ ($\alpha = e^2/\hbar c$) and the electron mass $m_e \sim \alpha^2 M_W$. It is quite possible that precisely this observation will turn out to be the guiderope on the path to solution of the enigmatic problem of μ-e universality.

In 1958, Zel'dovich proposed a method for the observation of short-lived particles by measuring the distributions of the numbers of events over the effective mass of the decay products [18]. This method has been one of the basic ones in the search for and study of unstable particle resonances.

Zel'dovich greeted the appearance of the quark hypothesis with high enthusiasm. He submitted estimates of the possible quark concentrations in matter (jointly with L. B. Okun' and S. B. Pikel'ner), suggested a whole series of ingenious experiments for the detection of quarks, and discussed the possible existence of "exotic" baryon states consisting of four quarks and an antiquark [19].

Astrophysics. In the early 1960's, Zel'dovich's scientific interests were turning increasingly to astrophysics. His first studies in this field related to application of the general theory of relativity to astrophysical processes. He formed the Department of Theoretical Astrophysics at the USSR Academy of Sciences Institute of Applied Mathematics, and still heads it today. His school of theoretical astrophysics quickly won international recognition. Many of Zel'dovich's astrophysical papers, which we shall discuss below, were written jointly with his junior colleagues. They are characterized by the infusion of totally new and original methods into this venerable science. The beginning of his work in astrophysics coincided with the discovery of objects of a totally unique class—the quasars, whose nature has not been definitely deciphered to this day, and with the discovery of the so-called "relic" radiation of the Universe, which proves that matter had a very high temperature during the early stages of the cosmological expansion, i.e., that the Universe was "hot."

The most pressing problems of theoretical astrophysics invariably attract Zel'dovich's attention. These are the problems of the last catastrophic stages in stellar evolution, the quasar problem, the problem of the initial stages of the expansion of the Universe, and the problem of development of inhomogeneities in the expanding Universe, which led to the appearance of individual celestial bodies.

With his usual profound appreciation of the role of the experiment, Zel'dovich pointed out new observational methods in optical, x-ray, and radio astronomy, some of them making use of satellite-, rocket-, and spacecraft-borne instruments, may aid in verifying the theories that are being developed in astrophysics and produce new and unexpected discoveries. Specialists have designed many experiments on his initiative.

Zel'dovich is the author of a theory of the structure of supermassive stars with masses from hundreds of thousands to billions of sun masses. The effects of the general theory of relativity and production of e^+e^- pairs in high-temperature plasma are important in explaining the equilibrium of such stars. Zel'dovich pointed out the importance of rotation in these bodies. The entire theory is important for description of the possible processes in the nuclei of galaxies and quasars, whose nature still remains unclear. A theory of large stars has been developed independently by various foreign scientists. Another possible model for quasars and galactic nuclei is the compact stellar system. Zel'dovich constructed a theory of such systems, for the final stages of whose evolution relativistic effects are also important.

Zel'dovich was the first to sketch out the complete qualitative picture of the last stages in the evolution of ordinary stars with various masses and to submit estimates of the effects of various factors on this evolution and its stability. Following publication of the half-forgotten astrophysical papers of Landau, Oppenheimer, and others in the 1930's, he developed a theory that indicates the circumstances under which, at the end of its evolution, a star should either become a neutron star or experience catastrophic compression under its own gravitation. This last process has come to be known as gravitational collapse. When a star is compressed to critical dimensions—to its gravitational radius—the effects of general relativity theory come into play. The crushing gravitational field releases no radiation. These hypothetical objects were later named "black holes."

With his co-workers, Zel'dovich investigated in detail the properties of "black holes" and the processes that should unfold in their vicinity. It was shown that the external gravitational field of a "black hole" should be described solely by conserved quantities—mass and angular momentum. Any other asymmetries in the field are radiated in the form of gravity waves in the course of formation of the "black hole."

Zel'dovich investigated processes that might aid us in discovering "black holes." He proposed that they be looked for as invisible components of binary stars. He stressed that when gas enters the field of the "black hole" (the so-called gas-accretion process), this gas is heated and radiates very strongly even before it "collapses" into the "black hole," an effect that might be of assistance in the observation of such objects. In [20], he was the first to observe that the accretion of gas should be especially strong in close binary systems in which one component is the normal star and the other is a "black hole." Accretion should result in the emission of x-rays and, consequently, "black holes" should be looked for as x-ray sources in binary systems. His students later elaborated the theory of this accretion in detail. It can now be considered highly probable that a "black hole" has already been discovered as an x-ray source in the binary system Cyg X-1.

Cosmology has been another important direction taken by Zel'dovich's astrophysical research. At the beginning of the 1960's, the problem of the beginning of the cosmological expansion was a rankly theoretical one and far from a solution based on observations. At that time, Zel'dovich was a partisan of the so-called "cold" version of the start of the expansion, which explains the chemical composition of certain old stars. However, with his characteristic objectivity, he did everything in his power to stimulate research on the "hot" variant as well. His colleagues calculated how the radiation of this once "hot" expanding matter might appear to us today, i.e., how the "cold" variant might be distinguished from the "hot" one by observations. Immediately after discovery of the relic radiation, he acknowledged that observations had supported the "hot" variant, and became active in the development of the theory of processes in a "hot" Universe. He and his colleagues have obtained fundamental results in this aspect.

A theory of the interaction of the hot plasma of the expanding Universe with radiation was developed. Processes that might distort the spectrum of the relic radiation and give rise to small-scale fluctuations of its intensity have been analyzed.

These problems are important for solution of yet another problem—that of the formation of galaxies in the expanding system.

In the generally accepted conception, galaxies should be formed as a result of gravitational instability of originally small fluctuations. Continuing the early research of E. M. Lifshitz on this problem, Zel'dovich and his colleagues created a physical theory of the growth of disturbances in a "hot" Universe. However, his most important contribution to the theory of this problem was made in a study of the last stage in galaxy formation, when the disturbances are no longer small and the theory becomes nonlinear. Before Zel'dovich, it was "naively" supposed that gravitational instability leads to the appearance of "lumps"—protogalaxies that are spherical in the first approximation. Zel'dovich showed that what happens is something entirely different. In the so-called adiabatic theory, small density perturbations build up owing to gravitational instability. However, the formations that result do not have the form of "lumps," but that of "pancakes"—"flat," two-dimensional formations of high density that are probably protoclusters of galaxies. The physical processes in formation of galaxies in this way are calculated in detail, with the advice that is typical of all of Zel'dovich's work: the theory should be verified by observations.

With his colleagues, Zel'dovich carried out a cycle of studies of the induced Compton effect [21]. These processes should be important in astrophysics for the study of powerful radiation sources such as pulsars, quasars, and galactic nuclei. They are also interesting from the standpoint of the interaction of laser radiation with matter.

One of the most puzzling problems of astrophysics is that of the cosmological singularity in the past. The cosmological expansion began from the singularity about 10 billion years ago.

A number of difficulties arise, among them the question as to what existed before the singularity, and why did the expansion become isotropic (as we observe it today) very quickly, if not from the very beginning? These questions are still unresolved. But the inexhaustible scientific acumen of Ya. B. Zel'dovich has made a major contribution toward their solution. It was known that the quantum properties of gravitation should be manifested in the vicinity of the singularity. Zel'dovich showed that if the start of the expansion were anisotropic, quantum effects near the singularity would result in intensive particle-antiparticle pair production. The gravitation of these particles would have a strong effect on the dynamics of the expansion, working to reduce the anisotropy and make the expansion isotropic. This might perhaps explain the isotropy of the Universe.

The work of Zel'dovich and his school in cosmology and peculiar celestial bodies has, in essence, given origin to a new branch of astrophysics—relativistic astrophysics.

He summarized these studies in three monographs (jointly with I. D. Novikov) (see the list of monographs at the end of this article).

In 1970, at the Fourteenth General Assembly of the International Astronomical Union, Zel'dovich was elected the first Chairman of the newly created IAU Cosmological Commission.

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The work of Ya. B. Zel'dovich has won the widest international recognition. He is a member of numerous international and foreign societies.

We have repeatedly stressed one of Zel'dovich's rare gifts—the ability to develop fundamental scientific ideas to tangible maturity—vindication in observations and experiments or implementation in technology and industry. This quality is especially valuable in our scientific and technological age.

The work of Yakov Borisovich Zel'dovich is held in high esteem by his country. He has been three times named a Hero of Socialist Labor and has been awarded two Orders of Lenin and other orders and medals.

His honors include a Lenin Prize and four USSR State Prizes.

A brilliantly talented physicist, an inquirer of indomitable temperament into the mysteries of nature, the bane of pseudoscientific prattle and routine, instructor and educator to several generations of scientific youth, a remarkable promoter and popularizer of science, and an honest, acutely intelligent, and spirited human being—this is Yakov Borisovich Zel'dovich on the eve of his sixtieth birthday.

We warmly wish him sturdy good health and further creative successes.

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Translated by R. W. Bowers