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Andrey Sakharov: The Man and The Scientist

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Andrey Sakharov: The Man and The Scientist

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[Cover-to-cover translation of a special issue of the journal "Nature" on Andrey Sakharov. Text of and commentary to the article on pp 62-65 (originally written and published in English; published by S.L. Adler of the Institute of Advanced Studies, Princeton University) is not translated here. Photographs are not reproduced.]

Preface

917F0007A Moscow PRIRODA in Russian No 8, Aug 90 p 2

[Text]

Preface [English preface is as received]

One has to admit that the nation made its acquaintance with Andrey Sakharov and recognized his merits too late. For many years he was engaged in classified research. When he emerged on the political scene, his name and ideas were outlawed. For these reasons only a lucky few met him at the conferences and seminars and were able to witness his style of work and appreciate it. Even those who know some of Sakharov's works failed to get the whole picture.

This issue is an effort to fill the gap. It will tell you about Sakharov, the man and the scientist, his contribution to the development of the Soviet hydrogen bomb, thermonuclear fusion, cosmology, and the theory of gravitation, and it will also cover his humanitarian work.

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Outlines of Biography

917F0007B Moscow PRIRODA in Russian No 8, Aug 90 pp 3-8

[Ye. L. Feynberg, corresponding member USSR Academy of Sciences, Physics Institute imeni P. N. Lebedev, USSR Academy of Sciences, Moscow]

[Text] Andrey Dmitriyevich Sakharov was born on 21 May 1921 in Moscow "into an intelligent and friendly family," as he wrote in the autobiography that prefaced the collection of his articles published in the West in 1974. He felt it necessary to note the following: "Since childhood I lived in an atmosphere of orderliness, mutual help and tact, and love of work and respect for a high mastery of one's chosen profession." These scant but precise words nevertheless merit commentary. It is impossible to understand Sakharov apart from his roots and the spirit of one born of a family and the entire environment of the Russian intelligentsia at the beginning of the 20th century—a phenomenon that is remarkable in and of itself and that still awaits its own study.

Andrey Dmitriyevich's family did not belong to the rich arm of the intelligentsia, represented, for example, by prosperous engineers. Nor did they belong to the revolutionaries, for whom everything was determined by the merciless principle "My life belongs to the revolution." His family was typical for the majority of the average well-off working intelligentsia who created their own moral norm, their own criteria of life values, and their own solid understanding of how to live, of where it was permissible to yield, and of where one had to be unbending.

Andrey Dmitriyevich's parents—his father Dmitriy Ivanovich (the son of an attorney and himself a physics teacher) and his mother Yekaterina Alekseyevna nee Sofiyano (the surname of Greek origin), and to a large degree, his grandmother Mariya Petrovna with her kind, even-tempered, and optimistic nature—had a great effect on the formation of his personality. Religion did not play a role in his family. Indeed only his mother was religiously inclined, albeit without observing the rites (incidentally, his grandfather Dmitriy Ivanovich was a priest). Dmitriy Ivanovich played the piano well and admired Scryabin. And this admiration was transferred to the son.

To the number of fundamental principles of his family as noted by Andrey Dmitriyevich one should probably add personal modesty and disdain of vanity (its appearance evoked a smile and almost compassion). Excesses in the material sphere were excluded, and it went without saying that the pre-eminence of the spiritual was the basis of behavior. Just as fundamental were a sense of social duty and responsibility to the people.[1] Through complexly interwoven familial and simply friendly ties, his family was connected with a Moscow intelligentsia that was even more extensive and that had preserved its traditions.

At that time Dmitriy Ivanovich taught in the so-called second Moscow State University (now the Pedagogical Institute imeni V. I. Lenin) and belonged to that natural science and technical intelligentsia that the government needed. Scientific institutions with this profile mushroomed, and the ignorant intervention by official ideologs was not yet as crude as it was in the case of humanitarians and artists.

Upon entering school, Andrey Sakharov proceeded immediately to the seventh class. Before that he studied in a group of peers with invited teachers and only took and passed his school examinations at the end of the year. (Such cases were not exceptional—I knew of other such families.) Upon completing school in 1938 he entered the physics department at Moscow State University.

At home his parents tried not to focus attention on political events and problems. The grave years of collectivization and terror evidently bypassed Andrey Dmitriyevich. Like many others at the time, he did not imagine the full scale of the lawlessness that had been created. His political stand was shaped in accordance with the reigning norms (although Sakharov was never a pioneer, komsomol member, or party member), and he accepted Marxist teaching without criticism as fully logical.

In autumn 1941 Sakharov was evacuated along with the university to Ashkhabad. There he lived in a dormitory and became gravely ill with dysentery. Perhaps it was only the care of his comrades that helped him recover from the illness. Upon completing a 4-year abbreviated course in 1942, he was sent first to a small plant in

Kovrov. He worked at timber enterprises and later in the same year went to work in the laboratory of the military plant in Ulyanovsk. There he met Klavdiya Alekseyevna Vikhrevaya, a chemist who, because of the war, had completed only four courses at Leningrad Technological Institute. They married in 1943, and the difficult matter of caring for Andrey Dmitriyevich's health fell onto Klavdiya Alekseyevna.

There began his creative work. He had four inventions in the field of product quality control (one was patented) and completed four works in theoretical physics. They were not published, but as he himself wrote, they made him certain of his own strengths. In one of these works he examined the chain reaction in uranium mixed with a moderator and understood that one of the main problems on the path to implementing it, i.e., the resonance capture of neutrons by the uranium, could be overcome by putting the uranium in the form of blocks rather than mixing it evenly with the moderator. This important principle was already known in various countries but was kept secret.

Andrey Dmitriyevich sent his work to Igor Yevgenyevich Tamm, director of the theoretical department of the Physics Institute imeni P. N. Lebedev of the USSR Academy of Sciences, and in January 1945 the institute accepted him for graduate studies. He soon earned forever general liking for his soft intelligence, calm benevolence, and talent, which was rapidly becoming apparent.

Soon Klavdiya Alekseyevna arrived in Moscow with their newborn daughter Tanya. There was nowhere to live (his parents' apartment was bombed during the war), and his stipend was pitiful. Sakharov nevertheless involved himself in science intensely. For 2 years he published articles on completely diverse problems (generation of pions during the collision of high-energy nucleons, optical determination of the temperature of a gas discharge, and the theory of the nucleus). These were mature works in which the sparks of his outstanding talent already glimmered. One of his publications was based on the results of his candidate's dissertation, which he had already prepared by the spring of 1947. Its defense would, however, be put off until autumn since Andrey Dmitriyevich could not pass his examination in "political studies." There was no hidden political motive here. At the time it was simply that Andrey Dmitriyevich set forth his own thoughts in a such a way that he could not always be understood: the very course of his discussions was unconventional, and if something seemed obvious to him, he simply omitted it. The delay of his defense only bothered him because it delayed the improved material standing that came along with an academic degree.

Nevertheless, he soon received a room from the institute in an old, run-down home with a corridor system around the state department store. His daily living conditions improved somewhat, and to earn additional income, Andrey Dmitriyevich began teaching physics at the Moscow Power Engineering Institute.

In 1948 Tamm included him in a group of associates from the theoretical department that had been organized to research the possibility of creating a hydrogen bomb. The important ideas set forth here placed the problem on a realistic foundation. Sakharov was soon counted among the staff of a special institute outside Moscow; up to 1950, however, while the group in the theoretical department still existed, he spent a great deal of time in Moscow. At the "facility," besides his direct work in creating weapons, to which he devoted many years and much effort, he was involved with other research that was related to this theme in one way or another.

It is to Andrey Dmitriyevich that the fundamental ideas in three of the most important methods of implementing controlled nuclear synthesis developed to date belong. These are as follows: the magnetic thermonuclear reactor (1950), which he proposed and subjected to theoretical research together with Tamm (essentially, the tokamak); muon catalysis of nuclear synthesis reactions (1948); and the use of pulsed laser radiation to heat deuterium (a proposal made in 1961 as he writes in his autobiography and the author's abstract of his works published in the United States). In the same period he proposed a method of producing ultrastrong magnetic fields by using the energy of an explosion.

Andrey Dmitriyevich worked with enthusiasm, being certain (like his comrades in work) that only a balance of weaponry could save the world from thermonuclear war. In July 1953 he was awarded a doctorate, and after successful testing of the first hydrogen bomb he was selected as an academician in October.

His life during that period was confined to work and communication with his colleagues and friends—people with outstanding minds, talent, and personal qualities (I. Ye. Tamm, Ya. B. Zeldovich, Yu. B. Khariton, and others no less distinguished)—and family. He spent his leave with his wife and children (in 1949 his daughter Lyuba was born, and in 1959 his son Dima was born) whom he loved very much.

A new view toward the sociopolitical problem gradually began to form within him, however. The unmasking of Stalin's crimes at the 20th congress was probably an important impetus here. He began to realize that politics and the military, which had received nuclear weaponry from the hands of scientists, did not intend to consult with them in matters of using it. Having realized his responsibility for the problem of radioactive contamination during nuclear tests, Andrey Dmitriyevich began to fight to halt those tests that were not needed to improve weaponry. By special calculations he proved the threat they pose to the life and health of thousands of people. He was able to play an essential role in concluding an international agreement regarding halting tests (except underground tests), but his alarm grew, and his relations with the political leadership deteriorated. The catastrophic state of the economy and the deprivation of people's rights, which are completely unfathomable when a country is in a period of peace, were becoming increasingly obvious.

Andrey Dmitriyevich began to frequent Moscow more often, visiting without fail the weekly seminar at the theoretical department, and in his own scientific work he began to devote increasing attention to theoretical problems of particle physics, cosmology, and gravitation, which always interested him.

Already in 1965 he published his first in-depth work in cosmology, in which the formation of inhomogeneities (stars, galaxies) was explained in terms of quantum fluctuations in metrics. Next followed one of his most important works, an explanation of the baryon asymmetry of the universe. Soon after came a work that laid the beginning of a new direction that was termed "induced gravitation" abroad. And there were other works containing completely new ideas in the field of cosmology.[2]

At the same time, the evolution of his sociopolitical stand continued. I remember how back in 1965 he came to my home in a state of extreme excitation with a manuscript of Zhores and Roy Medvedev's book about Stalin (if I am not mistaken it was called "Put k vlasti" [Path to Rule]). It contained facts that had in large part already been published in scattered form during the "Khrushchev thaw." Gathered together, however, they created a very strong impression for Andrey Dmitriyevich that, as it turned out, was largely new.

The result of this evolution of views and intense intellectual and spiritual work was "Razmyshleniya o progresse, mirnom sosushchestvovanii i intellektualnoy svobode" [Thoughts on Progress, Peaceful Coexistence, and Intellectual Freedom] (1968). Published abroad and made known to use thanks to "radio voices" and the "underground press" [samizdat], these thoughts made a startling impression. Of course, Sakharov was removed from secret work.

This break coincided in time with a tragic event in his personal life. In 1969 Klavdiya Alekseyevna died from cancer diagnosed late.

His calm, courageous, and directly stated political remarks, each of which if stated by any other person could lead to a loss of freedom, placed Andrey Dmitriyevich in a singular position. On the one hand, his enormous service to the country, which earned him the highest awards, protected him from direct repression to a certain degree. On the other hand, in the atmosphere of the time, many feared even simple contact with him.

In 1969 Tamm, who had already been bedridden with an untreatable illness, invited Andrey Dmitriyevich to return to the Physics Institute imeni P. N. Lebedev of the USSR Academy of Sciences. He accepted this invitation and soon, after overcoming the vacillations and resistance of the heads of the most diverse levels, he again became an associate of the theoretical department. But that was already at the end of his days.

Andrey Dmitriyevich's social stand attracted to him all those who were to some degree or another involved in defending rights and in protest activity in general. As a result, his (so to speak) theoretical social activity, which was continued in new works developing the line of his "Razmyshleniniya," was tightly interwoven with his active personal involvement in the movement in defense of human rights. He threw himself into defending people subjected to persecution; despite this, however, he still found the time and strength for new scientific works.

In 1971 Andrey Dmitriyevich met Yelena Georgiyevna Bonner, and they soon married. Yelena Georgiyevna, the daughter of renowned Komintern worker G. S. Alikhanov who was done away with in 1937, had studied at the Institute of Philosophy, Literature, and History before the war and then volunteered as a nurse at the front and was wounded and shell shocked. She nevertheless returned to medical work at the front. After the war she completed the medical institute and worked as a pediatrician. Before their meeting, she had already had a long period of service in dissident activity. This union brought Andrey Dmitriyevich a much-needed feeling of personal happiness.

By that time Sakharov had already become a legend. His moral and political effect in the country and throughout the world was enormous. Having himself recognized this long ago, it showed others that only a rule-of-law and open society can ensure trust between countries. In 1975 he was awarded the Nobel Peace Prize. But it was in those same years that Andrey Dmitriyevich's persecution in our mass media began. Streams of hatred and slander were hurled at him and at Yelena Georgiyevna. Finally, after a protest over the Afghanistan uprising, he was exiled to Gorkiy without a trial and without announcement of any formal charges or decrees (and in August 1984 his wife was also sentenced to exile there). The administration of the theoretical department succeeded in preventing his discharge from the Physics Institute imeni P. N. Lebedev of the USSR Academy of Sciences and in reaching an agreement with the "leading party authorities" to allow his coworkers to visit him for scientific consultations. Those whose scientific interests were closest to Andrey Dmitriyevich's were selected for the visits, and of course, they went on a completely voluntary basis.[3]

In Gorkiy, Sakharov spent three years (1981, 1984, and 1985) defending the rights of the members of his new family (specifically, demanding permission for Yelena Georgiyevna to travel abroad for treatment) and experienced the very grave torture of forced feeding.[4] But in addition to his directly announced goals, his hunger strikes were a manifestation of the insurgent spirit of an unsubmissive citizen.[5]

The storm of outrage throughout the world and speeches in his defense were important moral support for Sakharov, but of course, he could not have a serious impact on the country's leaders. Even the criminal war in Afghanistan, which cost the lives of many thousands of Soviet troops, left an enormous number of cripples and killed hundreds of thousands of Afghans, continued despite universal indignation throughout the world and its discussion by members of the United Nations. And the promise that Andrey Dmitriyevich made before his final year to concentrate on scientific work if his demand was satisfied had no effect. However, a week after its beginning, the celebrated April (1985) Plenum of the CPSU Central Committee convened, and by May 31 a high official from the KGB visited Sakharov. From conversations with him, Yelena Georgiyevna concluded that "Gorbachev ordered the KGB to deal with our problem." But the GB [as received] was conducting its own politics. So they were having their own struggle in which it was not clear who was stronger—Gorbachev or the KGB.[6] This was cleared up after 5 months, when after a repeat promise by Andrey Dmitriyevich to refrain from open political speeches, Yelena Georgiyevna was permitted to travel to the United States, where she underwent heart surgery that saved her life. And in December 1986 M. S. Gorbachev, ignoring Sakharov's promise to cease political activity, invited him to return to Moscow and "begin his patriotic activity."

The next 3 years of Andrey Dmitriyevich's stormy life were in full view of all. I cannot fail to add that on the very day of his arrival in Moscow, Andrey Dmitriyevich appeared at the Physics Institute imeni P. N. Lebedev of the USSR Academy of Sciences, his second home, and spent about 6 hours at a seminar and in conversations with his colleagues.

Afterward, his political activity increasingly limited his ability to be involved in science; nevertheless, he participated in weekly seminars and spoke at scientific conferences.

The life of this great man ended abruptly on 14 December 1989.

Footnotes

1. Serving the people was embodied in the most touching form by, for example, many family physicians and teachers. I even found them pure and honest to the naivete of the very young.

2. The articles published in this issue do not reflect the cycle of Sakharov's four works (one joint with Zeldovich) in which, specifically, he derived a semiempirical formula for the masses of adrons based on a quark model. He always loved to take a problem "to the number," and there, success upon comparison with experimentally determined particle masses gave him real joy.

3. In all, 17 associates from the department visited him, some having gone many times.

4. Its acute sense of responsibility for others appeared earlier, for example, in his Nobel Prize speech, and in other cases he presented long lists of "prisoners of conscience" and fought for them. Once, at the beginning of the seventies, I said to him, "I think you are playing a game with no risk: if your ideas are accepted, there will be a victory; and if they jail you, you will be happy that you are suffering like those who think the way you do." He smiled and agreed.

5. If I am not mistaken, in what I thought was consolation, back during my first trip to Gorkiy in June 1980, I quoted Kaysyn Kuliyev's distich "Patience is the weapon of the hero as soon as another weapon is knocked from his hands." He was outraged, "What patience? The struggle continues!"

6. Bonner, Ye. G., "Postskriptum. Kniga o gorkovskoy ssylke" [Postscript. Book About Gorkiy Exile], Paris, 1988, p 129.

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Who Else, If Not I?

917F0007C Moscow PRIRODA in Russian No 8, Aug 90 pp 10-19

[Article by V. I. Ritus, doctor of physical and mathematical sciences, Physics Institute imeni P. N. Lebedev, USSR Academy of Sciences, Moscow]

[Text] In the beginning of 1989 preparations were underway at the Physics Institute imeni P. N. Lebedev [FIAN] of the USSR Academy of Sciences to select the institute's academic council. In accordance with the new democratic rules, a concise scientific profile of each candidate was compiled and hung in the vestibule for all to see. Among them was the profile of Andrey Dmitriyevich Sakharov, written with my participation.

Candidate for Membership in the FIAN From the Theoretical Physics Department

Sakharov, Andrey Dmitriyevich, born 1921, chief scientific associate of the FIAN, academician of the USSR Academy of Sciences, theoretical physicist of world renown, is known for his outstanding works in the field of thermonuclear synthesis, the theory of elementary particles, and cosmology.

The main results and directions of Andrey Dmitriyevich's research are as follows:

physics ideas and calculations regarding creation of thermonuclear weaponry

the pioneering idea of the magnetic containment of plasma and fundamental design calculations for installations to implement controlled nuclear synthesis

ideas and calculations regarding the creation of ultrastrong magnetic fields by the compression of the magnetic flux of a converging blast wave (magnetic cumulation)

works on quantum field theory, the theory of elementary particles, specifically, muon catalysis of nuclear reactions (jointly with Zeldovich)

a discussion of gravitation as the metric elasticity of space; gravitation occurs as a result of a change in the energy of the quantum fluctuation of fields in a vacuum upon the curvature of space the way the conventional elasticity of bodies results from a change in the energy of intermolecular bonds upon deformation;

works in cosmology, specifically about the origin of the universe's baryon asymmetry.

A. D. Sakharov is known for his outstanding social activity. He is a Nobel Peace Prize laureate, one of the founders and directors of the international Fund for the Survival and Development of Humanity, a member of the Presidium of the USSR Academy of Sciences, a member of the FIAN academic council, and a member of the U.S., French, and many other country's academies of sciences.

* * * *

This concise profile also demonstrates the entirely distinct evolution of Andrey Dmitriyevich's scientific activity: from his initial works (even these were of grandiose practical significance), which were developed to yield specific results, he switched to basic research of the foundations of the universe in which he expressed deep pioneering ideas.

His work on the hydrogen bomb was undoubtedly exceptional in all respects. It brought Andrey Dmitriyevich the glory of a most talented theoretical physicist—glory that initially spread among the Soviet physics elite and then throughout the entire world. It is precisely for this work that he was made an academician and awarded the titles Hero of Socialist Labor and Stalin Prize Laureate (on a previously unheard-of scale—0.5 million rubles), not to mention such related governmental gifts as a summer cottage and car.

The time has come to tell the main idea of this work and of my own impressions of Andrey Dmitriyevich in those intense years when I worked under his direction (1951-1955) and later when, after having been removed from secret activity, he returned to the FIAN and we again became colleagues at one department—the Department of Theoretical Physics imeni I. Ye. Tamm.

* * * *

For the 2 days after my arrival at the facility,[1] which were spent arranging a pass into the theoretical department, I remet all of the theoreticians except for Sakharov and Tamm, who were in Moscow at the time. When I entered the department, Andrey Dmitriyevich came to me from his room with a wide grin and energetically shook my hand as if a foretaste of satisfaction from a prospective acquaintance. Then I remembered that this habit of his was simply a sign of a good mood.

He was a round-faced man with long dark hair, with a few hairs falling down to the side and a slight paunch. A photo of him and Kurchatov gives a good picture of the way he looked at the time. When I look at it, I hear his soft speech and the way he pronounced his r's in the French manner. We got acquainted. Suddenly it all disappeared somewhere. Andrey Dmitriyevich led me to a blackboard, took a piece of chalk into his left hand, and drew a large circle around the words "The facility is organized in the following manner." He is an original, I thought. He wants to familiarize me with the layout of the city and, for economy's sake, is drawing his diagram centrosymmetrically, even though I knew that it was not that way in reality—I had already walked along the streets. Andrey Dmitriyevich drew a smaller circle ideally concentric with the first and uttered a few more phrases in which, with some difficulty, I found logic. Only 2 minutes later I finally began to understand that he was talking about something else entirely—the hydrogen bomb.

Although the main principles of the hydrogen bomb's configuration are now well known,[2] it is apropos to explain what Andrey Dmitriyevich's idea consisted of. The main problem was to use the energy released in an atom bomb's explosion to heat and "ignite" heavy hydrogen, i.e., deuterium, to effect thermonuclear reactions

$$d + d \rightarrow p + t + 4 \text{ MeV},$$

$$d + d \rightarrow n + {}^3\text{He} + 3.3 \text{ MeV}$$

leading to the release of energy and, thus, having the capability of sustaining itself. It would seem that this requires placing a layer into a conventional atom bomb between the fissioning matter (a hollow sphere of ^{235}U or ^{239}Pu) and surrounding it with a conventional explosive, the cumulative explosion of which sends the fissioning matter from a subcritical to a supercritical state. It turned out, however, that the deuterium does not have time to heat sufficiently and double and that a thermonuclear reaction barely occurs.

In this context, we will recall that the speed of a dd-reaction is determined by the cross section $\sigma_{dd}(v)$ of this reaction (which depends on the relative speed of the colliding nuclei) and by the concentration of deuterium n_D. In fact, in a unit of time each deuteron may collide with $\sigma_{dd}(v)vn_D$ other deuterons. After thermal (Maxwell) distribution averaging of the speeds, this collision frequency, or the mean inverse "lifetime" of a deuteron, i.e.,

$$\overline{\sigma_{dd}(v)v}n_D$$

depends solely on the temperature and deuterium concentration and is determined by the fraction of deuterium "burned" during the time of the explosion Δt:

$$\frac{\text{number of "burned up" deuterons}}{\text{total number of deuterons}} = \overline{\sigma_{dd}(v)v}n_D\Delta t.$$

To increase the fraction of "burned-up" deuterium, Andrey Dmitriyevich proposed surrounding the deuterium in the structure described by a shell of conventional natural uranium that should moderate the separation and, above all, increase the deuterium concentration significantly. In fact, at the temperature occurring after the explosion of a driver atom bomb, the surrounding matter turns out to be practically completely ionized. The pressure p of such gas equals nkT, where n is the total concentration of nuclei and electrons. Here it is very important to recall that a uranium nucleus is surrounded by 92 electrons, whereas a deuterium nucleus is only surrounded by 1. It is here that the "game" takes place. From the equality of pressures and temperatures at the interface of the deuterium and uranium, we find that the concentration of deuterium nuclei amounts to

$$n_D = \frac{Z_U - 1}{Z_D - 1} n_U = \frac{Z_U - 1}{2A_U M} \rho_U \sim \frac{1}{4M} \rho_U,$$

i.e., it is proportional to the density ρ_U of uranium with a proportionality coefficient that is weakly dependent on the material of the shell (Z, atomic number of the matter; A, mass number; and M, atomic mass unit). For this reason, a uranium shell, which has a density 12-fold that of a conventional explosive's shell, causes a more-than-10-fold increase in deuterium concentration and, consequently, in the speed of the thermonuclear reaction. Our colleagues called that technique of raising it "sakharovization."

The increase in the speed of the dd-reaction leads to a marked formation of tritium, which also enters into a thermonuclear reaction with deuterium:

$$d + t \rightarrow n + {}^4H + 17.6 \text{ MeV}$$

with a cross section that is 100-fold the cross section of the dd-reaction and has a 5-fold greater energy release. Moreover, the nuclei of the uranium shell willingly fission under the effect of the fast neutrons appearing in the dt-reaction and increase the explosion's power significantly.[3] It is precisely this fact that has led to the selection of uranium as a shell rather than some other heavy matter (for example, lead).

The power of the thermonuclear process in deuterium could be increased significantly if a portion of the deuterium were replaced by tritium from the very outset. But tritium is very expensive and, above all, radioactive. V. L. Ginzburg therefore proposed using ^6Li instead. Under the effect of neutrons it effectively generates tritium in the following reaction:

$${}^6Li + n \rightarrow {}^4He + t + 4.8 \text{ MeV}.$$

In fact, a thermonuclear charge in the form of lithium deuteride (LiD) resulted in a radical increase in the power of the thermonuclear process and a release of energy from the uranium shell owing to fission that was severalfold higher than thermonuclear energy release.

Such are the physics concepts embedded in the first version of our thermonuclear weaponry.[4]

* * * *

In this same period, parallel with his main activity, Andrey Dmitriyevich worked intensively on the idea of a magnetic thermonuclear reactor. He conceived such a reactor in the form of a solenoid convoluted into a torus, i.e., having the appearance of a dinner roll whose inside is filled with deuterium. The deuterium is heated by strong discharges of current flowing along a winding that simultaneously creates a magnetic field inside the dinner roll that keeps the plasma from getting on the walls of the torus. The proximity of the scales (about 10 m) and other characteristics of these units that Andrey Dmitriyevich calculated back then to the characteristics of the tokamaks created many years later both by us and abroad is striking.[5]

Andrey Dmitriyevich's third idea expressed in those years was to create ultrastrong magnetic fields by compressing a magnetic flux inside a hollow metal cylinder. The cylinder was compressed by a cumulative explosion. The intersection of the magnetic force lines with the cylinder's moving walls created a current in the walls that in turn created an additional magnetic field inside the cylinder. Because of all this, the magnetic flux of $\Phi = \lambda R^2 H$ inside the cylinder remained constant, and consequently, the intensity of the field increased in inverse proportion to the square of the cylinder's radius.[6]

It later turned out that Ya. P. Terletskiy expressed an analogous idea at about the same time. It seemed to me that Andrey Dmitriyevich was a bit annoyed by this fact.

Experiments on compressing a magnetic flux that were begun at Andrey Dmitriyevich's initiative were conducted in 1964 to the record value of a magnetic field of 25 million gauss.

* * * *

All those years Andrey Dmitriyevich worked with exceptional intensity. He arrived at the department before everyone else and left later than everyone else, and by that time he had a family—his wife Klavdiya Alekseyevna and two small daughters Tanya and Lyuba. The rest of us were 5 to 8 years younger than him and were bachelors.

I still cannot forget the direct physical sensation of the intensity of Andrey Dmitriyevich's work. Once I entered his office.[7] He was sitting at a table holding his head in his hands and trying to look at a sketch. Then he raised his head to me, and I saw several of his long black hairs had fallen onto the sketch. It is not strange that the "vast majority" saw him as someone else entirely.

Besides conducting his own work and participating in numerous conferences at which he had to make very critical decisions, Andrey Dmitriyevich spent a great deal of time directing the work of his associates. I remember that Yu. A. Romanov and I were calculating the probability of a rare process in a mark system, where it was natural to make significant use of probability theory. We wrote a rough draft of the calculation and gave it to Andrey Dmitriyevich. On the third or fourth page he discovered a logic error. We grabbed our heads and corrected the spot and all the rest. Andrey Dmitriyevich read further and again found an error. We again expressed our insufficient mastery of probability theory and again corrected the end. And what do you think? Andrey Dmitriyevich found yet another error—this time the last one. The feelings of shame did not last only because the three of us were the only ones who knew. Andrey Dmitriyevich's remarks were so soft and tactful, but he was on a level so different from our own! In that case we were prepared for a conversation and grasped his comments rather quickly. It was difficult when some unclear problem was being discussed. Each person expressed his own ideas, but Andrey Dmitriyevich's ideas were generally hard to understand—he thought in an unorthodox manner. It was like we were all looking for an answer by using rules that we had learned while he felt the answer intuitively and substantiated his path to the answer in general rather than in individual steps.

* * * *

With such intense work, we rarely saw him resting; nevertheless, there were several "nonworking" episodes.

Somehow, in the very beginning of our stay at the facility, Sakharov and Romanov went beyond the city to stroll in the woods and happened upon barbed wire—the boundary of the "zone." Soldiers held them, phoned for a truck, sat them on the floor of the bed with straightened legs, and took them to the regiment command post in that posture. During the trip our legs became numb, and our knees hurt. It turns out that this is a standard detention technique to keep prisoners from fleeing. Wasn't it a significant beginning!

Three weeks after my arrival, Andrey Dmitriyevich reached his 30th birthday (21 May 1951). That evening about 20 to 25 people gathered for a celebration (Andrey Dmitriyevich and his family occupied half a two-story wooden home—three rooms plus a kitchen). Klavdiya Alekseyevna baked a big pie and covered it with 30 lit candles. Although I had heard that this is the custom, that was the first time I saw it! I very much enjoyed the evening. There was much gaiety and wit. And there was wine too. That was possibly why after a time I felt the need to step out onto the street to breathe some fresh air. It was a warm, almost southern starry night. Suddenly I heard steps behind me, I looked, and Andrey Dmitriyevich was chasing me: "Volodya, how do you feel?" I was touched by his attention. We walked for a while and returned.

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When our activity was in full swing, the department was given a Pobeda car and chauffeur (more precisely, it was given to Tamm and Sakharov), and even though it was a 20-minute walk from our residence to work, we often used this car. Andrey Dmitriyevich usually rode to work first. A crowd of youths came in the second trip. Igor Yevgenyevich arrived on the third trip—much later. Once I decided to use this car to do errands at the "plant" (i.e., to go to the experimenters) after agreeing with Andrey Dmitriyevich that I would leave the car there after I arrived. We both forgot about Igor Yevgenyevich! He had to arrive on foot and gave Andrey Dmitriyevich a thrashing. He listened to it all in silence, but he didn't say a word about me. For the young people standing around, the scene was unpleasant but instructive. Later I witnessed Igor Yevgenyevich apologize to Andrey Dmitriyevich for his hot-headedness.

In the facility's green nook (in the territory of the "general's cottage" for important guests) were volleyball and tennis courts that, as strange as it seems, were most often empty. Once we dragged Andrey Dmitriyevich to play tennis. Klavdiya Alekseyevna came to watch. Andrey Dmitriyevich's rival served the ball. Andrey Dmitriyevich followed it with his eyes, thinking about something else. Then, rousing himself, somehow like Don Quixote he waved his racquet, which described a "free-running" semicircle.

"Klava, did you see how I swung?" he asked his wife.

"It seemed to me, Adik, that you missed."

"Yes, but what a blow it would have been had I hit it!"

* * * *

Somehow I was ordered to Moscow to L. D. Landau's group, which was working on the numerical solution of the mathematical problems compiled by our group. The interim results were needed at once. I met and talked with Lvov Davidovich for the first time, and after taking me to his group's room he said "Now I will introduce you to your children." I was 25 years old at the time, and I talked willingly for 2 hours with "children" that truly seemed older than me (one had a big bald spot, and another had an even more noticeable barren spot on his head). I remember that they were very interested in Andrey Dmitriyevich and were trying to understand what rank of physicist he was and with whom he could be compared. To me, at that time in the USSR there was no physicist more talented than he.

On the way I had to perform a somewhat delicate mission. The assignment, the results of which interested me, was compiled by Andrey Dmitriyevich and me. To be more precise, he tossed me an outline, and I filled in the necessary details. It turned out that Andrey Dmitriyevich had forgotten one important member of a partial different equation, and I did not notice the mistake. When we found it later, I was very distressed and wanted to send a correction to Moscow. But Andrey Dmitriyevich said that the people there were qualified and that they would handle the problem and correct the mistake. And so it happened. The people involved were clearly flattered when I told them what Andrey Dmitriyevich had said. Before my departure, a small discussion arose among them—who would sign my pass. It turned out that one of them was Ye. M. Lifshits and another was I. M. Khalatnikov.

* * * *

Soon after Stalin's death, Andrey Dmitriyevich once answered the following to the frequently arising question of what would happen next: "But nothing, everything will be as before. A complex system is subject to its own internal law and sustains itself." And he added that the individual person, even the highly placed individual, affects only his closest circle. Andrey Dmitriyevich was generally politically passive during those years. V. N. Klimov, who was a younger associate than Andrey Dmitriyevich and evidently a party member, worked in the department during those years (he died tragically in the mountains before reaching the age of 30). Valya read the newspaper "with a pencil," could see much between the lines, and openly made ironic comments regarding the contradictions and lies that were then being spread in the press. Sometimes he even "swayed the truth." More than once he was called to the town committee [gorkom] (as we termed the "political department"), picked to pieces, and (thank God) let go. We all understood him on a human level but viewed his activity with surprise, considering it useless and dangerous. It seems to me that Andrey Dmitriyevich shared the same attitude to the activity, although I never heard any approvals or condemnations from him. Essentially, for many of us Valya was the first "heterodox" or even "rights defender," and that was in Berea's time.

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After the successful test of the first version of the Soviet hydrogen bomb, Tamm left the facility and concentrated completely on his work at the theoretical department of the Physics Institute imeni P. N. Lebedev, where I was also sent in 1955. Therefore, not counting rare meetings, there was a pause in my communications with Andrey Dmitriyevich until 1969, when he returned to the theoretical department. During those years (1956-1969) Andrey Dmitriyevich continued to work on improving thermonuclear weaponry, for which he received two more Hero of Socialist Labor stars. However, he was devoting increasingly more attention to his works on open themes—muon catalysis of nuclear reactions (1957), the baryon asymmetry of the universe (1967), the connection between gravitation and the physics of elementary particles (1967), and his discussion of

$$K^0 \to \bar{K}^0\text{-transitions}$$

that we would now call transitions with the exchange of two W-bosons (1967).

In the past few years, in the context of searches for proton decay, his work on the baryon asymmetry of the universe has received wide recognition since this type of decay was first forecast in it.[8] Andrey Dmitriyevich proceeds from the model of a hot expanding universe and shows that the following three conditions are necessary for the occurrence of the observed baryon asymmetry of the universe:

1. the existence of interactions in which the baryon number is not maintained
2. violation of charge (C) and combined parity (CP) in these interactions,
3. a universe that is in a state far from thermal equilibrium

Since reactions involving a change in baryon number have never been observed, Andrey Dmitriyevich hypothesizes that interactions between quarks and leptons that do not maintain the baryon number occur by intermediate fractionally charged bosons with an extremely large mass of a planckian order. Such reactions could therefore only occur at grandiose energies or when the universe had a temperature on the order of or higher than the threshold temperature of the generation of intermediate bosons. This also means that such X-bosons may decay along channels with different baryon numbers B_1 and B_2 and relative probabilities r and (1 - r). The decay of the system $X + \bar{X}$ consisting of a boson and antiboson then results in a system with a nonzero baryon number

$$\Delta B = rB_1 + (1 - r)B_2 - \bar{r}B_1 - (1 - \bar{r})B_2 = (r - \bar{r})(B_1 - B_2),$$

if the probabilities r and $\bar{r}$ of the partial charge-conjugated channels differ. This may actually be a result of nonconservation of the charge and combined parities.

If, however, the universe is in a state of thermal equilibrium at such temperatures, the number of baryons must necessarily equal the number of antibaryons. This was a consequence of the CPT-theorem (CP = combined parity; T = time reversal), in accordance with which the mass M and lifetime of particles and antiparticles must be identical and their distributions must be proportional to exp (-M/kT). Since the universe is nonstationary and is moving rapidly from a thermal equilibrium, this makes Andrey Dmitriyevich's hypothesized mechanisms of the violation of its baryon symmetry effective.

* * * *

In 1967 Andrey Dmitriyevich published a very interesting article entitled "Vacuum Quantum Fluctuations in Curved Space and Gravitation Theory."

To understand its essence, it is important to remember that, according to Einstein, gravitation is the curvature of space caused by the presence of matter, i.e., real particles and fields possessing energy density. The curvature of space is proportional to the energy density, and

Newton's gravitation constant G divided by the speed of light raised to the fourth power serves as the the proportionality coefficient:

$$\text{curvature} \sim \frac{G}{c^4} \times \text{energy density.}$$

This is Einstein's famous equation.

In his own work, Andrey Dmitriyevich asserts that this equation is actually dynamic in nature and that the curvature multiplied by c^4/G is nothing other than the change in the energy density of a vacuum owing to the curvature of space, i.e., owing to the introduction of real matter with a specified energy density into the vacuum. Thus, in Andrey Dmitriyevich's opinion there is hope that quantum field theory will make it possible to find the change in the energy of quantum fluctuations of fields in a vacuum as a function of the curvature of space. In the first approximation, this function should be linear with respect to curvature with a proportionality coefficient that is entirely determined by the properties of the ultra-short-wave portion of the spectrum of quantum fluctuations. On the other hand, according to Einstein, this coefficient equals c^4/G. The gravitation constant is thus determined by the physics of elementary particles at very high pulses.[9]

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During the years from 1956 to 1969, serious events occurred in Andrey Dmitriyevich's life. One was a joyful event—the birth of his son. The other was a tragic event—the death of Klavdiya Alekseyevna. These years were also marked by the significant evolution of Andrey Dmitriyevich's sociopolitical views.

Nuclear weapons tests were becoming increasingly frequent and more powerful. They were harming nature, necessitating the resettlement of thousands of people, and threatening their health and life. Because of his participation in their preparation and implementation, Andrey Dmitriyevich was faced with a number of acute moral problems. He began to actively speak out for the halting of nuclear weapons tests, which led to his conflict with N. S. Khrushchev and other highly placed individuals. Despite the fact that nuclear parity had been achieved, weaponry produced above all measure began to be transformed into a means of political blackmail, of spreading political supremacy, and of threatening the peace and life of all mankind. Andrey Dmitriyevich came to the conclusion that eliminating the threat of mankind's self-destruction required bringing our country closer to the democratic governments of the West and giving common human values priority over ideological ones. He formulated this concept in "Razmyshleniya o progresse, mirnom sosushchestvovanii i intellektualnoy svobode" [Thoughts About Progress, Peaceful Coexistence, and Intellectual Freedom], which was published abroad in 1968.

The authorities removed Andrey Dmitriyevich from secret work. He returned to the Physics Institute imeni P. N. Lebedev and became the leader of the country's human rights movement. In addition, he regularly participated in the work of the theoretical department's seminar, frequented the meetings of its academic council, and sometimes talked about his own works. We were able to discuss both physical and political problems with him—of course, the latter discussions were private. It was precisely at that time that heterodoxy was blossoming, and such concepts as glasnost, pluralism, alternative choices, a multiparty system, and convergence appeared in and even filled conversations.

Many of us shared Andrey Dmitriyevich's convictions even though some of his went too far. In all of us there was a deep fear for his fate—and yes, for the fate of the department. And even though the department's associates did not sign even a single letter discrediting Andrey Dmitriyevich even during the most malicious campaigns, we really did not help him. Speaking for myself, I can say that I signed a letter written by Andrey Dmitriyevich in defense of Zh. Medvedev (this name was already well known to me) and was very glad when he learned of his freedom from a psychiatric hospital. This was evidently one of a few cases, if not the only one, where the voice of the public was heard. But I did not sign the letter in defense of the participants in the so-called aircraft affair. With a feeling of deep awkwardness before Andrey Dmitriyevich, I gave him three reasons at the time: one must not endanger other people's lives for the sake of one's own personal goals, I was unfamiliar with the participants and details of the affair, and I had no hope of immunity from the authorities' repressions. Of course, except for the last, Andrey Dmitriyevich himself also faced these problems. But having decided them for himself, he evidently believed that that was where he should stand on the matter. With regard to immunity, he said that the degree of doctor of sciences was sufficient to gain immunity. Until that time, it seemed to me that I had acted correctly, but then why then was there an "itching" in my soul? This was a long, open conversation in his old apartment in Shchukin during which I said that I was ready to make the sacrifice, meaning specifically exile.

In general, I never spoke with Andrey Dmitriyevich regarding his human rights activity. It seemed to me that he should confine himself to concentrating on compiling program articles and speeches on global matters worrying mankind and our country and that he was doing so carefully and with deep thought. His speeches in defense of individuals and on certain particular matters sometimes seemed to me to be too stinging for the orthodox critic and must take a great deal of time, energy, and nerves from him (if only to obtain reliable information and sign the numerous petitions). Once I expressed my doubt with Yelena Georgiyevna. "Yes, I too speak to him about it all the time," she answered. But the circle of matters into which Andrey Dmitriyevich was drawn kept expanding and expanding.

To may question of why he had written so stinging a telegram to Pinochet regarding P. Neruda, he responded that the text had already been prepared when he was asked to sign it and that it is always possible to pick someone apart if if you want to and if it is important that you reach your goal. And so more than once I felt that he simply had no feeling of fear: the main thing was to reach the goal; he never thought about harm to his own person.

Another time I asked him why he was defending a cause that seemed hopeless to me. "Who else, if not I?" he asked. Yes, there were other heterodoxes, but only a few of them knew how to overcome the feeling of fear within them. In fact, he acted like a normal man should and taught us this by his own example.

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The war in Afghanistan worried the entire country. No matter whom I talked with, everyone expressed his indignation over this act. But only Andrey Dmitriyevich and a very few said so openly. The reaction came swiftly—exile to Gorkiy, deprivation of all of his government awards.

My first visit to Andrey Dmitriyevich in Gorkiy (together with I. V. Andreyev, an associate in our department) was in January 1983. We found his home, entrance, and apartment without difficulty based on the stories of previous visitors, and in joyful excitation, shaking the snow from in front of the door, we dashingly shook our hand to the man on point duty. A smiling Andrey Dmitriyevich came out to the noise, and we wound up in his apartment. A minute past 10 the strum of the entry bell rang out. Andrey Dmitriyevich opened the door, and we heard the kind requests of the man on point duty, "Andrey Dmitriyevich, permit me to examine the documents of your guests." Evidently he took us for authorities or, perhaps, was a decent person. The head of the post office next door came during the day and brought Andrey Dmitriyevich letters, including ones from abroad. We likes that his conversation with A. D. was also very respectful. People with whom he was not acquainted and a priest—all connected with humanitarian organizations in one way or another—wrote to him.

We told Andrey Dmitriyevich everything that we knew and a little about our own work. During the day, Andrey Dmitriyevich served dinner, a noticeable portion of which was prepared by Yelena Georgiyevna, who was in Moscow but sent it to him in a special bag, and the other part of which was prepared by Andrey Dmitriyevich himself, entrusting us with only the unskilled work, washing dishes, etc. After dinner Andrey Dmitriyevich announced a rest hour, lay down himself, and made us do this too. I was not accustomed to this and soon began wandering around the apartment, unwillingly focusing attention on possible bugging sites. I did not find anything suspicious. On the desk I happened to see the beginning of a memo by Andrey Dmitriyevich about the Arab-Israeli conflict. Later Andrey Dmitriyevich showed me a book by A. Pays [transliteration] about Einstein, which mentioned Einstein's serious interest and participation in the Wallenberg matter, which was not secret. Andrey Dmitriyevich related the details. It was strange that, despite glasnost, the recent Russian translation of this book (1989) does not contain the name Wallenberg.

During my second visit (9 February 1984), after we had exchanged views about the news, Andrey Dmitriyevich demonstrated his ability to work with a small computer sent to him from abroad. Specifically, he programmed and solved the problem of Mercury's motion around the Sun with an allowance for the effects of general relativity theory and, thus, numerically found the rate of shift of Mercury's perihelion. Working with an "intelligent" computer gave him true satisfaction. After dinner, which passed in the same spirit as the last time, and a short rest Andrey Dmitriyevich told me what was torturing him. His letter to Yu. V. Andropov requesting permission for Yelena Georgiyevna to continue treatment abroad had already gone unanswered for 3 months. "I will wait another week and them announce a hunger strike," he said. I implored him not to do so and asked him to wait, saying that rumors were circulating about Andropov's serious illness in view of his absence and that changes "at the top" and consequently changes in the attitude toward Andrey Dmitriyevich were possible.

And what a coincidence! That was precisely the day Andropov died, but he was replaced by K. U. Chernenko. Andrey Dmitriyevich wrote a new letter—this time to Chernenko. At first, a long period passed with no answer. Later he was informed that the answer would come after May Day. As is well known (see the journal ZNAMYA, No 2, 1990), on 2 May Yelena Georgiyevna was detained before Andrey Dmitriyevich's eyes and later tried. Then came the hunger strike Andrey Dmitriyevich announced on 2 May 1984, his being hospitalized, and his ensuing barbaric treatment by the medical personnel and KGB that made him unrecognizable.

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I only met him once after these events—on the day he returned to Moscow in December 1986. Although joyful excitement reigned, it was hard to see his emaciated face, tender sunken eyes, drooping shoulders, and emaciated figure. And although spiritually he survived and emerged victorious, the physical trauma turned out to be incurable.

One frequently hears the question of how so great a humanitarian as Andrey Dmitriyevich could be involved in the creation of thermonuclear weaponry—and for so unhumanitarian, undemocratic a regime as the Stalin-Berea regime? Another question is asked: what made him switch from the so-successful development of increasingly new models of nuclear weaponry to problems of peace and disarmament and to the defense of human rights?

It seems to me that the answers to these questions are connected with the evolution of Andrey Dmitriyevich's creative spirit. He was, above all, a most talented physicist and inventor, and he viewed his ideas of creating a thermonuclear bomb and thermonuclear reactor, which came to him in their own time, exclusively as possible solutions to grandiose scientific-technical problems rather than solutions to problems of military and political opposition. His belief in the correctness of their ideas and their implementation were a satisfaction of his creative curiosity. Despite the propaganda, we did not believe in any real threat on the part of the United States, but the spirit of competition (who would do it faster and better) was undoubtedly common in all scientific research work—all the more so in the beginning when we lagged behind. And then in the mid-fifties when these ideas were implemented and not only the physical picture but its prospects became clear, the interests of the leading scientists began to shift to other fields. In addition, they had won enormous authority, and the depth of their creative potential had been realized. AT the time Andrey Dmitriyevich saw that in the hands of a narrow power-hungry group of people his little baby was becoming a tool for the propagation of geopolitical supremacy. In essence this was a call of autocracy to the creators of scientific-technical progress. And we had to be happy that this call was accepted by a man with an enormous intellectual capability, the highest humanitarian principles, and a man of conscience and duty. And he gave all his efforts to developing ways to get out of the crisis that had been created. Could another have done it instead of him?

Footnotes

1. After completing the Physics Department at Moscow State University in December 1950, I was kept for graduate studies. In the meantime, M. A. Markov recommended me to I. Ye. Tamm for a group implementing the idea that A. D. Sakharov created at a research center far from Moscow. When I was "ordered" there in the beginning of May 1951, it seemed to me that this was precisely the location of the large secret accelerator about which rumors were circulated in Moscow.

2. "Nuclear Weaponry," BSE, Vol. 51, 1958, pp 320-321; "Nuclear Explosion," FIZICHESKIY ENTSIKLOPEDICHESKIY SLOVAR, 1984, PP 917-918.

3. We will recall that natural uranium consists of ^{238}U (99.3%) and ^{235}U (0.7%). Unlike ^{235}U, which fissions by both fast and slow neutrons, ^{238}U is only divided by fast neutrons with an energy of more than 1 MeV.

4. See Romanov, Yu. A., "Father of the Soviet Hydrogen Bomb," in this issue.

5. See Golovin, I. N., and Shafranov, V. D., "At Sources of Thermonuclear Fusion," in this issue.

6. See Pavlovksiy, A. I., "Magnetic Cumulation," in this issue.

7. He nevertheless remained one of the two bodyguards who were likable young people and did not bother us; but wherever Andrey Dmitriyevich was, they watched him around the clock.

8. See Linde, A. D., "Inordinate Questions—Were They Bold or Reckless?" in this issue.

9. Adler, S. L., "A. D. Sakharov and Induced Gravitation" (a Russian translation of this English work appears on pp 62-65 of the Russian text of this issue of PRIRODA but has not been retranslated into its original form here).

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Review of Scientific Activity of Andrey Dmitriyevich Sakharov

917F0007D Moscow PRIRODA in Russian No 8, Aug 90 p 12

[Article by I. Ye. Tamm dated 1953]

[Text] A. D. Sakharov is one of the most outstanding and leading physicists in our country.

It would not be enough to say that he possesses extensive erudition—the entire style of his scientific creativity confirms that, for him, the physical laws and links between phenomenon are directly visible and perceptible in all their internal simplicity.

This gift, in conjunction with the rare originality of his scientific thought and the intensity of his scientific creativity, has made it possible for him to advance three paramount scientific-technical ideas in the past 5 years. Each of them is based on the use of unexpected combinations of undisputed physical principles that make it possible to indicate fundamentally new and exceptionally effective ways of solving critical problems of new technology.

Because of the paramount state significance of these ideas of A. D. Sakharov, very large amounts of human and physical resources are currently being expended to implement them. The general ideological and scientific direction of this entire extensive activity is being handled exceptionally successfully by A. D. Sakharov himself.

There can be no doubt that A. D. Sakharov deserves not only the academic degree of doctor of physical sciences but that he also be inducted into the USSR Academy of Sciences.

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Father of Soviet Hydrogen Bomb

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[Article by Yu. A. Romanov, doctor of physical and mathematical sciences, All-Union Scientific Research Institute of Experimental Physics]

[Text] The year 1948 passed. That was the year when a small group of theoreticians under the direction of I. Ye. Tamm was created at the Physics Institute imeni P. N. Lebedev. By special degree of the government, the group was charged with researching the possibility of creating thermonuclear weaponry. Just 3 years before, the bloodiest war in the history of mankind ended, and already Churchill's famous Fulton speech in which the "old doctrine of a balance of forces" was deemed "a failure," thus marking the beginning of the "Cold War," had already been sadly uttered. Tired out by the sufferings and deprivations of war, our country quickly undertook the development of atomic weaponry to restore military parity and prepared to test the first atomic bomb, the terrifying power of which was demonstrated by the Americans at Hiroshima and Nagasaki. And it was already known that the United States was conducting research to create a hydrogen bomb based on the reaction of the synthesis of nuclei of heavy isotopes of deuterium (d) or deuterium and tritium (t). The distinction of such a bomb lay in the fact that the energy of its explosion is largely determined by the amount of thermonuclear fuel in it and may amount to megatons, whereas the energy of the explosion of an atomic fission bomb is restricted by a whole series of factors, including the need to use a large quantity of expensive fissioning matter. The point is that separating and producing deuterium is much simpler and cheaper than is separating uranium isotopes and releasing plutonium.

In the United States, the initiative to create a hydrogen bomb belonged to E. Teller back in 1942. In the USSR, as far as I know, the problem was formulated in 1946 in a special report presented to the government by I. I. Gurevich, Ya. B. Zeldovich, I. Ya. Pomeranchuk, and Yu. B. Khariton. A small group of associates (A. S. Kompaneyets and S. P. Dyakov) under Zeldovich's direction was soon formed at the Chemical Physics Institute of the USSR Academy of Sciences, and research on the problem was begun. Obviously, in view of its exceptional secrecy, information about the level of the respective developments in the United States was lacking. As is now known, however, at the end of the forties, the status of their research was about identical.

It was clear that sustaining a thermonuclear reaction requires a temperature of several million degrees and that this may be achieved only by using an atomic bomb as a driver. If, however, it is simply surrounded with deuterium, there will be no noticeable increase in the power of the explosion. And here is why. Because of the dispersion of matter under high pressure and the drop in temperature owing to heat release, the speed of a thermonuclear synthesis reaction is too low, so that there is only time for a minute portion of the deuterium nuclei to react in such a design. The situation would be improved significantly by using tritium since the speed of a dt-reaction at a specified temperature is about 100 times greater than that of a dd-reaction. However, tritium does not exist in nature, and it must be produced in nuclear reactors by irradiating lithium with neutrons. It is therefore natural that tritium is expensive. In addition, it is radioactive with a half-life of 12.6 years, i.e., it requires constant replenishment. Thus, not only was creating a hydrogen bomb a complex technical and production task, it also necessitated solving many fundamental, purely scientific problems. For this, a group was created that was headed by Tamm—a scholar with a world-class name and a man of great spirit and exceptional honor and adherence to principles.

The group was located on the third floor of a home on Miusskaya Street, in three small rooms and naturally behind a closed door. One of the rooms served as Igor Yevgenyevich's office. There were a large desk, a blackboard needed for discussions, and over it a portrait of L. I. Mandelshtam—Tamm's friend and teacher. Next to it was the office of V. L. Ginzburg and S. Z. Belenkiy, and the third room was intended for a pupil of Igor Yevgenyevich who had recently defended his candidate's dissertation, Andrey Sakharov. This office also included a place for me. I had been signed up for graduate studies at the Physics Institute imeni P. N. Lebedev in June 1938. It was here that I became acquainted with Andrey Dmitriyevich under whose direct supervision I was lucky to work all the way until 1955.

This lanky, modestly dressed man in his 27th year had already gained authority in scientific circles, becoming distinguished for his brightness and keen thinking and his laconic expression of his ideas. His candidate's dissertation was devoted to theoretical problems of the physics of the atomic nucleus. He energetically threw himself into these problem of a defense nature, which were new to him, and lent all his creative efforts to this important government matter.

During those first months we became acquainted with a field of engineering physics that was new for us, studied the literature, went to Zeldovich and his colleagues at the Institute of Chemical Physics, became familiar with their works, and discussed problems that arose at the blackboard and thus grasped the ABC's of a science that was new to us.

It may seem improbable, but after a couple of months Andrey Dmitriyevich was expressing fundamental ideas determining the further development of the entire problem.

Before this, the Zeldovich group had been looking at deuterium (possibly mixed with tritium) as a fuel for the thermonuclear device. Sakharov proposed his own version: a heterogeneous design of alternating layers of light matter (deuterium, tritium, and their chemical compounds) and heavy matter (^{238}U) in what he termed "layering." It turned out that Teller expressed very similar ideas in 1946; however the American developments initially proceeded down another path that turned out to be a dead end.

What was the advantage of this "layered cake"? First, it affords the possibility of realizing the principle "fission-synthesis-fission" necessary to increase the energy of the explosion. Neutrons from a dt-reaction with an energy higher than the fission threshold of ^{238}U split it, as a result of which additional energy is released. But, what is more important, thanks to the low heat conduction of uranium the flow of heat from the bomb's matter is greatly reduced. Finally, because it is located in direct proximity with the uranium, the light matter is compressed severalfold when heated to temperatures of tens of millions of degrees. In the circles of the developers of nuclear weaponry, this phenomenon received the name "sakharovization." The physical cause of sakharovization is ultimately simple: at superhigh temperatures when matter is practically completely ionized, an identical density of the electrons in heavy and light matter corresponds to an equalization of the pressures in them.[1] This means that light matter should be in a highly compressed state and that it is, in fact, necessary to increase the speed of the synthesis reaction. If lithium is also included in this "layering," it will, under the effect of neutrons, be very effectively transformed into tritium, which, as has already been said, participates in a thermonuclear reaction.

The idea of using the isotope ^{6}Li in the "layering" belongs to V. L. Ginzburg. He tenderly called lithium deuteride (LiD) "lidochka," although in calculations that were generally written out by hand he designated it with the conventional letters. I. V. Kurchatov correctly estimated the great promise of using ^{6}Li and quickly set up its production. As a result the Soviet Union was the first to use it in hydrogen weapons tests.

The work on "layering" received increasing priority and required Andrey Dmitriyevich's presence at the "facility" in the All-Union Scientific Research Institute of Experimental Physics, where the main research in creating weaponry has been concentrated since 1946. On 17 Mar 1950 on an LI-2 transport aircraft, Sakharov was sentenced to permanent work at the institute. I was flying on the very same aircraft. Five intense years of joint work stood before us.

Back in 1949, after having arrived at the facility on professional business, Andrey Dmitriyevich was familiarized with the results of the first tests of the atomic bomb. After this, the structure of the hydrogen bomb began to assume a realistic face. Kurchatov was responsible for the general direction of the problem, and Khariton was the scientific director of operations and chief designer.

Development of hydrogen weaponry required the participation of specialists of the most diverse profile. Thus, without modeling the process of thermonuclear combustion it was impossible to produce any reliable results. For this it became necessary to develop methods of calculating the thermal, gas dynamic, and other physical phenomena in a structure with a complex geometry. To solve the mathematical physics problems connected with the atomic problem, a number of scientific groups that developed numerical methods were formed at the end of the forties. N. N. Meyman, K. A. Semendyayev, and A. N. Tikhonov were the directors of these scientific collectives. However, our situation regarding computer technology was much worse than that in the United States: the highest-speed computer at our disposal was a keyboard machine produced by the firm Mercedes that was obtained from Germany as reparation. Individual computations were made by using a large number of little girls [with math ability] who act as calculators, and the calendar periods required for each computation were very great—from weeks to half a year. In 1951 the uncoordinated groups of mathematicians were united under the supervision of M. V. Keldysh at a special institute in Moscow named the Applied Mathematics Department. Such prominent scholars as I. M. Gelfand, K. I. Babenko, and others were also brought into the institute.

The first domestic computer, the Strela, was started up in 1953. On it the "layering" calculations were performed under Tikhonov's and Semendyayev's direction. With their help, some design diagrams were rejected, and the initial estimates were corrected significantly.

Experiments studying the kinetics of neutron processes in complex assemblies simulating the "layering" design were conducted intensively. Work on them was done at our institute (Yu. A. Zysin, A. I. Pavlovskiy), at the Physics Institute imeni P. N. Lebedev (I. M. Frank, I. Ya. Barit), and in Dubna (V. A. Davidenko, I. S. Pogrebov) at the institute then called the Hydraulic Engineering Laboratory (evidently in view of the proximity of the Moscow-Volga channel), although the only hydraulic structure there was the proton accelerator's cooling system. It is now the Joint Institute for Nuclear Research. Full-scale experiments (K. I. Shchelkin, A. D. Zakharenkov) were conducted with trinitrotoluene (TNT) charges to determine the key gas dynamic parameters of the bomb design selected. Works to prepare research on the effect of such an explosion on various structures and military technology were conducted in the Semipalatinsk proving ground on a broad front.

In general, there was intensive preparation for the first test of the hydrogen bomb in the Soviet Union slated for 1953. We had not yet had so powerful an underground test.

What was being done in the United States at the time? We now have the capability of finding out how works on thermonuclear weaponry were proceeding in the United States[2] and comparing the course of their developments with ours.

The American hydrogen bomb project did not become a lightning speed program as E. Teller publicized it in autumn 1949. The first computer calculations were made only at the end of 1949. One after another diagrams that proved to be unsuccessful were rejected, so their authors Teller and S. Ulam were deeply pessimistic.

In January 1950 President Truman decided to boost work to create a hydrogen bomb owing to the successful Soviet test of an atom bomb in December 1949.

During that period at Los Alamos, where thermonuclear weaponry was being developed, it was proposed that a deuterium-tritium mixture be used for thermonuclear combustion inside an "incinerator"—a fission bomb. This design is essentially an intensified atom bomb in which the TNT equivalent has been increased. The idea was confirmed in 1951 tests conducted under the code name Greenhouse in the George explosion.

The year 1951 was a period of enlightenment for the creators of American thermonuclear weaponry. In February Ulam and Teller expressed a number of basic ideas that significantly accelerated the process of developing thermonuclear weaponry.[3] After a month they proposed using a "fission-synthesis-fission" scheme to amplify the power generation effect. The tests Mike (1952) and Bravo (1954) confirmed the correctness of the chosen approach.

Our first hydrogen bomb was tested on 12 August 1953 at the Semipalatinsk proving ground. The tests confirmed the anticipated characteristics of the "product" and determined the effect of the explosion on various military technology and structures. Sakharov's fundamental idea was implemented in the bomb's design, which is why he is termed the "father of the hydrogen bomb."

Analyzing the consequences of the results of our first test, H. Bethe noted that it was not a true hydrogen bomb since high thermonuclear fuel combustion indicators were not achieved in it. Yes, in fact, we exploded a "real" hydrogen bomb later in 1955. However, unlike Mike, which weighed 65 tons, our 1953 bomb was not a structure but was instead transportable on an aircraft. It was precisely at that time that S. P. Korolev's design office began work to create a carrier rocket for it. Afterward, thermonuclear devices were made significantly lighter, and the carrier rocket developed by Korolev's office served as the basis for launching the first man into space.

After receiving heated congratulations on account of the successful test, being selected as an academician, and receiving the titles of Hero of Socialist Labor and State Prize Laureate, Andrey Dmitriyevich again immersed himself in his work on the thermonuclear problem. Not all of the plans made at the end of 1953 and beginning of 1954 were realized. In early spring 1954 in conversations with Zeldovich, the idea that Ulam and Teller came upon in 1951 was born. Possibly, it should not be surprising that scholars—even those completely deprived of mutual information—think identically. Scientific research has its own internal logic of development, and with such a concentration of the efforts of the best minds in both countries, the course of developments could not but proceed more or less in parallel.

I recall how Andrey Dmitriyevich gathered the young associates in his tiny room (at the time my length of time on the job—almost 6 years—was more than that of the others present) and began talking about the amazing ability of materials with a high atomic number to be an excellent reflector of high-intensity, short-pulse radiation. Without numerical calculations and with only a surprisingly simple diagram of the phenomenon based solely on similarity considerations, he was able to derive a qualitative result that reflected the physical aspect of the problem precisely enough. He told it all very laconically, and I, who had become accustomed to his style of narration, frequently had to explain his ideas to those present. He could explain the most complicated problems on a small piece of paper. Where and when he could think of all of this was beyond me. In addition to everything else, he tried to embody his thoughts into a specific design—discussing production problems at the plant in a qualified manner and staging measurements with the experimenters and computation schemes with the mathematicians. He combined breadth of knowledge with a nonstandard approach. I think I have never met another such universal scholar.

Preparation of the "real" hydrogen bomb for testing went surprisingly quickly. All of the scientific, engineering, and production tasks were solved a year and a half after the birth of the basic idea expressed by Zeldovich and Sakharov. Participating in this service were not only the research leaders but also a strong, experienced collective of young and very energetic scholars and engineers. The time has come for a detailed historical analysis on the theme of their role in creating a "nuclear shield." There were no second-degree tasks in the project. I remember heatedly discussing the problem of how to paint the aircraft so that the bomb, which was dropped on a huge parachute, would not burn it. There were a great many such problems, and they were solved quickly and in a qualified manner.

On 22 November 1955 a stage in the development of the foundations of thermonuclear weaponry had culminated with the successful test of a hydrogen bomb. Many of those participating in this work received high awards. Sakharov was awarded a second Hero of Socialist Labor star and, together with Kurchatov, Khariton, and Zeldovich, was given the recently re-established Lenin Prize. They were awarded prize numbers 1 through 4 in the laureate order. Andrey Dmitriyevich received a third hero's star for testing a superpower hydrogen bomb in 1962 at the Novaya Zemlya proving ground.

Thus, after taking somewhat different paths and after failures and successes, the United States and USSR arrived at the modern nuclear weaponry profile at approximately the same time (1954 and 1955). Further development proceeded along the path of modification and specialization.

The story of Andrey Dmitriyevich during the period of the hydrogen bomb's creation would be incomplete and inexact without mention of two fundamental proposals that he made at the beginning of the fifties. The first (1950) concerns a device for commercial use of thermonuclear power that in those years was called a magnetic thermonuclear reactor and is now called a tokamak.[4] Sakharov's fundamental role in formulating the problem of peaceful thermonuclear synthesis is undisputed; in those years, however, the disgrace of his priority in this matter was persistently hushed up.

Another proposal (1952) was literally born before my eyes. The point is that, when work on "layering" was nearing an end in 1951, I shared my concern over what we would work on next with Andrey Dmitriyevich. Literally the next day he told me of the idea of magnetic cumulation, which he had just thought of. It was particularly promising for producing ultrastrong fields. My fears of looming "unemployment" turned out to be for naught. And yes, the problem, which was sent to the institute to solve in 2 to 3 years, turned out to be much more extensive and required decades.

Footnotes

1. For greater detail, see Ritus, V. I., "Who Else If not I?" in this issue.

2. Rhodes, R., "Making of the Atomic Bomb," London, 1986; Hansen, Ch., "Nuclear Weapons: The History," New York, 1988.

3. The essence of these ideas is presented in the book Rhodes, R., Op. cit.; Hansen, Ch., Op. cit.

4. See Golovin, I. N., and Shafranov, V. D., "At the Sources of Controlled Nuclear Fusion," in this issue.

5. See Pavlovskiy, A. I., "Magnetic Cumulation" in this issue.

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From Reminiscences of Yu. A. Romanov

917F0007F Moscow PRIRODA in Russian No 8, Aug 90 p 24

[Article by Yu. A. Romanov]

[Text] In 1955 I was sent to work at a newly created institute where I headed a large collective of theoreticians. The many hundreds of kilometers separating us from Andrey Dmitriyevich did not hinder our friendly relations, and we always remained on familiar terms with one another.

I always loved being with his hospitable family, and both he himself and his wife Klava had a very modest life-style and did not feel the need to dress beautifully or expensively even though their income had been more than adequate since 1950. Sakharov gave his unspent resources (amounting to hundreds of thousands) to charity. He was unflinchingly severe in the face of all manifestations of dishonesty and dishonorable conduct although he was a delicate and soft-natured man who could not, as they say, even hurt a fly.

I remember such an episode. Andrey Dmitriyevich's family often went to Moscow, and he remained alone in the cottage. Immersed in his own scientific problems, he worried little about order in the house. Mice were running around the kitchen. His neighbors suggested calling the appropriate service to destroy the rodents. "Not on your life," responded Andrey Dmitriyevich, and he began leaving little pieces of bread and cheese especially for them.

Yet another comical incident occurred in summer 1950. Andrey Dmitriyevich, Valentin Nikolayevich, and I got lost in the forest surrounding the city on a Sunday. Unfortunately we came to close to the fence guarded by soldiers. "Stop or I'll shoot," we heard. We stopped. "Who are you—are you prisoners or are you free?" The problem was that there were many "prison camp detainees" [zeki] in the town. A truck arrived. "Sit on the floor," we heard the corporal's voice. The three of us, who at the time were rather thin fellows in sports clothes that were not exactly fresh, shook in the truck as it went over the hummocks of the dirt road, rested with our palms against the floor to ease the pain of sitting that way. We arrived at the military barracks. "Get out and stand against the wall!," the order rang out. And then they led us into a large room where a very simple commission of state security associates had already been convened for the case. It was certain they knew who we were, but after assuming a serious pose, they asked each of us for his first and last name, patronymic, birthplace, and place of work. They then told us that we must not violate the walking rules and left.

I must admit that in those years the state security organs took good care of the scientific associates. Because of the danger to their health and life and also because they were responsible for the "safekeeping" of secret thoughts, they let few of us out for a furlough, even for a trip to the "open country," and they compensated those who did not leave in the amount of a month's wages. In the country's difficult postwar years they created all of the conditions scholars needed for productive work in the name of guaranteeing the safety of our Motherland.

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At Sources of Thermonuclear Fusion

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[Article by I. N. Golovin, doctor of physical and mathematical sciences, and V. D. Shafranov, corresponding member USSR Academy of Sciences, Atomic Energy Institute imeni I. V. Kurchatov, Moscow]

[Text] On 25 April 1956, while visiting England as part of a Soviet state delegation, academician I. V. Kurchatov presented a lecture entitled "The Possibility of Creating Thermonuclear Reactions in a Gas Discharge" at the English atomic center at Harwell.

Thermonuclear synthesis reactions had previously been implemented in the first hydrogen bombs (first in the enormous device Mike by the Americans at the end of 1952 and then in transportable products on 12 August 1952 in the USSR and in March 1954 in the United States). Triggering thermonuclear fuel in bombs, i.e., heating it to hundreds of millions of degrees, had been done by exploding an atomic bomb. In his Harwell lecture Kurchatov spoke of creating a controlled, i.e., relatively slowly occurring, thermonuclear reaction in a very small quantity (a fraction of a gram) of "heavy" hydrogen, i.e., deuterium.

Heating and thermonuclear "combustion" with continuous replacement of the burned-up fuel by fresh fuel requires keeping the nuclei of hydrogen atoms moving at a speed of thousands of kilometers per second from colliding with the walls. "One of the ideas that arose in connection with the problem," stated Kurchatov in his lecture, "was to use a magnetic field for thermal insulation of the plasma. Academicians Sakharov and Tamm first pointed this out in 1950." And so the worldwide community first heard the name Andrey Dmitriyevich Sakharov. Igor Yevgenyevich Tamm (a corresponding member of the USSR Academy of Sciences in 1950) was already a well-known physicist for his work in the field of solid-state physics, nuclear forces, elementary particles, the theory of Cherenkov radiation, and the now classic higher educational institution text "Teoriya elektrichestva" [Theory of Electricity]. As far as Sakharov was concerned, he was then known only in a narrow circle of physicists. However, after having noticed that Sakharov was selected as an academician simultaneously with Tamm at the end of October 1953, thus bypassing the title of corresponding member at the age of 32 years, and after having compared this selection with the communication regarding the testing of thermonuclear weaponry in the USSR, "observant readers" would have been able to guess that it was this new bright talent—one of the main creators of thermonuclear weaponry and now the author of the idea of magnetic thermal insulation of plasma—who was being discussed.

Thirty-four years passed after Kurchatov's speech at Harwell. Solving the problem of controlled thermonuclear synthesis did not turn out to be simple. During that time, an extensive international collaboration was established in the field, which was considered among the most secret. A strong direction in science developed, i.e., plasma physics and the problem of controlled thermonuclear synthesis. Many versions of magnetic thermal insulation of plasma were tested: pinch systems, self-compressed charges (which Kurchatov mentioned at Harwell), open magnetic traps with magnetic probes, stellator systems of American origin, and other systems. And what was the result? The tokamak, the key components of which were a toroidal magnetic field and a toroidal electric current induced in plasma, became the main direction in research on the problem of controlled thermonuclear synthesis through the entire world. Sakharov proposed it in 1950. The Soviet physicists' breakthrough in this direction (heating plasma to a temperature of 1 keV, i.e., 10 million degrees, and observing neutrons with a clearly thermonuclear origin) occurred abroad in the sixties and seventies, i.e., 20 years after the idea was born. Another two decades passed before deuterium plasma would be produced at the very large JET (Joint European Torus) tokamak. The new plasma would have a temperature of 300 million degrees and a containment quality such that if a mixture of deuterium and tritium was used instead of deuterium (tests with tritium were still not being conducted on account of its radioactivity), the power released in the synthesis reactions would turn out to be greater than that going to heat the plasma. Very similar results were obtained at the American TFTR tokamak. A great landmark on the path toward realizing Sakharov's idea of a magnetic thermonuclear reactor had thus been passed. The development of an international thermonuclear research reactor based on the tokamak concept, the ITER, is now underway in a joint effort of scholars from Western Europe, the USSR, the United States, Japan, and Garching (FRG). Such are the present scales and results of the activity initiated 40 years ago by the then-30-year-old Andrey Dmitriyevich Sakharov.

Birth of the Controlled Thermonuclear Synthesis Program

In 1948 Sakharov, a young associate at the theoretical physics department of the USSR Academy of Sciences' Physics Institute imeni P. N. Lebedev who had recently defended his candidate's dissertation, participated in work to create thermonuclear weaponry together with his director Tamm. In the eyes of those around him, he was already a mature scholar with a distinguished bright mind, deep understanding of the laws of physics, and superior creative activity. It was known that while still working at the military plant during the war he completed two small theoretical works (that later delighted Tamm with the originality of their solving physics problems) and simultaneously showed the rare combination of theoretical and concrete engineering thinking that developed a number of inventions in the field of production control.

There is still no information that thermonuclear weaponry was being developed anywhere. But the popular

American journals were toying with the possibility of creating a "superbomb," but many years ago, Igor Yevgenyevich who, together with pupils had developed the theory of intranuclear forces, knew well that synthesizing helium nuclei from the nuclei of hydrogen-deuteron (d) and triton (t) isotopes would lead to a release of energy that, per unit mass, was fivefold that occurring during the fission of uranium. It was apparently impossible to increase the force of a uranium bomb's explosion many times over, but would it not be possible to use its explosion to induce detonation in a mixture of deuterium and tritium? To answer this question the theoretician again had to become an inventor. Young Sakharov was distinguished by a singular store of brains. Easily mastering the most complex problems of theoretical physics, he thought very concretely, and on the basis of the general ideas expressed in the collective of theoreticians headed by Tamm, he was soon giving so distinct a model of the hydrogen bomb that after comprehensive calculations of the reaction speed, radiation intensity, and the dispersion of its parts, he would be able to propose its development to the designers. Sakharov's model received approval, and in 1949 he and Tamm were ordered to a secret design office headed by Yu. B. Khariton. Once there, he gave all of his efforts to developing weaponry with youthful enthusiasm, certain of the fact that the military superiority of the United States over the Soviet Union represented a threat to peace on earth.

From time to time inventions are sent to scientific centers for a response—most often, the more significant the goal, the more naive the invention. After the appearance in the United States of publications about the possibility of creating a hydrogen bomb, there were proposals on that theme. One proposal, written in the summer of 1950, was sent to the CPSU Central Committee from 24-year-old O. A. Lavrentyev,[1] who was completing military service at Sakhalin. Naturally it wound up in Tamm's department. The young sergeant with his tenth class education proposed creating conditions for thermonuclear reactions by analogy with those reactions occurring in the Sun, replacing the gravity forces keeping solar matter scattering with electrical forces. The positive and negative potentials fed to the grid system should be keep the electrons and positively charged hydrogen nuclei from scattering.

The proposal was by no means naive! Sakharov was delighted with the formulation of the problem by a young man with no special education, but he saw that the idea was not realizable. The intensity of the field between the grids had to be improbably high (more than 10^6 V/cm), and the grids would inevitably be bombarded with high-energy particles and destroyed. Sakharov thought about the problem. Should not wires be shielded by passing an electric current along them? In fact, the magnetic field of a current might protect the wires from "bombardment" by the plasma particles, but it is not uniform (it increases nearer to the wire). Because of this, charged particles will drift along the direction of the current, settle on the vacuum chamber's walls at those places where the wires pass through them, and as a result give up their energy to the walls. The desired thermal insulation is not produced....

But Lavrentyev's letter made us think more and more about other possible ways of implementing a thermonuclear reaction. Indeed one could be used for more than producing power—a thermonuclear reactor could also be used to produce weaponry. In fact, when the deuterium nuclei merge in the reactor, tritium would be formed, and it is needed for a thermonuclear bomb. In addition, by irradiating thorium with neutrons from a dd-reaction it would be possible to produce ^{233}U, which like ^{235}U, is suitable for an atomic bomb. At the time there were only a few nuclear reactors in which tritium and fissioning material were produced. And a thermonuclear reactor—if one could be implemented successfully—would soon solve the problem of charges for both atomic and thermonuclear bombs. It is therefore not surprising that these matters were discussed with excitement in I. Ye. Tamm's collective and were presented to Ya. B. Zeldovich and Yu. B. Khariton for judgment.

Sakharov understood that this bit of ingenuity would make practical sense only if the thermonuclear reaction could be made to be self-sustaining. Above all, this required good thermal insulation of the plasma (which must at an amazingly high temperature) from the walls. Could not a magnetic field be used for the insulation? In fact, in a homogeneous magnetic field a charged particle will move in a spiral and "wind itself" around one and the same tube of magnetic force lines. Transfer from one tube to another can only occur as a result of particles colliding and scattering against each other. The required high-temperature plasma could be created by ionizing deuterium gas and then heating it with high-frequency radiation directly in this magnetic field—inside the chamber, which is surrounded by turns with a current.

Andrey Dmitriyevich discussed his ideas with Tamm. The idea easily generated the principle of restricting the motion of the charges in the direction transverse to the magnetic force lines. In fact, what physicist did not know of the circular orbit of an accelerated particle beam in a cyclotron and other cyclic accelerators. Only now the magnetic field had to be created not along one orbit but throughout the entire volume of plasma. The radii of curvature of the particles' trajectory should be the minimum possible (fractions of a centimeter for nuclei and tenths to hundredths of a millimeter for electrons); this would mean the maximum possible magnetic field. To eliminate plasma losses in the longitudinal direction, it seemed natural to make the chamber (and the magnetic field within it) toroidal.

Intensive theoretical work began. Tamm solved the kinetic equations for plasma in a magnetic field and derived the expressions for the fluxes of heat and particles from high-temperature plasma that were needed to design a magnetic thermonuclear reactor. The role of boundary plasma in which "cold" neutral atoms appear owing to recombination of charged particles at the chamber wall was investigated. The great danger of "toroidal drift" of the charged particles, i.e., their continuous shifting in the direction perpendicular to the plane of the torus as a result of the fundamental heterogeneity of a toroidal magnetic field, was realized. Sakharov found possible methods of compensating for this drift (while using the term "drift stabilization"), namely, giving the magnetic force lines a helical form by suspending a ring with a current in the torus or by inducing an axial (toroidal) current in the plasma itself. It was this second method that lay at the basis of the tokamak. Several years later G. I. Budker proposed another method of eliminating longitudinal losses, i.e., not twisting the chamber into a torus but creating an intensified magnetic field at its ends (by opening a trap with magnetic probes, i.e., a "magnetic bottle" [probkotron]). Both these systems were developed. But the fundamental realizability of a controlled thermonuclear reactor with magnetic plasma containment still had to be assessed.

Together with Tamm, Andrey Dmitriyevich made the first calculations of the parameters of "small" and "large" models of a thermonuclear reactor by ignoring the effects of curvature of the torus and without an axial current. In the small model reactions could proceed only with a continuous expenditure of energy. The "large" model was already designed for self-sustainment of the thermonuclear reaction. The calculations showed that for a thermonuclear reaction with an intensity of practical interest, the plasma temperature would have to be above 32 keV (350 million degrees), and it would have to have a density of 10^{14} cm^{-3}. Below 32 keV, no thermal insulation would help since the bremsstrahlung of the electrons would be more intensive that the energy release due to synthesis of the nuclei. If the magnetic field is given a magnitude of 50 kG (Sakharov estimated that copper windings and their cooling could be implemented to produce such a field), then self-sustainment, i.e., burning, would occur if a rather large chamber radius were used—at least 2 m. The heat flux to the chamber walls under these conditions is 10^{14} (!) times smaller that it would be in the absence of a magnetic field. It is possible that people working on another problem would find this figure unsettling and would be paralyzed from further analysis. But the task of the collective at the design office in which Sakharov was working was to create thermonuclear weaponry thousands of times more powerful than the atom bomb, which also boggles the mind. Sakharov therefore spoke about this quantity of 10^{14} times as calmly as he would about a conventional quantity and continued the analysis.

Upon returning home to Moscow for a short rest, Sakharov and Tamm discussed the problems that had come up with their colleagues at the Physics Institute imeni P. N. Lebedev—V. L. Ginzburg, S. Z. Belenkiy, and Ye. S. Fradkin.

Tamm estimated the deterioration of thermal insulation in a toroidal magnetic field with a current flowing along

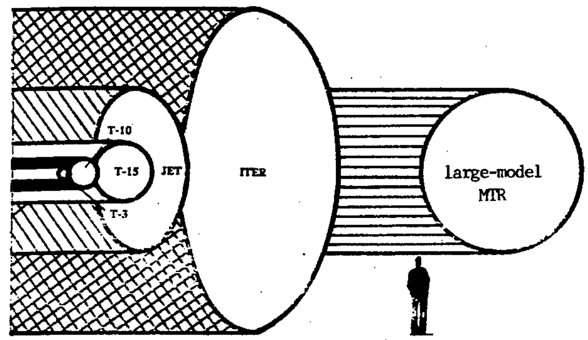

Figure 1. Comparative Dimensions of the Plasma in Tokamaks and Models of Magnetic Thermonuclear Reactors [MTR] With dd-Reactions

the plasma versus in the case of the cylindrical reactor model for which the calculations had been made. The possible deterioration did not seem catastrophic. After 17 years, the corresponding detailed calculations of A. A. Galeyev and R. Z. Sagdeyev lead to new ideas in physical kinetics—the "neoclassical" theory of transfers in high-temperature plasma of toroidal form.

Also examined were the problems of initial energy losses from the plasma initially because of "cold" atoms from the walls ending up in the plasma but then being transformed (as a result of recharging) into high-energy atoms vacating the plasma unimpeded. In near-wall plasma these problems have become one of the main problems in dozens of years of developing a reactor design.

The problem of the plasma's stability became increasingly worrisome. Would not hot plasma be carried outward by convective fluxes like hot air rises in the earth's atmosphere? Would not wave processes intensifying the heat transfer arise in the plasma?

The volume of works snowballed, but no one took solving the main problem—creating thermonuclear weaponry as quickly as possible—off of Sakharov's and Tamm's shoulders. Stalin was impatient. Then B. L. Vannik, head of the First Main Administration of the USSR Council of Ministers, proposed involving Kurchatov's associates at his institute (then called the USSR Academy of Sciences Measurement Instruments Laboratory), who had finished solving the physics problems involved in electromagnetic separation of uranium and lithium isotopes, in solving the problem of controlled thermonuclear synthesis.

Before approaching the government with his proposal for development of a new problem, Kurchatov decided to try it out with those who were authorities in the field of physics. In that context a conference that included I. Ye. Tamm, A. D. Sakharov, Yu. B. Khariton, Ya. B. Zeldovich, I. N. Golovin, L. A. Artsimovich, N. N. Bogolyubov, and M. G. Meshcheryakov was held in January 1951. The ideal of magnetic thermal insulation received general approval at the conference. In February Kurchatov prepared a draft of his proposal to the government and sent it and a letter to Berea for Stalin's signature. March passed, and it was uncertain how long he would have had to wait for Stalin's signature if the president of Argentina J. Peron had not announced that the German physicist R. Richter implemented controlled thermonuclear synthesis in a laboratory on Lake Khyuemel [transliteration] on 16 February 1951. The error of this statement became clear later. At the time, however, Peron's announcement forced our government to make a decision (indeed, "no man is a prophet in his own country"). In mid-April the draft proposal was discussed in Berea's office. It was decided to designate L. A. Artsimovich director of the magnetic thermonuclear reactor experimental program and M. A. Leontovich director of theoretical research. On 5 May 1951, after Stalin signed it, the CPSU Central Committee and USSR Council of Ministers issued a decree regarding organizing work on controlled thermonuclear synthesis. So began our country's research on controlled thermonuclear synthesis.

At first Sakharov periodically visited the USSR Academy of Sciences Measurement Instruments Laboratory—each time with a new idea on formulating the experiments. One time his idea was to use a copper sheathing to maintain the current in equilibrium. Another time his idea was to base the reactor on a mixture of deuterium and tritium, in which case a reaction would be stimulated much more easily than with deuterium alone. Once he arrived with a detailed report about the work that D. N. Zubarev and V. N. Klimov were doing on the interaction of thermonuclear plasma with the walls of a vacuum chamber under his direction. As the time of hydrogen bomb tests drew nearer, his appearances at the USSR Academy of Sciences Measurement Instruments Laboratory became increasingly rarer.

It should be added that at that time research in pinch discharges had begun in England and the United States under condition of total secrecy. The communication of Richter's apparent success stimulated L. Spitzer, the astrophysics professor from Princeton, to invent the stellarator—a toroidal magnetic system with compensation for the toroidal drift of charges without excitation of a current in the plasma. Somewhat later in the Livermore laboratory G. York and R. Post proposed using open magnetic systems with "magnetic mirrors" (the analogue of Budker's "magnetic bottle") to contain the plasma.

After many years of rivalry among the various systems with magnetic containment (which have been open for discussion since 1958), the tokamak—a toroidal system based on Sakharov's ideas—took first place. The group of I. N. Golovin and N. A. Yavlinskiy at the Institute of Atomic Energy imeni I. V. Kurchatov worked on its development during the initial years. Later, research in this field was directed by L. A. Artsimovich.

From the Magnetic Thermonuclear Reactor to the ITER

Tamm's and Sakharov's basic research on controlled thermonuclear synthesis entitled "Teoriya magnitnogo termoyadernogo reaktora" [Theory of Magnetic Thermonuclear Reactor] was formulated in 1951 in the form of a report and published in 1958. They opened the four-volume "Fizika plazmy i problema upravlyayemykh termoyadernykh reaktsiy" [Plasma Physics and Problem of Controlled Thermonuclear Reactions] edited by the academician M. A. Leontovich, which was prepared for the Second Geneva Conference on the Peaceful Use of Atomic Energy, where the wide-scale exchange of information on the controlled thermonuclear synthesis programs of the USSR, United States, and England occurred for the first time. Even now, after the passage of four decades of very extensive research in this field by a huge army of physicists, there is great praise for the high scientific level of the first theoretical works. Not only did they formulate the fundamental ides and make the first computations, but they also enumerated the basic problems on which thermonuclear physicists worked for many years thereafter.

The first and third parts of "Teoriya magnitnogo termoyadernogo reaktora" belong to Tamm. In them Igor Yevgenyevich examines mainly the fundamental problems of the theory of plasma containing a magnetic field and estimates (in Part 1) the parameters of the small model of the magnetic thermonuclear reactor (with a low plasma density).

The following excerpt from the short introduction to Part 2 of "Teoriya magnitnogo termoyadernogo reaktora," which was written by Sakharov, gives an idea of its content:

"The work of I. Ye. Tamm [Part 1] discusses the properties of high-temperature plasma in a magnetic field that give hope of the possibility of implementing a magnetic thermonuclear reactor. The following is a discussion of other aspects of the theory of a magnetic thermonuclear reactor, namely:

1. Thermonuclear reactions. Bremsstrahlung. 2. Calculating a large model. Critical radius. Boundary phenomena. 3. Power of Magnetization. Optimal Design. Productivity with respect to active matter. 4. Drift in a heterogeneous magnetic field. Suspended current. Induction stabilization. 5. Problem of plasma instability."

Let us mention the results of this work that are most interesting from today's perspective. The parameters of the "large model" of the reactor are impressive. The torus had a major radius of 12 m, the plasma had a radius of 2 m, and the magnetic field had an intensity of 50,000 G. In deuterium plasma with a temperature of 100 keV (1.1 billion degrees), 150 g deuterium should burn in a day. As the author writes, "one can plan on producing about 100 g of tritium a day and 80 times more ^{233}U." The latter part of the sentence relates to Sakharov's idea of producing nuclear fuel (including for nuclear power plants) as the first stage of using magnetic thermonuclear reactors. It would subsequently be produced in the "hybrid reactor" programs, on which, specifically, China and a number of other countries were focusing a great deal of attention.

Serious attention is being paid to the phenomena close to the wall. Sakharov shows how the flux of heat transferred from the plasma to the wall permits a "temperature jump" at the wall (a phenomenon involving a cold wall and hot near-wall plasma that was discovered by Tamm) of 100,000 degrees, which is not dangerous for the wall.

In Section 4, besides discussing a method of compensating for (stabilizing) drifts occurring on account of the inhomogeneity of the toroidal magnetic field by using a suspended ring with a current, Sakharov thus formulates the idea lying at the basis of the tokamak:

"Another method of antidrift stabilization that is, from an engineering standpoint, incomparably more suitable and that therefore requires further study is the creation of an axial current directly in the plasma by using the induction method. In this method, it is not clear whether or not high-temperature plasma is destroyed at the moment when the induction current vanishes."

Sakharov himself never worked on developing his ideas in the field of controlled thermonuclear synthesis. Development of research in the USSR initially proceeded along the line of pinches (since an axial electric current is required in a torus, it was decided to reject an internal longitudinal magnetic field altogether and look to the the magnetic field of this current to bear the entire role of containing the plasma). Different versions of magnetic plasma containment, including open traps with probes, high-frequency containment, etc., were thought of and subjected to experimental testing. The scourge of all the research was the instabilities of the plasma and the anomalously high (compared with the calculated values) losses of heat and particles. These same problems accompanied the tests on exciting a current in plasma located in a toroidal magnetic field. Gradually, however, after recognizing the importance of special preparation of the discharge chamber and correction of the transverse (to the plane of the torus) magnetic field that kept the plasma torus with a current from spreading out and touching the walls, an optimal technology for producing macroscopically stable plasma with a suitable level of anomalous heat and particle losses was developed. The switch in the seventies of most world research in the field of controlled thermonuclear synthesis to tokamaks helped them reach a level permitting the presently well-founded development of an experimental tokamak reactor.

In the 40 years since the birth of the idea of a magnetic thermonuclear reactor, ideas about using a magnetic field to contain plasma and the concept of a thermonuclear reactor have undergone a number of changes.

Closing the system into a torus with an allowance for the constraints imposed by plasma stability criteria resulted in a reduction in the allowable radio of plasma pressure to the pressure of the external magnetic field. While it was close to unity in Sakharov's model, it is an order of magnitude lower in existing tokamaks.

In toroidal plasma, both the theoretical and (even more so) the actual heat conduction and plasma diffusion coefficients turned out to significantly higher than in Sakharov's model.

Ideas about the exit of a flux of heat to the chamber walls also changed. The concept of energy release to the chamber elements—not across but rather along the magnetic force lines—was confirmed. For this purpose, a region from which the magnetic force lines (and along with them, the heat flux leaving the central plasma) end up in special receiving plates was created between the primary plasma and chamber wall. The temperature in this region turned out to be significantly higher than in the near-wall plasma of Sakharov's model (because the density of the near-wall plasma, which in the case of the specified heat flow singularly determines the temperature of the near wall plasma, is much lower than in Sakharov's classic model). To reduce the energy of the particles bombarding the plate to a safe level conditions are created (by using a "cushion" of neutral gas) for strong "recycling" of the particles (upon reaching the wall, a charged particle returns to the plasma after recombination in the form of a neutral particle and is ionized there; this process is repeated many times, and as a result the energy of the "hot" particles is transferred to the plates in small portions).

There was a complete switch from deuterium as fuel for the reactor to a mixture with an equal amount of tritium. It was proposed that tritium produced in fission reactors be used to start up the reactor and that it then be recovered in the lithium-containing "blanket" surrounding the thermonuclear reactor. Using a deuterium-tritium (DT) mixture with a temperature an order of magnitude below the thermonuclear reactor's "ignition" temperature simultaneously eliminates the problem of additional energy losses to cyclotron radiation. Because of the plasma's lower temperature, despite the increase in actual heat transfer compared with that assumed in the "large model," the resultant DT reactor is close to an idealized DD reactor from an overall dimensions standpoint (for example, in the ITER plan the volume of plasma is approximately the same as in Sakharov's large model).

The problem of the inevitable vanishing of the induction current, resulting in a loss of the plasma's thermal insulation, that worried Andrey Dmitriyevich was fundamentally solved. Experience in the long-term sustainment of current in a tokamak by a current of high-frequency radiation has already been accrued. When Andrey Dmitriyevich was invited to a seminar at the Atomic Energy Institute in 1988 and acquainted with the status of works on controlled thermonuclear synthesis, he (in his characteristic unhurried manner) said with satisfaction, "And I was totally unaware of this success in creating current by the mechanical effect of high-frequency waves on electrons."

The problem of the radiation safety of a thermonuclear reactor acquired new understanding. In 1950-1951 it was stated that, in and of themselves, thermonuclear reactors give off insignificant radioactivity. In the seventies, however, attention was focused on the inevitability of neutron-induced radioactivity in construction materials. Although the biological danger of a thermonuclear reactor is, according to calculations, two orders of magnitude less than that of a fission reactor, the possibility of a "low-radioactivity," almost completely safe reactor using a mixture of deuterium with ^{3}He as its fuel is now being investigated alongside the development of a "neutron-rich" DT reactor. Tamm and Sakharov did not consider this possibility because of an absence of reserves of ^{3}He on earth. But thanks to the development of space research the idea of getting it from the moon, where large reserves of this isotope have been detected,[2] no longer seems so fantastic. Thus, in the future thermonuclear power generation has the possibility of becoming an ecologically clean and practically completely safe type of power generation.

Scientific-technical progress in the field of superconductivity and computer technology are of fundamental importance in solving the problem of controlled thermonuclear synthesis. Progress in the area of engineering superconductivity has eliminated the problem of expending great power to sustain a magnetic field ("magnetization power" to use Sakharov's term, which in his large model constitutes half the power released in thermonuclear reactions). Four tokamaks with superconducting magnets (in the USSR, France, and Japan) are already being tested. The ITER plan is also geared toward using superconducting coils to create a magnetic field.

The development of the physics of high-temperature plasma—a multiparametric object with many degrees of freedom—would have been impossible without the use of numerical modeling methods. Already in the first works of Tamm and Sakharov, the solution of differential equations describing heat transfer in which the coefficients themselves depend on the temperature distributions, plasma density, and magnetic fields that are being solved for, required numerical calculations. At the time they were done by laboratory assistants on desk calculators. Modern computers not only make it possible to perform calculations of the global parameters of a system and service an experiment, but they also make it possible to model the extremely complex internal dynamics of plasma.

It is thus as if the general trend in the development of science were specially coordinated with the needs of the problem of controlled thermonuclear synthesis and is helping to solve the complex and very important scientific-technical problem initiated by Sakharov's ideas. In this coordination one can also see a confirmation of the timeliness of the path slated 40 years earlier and the realizability of its end goal.

Research on controlled thermonuclear synthesis, even when it was conducted under conditions of the strictest secrecy, developed in parallel and virtually simultaneously in a number of countries. Nevertheless, the pioneering works of Sakharov and Tamm played a great role in the development of this problem not only in the USSR but throughout the entire world.

The high level of these works largely determined the scope of the controlled thermonuclear synthesis research of Kurchatov, who believed in Sakharov's genius. As far as current worldwide achievements in the field of controlled thermonuclear synthesis is concerned, there too one can see the merit of Andrey Dmitriyevich. Specifically, the systematic development in the fifties and sixties at the Institute of Atomic Energy of the Sakharov system that was christened in 1957 with Golovin's and Yavllinskiy's "tokamak" led to a complete break in world research on controlled thermonuclear synthesis abroad in the sixties and seventies. It resulted in the achievement of plasma parameters that made it possible to develop an experimental thermonuclear reactor based on the tokamak. Regardless of the paths that further development of controlled thermonuclear synthesis take, tokamaks have undoubtedly already played a great role. They demonstrated that stellar matter to implement controlled thermonuclear reactions may be created on earth and have made it certain that thermonuclear power generation is within mankind's powers.

Andrey Dmitriyevich won the glory of an outstanding scholar, above all, for his works in creating thermonuclear weaponry. In the world development of mankind, this aspect of his activity may in the future turn out to be only an episode. Then he will remain in the memory of his noble descendants not as the creator of weaponry of terrifying force but as the founder of the power generation of the future, a power generation that is ecologically clean and adequate for a new human society based on Reason and Humanism, for the ideals of which he fought selflessly and for which he gave up all his remaining efforts.

Footnotes

1. Lavrentyev soon entered Moscow State University, and after completing it worked at the Physics Engineering Institute of the UkSSR Academy of Sciences in the field of controlled thermonuclear synthesis.

2. For more detail, see Kulchinskiy, J., and Shmitt, Kh., "Thermonuclear Fuel...From Moon," PRIRODA, No 1, 1990, pp 62-68.

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From Memoirs of I. N. Golovin

917F0007H Moscow PRIRODA in Russian No 8, Aug 90 p 29

[Boxed article by I. N. Golovin]

[Text] B. L. Vannikov entrusted the job of organizing the involvement of the USSR Academy of Sciences Measurement Instruments Laboratory in solving the problem of controlled thermonuclear reactions to N. I. Pavlov, who was then head of the First Main Administration and who directed the work of the design office in which Tamm and Sakharov were working. Kurchatov himself, who was involved in work on the hydrogen bomb, spend a great deal of time on out-of-town assignments, leaving Moscow for a week or sometimes for months. Therefore Pavlov called me to his office as first deputy to Kurchatov at the time.

"Igor Nikolayevich! Come to me after you have met with your dear teacher Igor Yevgenyevich and with Andrey. They will tell you about something remarkable."

"I was always glad to meet with Igor Yevgenyevich. But who was this Andrey?"

"You don't know Andrey? He is Sakharov. He is a pupil of Tamm just like you. A remarkable young man. And he's a good fellow. A light head!," such was how the general director of the design office characterized young Sakharov.

The meeting took place on 22 October 1950 in Pavlov's office on Novo-Ryazanskaya Street in a building at the First Main Administration.

Sakharov slowly told of the results of his calculations with Tamm. Pavlov noted that Tamm and Sakharov should first solve their main problem and not spend more than a third of their time on this. And he recommended that I discuss the problem with the "electromagneticists," i.e., with the creators of electromagnetic units for separating isotopes, and formulate experiments to develop the ideas presented. I left, shaken by the boldness of the proposal in which plasma was so dissimilar to the conventional diffuse plasma of gas discharges.

After 10 days Kurchatov returned and I told him the exciting news. Igor Yevgenyevich quickly invited Tamm and Sakharov to his office, discussed their proposal in detail, and after agreeing with it promised his all-out support. That was also where, based on Tamm's proposal, the work was given the name "the MTR, i.e., magnetic thermonuclear reactor, problem." Considering its close connection with the hydrogen bomb, all papers on the MTR problem were classified as being of the highest secrecy: "top secret" and "special folder."

It was also there that Kurchatov demanded everything that had been written about the MTR problem up until that time. Tamm had already prepared a report that in 1958 was the first article in the four-volume "Fizika plazmy i problema upravlyayemykh termoyadernykh reaktsiy" [Plasma Physics and Problem of Controlled Thermonuclear Reactions]. Besides that, there were only two reports by V. L. Ginzburg devoted to analyzing the laws governing the plasma of a gas discharge in a magnetic field (an open publication in TRUDY FIAN [Works of the Physics Institute imeni P. N. Lebedev], Vol 18, 1962).

* * * *

In mid-April 1951, an excited D. V. Yefremov (at that time minister of the electrical engineering industry) tore into Kurchatov's office. He was holding a journal communicating sensational news: the German scholar Richter, who had emigrated to Argentina, produced a thermonuclear reaction with the emanation of neutrons in a gas discharge in deuterium!

Kurchatov quickly sent a letter about this to Berea, indicating the delay in the decree. The response was quick, and after several days Sakharov, Tamm, Pavlov, and I were called to Berea's Kremlin office for a meeting of the Special Committee, the supreme organ under Berea's chairmanship, which had been handling the problem of nuclear and thermonuclear weaponry. The members of the special committee—Kurchatov, Vannikov, Zavenyagin, Pervukhin, and others—were already in the office. Sakharov briefly related the essence of his proposal and noted that Tamm had made the basic calculations for a magnetic thermonuclear reactor. Tam was nervous and, asking for a word after Sakharov, began to explain excitedly that the main ideas belonged to Sakharov and that Sakharov deserved most of the credit. Impatiently waving his arm, Berea interrupted Tamm with the words "No one will forget Sakharov," and told him to sit down. When Kurchatov, who had begun to speak, added that he was requesting confirmation by the directors of the theoretical and experimental works (Leontovich and Artsimovich, respectively), General Meshik, who was sitting at the table to Berea's right, bent over to Berea and said to him in a theatrical whisper that Leontovich is known for his free though. Berea answered loudly, "You will see that he does no harm." Kurchatov also asked for confirmation of the creation of the Council on MTR under his direction and with Sakharov as his deputy.

On 5 May 1951 Stalin signed the decree. The problem of controlled thermonuclear synthesis had been given the status of one of the most important state problems.

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Principles of Assessing Radiation Hazard

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[Article by V. I. Korogodin, doctor of biological sciences, Joint Institute of Nuclear Research, Dubna]

[Text] In the last years of his life, A. D. Sakharov focused a great deal of attention on the problems of radiation safety. His clear convincing speeches against nuclear weapons tests and his attitude toward the Chernobyl accident are well known. No less well known is the citizen's position he took even 30 years ago when there was no nuclear power generation in the country and when there was no radiophobia. Even then Sakharov felt his responsibility before humanity, even then he began to fight for the halting of nuclear weapons tests, having turned to problems of quantitative estimation of the possible victims after test explosions.

The problems of radiation safety became the object of intense study at the end of the forties and beginning of the fifties in connection with the atomic bombing of Hiroshima and Nagasaki, the increase in the number and the expansion of the geography of nuclear weapons tests, and the development of nuclear technologies. The problem did not catch biologists and physicians unaware: research on radiation genetics and the radiation biology of animals that had already been going on for several decades permitted a keen formulation of the main aspects of radiation safety and mapping out of paths for its scientific development.[1]

Back in 1927 at the Fifth International Genetics Congress G. Meller (United States) informed the scientific community that ionizing radiations may induce genetic changes (mutations) in the fruit fly Drosophyla. It later became known that the mutagenic effect of ionizing radiations is universal—the frequency of gene and chromosome mutation increases as a result of irradiation in all living beings from microorganisms to man. The laws governing radiation mutagenesis became clear in the thirties: it was established that the frequency of new mutations increases in direct proportion to the irradiation dose. This means that the genetic effect of radiations has no threshold: no matter how small the dose and even if the frequency is low, some mutations or others must necessarily result, thus increasing the "mutation load" of the population of irradiated organisms. These mutations result in an increase in the mortality of the irradiated organisms' offspring (even the very long-range offspring) who "inherit" these mutations. The "doubling doses" (i.e., those doses that double the mutation frequency as compared with the "spontaneous background") have been determined for Drosophyla flies and mice, which have been studied the most in this respect.

According to the first calculations of the doubling dose for humans that were based on the results of studies in the fifties, this value varied over a wide range (from 3 to 150 rad), but the most well founded seemed to be a dose of 15 to 30 rad.[2] The doubling dose for a human being means that while in terms of the spontaneous radiation background about 70,000 of 1 million infants born on earth each year will have hereditary defects causing various illnesses, additional irradiation in a dose of 15 to 30 rad will increase the number of "genetically aggravated" offspring to between 120,000 and 140,000 per million, i.e., there will be a per-rad "increase" of 2,000-4,000 per million. Radiation mutagenesis is thus characterized as "having no threshold," i.e., the frequency of the occurrence of mutations per unit dose depends neither on the dose nor on the distribution of the radiation over time. Another peculiar fact is that genetic defects occurring in the reproductive cells of irradiated individuals necessarily appear in one form or another even in the most removed offspring, all the way to several tens of generations, so that the consequences of even one-time irradiation will be drawn out for hundreds and thousands of years.

By the mid-fifties it had become clear that some "no-threshold" effects of irradiation are noted not only among offspring but also among those organisms who were themselves irradiated. The occurrence of malignant tumors related to mutations in somatic cells have been observed in laboratory experiments on animals and even on people irradiated because of the specifics of their work or for therapeutic purposes. The no-threshold nature of the carcinogenic effect of radiation is due to the fact that a mutagenic effect lies at its foundation. But tumors occur only many years (up to 10 or more) following irradiation. This fact along with the large individual variations in organisms' sensitivity to this effect of radiations and the relatively low frequency of "x-ray induction" of tumors (approximately several cases per 100 persons at a dose of 100 to 200 rad) does not permit a reliable determination of any link between the incidence of cancer and irradiation dose, and all estimates made to date are approximate in nature.

Among the "no-threshold" effects, or to be more precise, those appearing at small doses (10 rad), is an increased sensitivity to stress effects and different types of diseases related to immune system impairments. Such effects of small doses have been the least studied—basically for two reasons. First, tests on animals require great inputs of labor, and their results are poorly extrapolated to humans. Second, observations of people who have received a small dose require large samples and well-formulated "control groups." In each individual case it is impossible to decide whether a reduced resistance to diseases in fact began before the irradiation or is due to some other factors. Estimates here are therefore the least reliable.

Such, in general terms, was the "scientific background" when A. D. Sakharov published his work "Radioactive Carbon of Nuclear Explosions and No-Threshold Biological Effects."[3] And although the author was far from being a radiobiologist, the principles he formulated in this work were exact and are still relevant today. What are these principles and what is their significance today?

During the explosion of all kinds of nuclear weaponry, including the so-called clean (fragmentless) hydrogen bomb, an enormous quantity of neutrons enter the atmosphere by being captured by the nitrogen in air in accordance with the following reaction:

$$n + N^{14} \rightarrow p + C^{14}$$

with the formation of the long-lived radioactive carbon isotope ^{14}C. Falling into the water basins and onto the tissue of living organisms, including the human organism, decaying radioactive carbon "causes radiation damage measured at a dose of 7.5×10^{-4} rad per megaton of explosion power." The isotope has an average lifetime of 5,570 years, and its effect can extend for about 8,000 years.

In estimating the possible consequences of such additional (when compared with the natural background) radiation, Sakharov used the idea of "the no-threshold biological effects of radiation," i.e., the frequency of mutation caused by difference anomalies in offspring, various malignant neoplasms (including leukemia), and impairments in immune reactions resulting in increased risk of the most diverse diseases and accelerated aging. According to Sakharov's calculations, possible death to people because of these effects amounts to 5×10^{-4} per rad. Testing a 1-megaton bomb would in turn cause the death of an additional 6,600 persons over the course of 8,000 years. As Sakharov emphasizes, this is a low estimate. In reality the number of victims might be much larger.

Without judging the precision of such estimates (for which we still do not have the data even 30 years later), we will pause to examine the distinctive features of Sakharov's approach to the problem of radiation risk.

The **first distinctive feature is his estimation of radiation risk based on no-threshold effects. In other words, it is an estimate of the negative consequences of small doses, i.e., radiation doses after which appear no symptoms of radiation sickness proper, which is manifested in the form of various impairments in the hematopoietic organs and functions of the small intestine.**

Unfortunately, the biological effects of small doses in mammals and man have not been studied systematically to date. Classical radiation biology and radiation medicine as a consequence of it have devoted a great deal of attention to explaining the mechanisms of the effect of radiation on the organism at relatively high doses (hundreds and thousands of rad). At such doses irradiated cells or animals die over the course of several hours, weeks, or months. The success here has been very high: today we know a great deal about the laws of the manifestation of the "acute consequences" of irradiation and about the molecular and cellular mechanisms lying at their foundation. There is yet another distinctive feature of the classical approach—the requirement of the high uniformity of the objects and samples used in the experiments. During the course of such research the concept of the "threshold" of the effect of radiation has evolved. In accordance with it, the manifestation of "acute effects" requires a "threshold" (for example, several tens of rad). From a pragmatic standpoint, the "threshold concept" played a positive role, particularly in the early stages of the development of nuclear technologies when personnel at the respective enterprises were inevitably irradiated. The threshold concept made it possible to establish the limit allowable irradiation dose for "category A" persons (5 rem yearly)[4] that does not threaten their health directly. As far as no-threshold effects of the irradiation of "category A" persons is concerned, they are very difficult to find in view of the relatively small sample sizes. For practical purposes, they must therefore be ignored.

Beyond the framework of classical radiation biology and medicine, however, both the distinctive features of the effect of low doses of irradiation on animals and man and the problem of differences in individual radiation sensitivity have remained. Studying these topics has required special methodological approaches: using a very large number of problems in experiments, protracted observations, recording a number of indicators not directly related to radiation sickness, etc. This has required great amounts of resources and time, which has not always seemed feasible. Nevertheless, a good knowledge of the "classical effects" has made it possible to find those types of consequences that do not fit into the classical scheme; these may be termed "nonclassical." During the course of research devoted to nonclassical effects it became clear that the biological effect of low doses is fraught with a number of previously unknown and virtually unstudied distinctive features.

Thus, in the past decades, it has been established that even one-time irradiation of cells with low doses increases the frequency of the appearance of nonviable offspring. This is observed in all types of radiated cells over the course of hundreds of cell divisions and is accompanied by the increased sensitivity of those cells to the most diverse unfavorable effects. It was also discovered that many cells surviving after irradiation may later manifest genetic impairments with a very high frequency over the course of hundreds of cell divisions. In higher plants, one-time irradiation of the seeds also leads to long-developing genetic anomalies that are often observed "without attenuation" in a minimum of three generations.[5] It is also known that the frequency of chromosomal mutations in human lymphocytes and the frequency of cell-transforming oncogenes are much higher under the effect of low doses of radiations than would be anticipated from direct linear extrapolation from high doses and that irradiated animals and their offspring are more sensitive to chemical oncogenes than are nonirradiated animals.[6] As is confirmed by the sad experience at Chernobyl, people experiencing a small dose become ill much more frequently, which gives direct indication of irradiation-induced depression of their immune system. All this makes us think that, even when the no-threshold concept is used, the risk of small doses of irradiation may also be underestimated by a factor of 10.[7] Although the results of such studies have not yet been systematized, what we do know makes it possible to state that the concept of the no-threshold biological effects of radiation on which Sakharov based his estimates is the only true approach to estimating the possible risk of irradiation in small doses.

In this respect, it is instructive to compare the no-threshold concept with the now generally acknowledged concept of "limit doses." In accordance with official radiation safety standards, the limit dose for "category B" persons (i.e., those not working directly with radiation sources) amounts to 0.5 rem/yr. It is assumed that irradiation in such a dose will not pose a threat of radiation sickness and is therefore safe. If one takes the approach developed by Sakharov, individuals who have received a small dose have a probability of manifesting no-threshold effects that may reach 0.1. That is, up to 10% of irradiated persons or their offspring may experience different types of anomalies. Mankind must obviously come up against this not only in nuclear weapons tests but also as a result of nuclear reactor accidents, radioactive waste leaks, etc.

The problem of the "limit doses of irradiation" becomes even more complicated in view of the following two facts. First, in Chernobyl-type nuclear accidents radioactive isotopes of the most diverse elements, including α-radiation sources and "hot" particles (microscopic alloys of different isotopes), enter the environment and later the human organism. Their effect on human health has been virtually unstudied. Second, we still know very little about people's individual sensitivity to the effects of small doses, particularly about the effects of different types of isotopes. It is known, however, that in animals such as mice the radiation sensitivity of representatives of a heterogeneous population may differ by a factor of 10 given external irradiation (after irradiation at a dose of 50 rad some animals will feel poorly while others will feel poorly after a dose of 500 rad). Embryos in the period in which various tissues and organs are being formed are particularly sensitive to irradiation. Thus, analysis of data on Hiroshima and Nagasaki shows that irradiation of women who were in weeks 8 through 15 of pregnancy at doses of 1 to 2 rem have a doubled incidence of births of children with serious mental retardation.[8] If the individual differences in man's radiation sensitivity are as great, the pernicious consequences of irradiation may be much higher for individual population groups than "on average" for a large population. It is obvious that when answering the question of limit doses, one must pay special attention to the most radiation sensitive representatives of the population.

And there is yet an additional factor. When we came up against the Chernobyl catastrophe, we turned out to be ignorant in so significant an area as the effect of irradiation of the entire biota in the extensive territory on biocenosis overall. Even those irradiation doses that several authors[9] term "stimulating" and lightly classify as "harmless" may result in grave consequences and cause deformation of the species make-up of cenoses and thereby reduce their resistance to various additional effects. The approaches to estimating the risk of radioactive contaminations for people and biocenoses has thus recently become even more relevant.

The **second distinctive feature of the ideas set forth by Sakharov is the estimation of the risk of radiation effects on man not based on an increase in the percentage of anticipated anomalies (such as cancers) but rather on the basis of the absolute number of similar effects. This is a very important point. In percentages, particularly with regard to the population of a large region, republic, country, or hemisphere, the consequence of atomic tests or radioactive contamination may constitute a small figure that is sometimes said to be "within the limits of the measurement errors." "But this argument does not change the fact that the additional suffering and death of hundreds of thousands of victims, including in neutral countries as well as in future generations, will be added to the suffering and death already existing in the world. Two world wars also added at least 10% to the mortality of the 20th century; however, this does not make war a normal phenomenon" (p. 45 in Sakharov[3]).**

The moral aspect of the problem of nuclear weapons tests worried Sakharov particularly. He mentions the widespread (in the literature) argument, "it is reduced to the fact that the progress of civilization and the development of new technology results in many human victims in many other cases. The example of vehicular accident victims is frequently presented. But the analogy here is imprecise and invalid. Automotive transport improves people's way of life and unfortunately leads to accidents only in individual cases as a result of the negligence of the specific people bearing the narrow responsibility for the accidents. The misfortune caused by tests is an inevitable consequence of each explosion." In the author's opinion, the sole specific point in the moral aspect of this problem is "the total impunity of the crime since in each specific case of human death it is impossible to prove that the reason is radiation and prove the total defenselessness of the offspring with regard to our actions" (pp 43-44 in Sakharov[3]).

This ethical principle is also entirely applicable to those consequences of the large-scale accidents that occurred in 1957 in the Chernobyl Oblast and in 1986 at Chernobyl, as a result of which hundreds of thousands of people turned out to be participants in "experiments" conducted without their knowledge or consent. This should be clear to those who still sanction nuclear weapons tests, to those who support the construction of "cheaper" nuclear power plants, to those who are called upon to ensure the radiation safety of our country's population, to those who are responsible for eliminating the consequences of this type of accident, to those who are responsible for recommendations of the type concerning "deactivating" radioactive isotope-contaminated agricultural products by adding them to "clean" products and disseminating them throughout different regions of the country,[10] and to those advocating an increase in the limit allowable irradiation doses to people. The recently published "Announcements of a Group of Scholars

Working in the Field of Radiation Safety and Radiation Medicine in Connection With the Situation Caused by the Chernobyl Accident at the Chernobyl Nuclear Power Plant"[11] thus "substantiated" the new limit dose (or the "concept of the allowable lifetime dose") of 35 rem for "category B" persons that was proposed by the National Commission on Radiation Protection of the USSR Ministry of Health. This figure was derived by multiplying the "old" limit dose of 0.5 rem per year by 70 years, which the authors took as the "conceptual" human life span. No indication was given of the period in which this dose may be accumulated—as the result of one-time irradiation or even irradiation over the course of an entire lifetime including in old age. Two facts were not considered. First, 35 rem in the case of one-time irradiation (or over 2 or 3 years) is much higher than the limit dose for "category A" persons (i.e., 5 rem/yr), which is fraught with various pathologies in those irradiated and particularly in children. Second, a dose of 35 rem is close to those doses that double the frequency of mutation in man, which is fraught with a twofold increased in genetic anomalies in the offspring whose parents received such a dose, particularly in large population groups.

The approaches to estimating the consequences of nuclear weapons tests developed by Sakharov provide an understanding of his uncompromising position regarding the development and testing of nuclear weaponry: "Halting testing will directly save hundreds of thousands of human lives and will have greater indirect significance, helping weaken international tension and helping reduce the threat of nuclear war—the main danger of his epoch" (p 44 in Sakharov[3]). In addition, this work contains a number of fundamental principles that, from a mythological standpoint, are of the greatest importance for the entire problem of estimating the radiation risk associated with using nuclear technologies even for purely peaceful purposes.

Footnotes

1. "Materials From International Conference on Peaceful Use of Atomic Energy. Geneva, 8-20 August 1955," in "Biologicheskoye deystveye izlucheniy" [Biological Effect of Radiations], Vol 11, Moscow, 1958.

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Magnetic Cumulation

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[Article by A. Pavlovskiy, corresponding member USSR Academy of Sciences, All-Union Scientific Research Institute of Experimental Physics]

[Text] The years from the second half of the forties through the end of the sixties were a productive period in A. D. Sakharov's life when his unique creative gift and inventiveness were especially clear. Besides being years in which he made a decisive contribution to the creation and development of domestic thermonuclear weapons, they were also years in which various aspects of the problem of thermonuclear power generation were at the center of its interests. In 1950 I. Ye. Tamm and A. D. Sakharov expressed the idea of the magnetic thermal insulation of high-temperature plasma, and this marked the beginning of research on controlled nuclear synthesis in our country. In 1951 Sakharov developed the theory of a magnetic stationary thermonuclear reactor and conducted theoretical research on the properties of plasma. (Today many laboratories throughout the world are studying tokamaks that are close in concept to the reactor he examined as one possible way of solving the problem of power generation in the future.) In about 1960-1961 he was evidently the first to examine the possibility of laser thermonuclear synthesis by using the compression of a spherical target.

Sakharov advanced the idea of magnetic cumulation as one possible way of implementing a pulsed controlled thermonuclear reaction.

Birth of the Idea

"In 1952 experimental works on the creation of explosively driven magnetic field generators (devices in which the energy of a chemical explosion or nuclear reaction is transformed into magnetic field energy) were begun at my initiative" (A. D. Sakharov. "Avtobiografiya").

Sakharov proposed two types of such devices. In the first an axial magnetic flux is compressed by a conductive cylindrical shell converging to the center under the effect of an explosion. Such devices have received the name magnetocumulative generators of ultrastrong magnetic fields, i.e., the MK-1. "Imagine a hollow metal cylinder placed in a coil with a current. It is as if the cylinder encompasses a bundle of magnetic force lines created by the coil of the 'initial' field. An explosive charge is located outside the cylinder. At some point in time it is ripped along the entire outer surface. The hollow cylinder is compressed by the pressure of the explosion products, and in turn, like a giant 'fist,' it squeezes the bundle of magnetic force lines and increases the intensity and energy of the magnetic field."[1] The transformation of the cylinder's kinetic energy into the energy of a magnetic field occurs when the shell is decelerated by magnetic pressure. As a result of magnetic cumulation, the energy of the explosive (chemical or nuclear), which is initially distributed throughout a significant space, is concentrated in a small region of space in the form of magnetic field energy. The high density of the magnetic energy makes it fundamentally possible to heat a mixture of deuterium and tritium to the temperature of 10^8 K (10 keV), which is needed to ignite a thermonuclear reaction. Sakharov proposed a circuit for heating plasma by a high-power gas discharge that is induced by a quickly changing field. And although a subsequent, more detailed analysis conducted by him showed the difficulties in implementing one of the first inertial thermonuclear synthesis circuits, the idea itself proved fruitful. The magnetic cumulation of the energy of so powerful a source as an explosion made it possible to study the strongest magnetic fields on earthly scales.

At the end of 1952 Sakharov examined the possibility of using magnetic pressure to compress fissioning heavy matter to transfer small amounts of mass of such matter (about 100 g) in a supercritical state and implement low-power nuclear explosions. Since the critical mass depends in principle on the density of the fissioning matter, it is possible to bring even small masses into a supercritical state; however, this requires compression to a high density and means concentrating significant energy into a small volume. Magnetic cumulation turns out to be more successful than the gas dynamic method of concentrating energy that is implemented by making direct use of the energy of an explosion. In this context, Sakharov proposed a scheme for another type of device called the magnetocumulative energy generator, i.e., the

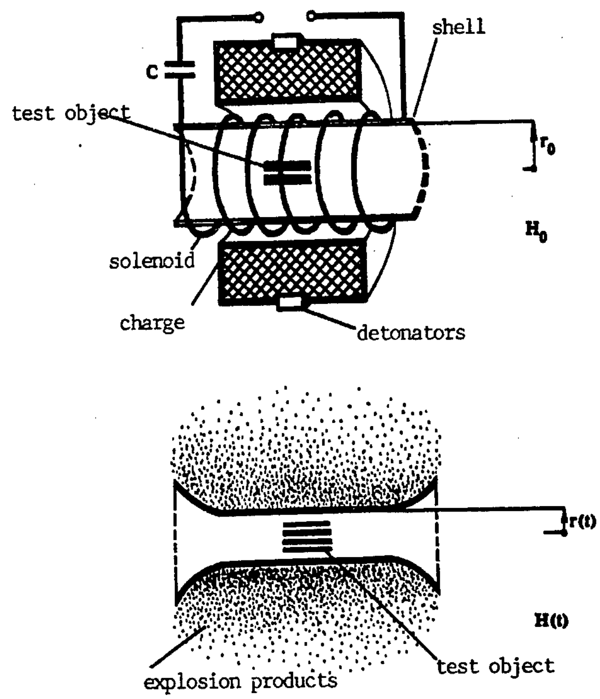

Figure 1. Block diagram of the MK-1 ultrastrong magnetic field generator. Upon the discharge of the capacitor bank C to the solenoid because of diffusion of the field through the shell, which has a radius of r_0, a magnetic field with a flux of Φ is created inside it. The blast of the explosive charge is synchronized such that under the effect of the explosion products, the shell is set into motion when the initial field H_0 reaches a maximum. Upon converging to the center, the shell compresses the magnetic flux, and since it is maintained approximately constant, the intensity H(t) and energy W(t) of the magnetic field increase: $H(t) = H_0r_0^2/r^2(t)$; $W(t) = W_0r_0^2/r^2(t)$.

MK-2. In such devices, electromagnetic pulses are generated by direct transformation of the energy of an explosion into field energy in the process of the compression and displacement of the magnetic flux into a load. MK-2 generators have become compact and powerful pulsed sources of electromagnetic energy with characteristics corresponding to the limit possible of modern technology.

Sakharov also pointed out a number of other possible uses of magnetic cumulation. "A study of the electrical, magnetic, optical, and elastic properties of different substances in such fields, which were previously inaccessible to researchers, is of great scientific interest. This research may turn out to be important for the physics of semiconductors, metals, and polymers."[2] Using compact pulsed energy sources for radio- and optical-range communications over long distances and for research on plasma physics, modeling astrophysical phenomena, and achieving high pressures seemed promising to him.

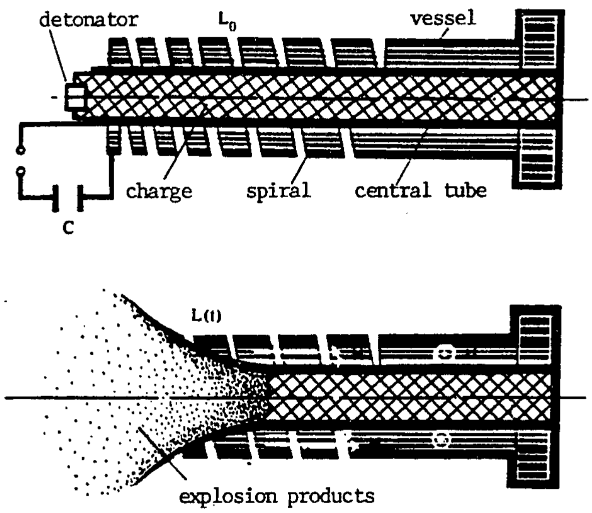

Figure 2. Block diagram of an MK-2 power generator. A deformable current loop with an initial inductance of L_0 consists of a spiral that crosses into the vessel and central tube. Under the pressure of the explosion products, the walls of the tube are stretched in the form of a cone and fly to the beginning of the spiral at the moment of the maximum initial current I_0. Upon propagation of the detonation front, it is as if the cone moves into a spiral and, like a piston, pushes the magnetic flux Φ into the vessel. The inductance of the current loop L(t) decreases, while the current I(t) and energy W(t) of the electromagnetic field increase: $\Phi = L(t)I(t) \; L_0I_0$; $I(t) = \Phi/L(t)$; $W(t) = \Phi^2/2L(t)$.

Sakharov considered using magnetocumulative generators as a power source for high-power charged accelerators to be one of their fundamental scientific applications. The energy of a particle in a cyclic accelerator is determined by the radius of its orbit and intensity of the controlling magnetic field. Using ultrastrong magnetic fields opens the possibility of creating compact accelerators based on high energy.

In 1952 Ya. B. Zeldovich and A. D. Sakharov noted the possibility of creating a proton accelerator for an energy of 10 GeV based on magnetocumulative generators using a chemical explosion. Several years later, Sakharov examined the plan for an accelerator designed for an acceleration of 10^{18} protons per pulse to an energy of 10^3 GeV by using a thermonuclear explosion with an energy release of about 10^6 metric tons of TNT equivalent.[3] In such an accelerator the magnetic field changes in space and over time, and a particle will be accelerated in an orbit with a smaller radius. Producing a magnetic field with an intensity of 10^8 Oe in an end orbit with a radius of 30 cm requires compressing the magnetic flux with a shell weighing about a ton and a velocity of more than 10^7 cm/s. The beam energy amounted to about 10^{11} J. Another "almost fantastic" (in Sakharov's estimation) possibility was related to using pulsed magnetic lenses (which may be created during explosions with an energy of hundreds of kilotons of TNT equivalent) to focus a beam with an intensity of 10^{23} protons/s in an area of 1 mm^2. In his opinion, it is possible to reliably record interaction processes with a cross section on the order of 10^{-30} cm^2 in the crossbeams from two accelerators.

The idea of magnetic cumulation proved to be very fruitful apart from the ultragrandiose plans described.

Principle of Magnetic Cumulation

Magnetic cumulation is based on the law of electromagnetic flux density and is fundamentally no different from the conventional method of producing electric power by using a dynamo. When the current loop's area changes, a current that keeps the magnetic flux inside the loop constant is induced in it. Let us examine ideal magnetic cumulation—the compression of an axial magnetic flux by a cylindrical shell of superconductive incompressible matter with a constant density. In this case, a magnetic flux of

$$\Phi = \int_S \vec{H} d\vec{S}$$

is maintained at all compression velocities. As the shell's cross section S and intensity H decrease and with a pressure P of about H^2 and a magnetic field energy of $W \approx SH^2$, the following all increase: $H(t) \approx S^{-1}(t)$, $P(t) \approx S^{-2}(t)$, and $W(t) \approx S^{-1}(t)$. When the shell converges to the center, the velocity of its inner boundary $u(t) \approx r^{-1}(t)$ also increases. That is, the kinetic energy of the shell W_k is concentrated at its inner boundary. The intensity, energy, and pressure of the magnetic field reach maximum values at the moment when the magnetic field's pressure leaves the shell and its kinetic energy is completely transformed into magnetic field energy.

In the case of a current loop made of a real conductor (the resistance of which does not equal zero so that the density may increase upon compression), sustaining the magnetic flux depends on the rate at which the loop is deformed. The magnetic flux is lost on account of diffusion of the field into the conductor's walls. At fields above 4×10^5 Oe, there begins an intensive heating of the conductor and an increase in its resistance. When, on the other hand, $H > 3 \times 10^6$ Oe, the surface layer vaporizes at the "matter-field" interface, and the zone of conductivity loss spreads rapidly into the depths of the material. Under such conditions the magnetic flux will be maintained if the rate of its compression by more remote conductive layers of matter is greater than the velocity of the conductivity loss front. At the same time, formation of a plasma layer that at fields above 2×10^7 Oe may have a rather high conductivity and participate in compression of the magnetic flux is possible on the boundary surface.

The compressible magnetic flux, conductor and all, is subject to compression. When the magnetic pressure at

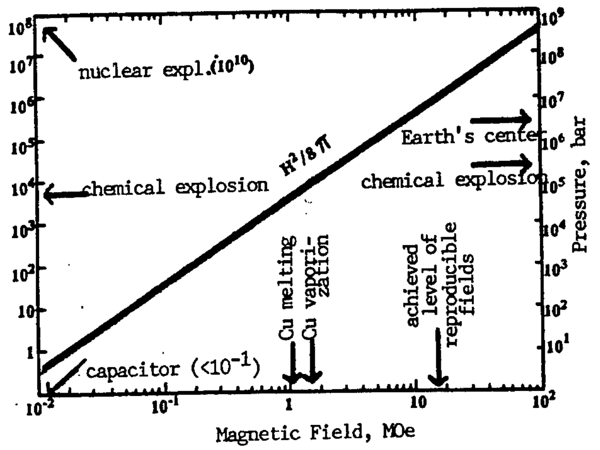

Figure 3. Effects caused by strong magnetic fields. When H 8 x 10^5 Oe, melting of the surface layer of the conductor begins; when H 1.5 x 10^6 Oe, vaporization of the matter begins, and the energy density reaches the density of the chemical explosive energy. An intensity of H = 1.6 x 10^7 Oe corresponds to an achieved level of reproducible magnetic fields at which the energy density (10^6 J/cm^3) exceeds the bond energy of most solids while the pressure of the field is more than twice that in the Earth's center.

the "matter-field" interface increases, there is a compressional wave that then turns into a shock wave, which in turn increases the density of the shell's matter and its internal energy (its elastic, thermal, ionization, and electromagnetic radiation energies). Upon convergence of the shell of compressible matter, u(t) changes as $r^{-n}(t)$, where $0 < n < 1$, i.e., and in this case there is a concentration of the shell's kinetic energy at its inner boundary. Thus, at a high energy density, it is the hydrodynamic processes in the layer of matter at the boundary with the magnetic field that are decisive. From qualitative considerations, it is possible to derive a criterion of effective magnetic cumulation, i.e., $\rho u^2 > H^2/8\pi$ (ρ being the density of the shell's matter). It follows that when considering the end conductivity and compressibility of real conductors, the magnitude of the resultant magnetic field is determined by the constraints on the density of the kinetic energy of the explosion-accelerated shell. In 1952 A. D. Sakharov and M. P. Shumayev found an analytical solution for the case of constant conduction σ and showed that the magnetic flux is maintained if $\eta = (4\pi\sigma ru/s^2)^{1/2} >> 1$. In the general case, a magnetohydrodynamics equation system complemented by a state equation for the conductor's matter and the law governing the change in its conductivity must be solved numerically.

Magnetic cumulation may be seriously restricted by the instability of a cylinder shell's convergence (violation of symmetry) owing to an unrestricted increase in the initial perturbations. It is therefore important to ensure good initial cylindrical compression symmetry, i.e., high-quality detonation wave formation and precise manufacture and assembly of the charge and shell.

First Experiments

In the USSR work on the magnetic cumulation of energy began with an experiment with the MK-1 generator that was conducted in the first half of 1952 at Sakharov's initiative.[4] A 25-fold amplification (with a maximum value of about 10^6 Oe) was recorded in the experiment. Unfortunately, this result, like Sakharov's idea, was not published at the time. That only happened in 1965.[5] The first publication, a short note devoted to an explosive method of producing ultrastrong magnetic fields, was published in 1957. It belonged to Ya. P. Terletskiy. As later became known from an outstanding article by American researchers, at about the same time as in the USSR, works on magnetic cumulation were independently begun at the Los Alamos laboratory at the proposal of F. Willing and E. Teller.

From 1952 until the mid-sixties work in the USSR was conducted very intensively. A series of complex experiments with a combination of the MK-1 and MK-2 generators was conducted in 1955-1956 (the MK-2 generator was used as an energy source to create the initial magnetic field). Fields with an intensity of about 5 x 10^6 Oe in a cavity 10 mm in diameter were stably recorded in tests. A cycle of studies geared toward improving the symmetry of compressing the magnetic flux and increasing the density of the shell's kinetic energy culminated in 1964 with a test in which a record magnetic field value of 2.5 x 10^7 Oe was recorded in a cavity 4 mm in diameter. A stainless steel shell manufactured with a high precision and covered from within with a thin (20 μm) layer of copper was used. The rate of compression of the magnetic flux in the first third of the initial diameter amounted to about 10^6 cm/s. A magnetic field was registered by induction sensors with a massive dielectric shield, and the induced signals were monitored by background sensors. The values of the coefficient of the maintenance of the magnetic flux ($\Phi/\Phi_0 = 0.3$) that were obtained in the experiment corresponded to the anticipated value. An attempt to reproduce the record result in several complex experiments failed. The unstable operation of the initial field coil (breakdowns of the insulation) was noted. The main reason for the tests' poor reproducibility, however, as demonstrated by further studies, was the instability of the magnetic cumulation, which does not exclude the possibility of producing large fields in single experiments.

A 1960 publication reporting that a field with an intensity of about 1.5 x 10^7 Oe had been produced at the Los Alamos laboratory resulted in the intensive development of works in laboratories in the United States, Italy, France, and other countries. The results of the initial periods of work were presented in an international conference held in 1965 in Frascati (Italy). It was noted that although American and Soviet researchers managed to produce record fields in single tests, the results of most of the works indicated that the level of reproducible fields do not exceed 5 x 10^6 Oe. No explanation was found for this fact. It became clear that the task of stably producing ultrastrong magnetic fields was much more difficult than it seemed initially, whereas the levels of reproducible fields were less than expected. For one reason or another, soon after the conference works on generating ultrastrong magnetic fields were halted in most laboratories.

Critical Limitation of Cumulation

In the USSR works on the cumulation of ultrastrong magnetic fields were continued by a small group of researchers who had formulated the task of increasing the level of reproducible fields.[6] Reproducibility is extremely important for one-time explosion tests: without certainty of the fact that an announced magnetic field value can be reproduced with a high degree of probability in any experiment, research in such fields loses their sense.

By that time practically all possible methods of increasing the magnitude of stably generatable magnetic fields had been studied. The only remaining possibility was to increase the initial magnetic field so as to maximally limit the change in radius of the shell and thereby attempt to avoid disturbing the stability of its convergence on account of the development of initial perturbations. This required developing an explosion device guaranteeing the reproducibility of the initial test conditions, expanding diagnosis, and developing methods of mathematically modeling the processes in an actual generator structure.

Creating an initial magnetic field with an intensity up to 2 x 10^5 Oe inside a well-conducting shell with a cavity 5 x 10^3 cm^3 in volume that did not introduce noticeable perturbations into the magnetic flux compression system turned out to be very complicated. Protracted searches led to a fundamentally new solution—combining the functions of the solenoid creating the initial magnetic field and the shell compressing the magnetic flux into one device, a solenoid-shell. Initially the device was a cylinder solenoid with a special winding of thin (0.25 mm) copper wires that were insulated from one another. The solenoid was located inside a cylinder explosive charge. After the blast of the charge, a shock wave with a pressure of 1.5 x 10^5 bar at the front destroys the insulation as it passes through the solenoid's matter. The conductors are welded together, and the solenoid is transformed into a continuous shell with isotropic conductivity that effectively captures and compresses the magnetic flux.

Obtaining reliable information under conditions of an explosion and magnetic fields existing for fractions of a microsecond by using sensors that are subject to magnetic pressure comparable with that at the earth's center and also subject to the effect of high temperature, intensive flows of vaporized matter, plasma, and electromagnetic radiations is a far-from-simple task. Optical methods involving the use of laser radiation to measure the magnetic field based on the Faraday effect (rotation of the radiation's polarization plane) and probing the inner cavity, as well as on pulsed roentgenography methods, have undergone the most development. The equipment is located in a protective structure and, with the exception of the field sensor, may be used repeatedly. Experimental data in conjunction with numerical calculations have yielded a rather complete understanding of the processes studied.

The results of the first experiments turned out to be disheartening. The maximum recorded magnetic field did not exceed $3 \cdot 10^6$ Oe, and recording of the field ceased before the moment of greatest compression. When the field sensor was surrounded by a massive dielectric shield occupying the entire volume of the cavity at the moment of ultimate compression, it was possible to extend the field registration time and fix an intensity up to 5 or 6 x 10^6 Oe. Research on the cavity's state by the pulsed roentgenography method made it possible to establish the cause for the impairment in the stability of magnetic cumulation, i.e., development of perturbations at the "matter-field" boundary. Even with a magnetic field of 3 x 10^6 Oe the symmetry of the convergence of the shell's inner bound is noticeably distorted, the matter vaporizes intensely, and streams are formed. The temperature of the matter reaches 10^4 K, and the magnetic field has a pressure of 3.6 x 10^5 bar. Under such conditions, Rayleigh-Taylor-type instabilities quickly develop. They are characteristic for the bound between heavy (matter) and light (field) layers in the case of an acceleration directed to the side of the heavy layer (in other words, when the shell is decelerated by the pressure of the magnetic field). By the end of the compression ($H \approx 5 \times 10^6$ Oe), the distortions of the form of the shell's inner surface are so great that it is difficult to speak of its bounds. A channel of loss of the shell's kinetic energy appears that is faster than the compression of the magnetic flux, i.e., it is transferred directly into thermal energy. The process of cumulation of magnetic energy ceases.

Thus, the attempt to increase the values of reproducible magnetic fields by increasing the initial field thus turned out to be unsuccessful. Moreover, a fundamental limitation on cumulation was discovered, in light of which the prospects for magnetic cumulation did not seem very hopeful. A rather dramatic situation had evolved regarding researching magnetic cumulation.

Compression of a Shell System's Magnetic Flux

The way out of this situation was found on the road to stabilizing the process of magnetic cumulation.[7] It turned out be surprisingly simple and entailed compressing the magnetic flux not by one shell but rather by a system of coaxial shells. Each time a threat of loss of stability of the shell's inner bound arises, that shell is replaced by a new one to which the function of further compressing the flux is transferred. Thus, by using a system of coaxial shells it is possible to accomplish stable

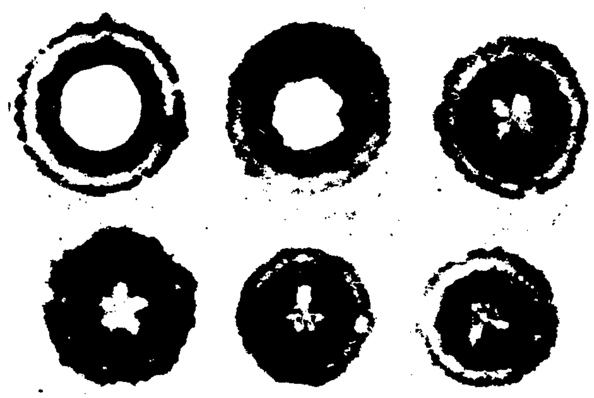

Figure 4. Reduced x-ray photos of a shell compressing a magnetic flux that were taken along its axis in sequential moments of convergence. When the intensity of the magnetic field exceeds 3.5 x 10^6 Oe, there begins an intensive unrestricted development of perturbances of the shell's inner surface that has catastrophic consequences—cessation of energy cumulation when H = 6 x 10^6 Oe. At that moment the shell decelerates and has a shape far from its initial shape. Inside it there is a mixing of vaporized matter and the field.

compression of a magnetic flux with a large change in the radius of the region of the field's existence and, accordingly, increase the intensity of the final field. A part of the kinetic energy and function of compression of the magnetic flux is transferred from one shell to another when the moving shell collides with a stationary one. The inner skin-layer boundary then moves to the inner surface of the connected shell, and its outer boundary remains in the matter of the preceding shell. Each time this occurs, the heated shell is replaced by a new cold one at the "matter-field" interface. In this compression method, the loads on the inner layer of each shell are reduced significantly, which slows the development of instabilities. The criterion of effective cumulation is satisfied at lower velocities, which makes magnetic cumulation promising.

Compressing a magnetic flux by using a shell system requires that each of them freely pass the magnetic flux inside itself while it is stationary and capture the flux when it begins to move. Shells with such properties were created on the basis of the very same principle as a solenoid-shell. The transformation of a shell that is permeable by an axial magnetic flux and that is made of insulated copper conductors into a continuous medium capturing and compressing the flux is accomplished by using the effect of the compressive shock wave that occurs as a result of the collision of a moving shell with a shell that is stationary.

Experiments With Ultrastrong Magnetic Fields

Stabilizing the compression of the magnetic flux at high energy densities made the continuation of works on the magnetic cumulation of energy feasible. Devices in which the magnetic flux is compressed by a system of coaxial shells have received the name cascade generators of ultrastrong magnetic fields. Two versions of such generators with a three-cascade flux compression system (the solenoid-shell is the first cascade) were implemented. They differ with respect to the amount of explosive used. A cascade generator with a charge having an outer diameter of 300 mm permits the reliable production of magnetic fields up to 1.3 x 10^7 Oe in a volume of approximately 4 cm^3. It is a rather simple and compact device with extreme output parameters and the first in world practice to be brought to the stage of being a series-produced physical instrument in which the magnitude of the final field and its volume may be changed without additional verification of its operability. Its high operating stability and the high reproducibility of the fields it generates have been confirmed by hundreds of experiments. A second version of the cascade generator (outer diameter of the charge, 650 mm) in a volume of 5 cm^3 helped stably reproduce fields of up to 1.6 x 10^7 Oe. It should be said that the possibilities of this version of the cascade generator have not yet been fully revealed. The fields produced in cascade generators are the current records. The stability of magnetic cumulation has made it possible to achieve a magnetic field energy density of 10^6 J/cm^3, which is 100-fold the density of the chemical energy of explosives. The magnetic field's pressure amounts to 10^7 bar. And what are its prospects?

In terms of reliably reproducible ultrastrong magnetic fields, which are the only ones of interest to researchers, there are at present no alternatives to the explosive method of generating them. It appears that in the coming years the energy of chemical explosions will be used to produce fields with an intensity of 3 x 10^7 Oe in a volume between 1 and 5 cm^3. Today the magnitude of the magnetic field that can be produced by using the explosion method appears basically unlimited. In this case the initial magnetic field should amount to at least several megaoersteds, which is difficult to guarantee by using a chemical explosion. Estimates show that magnetic fields up to 10^9 Oe may be created with a relatively small nuclear explosion and an energy release of not more than 100 tons TNT equivalent. Such fields are apparently not the ultimate ones under the conditions existing on earth.

The stable production of magnetic fields in the tens-of-megaoersteds range afforded physicists extensive possibilities. Experimental studies were conducted on the optical and magnetooptical properties of many substances in magnetic fields of up to 1.1 x 10^7 Oe, including at low temperatures. By analyzing the data from experiments in which the absorption index and Faraday effect were varied it was possible to draw a conclusion about the effect of an external field on the energy spectrum, band structure, and other quantum characteristics of a solid body. A shift in the paramagnetic and cyclotron frequencies to the optical range was noted in strong magnetic fields. A curious effect in the semiconductor

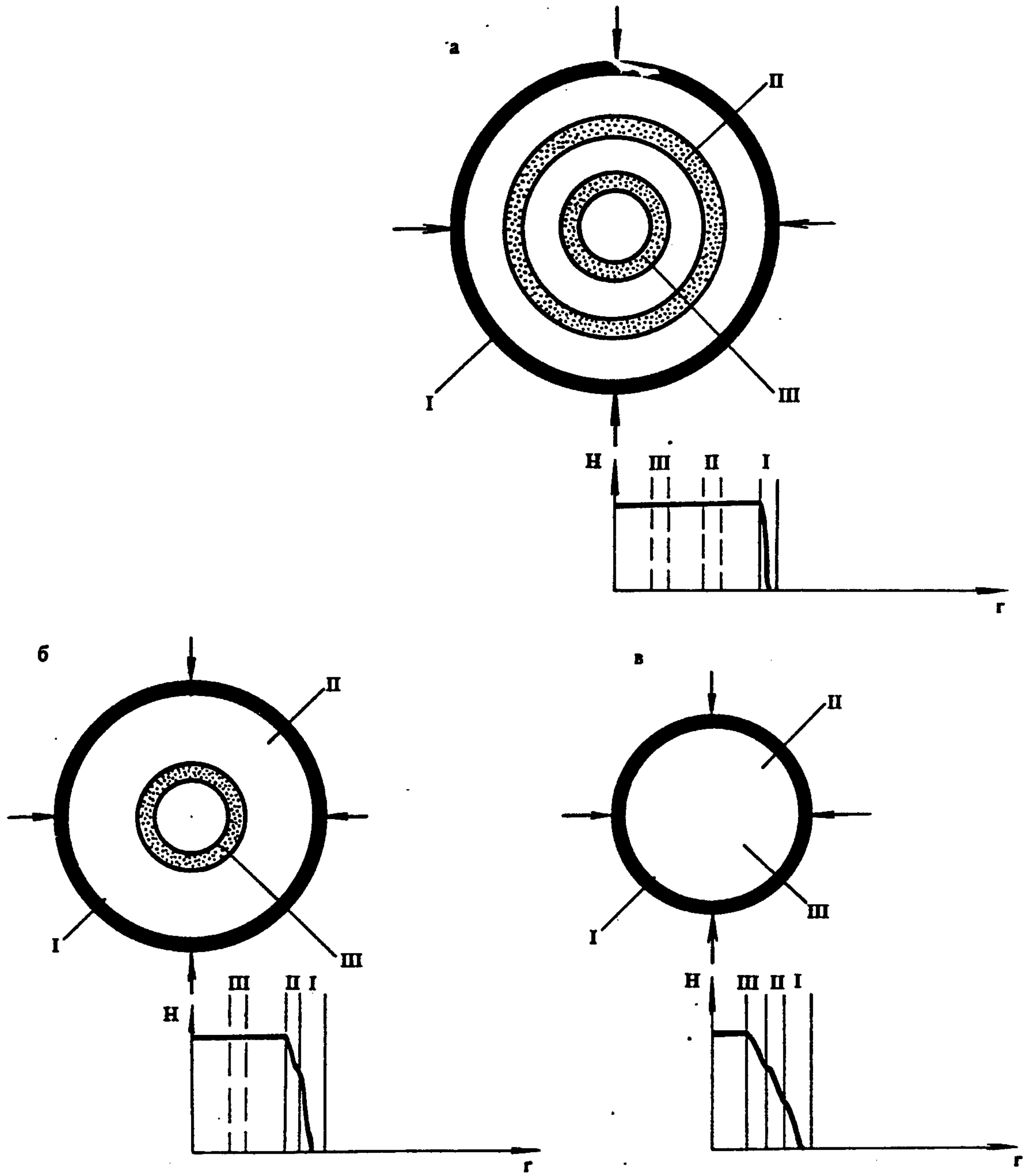

Figure 5. Diagram of the compression of a magnetic flux by a system of coaxial shells: a, compression of the magnetic flux is implemented by shell I, while shells II and III remain stationary and transparent for the magnetic field; b, generation of the magnetic field is implemented by shell II since, when shell I collides with it, the internal skin-layer boundary (shown in color) moves to the inner surface of shell II; c, generation of the magnetic field is accomplished by shell III. Upon each collision of shells and transfer of the function of field generation from one to another, a portion of the magnetic flux is lost in the matter of the connected shell. However, stabilization of the "matter-field" boundary, which is realized with such a compression scheme, makes it possible to achieve higher magnetic fields.

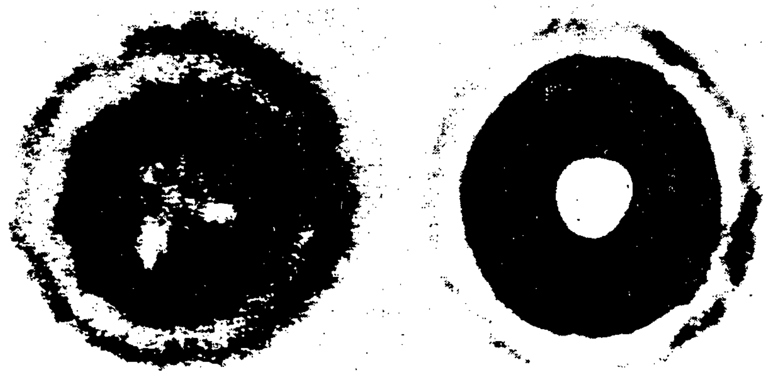

Figure 6. Reduced x-ray photos taken during compression of a magnetic flux by one shell (left) and three coaxial shells (right). In the first case the cessation of magnetic field cumulation is fixed at H = 5 x 10^6 Oe; in the second case the moment when the field intensity reached 10^7 Oe is fixed; the cumulation process continues.

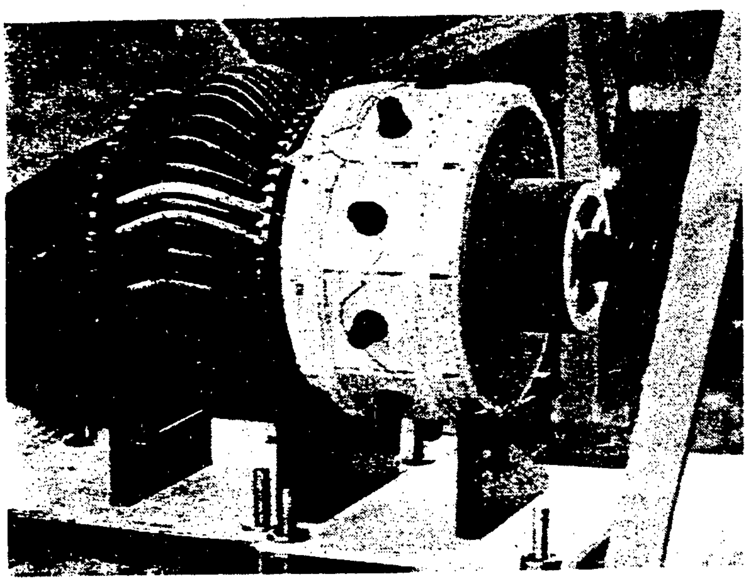

Figure 7. Cascade generator of reproducible magnetic fields with an intensity up to 1.3 x 10^7 Oe prepared for an explosion experiment. A bundle of coaxial cables approaches the generator from the left. Energy to create the initial field is fed along them out of the protective structure from a capacitor bank.

GaAs was noted for the first time: in fields greater than 4.3 x 10^6 Oe the specimen becomes transparent for radiation with a wavelength of λ = 0.633 μm, and in reflected light it should change color from red to yellow in a field of 10^7 Oe.

Experiments with bulk and film type Y-Ba-Cu-O superconducting ceramics were conducted in fields of about 3 x 10^6 Oe at T = 4 K. They were based on direct measurement of H_{K2}, a magnetic field in which superconductivity disappears completely.

One interesting research area involves using pulsed magnetic fields to produce high pressures. If a metal tube filled with some substance is placed in an intensified magnetic field, an evenly increasing magnetic pressure of $H^2/8\pi$ will act on the tube's walls, and the pressure in the matter will be determined by its compressibility. This compression mode guarantees maximum heating of the matter when high pressures are reached. The state equations of a number of substances at pressures up to 5 x 10^6 bar were thus studied, as were the spectrum and shift of the luminescence R-lines of a compressed ruby. The compression of solid hydrogen and deuterium (T $\approx$ 4 to 6 K) in the pressure range from 3 to 5 x 10^6 bar have been studied for a number of years. An important distinction of such experiments is that they afford the possibility of direct measurement of the conduction of compressed

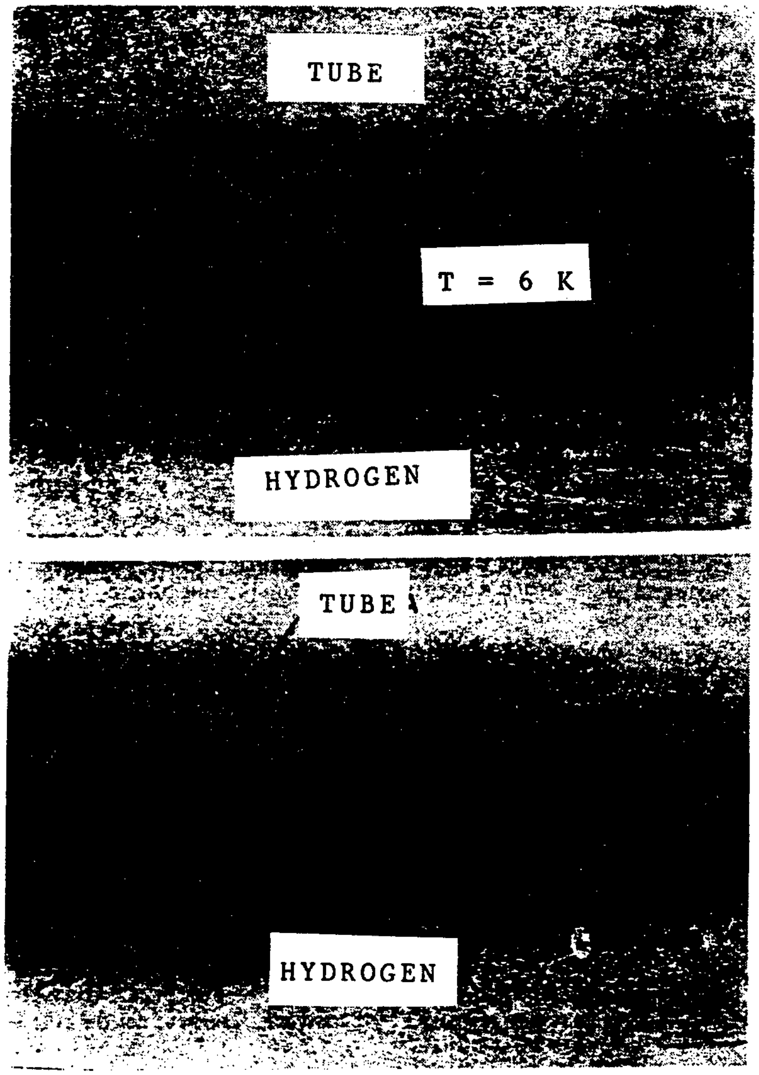

Figure 8. X-ray photos taken perpendicular to the axis of an MK-1 generator on which the initial (top) and end (bottom) states of the specimen (a tube with solid hydrogen) are fixed. The initial inner diameter of the tube is 16.4 mm; the end diameter is 4.53 mm, and the hydrogen's density increases from 0.089 to 1.16 g/cm^3.

matter. Essentially, all these works are the first step in mastering the field of ultrastrong magnetic fields. The level of magnetic fields that has been achieved and the imminent prospect of increasing them provide the foundations for returning to Sakharov's idea, i.e., implementing a pulsed thermonuclear reaction in MK-1 generators.

MK-2 Generators

Another direction in these works[8] involves realizing the idea of MK-2 magnetocumulative power generators. In them efficient transformation of the energy of an explosion during the deceleration of an accelerated conductor occurs in moderate fields of 0.25 to 1 x 10^6 Oe. During the deformation of a current loop with a speed of 2 x 10^5 cm/s, the losses of magnetic flux associated with diffusion of the field into the conductor and its compressibility are low. The losses are mainly determined by disturbances in the regularity of setting the inductance of the deformable loop and "cut-offs" of the magnetic flux in the dielectrics as well as during electrical breakdowns inside the generator. These losses can be reduced by selecting the optimal generator design.

The block diagram of an MK-2 generator that Sakharov proposed was researched rather completely in 1956. Currents up to 10^8 A and energy on the order of 10^7-10^8 J at a load with an inductance up to 10 nH were recorded in tests with such a generator. MK-2-type generators

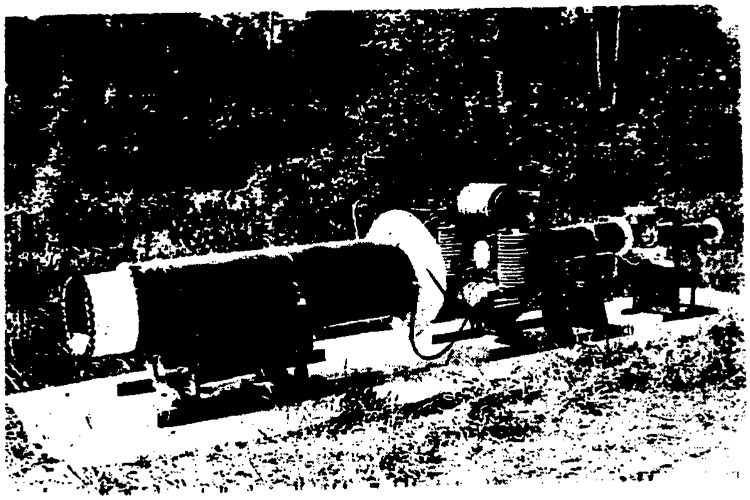

Figure 9. MK-2 cascade generator produced by the Elektrofizika Production Association in Leningrad. The device consists of three generators with a transformer link between each of them. Each preceding generator serves as the power source for the next. A high power gain factor (10^4) and efficient conversion of the explosion's energy (up to 10%) are achieved. The generator has an output energy of 1.5 x 10^7 J.

with diverse geometries of their deformable current loops were later produced. The generators' power was increased by simultaneously increasing the area of the deformable current surface by using a multipoint system to initiate the explosive charge. Coordinating the laws governing the energy release of an explosion and the generation of magnetic energy makes it possible to increased the efficiency of power conversion. Modern MK-2 generations are characterized by a specific energy of 6 to 7 x 10^2 J/cm^3, a specific power of 10^7 to 10^8 W/cm^3, and a power conversion efficiency of up to 20%.

One variety of MK-2 generator with a developed deformable loop surface is a disk generator whose loop is a toroid with a large outer-to-inner diameter ratio. A record current—above 3 x 10^8 A—and an energy of about 10^8 J in a load with an inductance of 3 nH were produced in 1967 tests of this generator. Its conversion efficiency amounted to 20%.

Type MK-2 generators operate efficiently at a small inductance when connected to an output circuit. With loads having a higher inductance, the generator is matched by using devices increasing the magnetic flux in the load.

MK-2 generators have a characteristic operating time between 10^{-4} and 10^{-5} s. Modern methods make it possible to change the law governing the increase in the current pulse and to shape pulses in the load that have a duration between 10^{-7} and 10^{-2} s. Energy from the generator may be transferred to a shielding structure guaranteeing the experimental unit's storage reliability. The following capability has been realized: an energy of 3 x 10^7 J (a power of 10^{12} W) was transferred from an MK-2 generator to an experimental device a distance of 30 m away. Several MK-2 generators may be connected into a bank with characteristics significantly exceeding those of a single generator.

The MK-2 has been well studied to date, and calculation methods make it possible to predict their characteristics with satisfactory precision. Industrial production of an MK-2 cascade generator providing an energy of 1.5 x 10^7 J with operation over a wide load range has been launched.

MK-2 generators are the most powerful pulsed sources of electromagnetic energy. They are widely used in research to feed pulsed charged particle accelerators, high-speed accelerators, gas lasers, and microwave generators and to generate high-voltage pulses.

A multiyear cycle of works studying magnetic cumulation and creating magnetocumulative generators has been conducted by a collective of researchers at the institute where Yu. B. Khariton is the scientific director. His active support was essential in developing this direction of work.

* * * *

Forty years has passed since A. D. Sakharov expressed the idea of magnetic cumulation. Research in the USSR on the problem of stable generation of record magnetic fields has made a decisive contribution to its successful implementation. International conferences on the generation of megaoersted magnetic fields and related experiments that have become regular events have made it possible to speak of developing a new promising direction in the physics of high energy densities—megaoersted physics. Sakharov was one of its creators.

He saw the grandiose prospects of ultra-high-power charged particle accelerators 25 years ago, and today they still remain "almost fantastic." Sakharov's idea regarding the formulation of extreme experiments under the conditions existing on earth still awaits embodiment. One such possibility of scientific interest is magnetic cumulation of the energy of a nuclear explosion. Similar experiments may be conducted without inflicting the ecological harm of underground nuclear explosions with a relatively small release of energy. Sakharov considered international cooperation a necessary condition of such experiments.

Footnotes

1. Sakharov, A. D., "Magnetic Field Reactors," IZVESTIYA, 29 Apr 66, p 3.

2. Ibid.

3. Sakharov, A. D., "Explosive Magnetic Generators," USPEKHI FIZ. NAUK [Progress in Physical Sciences], Vol 88, No 4, 1966, pp 725-734.

4. R. Z. Lyudayev, Ye. A. Feoktistova, G. A. Tsyrkov, and A. A. Chvileva conducted the experiment.

5. Sakharov, A. D., Lyudayev, R. Z., Smirnov, Ye. N., Plyushchev, Yu. I., Pavlovskiy, A. I., et al., DOKL. AN SSSR [Reports of USSR Academy of Sciences], Vol 196, No 1, 1965, pp 65-68.

6. Pavlovskii, A. I., Kolokolchikov, N. P., Tatsenko, R. M., et al., "Megagauss Physics and Technology," New York, 1980, pp 627-639.

7. Pavlovskiy, A. I., Dolotenko, M. I., Kolokolchikov, N. P., et al., PISMA V ZhTF [Letters to Jouranl of Engineering Physics], Vol 38, No 9, pp 437-479.

8. Pavlovskiy, A. I., and Lyudayev, R. Z., "Magnetic Cumulation," in "Voprosy sovremennoy eksperimenalnoy i teoreticheskoy fiziki" [Problems of Modern Experimental and Theoretical Physics], Leningrad, 1984, pp 206-270.

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Fate of Unpublished Article

917F0007K Moscow PRIRODA in Russian No 8, Aug 90 pp 50-55

[Article by S. S. Gershteyn, corresponding member USSR Academy of Sciences, High-Energy Physics Institute, Protvino, and L. I. Ponomarev, doctor of physical and mathematical sciences, Atomic Energy Institute imeni I. V. Kurchatov, Moscow]

[Text] It is known that half of all published scientific works are never cited at all. Of the remaining half, only 20 percent are cited after 10 years, and only about 5 percent are cited after 15 years. There are publications, however, that are referred to 20 and even 30 years after coming to light. It is precisely by this trait that classical works in any field of knowledge are distinguished.

Andrey Dmitriyevich Sakharov succeeded in accomplishing even more. His 1948 report "Passive Mesons" was never published. It is nevertheless still widely referred to throughout the entire world literature on muon catalysis. To some degree, it affected the selection of the life path of the authors of the present note.

By some logic that is completely incomprehensible to the contemporary reader (but in full conformity with the conventions of the time), this report was slow in being declassified. The first mention of it appeared in 1957 in a joint work by Ya. B. Zeldovich and A. D. Sakharov entitled "Reactions Caused by μ-Mesons in Hydrogen." Then, in 1960 it was mentioned in a review by Ya. B. Zeldovich and S. S. Gershteyn entitled "Nuclear Synthesis Reaction in Cold Hydrogen."[1] Few, however, knew the specifics of the content of this work until the past few years—it was mentioned and referred to second and, even more so, third hand.[2]

In spring 1989 we spoke with Andrey Dmitriyevich regarding his desire for the publication of the famed report. He gave his consent, saying that he truly did not know its whereabouts. Soon after Andrey Dmitriyevich's sudden death, it was somehow found in the archives of the Physics Institute imeni P. N. Lebedev. Efforts to remove it from the grip of secrecy and finally get our hands on the yellow pages of the manuscript that had to some measure anticipated the development of a very interesting field of physics decades in advance were successful.[3]

It is difficult for the modern reader to imagine the conditions in which many of Andrey Dmitriyevich's generation had to study science—constant monitoring, bodyguards, notebooks with numbered pages that were the only place even the most harmless calculations were permitted to be made, and many other problems were natural at the time. But uncontrolled thought managed to tear through even these barriers: two of Ya. B. Zeldovich's notebooks in which he made estimates of various muon catalysis processes while at the "facility" in 1957 were preserved (specifically, they contain a concise abstract of a secret report by Sakharov, or ADS, as was written in Zeldovich's notebooks).

The effect that Sakharov had on Yakov Borisovich and how highly he valued the rare intuition of this physicist is evident from these notes. On many pages one can encounter comments like the following: "ADS: recharging on identical particles," "ADS: 3 particles," "the very deep idea of ADS," etc. One of the notebooks also contains the manuscript text of a joint article by Zeldovich and Sakharov that was published in 1957 after the discovery of muon catalysis. We will say more about this later but for now will return to the 1948 report.

In it Sakharov analyzed for the first time what happens when a negatively charged muon (μ^-) remains in deuterium and came to the following conclusion. A muon with two deuterium (d) nuclei may form a ddμ mesomolecule, i.e., a molecule in which the electron has been replaced by a muon and in which, as a result, the nuclei are so close to each other (about 5 x 10^{-11} cm) that they are practically instantaneous and enter into a synthesis reaction, namely, d + d → ^{3}He + n (or t + p) with the liberation of a rather large amount of energy (3.3 and 4 MeV, respectively). The released muon can then form another mesomolecule in which a synthesis reaction again occurs, etc. This process can proceed until the muon, which has become a unique synthesis reaction catalyst, is for one reason or another "taken out of the game."

To assess the boldness of Andrey Dmitriyevich's idea and the speed of his reaction to new scientific discoveries, one should recall the "scientific background" in which his work was conducted. This will also make it possible to understand the title of the report.

The point is that, according to H. Yukawa's 1935 hypothesis, the short-acting nature of nuclear forces is related to the fact that the interaction between nucleons occurs by means of an exchange of particles with a mass of 200-300 electron mass units, which he termed a meson. The particle is approximately the same mass as that detected in 1936-1938 in cosmic rays at sea level. Further research demonstrated, however, that the particle detected (we now call it a μ-meson or muon) cannot pretend to be a Yukawa particle since it interacts only weakly with the nuclei of matter. Specifically, this was confirmed by the fact that it passes freely through the entire thickness of the atmosphere, surmounting distances approximately 10-fold greater than the length that a particle with the properties predicted by Yukawa should be able to be scattered or absorbed by atomic nuclei. On the other hand, it turned out that, at great altitudes, in the make-up of cosmic rays, along with the so-called hard component that penetrates through the atmosphere, there is also a soft component that interacts strongly with the nuclei of matter and is absorbed by them. Surprisingly, the masses of the particles of the soft and hard components were approximately equal. Since the precision of measuring this important characteristic of particles at the time was not high, it was assumed that one and the same particle was being observed in the soft and hard components. It was as if an unresolvable paradox had arisen: why would one and the same particle behave differently at high altitudes and at sea level? It was resolved only in 1947 when, in a photoemulsion, S. Powell, C. Lattes, and J. Occhialini recorded an event in which a new track corresponding to a charged particle with a kinetic energy of about 5.5. MeV and a mass approximately equal to the mass of a stopped particle emerged from the stopping point of some charged particle. The authors correctly labeled this event as the decay of the particle predicted by Yukawa (a π-meson or, in today's terminology, a pion) into a muon and something else. Pions are generated in the interaction of particles of cosmic rays with the nuclei of elements that are part of the atmosphere's make-up and decay into a lighter charged particle and some neutral particle that does not leave a trace in the photoemulsion. In modern conventions, these are the decays of charged pions into a muon and muon neutrino: $\pi^{+/-} \rightarrow \mu^{+/-} + \nu\mu$.

After the hypothesis that, unlike a pion, a muon does not interact strongly with nuclei (is passive), it was possible to understand the difference between the hard and soft components of cosmic rays. But what is even more important, the discovery of an "unplanned" particle, the muon, became the departure point for a whole chain of discoveries that led to an understanding of the universality of weak interactions and, ultimately, to the creation of a unified theory of electrically weak interactions.[4] But then in 1947, far before all of this, one had to believe that a new particle had actually been discovered after having preliminarily analyzed the other possible explanations of the phenomena observed.

The English physicist C. Frank attempted to interpret the event discovered by Powell, Lattes, and Occhialini without introducing a new particle. The following was among the versions he discussed: a negatively charged meson stopped in the emulsion may bind the proton and deuteron in its make-up into a mesomolecule with dimensions of about 10^{-11}cm. In such a mesomolecule the Coulomb repulsion barrier between the nuclei is much smaller than in an ordinary ("electron") one. Therefore, the nuclear synthesis reaction of the proton and deuteron in a ^{3}He nucleus in which an energy of 5.5 MeV is released should occur rather quickly. If this energy is transferred to the meson binding the nuclei into a molecule, a new track belonging to the meson with an energy of 5.5 MeV will begin from the stopping point of the meson that flew into the photoemulsion. This situation is really very close to that observed in the experiment. It should be said that Frank himself rejected this possibility, assuming that the deuterium impurity in natural hydrogen is too small to provide the marked yield of such a reaction. He did not see any other explanations for the event discovered besides the interpretation by Powell, etc.

It is curious that the Frank's reason for rejecting the possibility of this nuclear synthesis reaction in a pdμ mesomolecule was incorrect. It was precisely such a reaction that L. Alvarez later observed in a chamber with liquid hydrogen, thus discovering muon catalysis. This reaction is impossible in a photoemulsion since in the overwhelming majority of cases a negatively charged muon is recaptured by the nuclei of heavier elements. In addition, it is now possible to say with certainty that the event observed by Powell et al. was the decay of a pion that was not negatively but rather positively charged. This is because a negatively charged pion stopped in matter is virtually instantaneously absorbed by nuclei without having had time to decay.

Despite these provisos, Frank's hypothesis itself played a significant role in the further development of muon catalysis and was similar to the famed "Colombo egg." In fact, by that time, the muon had already been known for 10 years, mesoatoms had long been predicted, but the notion of examining the possibility of the formation of mesomolecules and calculating the speed of the nuclear synthesis reaction in them had never occurred to anyone.

Frank's work attracted the attention of Andrey Dmitriyevich, who while thinking about implementing heavy-hydrogen synthesis reactions, directed his thinking in an entirely different direction. Having accepted as very likely (as he writes in his report) the possibility of the existence of two sorts of mesons, "active" and "passive," he examined the behavior of passive mesons stopped in pure deuterium and came to the conclusions mentioned at the beginning of our story. Here is how he formulated them himself.[5] "The content of this note is related to one article in [omission][6] (note: all inclusions of the phrase [omission] are as received) containing a discussion of the experiments of Powell et al. [omission]. We will assume that in the gas of heavy hydrogen contained, for example, in a high-pressure bomb, there is a passive negative meson with a mass [omission] 200. After some time [omission] it sets into a K-orbit around one of the deuterons and forms a D-M "mesoatom" $0.25 \cdot 10^{-10}$ cm in size. The mesoatom, diffusing between the D nuclei like a neutron, eventually touches down onto another deuteron and forms a D-M-D mesonon[7] (after an amount of time equal to [omission]). Finally, the meson is an unstable formation because, in the process of zero oscillations in a mesonon, deuterons may surmount the potential barrier separating them and a reaction will occur (after a time of [omission-]).[omission]

"The meson is released, and the game begins again.

"By using the Wentzel-Kramers-Brillouin method it is easy to calculate the time [omission] (after having used the experimental probability of a DD reaction at over-barrier energies[8])"

As a result of the estimates he made, Andrey Dmitriyevich concluded that the time of the nuclear reaction in a ddμ mesomolecule is on the order of 10^{-9} s (modern calculations yield precisely the same value). Further, he noted completely correctly that the time of the formation of a "mesonon" from a mesoatom is the time when there is the "most risk" of the process occurring. Having estimated it, Andrey Dmitriyevich took the radiation transfer of a meson in a field of two deuterons as an example of the formation mechanisms of a "mesonon," but he failed to notice that a conservation approach with the transfer of the mesomolecule's bond energy to the atomic electron[9] is much more likely. On this basis, he concludes that "a meson-catalytic reaction is impossible with conventional 200 mesons." This may explain why, up until the experimental discovery of muon catalysis in 1956, Andrey Dmitriyevich did not do any more work on this problem.

As has already been noted, Andrey Dmitriyevich did this work fresh on the trail of the discovery of $\pi \rightarrow \mu$ decay. Back then the nature of the muon and neutral particle formed along with it had not been established. Moreover, there was no concept of the universality of weak interaction. In this context, in the first part of the work he expresses the thought that the neutral particle formed along with the muon possesses mass and is nuclear-active. It is evident from the text that he is essentially speaking about a π-meson decaying into two γ-quanta. With full justification, Andrey Dmitriyevich emphasizes the important role of such particles in explaining the characteristics of the Auger showers observed in cosmic rays "that were previously considered a classic cascade phenomenon." It is now difficult to understand what mass he proposed ascribing to the neutral pion by proceeding from the observed energy of a "passive" muon in a $\pi \rightarrow \mu$ decay. Another fact is important, however. Discussing the generation of "passive" mesons, Andrey Dmitriyevich hypothesizes that they may occur as a result of the decay of "active" mesons or else be generated in pairs in electromagnetic interactions. Having noted that, in cosmic rays, the second possibility would play an insignificant role when compared with nuclear and decay processes (as in charged particle accelerators), he writes, "It is therefore necessary to emphasize the fundamental value of experiments with electron accelerators, which give us the capability of answering the question of the existence and properties of passive mesons (charged particles that may thus be generated in pairs)."[10]

Andrey Dmitriyevich's words sound truly prophetic if one recalls that τ-leptons—charged particles that were, in Andrey Dmitriyevich's terminology, also passive—were discovered almost 30 years later in cross electron-positron beams (surely he could not have suspected their possibility in 1948). Andrey Dmitriyevich's comment about the promise of electron accelerators is just one of the examples of the scientific creativity of his attempt to tie his theoretical results with experimental research that was so characteristic of him. The point is that it is precisely at that time that the Physics Institute imeni P. N. Lebedev was equipped with an electron synchrotron. Another famous report by Andrey Dmitriyevich entitled "Effect of Scattering on the Beam Intensity in a Synchrotron" (dated 1948) confirms his direct interest in its creation.

But let us return to muon catalysis. Under conditions of secrecy, Sakharov's work on this problem remained unknown even to many of those working alongside him. Zeldovich, who published a work about the possibility of muon catalysis of nuclear reactions in deuterium in 1958, did not know of it either. As as already been said, Andrey Dmitriyevich himself returned to the problem after the 1956 discovery of a muon-induced pd-synthesis reaction (i.e., it was precisely this reaction that Frank had discussed. This discovery brought with it a whole series of questions that Zeldovich and Sakharov collaborated on in 1957.

Strictly speaking, muon catalysis was discovered "accidentally." Alvarez and his group were using a hydrogen-filled chamber to study the interaction of negative K^--mesons. Specifically, this research resulted in the discovery of resonances that play an important role in the construction of adron systematics (this work was later awarded a Nobel Prize). The bubble chamber was irradiated with K-mesons from an accelerator, and the negative μ-mesons that had flown into it were only an undesirable background. Nevertheless, the researchers noticed that several cases of the stopping of muons looked most unusual. Specifically, several millimeters from a muon's stopping point there began a new muon track confirming a muon energy of about 5.5 MeV. It also seemed as if the muon had decelerated in the chamber, stopped, and then suddenly got new energy from somewhere. Then came the idea that the muon received the energy as a result of a pd-synthesis reaction (for which just such an energy release is characteristic) proceeding in the pdμ mesomolecule. According to Alvarez's recollections, E. Teller expressed this hypothesis almost immediately. He also provided an explanation for the beginning of the "gap" between the muon's stopping point and the beginning of the new track. The stopped muon forms a pμ mesoatom with the proton. It is diffused in the matter until it encounters a deuterium nucleus. As a result of this encounter the muon moves to the deuterium's nucleus and forms a dμ mesoatom that acquires additional energy and surmounts the specified distance without (by virtue of its neutrality) leaving a trace in the chamber. After deceleration, a dμ mesoatom forms a pdμ mesomolecule together with the hydrogen nucleus. Nuclear synthesis occurs in it. Further experiments with an elevated concentration of deuterium confirmed this hypothesis.

The exact likelihood of "recapture" of the muon by the deuteron at the proton, whether we were observing a process and whether the concentration of deuterium was as low as in natural hydrogen, and the explanation for the high likelihood of transfer of the energy released in the $p + d \rightarrow {}^3He$ reaction to the muon in the pdμ mesomolecule were all unclear, however. Estimates made in a joint work by Zeldovich and Sakharov[11] answer all these questions. It should be noted that these estimates were made exceedingly gracefully and simply—essentially solely from dimensionality considerations. They turned out, however, to be much more precise than the approximate calculations made independently by other authors.

Andrey Dmitriyevich subsequently showed unwavering interest in the problem of muon catalysis. In 1958 he sent V. B. Belyayev and B. N. Zakharyev, his colleagues at the Joint Institute of Nuclear Research (Dubna), a thick stack of pages with calculations of the potentials of the interaction of nuclei in a mesomolecule that were needed when calculating different characteristics of mesomolecules. This example confirms that Andrey Dmitriyevich did not avoid "dirty work" in his scientific activity.

In 1963, having learned from Zeldovich about the new aspects of mesomolecular processes and their link with the experimental study of processes of the weak interaction of muons, Andrey Dmitriyevich agreed to be the official opponent in the doctoral dissertation defense of one of the authors of the present article (S. S. Gershteyn). With responsibility that is rarely encountered now but was characteristic of Andrey Dmitriyevich, he carefully studied the respective work and sent his response more than a month and a half before the defense. The comments he made later played a big role in refining the calculations of mesomolecular levels that led, specifically, to the discovery of a highly excited level in a dtμ mesomolecule.[12]

Andrey Dmitriyevich had time to live until the time when an entire field of physics that is now studied in 50 laboratories in 14 countries throughout the world and on which international conferences are held and a special journal is published developed out of his small (only five pages) closed report. Indeed, "manuscripts do not burn."

Footnotes

1. Zeldovich, Ya. B., and Sakharov, A. D., ZhETF, Vol 32, 1957, pp 947-949; Zeldovich, Ya. B., and Gershteyn, S. S., USPEKHI FIZ. NAUK., Vol 71, 1960, pp 581-630.

2. For example, J. D. Jackson, the first to examine the cycle of meson catalysis in a mixture of deuterium and tritium in 1984, said at one conference that he knew of Sakharov's report from a Western physicist who had visited the USSR and heard about Sakharov from a Soviet colleague who had heard of him from his teacher who had in turn heard about the report from his teacher, who had himself seen the report (this chain decodes as J. Fiorentini - L. I. Ponomarev -S. S. Gershteyn - Ya. B. Zeldovich).

3. The authors gratefully mention the participation of V. Ya. Faynberg, who readily responded to our request and found the report in the archives of the Physics Institute imeni P. N. Lebedev, as well as the participation of L. V. Keldysh, who helped in getting it declassified quickly.

4. The story of the unplanned discovery of the muon in Yukawa's search for particles, i.e., the pion, was repeated in the mid-seventies when the τ-lepton—a representative of the third generation of leptons (the electron belonging to the first generation and the muon belonging to the second)—was unexpectedly discovered during the search for mesons containing the charmed c-quark.

5. In the copy of the report discovered at the Physics Institute imeni P. N. Lebedev there are omissions of formulas and some estimates.

6. Undoubtedly, this omission corresponds to a reference to the article by Ch. Frank in NATURE (Vol 160, 1947, pp 525-527).

7. So Sakharov terms the mesomolecule ddμ. Most likely, a letter has been omitted here, and one should read mesoion (instead of mesonon), which is semantically closer to the object under examination than is the now-accepted term "mesomolecule." The designation D-M-D emphasizes the fact that the meson (M) binds two deuterium nuclei (D).

8. The words "above-barrier energy" are imprecise. In reality, as follows from what comes later, Andrey Dmitriyevich made correct use of the experimental data on a "below-barrier" dd-reaction at energies on the order of 10 keV. It would be more precise to say "for accelerated deuterium nuclei."

9. Ya. B. Zeldovich drew this conclusion in 1954 (DOKL. AN SSSR, Vol 95, 1954, pp 493-496).

10. Andrey Dmitriyevich evidently attributed special significance to this statement because the phrase is underlined in the report.

11. Zeldovich, Ya. B., Sakharov, A. D., UKAZ. SOCH.; Zeldovich, Ya. B., Gershteyn, S. S., UKAZ. SOCH.

12. We are intentionally passing over to the subsequent development of muon catalysis and its possible practical applications since this theme has already been discussed in detail in PRIRODA. See Ponomarev, L. I., "Muon Catalysis of Nuclear Synthesis Reactions," PRIRODA, No 9, 1979, pp 8-20; Petrov, Yu. V., "Hybrid Nuclear Reactors and Muon Catalysis," PRIRODA, No 4, 1982, pp 62-72; and " 'Cold Synthesis' or Third Way of Producing Nuclear Power," "Budushcheye nauki" [Future of Science], No 21, Moscow, 1988, pp 33-58.

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Symmetry of Universe

917F0007L Moscow PRIRODA in Russian No 8, Aug 90 pp 56-59

[Article by A. D. Sakharov; article is a section in an article that was originally published in BUDUSHCHEYE NAUKI in 1968 (pp 74-96) under the title "Symmetry and Laws of Conservation"; first five paragraphs are introductory note by I. G. Virko]

[Text] It began in 1966 with a small article by A. D. Sakharov in the journal USPEKHI FIZICHESKIKH NAUK [Progress in Physical Sciences] entitled "Explosively Driven Magnetic Field Generators" about the production of ultrastrong magnetic fields by using an explosion.[1] Having received the approval of the chief (Ye. B. Etingof, the editor-in-chief of the weekly BUDUSHCHEYE NAUKI [Future of Science], for which I worked at the time), I got Andrey Dmitriyevich's home phone number from some physicists with whom I was acquainted. Phoning him, I asked him to write us an article developing this theme. Andrey Dmitriyevich said that as far as he was concerned the subject had been exhausted and was no longer of interest to him but that he was prepared to write an article on the subject of cosmology.

And after some time he did so. I will say directly that the article turned out to be very ponderous. I had to visit Andrey Dmitriyevich's home several times (his old apartment alongside the Kurchatnik), where I tried to help him make the text somewhat more popular. I was hardly able to do so: I was unable to "grasp" more than half of what Andrey Dmitriyevich told me although I humbly bowed my head as a sign that at the time I had already understood everything for a long time.

On one of the days when I arrived at the editorial office somewhat later than usual I was informed that Sakharov's chauffeur had brought me the final version of the article. From the "chauffeur's" description I understood that it had been Andrey Dmitriyevich himself—he was not how my colleague pictured the father of the Soviet hydrogen bomb.

Those who kept this issue of BUDUSHCHEYE NAUKI, which has since become a rarity, have certainly noticed that 22 of the 24 articles included in it are prefaced by photographs and concise biographies of the authors. Andrey Dmitriyevich and I. V. Bestuzhev-Lada, the now-famous futurologist, were "not so lucky." Here is what happened. When I asked Andrey Dmitriyevich for a photograph he said that he would evidently have to get permission from the second department in the "Slavskiy system," and there were no photographs of his except, it seems, for a photo taken at the General Meeting of the USSR Academy of Sciences.

But could I find the telephone number of the second department of the USSR Ministry of Middle Machine Building, the address and phone number of which are not in a single book! The chief was drawn into the search, and the phone number was found. The answer was brief, however. They did not recommend it. This is how Ye. B. Etingof reconstructs the conversation, "Excuse me, but you are not forbidding the article! And so it turns out that 23 have a portrait and the 24th will not?" "It is your affair," came the response, but we do not recommend it." The way out that was found was a decision to "de-face" some other author. And it turned out to be I. V. Bestuzhev-Lada.

Modern physics has established a number of "laws of conservation" of the number of particles classified as baryons (the collective term for protons, neutrons, and their "excited" states), leptons (electrons, positrons, and neutrinos from a β-decay), and mu-leptons (mu-mesons and mu-neutrinos). In all transformations of elementary particles the total number of baryons minus the sum of the antibaryons, the so-called baryon charge n_b, is maintained. The lepton charge n_l and mu-lepton charge n_μ are determined analogously. All of these "charges" are analogous to an electrical charge n_e from the standpoint of their "arithmetic" nature (the sum of the positively charged particles minus the sum of the negatively charged particles).

The universe as a whole is undoubtedly neutral with respect to electric charge. But what about with respect to the baryon and lepton charge? If the baryon charge of the universe is equal to zero, this means that half of the galaxies consist of antimatter—antiprotons, antineutrons, and positrons. At present there are no observational data that would confirm or refute this viewpoint.

Antimatter is completely identical to matter from the standpoint of both its gravitational properties (its energy is positive!) and the nature of its electromagnetic radiation. The matter may be resolved by a neutrino radiated as a result of intrastellar thermonuclear reactions or... [as received] by direct contact (annihilation of 0.3 g antimatter with 0.3 g matter yields the effect of the explosion of an atomic bomb[1]).

In the hot mode, the currently existing number of "heavy" baryon particles is 10^8 times less than the number of photons. As we have already said, at the ultrahigh temperatures at the initial moment, all sorts of particles were represented in equal quantity. Perhaps there existed some processes of spatial separation of matter from antimatter that resulted in one hundred-millionth of all of the heavy particles avoiding annihilation when the temperature fell? Swedish scholars Alven and Klein hypothesize that such separation processes were possible in the presence of very strong gravitational and magnetic fields in the initial stage of the universe's development. In their opinion, particles and antiparticles separate by moving without collisions in homogeneous magnetic and gravitation fields. This hypothesis is, with difficulty, linked with the gigantic densities of matter proposed in the past in accordance with the theory of an expanding universe. In reality, motion without collision is only possible when matter has sufficient lack of density.

In our opinion, there is no basis for hypothesizing the existence of antigalaxies or other macroscopic masses consisting of antimatter. That is, we feel that n_b does not equal zero. The explanation for this "baryon asymmetry" must be sought by way of deeper analysis of the internal properties of the symmetry of elementary particles and conservation laws.

The departure point for the author's discussions is the aforementioned hypothesis of quarks and the disturbance of selected symmetry properties during transformations of elementary particles.

According to Gell-Mann and Zweig, baryons consist of three quarks, while antibaryons consist of three antiquarks. The author of the present article ascribes a "combined" baryon-muon charge of $n_k = +1$ to quarks and the mu-plus-meson (μ^+) and mu-antineutrino (ν_μ^-) embedded in them. He ascribes a charge of $n_k = -1$ to antiquarks and the mu-minus-meson (μ^-) and mu-neutrino (ν_μ). It is hypothesized that only n_k is a strictly maintained quantity, while n_b and n_μ may have several values, i.e., quarks may be transformed into antimuons (μ^+ and ν_μ^-) or, to say the same thing differently, one baryon is transformed into three muons. Let, for example, a quark q be transformed into a mu-antineutrino, i.e., $q \rightarrow \nu_\mu^-$. The combined charge in this reaction is preserved—there is unity on the right and left. Similarly, the baryon charge is equal to ⅓ for the quark (left) and to 0 for the mu-antineutrino (right). It is easy to verify that the mu-lepton (muon) charge is not preserved either.

In accordance with the hypothesis of a connection between conservation laws and force fields, the universe is neutral with respect to the strictly preserved charge n_k, and the formation of a small excess of matter over antimatter is simply the result of the asymmetrical distribution of this charge between baryons (quarks) and mu-leptons. In the initial burning "bowl," particles and antiparticles were formed from neutral matter M (photons, neutral pairs, etc.) in the following reversible reactions:

$$3\bar{q}+\mu^{+}+2\bar{\nu}_{\mu}\rightleftarrows M\rightleftarrows 3q+\mu^{-}+2\nu_{\mu}.$$

Here 3q designates the three quarks forming a proton, and $3q^-$ designates three antiquarks forming an antiproton. We assume that the yield of these reactions is shifted to the right in favor of matter. As the universe expands, there is an annihilation of baryon-antibaryon pairs, leaving a small excess of baryons. The asymmetry in baryons leads to a similar asymmetry in leptons and, finally, to conservation of the total lepton charge.

Thus, the total average combined charge n_k and lepton charge n_l are each equal to zero; the distribution of these charges by "types" of particles differs for particles and antiparticles. In one cubic centimeter of the universe there is an average of the following (arbitrary numbers): baryons, 10^{-5} (80% are protons); antibaryons, 0; mu-neutrinos, $125 + 3 \cdot 10^{-5}$; mu-antineutrinos, 125; electrons, 0.8×10^{-5}; positrons, 0; neutrinos, 75; antineutrinos, $75 + 0.8 \times 10^{-5}$; photons, 500; and μ^+ and μ^- mu-mesons, 0. The positive electric charge is thus concentrated in the protons, the negative charge that is equal to it with respect to absolute value is concentrated in the electrons ($n_e = 0$ as it should be), the positive combined charge is concentrated in the baryons, the equivalent negative charge is concentrated in the excess of mu-neutrinos ($n_k = 0$), the positive lepton charge is concentrated in the electrons, and the negative charge is concentrated in the excess of antineutrinos ($n_l = 0$)[2].

The disturbance of the symmetry of the distribution of charges between particles and antiparticles is, according to our hypothesis, a gigantic manifestation of the disturbance of several types of symmetry in transformations of elementary particles that was discovered in 1956-1964. Before 1956, the theory of elementary particles knew three types of symmetry: 1) P-symmetry, which expresses the identity of processes observed in nature and in a mirror; 2) C-symmetry, which expresses the identity of processes occurring with particles and antiparticles; and 3) T-symmetry, which expresses the possibility of the reversal of mechanical processes (i.e., if the process $A^{\rightarrow} \rightarrow B^{\rightarrow}$ is possible, it is equally likely that the process $B^{\leftarrow} \rightarrow A^{\leftarrow}$ can occur, with this type of reversal frequently being called a time reversal and with the arrows indicating the direction of each particle's motion, i.e., its speed and pulse, back and forth). The theoretical discoveries of Li, Yang, Landau, and other theoreticians

(1956), which were confirmed by a number of brilliant experiments, showed that in some processes (for example, in a β-decay) P- and C-symmetries are not observed apart from one another: so-called PC-symmetry is observed, which is to say that a process observed in a mirror may only occur with antiparticles (but not particles).

Thus, in the experiment of Garvin, Lederman, and Weinrich that established a μ^+-meson decaying into positrons, they are emitted primarily in one direction in accordance with the direction of their "internal" rotation. In the case of mirror reflection (physics generally refers to reflection in three mutually perpendicular mirrors), however, the direction of the rotation remains unchanged, and the direction of the positrons' emission reverses its sign, i.e., it becomes the same as the direction of the emission of electrons during the decay of a μ-meson with the same direction of internal rotation. An analogous situation has been discovered in an experiment by the American researcher Wu based on the decay of cobalt nuclei polarized in a magnetic field.

These discoveries did not shake T-symmetry. The blow to it was inflicted by a surprising discovery by the American physicists Christenson, Cronin, Fitch, and Torly, who observed the decay of a long-lived neutral K_2-meson into to π-mesons (1964). The probability of this process is very low—250,000 times less than the probability of an analogous process for a short-lived K_1-meson, and it could not be observed for a long time. Why then did so little-noticed an effect have such important consequences?

As is known, in optics the intensity of light is defined as the square of the amplitude of the light wave. In a number of interference effects it is the amplitudes rather than their squares that are added. Quantum mechanics extends the principle of interference to mechanical phenomena. A clear example of the principle of interference was the theory of neutral K-mesons created by Gell-Mann and Pays. The observed states of K-mesons are looked upon as the interference of a K^0-meson and its antiparticle. If T-symmetry is valid, the phases of this interference can either coincide or be opposite one another. A graphic example is that of two bicyclists moving at an equal speed around a circular track, with neither overtaking the other. There is T-symmetry if they are at one point on the track or at opposite points.

According to Gell-Mann and Pays, interference is extended to two types of decay of K-mesons. If the phases of this interference coincide exactly in one of the types of K-mesons (the K_2-meson) and are exactly opposite in the other type (the K_1-meson), decay into two π-mesons turns out to be completely forbidden in the first case, whereas in the second case this decay is entirely permissible (subtraction and addition of amplitudes).

The experimentally discovered decay of a K_2-meson into two π-mesons showed that there is no exact subtraction of amplitudes, i.e., the phases do not coincide exactly. This means that it is as if the states of a particle and an antiparticle are shifted relative to one another in time, i.e., there is a violation of T-symmetry and C-symmetry, with only combined TC-symmetry being preserved. (One of two bicyclists overtakes the other. If we change the direction of the motion, the bicyclist's relative location is maintained only in the case where they simultaneously change places, i.e., TC-s.) Combining this fact with the violation of C- and P-symmetry, physicists assume that universal symmetry, which applies to all physical processes, is "supercombined" CPT-symmetry.

The theory of an expanding universe provides the natural realization of this supercombined symmetry—we can assume that the state of the universe before the moment of infinite density is an exact copy of its state after this moment but with the replacement of particles by antiparticles and with the replacement of all spatial configurations of particles by their mirror images in the "beginning" of the coordinates. This pattern gives a noncontradictory answer to the first question of our article as to the state of the universe before the moment of maximum density. Its state when $t = 0$ must be assumed to be neutral. And this is our main hypothesis regarding CPT-symmetry of the universe.

Figure 1 is a schematic depiction of the transformations of elementary particles. The letter M designates hypothetical neutral particles (introduced into examination by the Soviet scholar Markov) possessing a mass on the order of the "gravitation unit of mass" $m_0 = 2 \times 10^{-5}$ g. Markov called such particles "maximons." Figure 1 shows that, as the universe expands, the antiparticles existing before the moment of maximum density merge into neutral maximons (for example, an antiproton merges with three antimuons: $p^- + \mu^+ + \nu_\mu^- + \nu_\mu^- \rightarrow M$), whereas, after the moment of maximum density, the maximons decay into protons and muons: $M \rightarrow p + \mu^- + \nu_\mu + \nu_\mu$. What happens at the moment of infinite density is only schematically depicted in Figure 1. To tell the truth, we essentially have very little understanding of such processes. Following the English scholar Milne, we will assume that at this moment the maximons somehow pass through one another without interacting (like the Martian and Earthling in Ray Bradbury's fantastic story).

Milne did not feel that the reflection he examined replaces particles with antiparticles; however, after experiments showing the absence of preservation of symmetry during simple reflection, such substitution (C-reflection) is mandatory. The spatial arrangement of particles, as is evident in Figure 1, undergoes mirror reflection, i.e., P-reflection. In the "reflected" world when $t < 0$, all processes occur in "reverse order" as compared with when $t > 0$, i.e., T-reflection. In general, the result is a supercombined CPT-reflection. It is understood that this reversal of the course of physical processes has an exact, absolute nature and is extended to all processes: the decay of particles corresponds to the

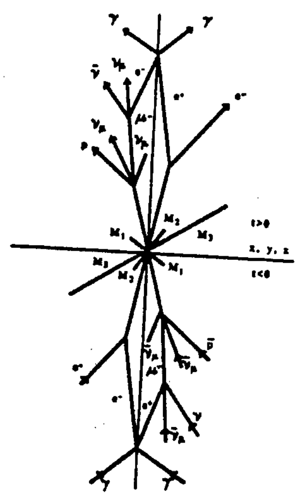

Figure 1.

reverse process of merging or synthesis, heat is transferred from a colder body to a warmer one, older people become younger, etc. But the inhabitants of the "reflected" world (consisting, to say it in words, of antimatter and having a heart with a right side) cannot fundamentally change all these disorders. In fact, THEY are WE (or WE are THEY) since, with a precision to the arbitrary determination of the sign of time, arbitrary difference between right and left, and arbitrary difference between matter and antimatter, the reflected world is no different from our own.

The "doubling" of physical reality that takes place should not scare us any more than does the "doubling" of the number of people in a room when a mirror is added.

How then does the different distribution of particles and antiparticles by type occur as the universe expands? The author cannot provide an exact answer to this question; he does, however, assume that the problem lies in the violation of T-symmetry and CP-symmetry (simply combined rather than supercombined) when particles with large mass are transformed. According to existing ideas, the disturbance of T- and CP-symmetry in the decays and reactions of elementary particles results in different probabilities of the formation of particles and antiparticles when the starting material is neutral. But this would also result in an asymmetry in the number of baryons and antibaryons were it not for the introduction of another baryon charge "reservoir" in the form of muons, thereby introducing the possibility of violation of the law of baryon charge conservation. Our hypothesis is thus as follows. It has been proposed that all effects and bodies are, before the moment of maximum density, an exact mirror copy of phenomena and that, after this moment, there is a replacement of particles by antiparticles and a change of the direction of processes' course (CPT-symmetry of the universe). At the moment of maximum density all particles are exactly neutral, and the occurrence of the baryon asymmetry of the universe is related to the fact that the processes of the decay of particles and antiparticles are somewhat different (a violation of CP-invariance). Furthermore, according to the author's hypothesis, a baryon charge is not a quantity that is maintained exactly (one baryon may be transformed into three muons).

We called this article "Symmetry of the Universe" in view of the author's natural weakness for his hypothesis. But even if this hypothesis is not true in this concrete instance, the title should focus the reader's attention on the importance of discovering the explicit and hidden laws governing the symmetry of the world around us.

Footnotes

1. After having received radio signals from inhabitants of another galaxy, we would be able to find the sign of its baryon charge if they could figure out how to communicate about those decay reactions that were different for a particle and antiparticle (for example, the decay of a K°-meson is different from than of a K° antiparticle). This difference is a manifestation of a violation of CP-invariance.

2. By the irony of fate, we now have a better idea of the number of neutrinos and μ-neutrinos based on just-discovered thermal radiation than we do of the number of "ordinary" protons and neutrons. While most of the mass of the universe consists of μ-neutrinos, the total number of baryons is only a tenth of that amount.

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Inordinate Questions—Bold or Reckless?

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[Article by A. D. Linde, doctor of physical and mathematical sciences, Physics Institute imeni P. N. Lebedev, USSR Academy of Sciences, Moscow]

[Text] Each culture, science, and country has questions whose very discussion is inappropriate in certain epochs: the existence of god, the correctness of the party line, the four-dimensionality of space-time, etc. One of A. D. Sakharov's main distinctions that appeared with singular clarity in his political activity as well as in his scientific work was his lack of fear to ask a question that is "not supposed to be" discussed for some reason.

At the end of the sixties the main structure of cosmology seemed already completed. The theory of a hot universe reigned. Everyone believed that, like a hot sphere, the universe arose from singularity 10 to 15 billion years ago and then expanded as it gradually cooled. Only a few questions lightly clouded cosmologists' peace of mind: What was there before the universe arose? Why is there not antimatter in it? Why is it so uniform on large scales? How could it happen that all of its different parts began to expand at the same time if there was no physical possibility of synchronizing this process. However, all these questions looked metaphysical, and there were previously prepared answers to all of them that, like an analgesic, while not providing cure, eliminated the pain. It was said that solutions to Einstein's equations should not be continued to singularity and therefore that attempts to understand what happened before the beginning of the universe were senseless. Discussing the remaining questions seemed just as inappropriate because they related to the initial conditions in the universe. For example, to explain the existing excess of matter over antimatter (baryons over antibaryons) it was sufficient that at temperatures exceeding the mass of a proton (about 1 GeV), i.e., in the earliest stages of the universe's evolution, the relative excess amounted to only 10^{-9}. When the universe cooled, the baryons and antibaryons were annihilated, and the initial insignificant asymmetry between them served as the source of all matter in the universe remaining after the annihilation.

What could be wrong with such an idea? Of course, it seemed somewhat strange that the initial asymmetry equaled not 0.5, or say 0.1, but rather 10^{-9}. But the cosmologists calmed themselves. It had evolved that way from the very beginning. The universe is alone, and it is senseless to discuss why this excess was so small. The universe is simply made that way. There is no sense in discovering why parallel lines do not intersect or why the universe's total entropy exceeds 10^{87}....

Sakharov's 1967 work made the first breach in physicists' coolness regarding such "metaphysical" questions.[1] In it he showed that the asymmetry of matter and antimatter may be explained if one assumes that nonequilibrium processes with a violation of CP-invariance (and C-invariance) as well as a violation of the law of baryon charge conservation occurred in the early stages of the universe's evolution.

In 1967 the idea that a baryon charge could not be conserved seemed implausible, and advancing similar ideas in order to eliminate a "tiny imperfection" of the world seemed unfeasible. For many years, an interesting work by V. A. Kuzmin[2] written 3 years later was the only continuation of Sakharov's idea. Only in 1976, when unified theories of strong, weak, and electromagnetic interactions had been proposed, did it become clear that a baryon charge can in fact not be conserved and our previous certainty in the stability of the proton did not have sufficient grounds.

In that year Andrey Dmitriyevich presented a report at the seminar of the theoretical department of the Physics Institute imeni P. N. Lebedev regarding the work of Y. S. Pati and A. Salam, in which the first version of a unified theory of weak, strong, and electromagnetic interactions was formulated. During the report he spoke about the fact that, within the framework of similar theories, it was fully possible to realize the scenarios of baryon generation proposed in his 1967 work. All this seemed curious, but no one dropped his problems and began working in this direction.

The break in physicists' mood came in 1978-1979 when dozens of works on this theme appeared. Most of the authors did not know of Sakharov's article, and as later became clear, many of these works turned out to be incorrect. Their authors did not consider that, as Sakharov had established, in processes with nonconservation of the baryon charge CP-invariance must simultaneously be violated and they must be nonequilibrious.

By the end of 1979, after the important work of S. Weinberg, the features of the mechanism of the occurrence of baryon asymmetry of the universe became clear, and many understood that the discovery of this mechanism was the most important achievement of the theory in 15 years.

However, specific models of the generation of baryon asymmetry turned out to be rather complex, and the initial enthusiasm began to wane under the load of doubts: is this all really necessary? The long-range significance of the discovery of the mechanisms of baryon synthesis was only realized several years later when it turned out that, without it, constructing a sequential theory of the universe's evolution would likely be impossible.

In 1978-1979 it became clear that the difficulties with the standard theory of a hot universe were arising in attempts to reconcile it with the modern theory of elementary particles (problems of monofields, domain walls, gravitinos, etc.). The so-called theory of an inflating (swelling) universe not only made it possible to eliminate the aforementioned difficulties but also to solve a number of other problems. It became possible to understand why the universe is homogeneous and isotropic on large scales and why its different regions began expanding nearly simultaneously, as well as why its spatial geometry is close to euclidean, why its total entropy is so great, etc. The main element of the inflation theory is the extremely fast (in many models exponential) expansion of the universe at the very earliest stages of its evolution. In the inflation stage, however, the density of baryons in the universe decreases to an insignificant quantity—tens of orders of magnitude smaller than its current value. The only possibility of obtaining a sufficient amount of baryons within the framework of "inflation" cosmology is to use the mechanism of baryon generation after the inflation stage.

Today it seems very difficult, and even impossible, to construct a sequential cosmology theory without including something similar to inflation. If this is so, the mechanism of the formation of baryon asymmetry by the universe is no longer an interesting theoretical possibility but rather a completely necessary component of modern cosmology.

Thus, it took 11 years (from 1967 to 1978) to assess the importance of Sakharov's idea about the generation of baryon asymmetry by the universe and the possibility of nonconservation of a baryon charge, and nearly the same amount of time passed again before its true significance for the development of cosmology theory was realized. Many of Andrey Dmitriyevich's ideas met a similar fate.

A significant portion of his last works on cosmology are related to the problem of singularity and "the arrow of time." We now know that time only "flows" forward, that entropy grows, and that the universe is expanding. Are not these facts connected with one another? Cannot time return again, either during maximal expansion of the universe or else (and more likely) in singularity when space-time disappears and the general laws of physics cease to operate? Why do we think that our space-time has three spatial measurements (or even more so, if a portion of them are "hidden," how is it predicted in multidimensional theories) and only one time direction. And what would happen in the universe without time directions or where there were two or three directions of "time." Is it possible that we live once in such a universe, but we do not know this because some time directions are also hidden and we can move along them? What if our universe consists of many regions that differ from one another with respect to their time dimension, method of "compactifying" space-time, and the number of time coordinates?

Was it boldness or recklessness to ask such questions and hope to answer all of them? For Andrey Dmitriyevich it was neither one nor the other. He simply understood that such problems exist, could not but investigate them, and not but try to find a solution for them. That is the way he was in his scientific work and in his other life manifestations.

Footnotes

1. Sakharov, A. D., PISMA V ZHETF, Vol 5, 1967, p 32.

2. Kuzmin, V. A., PISMA V ZHETF, Vol 12, 1970, p 335.

3. Weinberg, S., PHYS. REV. LETT., Vol 42, 1979, p 850.

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How Sakharov Was Misunderstood

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[Article by B. L. Altshuler, candidate of physical and mathematical sciences, Physics Institute imeni P. N. Lebedev, USSR Academy of Sciences, Moscow]

[Text] Revolutions in ideas about reality are marked by the arrival of a genius whose ideas change the entire system of generally accepted concepts and generally are not understood initially or even given a hostile reception. We were contemporaries of a man who completed such revolutions in consciousness for all time and who transformed not only consciousness but also reality itself. It is in this that I see the "miracle of Sakharov." This was just how I perceived Andrey Dmitriyevich's activity for the past 20 years, and this is the vision that I will try to substantiate.

In both science and social activity Sakharov's method of thinking was identical. In science, however, everything proceeded "with detachment." Proceeding from some general and rather indisputable idea, he drew specific conclusions. And it was this transition—from the general to the specific and through details to the solution of the entire problem—that was understood by virtually no one. Only later did it become clear that he was proceeding from a general premise.

* * * *

Sakharov's old and perhaps most curious, cosmology idea was the hypothesis of CPT-symmetry of the universe: nothing should change during the simultaneous replacement of particles by antiparticles (this transformation was designated by the letter "C"), mirror reflection ("P"), and time reversal ("T"). The idea is very general, but it follows from this idea that in the history of the universe there was a moment when all charges, including the baryon charge, equaled zero. But why do we now observe a world consisting only of matter, i.e., with a gigantic excess of baryons over antibaryons? This cannot be understood without rejecting the absolute law of conservation of a baryon charge, i.e., without rejecting the notion of the absolute stability of the proton. The entire chain of discussions was obvious to Sakharov back in 1967; however, the idea only received general recognition 12 years later, which surprisingly coincided with the time of his deportation to Gorkiy. Who knows? Perhaps this saved Andrey Dmitriyevich's life. (In the first weeks after 1980, among other abuse, the newspapers wrote that Sakharov had degenerated as a scholar. The entire nature of this clear campaign made one think that his exile was only the first step. In those days theoreticians at the Physics Institute imeni P. N. Lebedev tried to bring the authorities information about the extensive international recognition of Sakharov's pioneering contribution to solving the problem of the baryon asymmetry of the universe. An open "Letter to the United Nations" by a group of Soviet rights activities on this theme was sent independently. Somehow or another, but after the the U. S. Academy of Sciences announced a boycott of the Soviet Academy in the beginning of March, a very high decision was made to "leave" Sakharov at the Physics Institute imeni P. N. Lebedev, his associates from the theoretical department were permitted to visit him in Gorkiy, and the propagandistic record was replaced by a more moderate one.)

Yet another conclusion must follow from the concept of CPT symmetry of the universe: the existence on the time axis of the turning point of the "arrow of time." This idea is still in the "incubation" stage. For Andrey Dmitriyevich, however, the course of the discussion was rather unambiguous. The following was the basis of the thesis to which Sakharov persistently held: the "arrow of time" (i.e., the direction of the course of time) is determined exclusively by the growth in entropy and nothing else.

More than once in the past few years I discussed the problem of the "arrow of time" with Andrey Dmitriyevich. And to all my encroachments ("And what do you mean about small, nonstatistical systems in which there is no concept of entropy?" "And how about the delaying potentials in electrodynamics?", etc.), he answered approximately as follows:

"The laws of microphysics are invariant relative to the reversal of time, which means that they cannot single out a specific direction on the axis of time. The second beginning of thermodynamics is the only physics law containing irreversibility (an increase in chaos and entropy), and consequently, only it specifies the 'arrow of time.' You cannot assemble a broken cup from its pieces, and alas a dead person cannot simply be revived because these processes are not very probable. But if only irreversible processes existed in nature, the very idea of the course of time in a specific direction would never have arisen."

All this is evidently rather simple, but from this simplicity Sakharov deduced far-reaching conclusions. Because the observed baryon asymmetry of the universe can be combined with the general hypothesis of the CPT-symmetry of the universe only at the price of rejecting the law of conservation of a baryon charge, so too does combining this hypothesis with the observed irreversible course of time require introducing the idea of the turning point of the "arrow of time." And this is the moment of the universe's minimal, zero entropy, the moment in which there is no concept of "before" and from which time flows forward "on both sides"!

* * * *

Thus, from the most general ideas came specific, nontrivial conclusions and actions. And in everything he showed the highest professionalism. Whether in science, in his activities in defense of rights, or in his deputy activity, Andrey Dmitriyevich worked honorably everywhere, as they say, "reducing everything to intellect." He and only he had to solve the problem. The design had to be worked out, whether it was a bomb, a package on disarmament proposals and human rights, or a series of speeches in defense of a specific person.

On 18 December 1989, the day of Sakharov's funeral, I met Z. Romashevskiy, the Polish activist who, since 1989, had been a deputy of the Polish Seim. He was a physicist who worked at the Physics Institute imeni P. N. Lebedev in the seventies, and in 1979 he came to Sakharov's home on Chkalov Street to establish contacts between Polish and Soviet rights advocates. He came without recommendations, "off the street," so Andrey Dmitriyevich did not know what kind of man was standing before him. How did Sakharov handle the situation: He gave Romashevskiy an hour-long examination in physics. He said that until that time he had never communicated with a physicist on the level of Sakharov. As a result everything fell into its place. Such is the use of professionalism.

And now for more about Andrey Dmitriyevich's professionalism and responsibility. After my speech at the Sakharov lectures (Gorkiy, January 1990), A. V. Gaponov-Grekhov told me about an episode of past years. In the period when attempts were being made to implement the "Kosygin" reform in economics, an information meeting on the problems was held at the Presidium of the USSR Academy of Sciences. Everyone went there essentially to watch, but Sakharov appeared with a detailed plan for economic transformation of the country that was full of statistical data. Of course, nothing came of it, and Sakharov understood well how difficult it is to knock on the authorities' door and be heard much less convince them to change something. But he could not proceed any other way.

He approached this most difficult problem of "knocking until heard and then convincing" professionally—just as he approached any other problem, and he always looked for a constructive solution. One graphic example was his victory in the matter of banning nuclear tests in three media. (Sakharov's idea about eliminating the disputed and then unsolvable question of the "fourth" medium, i.e., underground explosions, was presented to N. S. Khrushchev at the required moment before his visit to the United Nations in 1962.) "For him it was unbearable to realize that some additional number of people—thousands or tens of thousands—would suffer oncological diseases. He was very sensitive," recalls Yu. B. Khariton.[2] But for others, it was "bearable"—not because they were all callous people but simply because man is made that way: his emotional and moral sphere is generally only tuned into what he encounters directly. Moreover, people attributed enormous importance to the problem in question. Why all the concern about these obscure victims of nuclear tests? After all, each year many times more people die in car accidents. Should cars then be banned? This is a standard example of the the difference of the two types "obviousness"—the generally accepted type and the Sakharov type. Andrey Dmitriyevich was really unique in his capability to react sharply to rather abstract things, as well as in his sense of his own personal responsibility for everything that happens.

What are his activity in defense of human rights and his persistence in the fight for each individual person if not extreme "sensitivity"? Indeed, there he worried not about thousands but about single beings.

In the opinion of many (very many), the solid academician did things that were "strange" from no matter where one stood: he stood before court buildings for hours, traveled around the country for legal proceedings, and went hungry. He did all this and more with some sort of pedagogical persistence. But his "re-education" proceeded with difficulty.

Just as the revolutionary theories of Copernicus or Einstein flowed from an "obvious" initial idea, so too was Sakharov's activity (and even his life) based on what I would call two simple principles:

—absolute moral justification of each action; justification from the simplest viewpoint that was common to all mankind and not distorted by any "ideas";

—the need for victory, albeit a small one; the achievement of a positive result by concentrating the maximum effort in the minimum "area" and ultimately at one point.

In and of themselves these principles seem entirely simple. But their consequences are not trivial—for Sakharov the conclusions were absolutely clear and necessary, as, above all, were his actions that to many seemed naive and absurd and that often caused irritation.

* * * *

And in the gravest times Andrey Dmitriyevich always continued studying physics; he evidently generally possessed the capability of thinking about several things at once.

In 1980 Sakharov published three works in the ZHURNAL EKSPERIMENTALNOY I TEORETICHESKOY FIZIKI [ZHETF; Journal of Experimental and Theoretical Physics]: "Cosmology Models of the Universe With Turning of the 'Arrow of Time'," "Mass Formula for Mesons and Baryons," and "Estimating the Constant of Quarks' Interaction With a Gluon Field." In a 1981 report sent to the theoretical physics department at the Physics Institute imeni P. N. Lebedev from Gorkiy, he set forth in detail the fundamental ideas of a new work that was later published in ZHETF under the title "Multisheet Models of the Universe." It discussed models of an oscillating universe, each cycle of which Sakharov termed a "sheet." The report ends with the words: "This work has still not been formulated or finished completely. I intend to do so in the near future. I also hope that the solution of my fiance's problem, which is worrying me, will in the near future make it possible to me to renew my scientific communication with my colleagues from the theoretical physics department at the Physics Institute imeni P. N. Lebedev. Respectfully, A. D. Sakharov."

The report was dated 16 November 1981, directly before the beginning of his hunger strike. As always, everything was precisely planned: the report was written, and it was then possible to proceed to solving another problem. And the fact that this entailed risking his life or that these days could be his last was secondary. The main thing was a positive end result. "It is important to proceed in the correct direction, and if you fall, it is unimportant." To understand this phrase is largely to understand Sakharov.

In May 1982 Andrey Dmitriyevich's wife Yelena Georgiyevna Bonner brought me a letter from him. That spring my family and I were befallen by trouble that in principle should have occurred long before. And Andrey Dmitriyevich responded to it. Omitting the personal portion of the letter, I will present the second, "scientific" half:

"And as far as science is concerned, now (as always) is an unusually interesting time. 'Blessed is he who visits this world....' Combining supergravitation with the GUT [Great Unification Theory], composite models of quarks, leptons, and gluons, the bang in cosmology-....Relative to cosmological ideas of an exponential initial phase. (With or without Linde's modification.) I am still approaching it cautiously (is this old age, perhaps?). It do not understand how, beginning with a gigantic cosmological constant, it is possible to end up with zero in a present-day vacuum. But the main thing is that I want to reject the multisheet model. Well, agreeably, we will wait. The future will show who is right and much else. Fortunately, the future is unpredictable (especially in view of quantum effects) and not determined.

With best wishes. A. S." 10 May 1982.

Let me explain something. Supergravitation is a generalization of the theory of gravitation based on a group of transformations of supersymmetry. These transformations "mix" particles with a whole and semiwhole spin, i.e., particles subject to Bose-Einstein and Fermi-Dirac statistics.[4]

The GUT, or Great Unification Theory, is the theory of the great unification of forces, electromagnetic and strong interactions, within the framework of which the instability of the proton naturally arises, i.e., Sakharov's 1967 hypothesis about the decay of baryons is supported. "The cosmological idea of an exponential initial phase" refers to the so-called models with inflation about which much was being written in the popular literature. The problem of the vanishing (going to zero) of the energy of a vacuum, i.e., the cosmology constant, is one of the central unresolved problems of modern theoretical physics.

I think the words "Fortunately, the future is unpredictable (especially in view of quantum effects) and is not determined" are more than a simple statement of the probabilistic nature of the laws of quantum theory. In both history and in one's personal fate, the future is not only unpredictable but simply does not even exist at any given moment. Different scenarios are possible, including those with directly opposite results. And the result may depend on personal efforts and action (or inaction) now. It is with this sense of responsibility and the impossibility of "drifting" that Sakharov lived.

"The future will show who is right and much else." Of course I would like to know what Andrey Dmitriyevich had in mind. But generally speaking, he did not like riddles. Sometime in 1977, after the arrest of most of the members of the Moscow Helsinki group, I met with Sakharov at the Physics Institute imeni P. N. Lebedev and asked, "What will happen?" He replied, "What is important is what has already happened." Andrey Dmitriyevich was a realist, and when making decisions he tried to base them on facts. And, generally speaking, whatever else happens depends on these decisions. And god forbid, do not make a mistake. This nonsimple problem of choice was a mystery to those who did not pose the problems for themselves that Sakharov posed. He had to make decisions in the most difficult internally conflicting situations. And to take the right step rather than misstep required intuition and some intuitively realized indisputable general principles.

The tragedy of one man—from a simple, everyday point of view it causes compassion, and a desire to help is even greater than when there is information about millions of victims of terror. All of the activity in defense of human rights arose as the result of such movement of the soul, and it set helping specific people as the main practical task. But why should saving one person have such global political, ideological, and geostrategic consequences. Why did the activity in defense of human rights turn out to be so effective? And again everything is brilliantly simple: a system that had exterminated millions of fellow citizens, a system consisting entirely of bans and automatically activating suppression mechanisms does not know how to and cannot yield in anything. There is no such feedback in it. Achieving even the smallest concession is only possible by getting the highest political mechanisms, perhaps even the person at the top of government, to solve the most private problem. And with our centralization, a nonstandard action on the part the highest authority has almost an irrational effect on the system as a whole—disturbing its firm ideological and organizational structures.

Quite recently a scholar who is no longer young and who knew Andrey Dmitriyevich for a long time told me that he nevertheless does not know what the movement in defense of human rights in the USSR (including Sakharov) accomplished. True, they saved several people. But indeed they did not solve global problems. This opinion (which, moreover, is very widespread) is a total misunderstanding of Sakharov and his social and (most importantly) moral position. The ancient wisdom "Kill the man, kill the universe; save the man, save the universe" simply did not exist for my partner in conversation, just as is the case for the overwhelming majority of people brought up in the postrevolutionary years. And how many times did I hear Andrey Dmitriyevich say quietly and as if with uncertainty, but in reality as if he were laying a cornerstone, "I would nevertheless certainly save his life."

He also understood the backward effect of the "small" on the "big." And it was in this direction that he worked for the past 20 years. Indeed each such nonstandard case is really a "little cloud"—a harbinger of a new reality analogous to two well-known "little clouds" on the bright sky of classical physics—just as were Michelson's experiment and the problem of the radiation of an absolutely black body, which led to the theory of relativity and quantum mechanics. "The existence of Sakharov and Solzhenitsyn is a violation of the law of conservation of energy," said Moscow physicists in the beginning of the seventies. It is just this way, i.e., as something absolutely impossible, hard to believe, and even senseless, that dissident activity was perceived. And that kind of attitude remained typical until perestroyka. ●

The revolutions in physics are still outside the field of view of the overwhelming majority of people. Specialists speak of these revolutions with delight. In time they appear in the form of wonderful (or terrible) technical achievements, but without the special baggage of special knowledge these grandiose changes cannot be understood. Moral attitudes and relationships between human beings are another matter, however. There almost everyone understands what is being talked about, and it is generally assumed that everything is understood. And so everyone considers himself a specialist in politics. And it is here in these generally accessible areas that Sakharov and a small group of others working to defend human rights are constantly doing something revolutionary as well as, it would seem, absolutely self-evident.

Kaysin Kuliyev has a line that says "It is easy to love all mankind, learn how to love your neighbor." Andrey Dmitriyevich recalled that Yelena Georgiyevna quoted these words to him more than once. Help specific people. Sakharov wrote a great deal about the effect that Yelena Georgiyevna had on him on this plane. But of course, it was also in him from the beginning.

The Sakharovs were rural priests for several generations. His grandfather, the well-known Moscow jurist Ivan Nikolayevich Sakharov, was the editor of the anthology "Protiv smertnoy kazni" [Against Capital Punishment] at the beginning of the century. His great-grandfather Nikolay Ivanovich Sakharov (1837-1911) served for 20 years as archpriest in the village of Vyyezdnoye (the the Arzamasa rayon), after which he served for nearly 40 years in Nizhniy Novgorod. Here is how Nikolay Ivanovich's daughter Nadezhda Nikolayevna Raykovskaya, younger sister of Ivan Nikolayevich (she was the fourth of 10 children, and Andrey Dmitriyevich's grandfather was the second) remembers him: "He was and remained until the end of his days a kind-hearted and modest man. His prayer book, which he always carried in his pocket, had an inscription on the first page: 'Do not insult anyone.' As I understand it, this meant not to cause anyone grief or sadness....He himself was simple and preferred simplicity....He was buried admirably and somehow particularly well. This unpretentious old man had many spiritual children, and several years earlier the lower city and suburban clergy selected him as their confessor...."[5]

I read these lines and recognize Andrey Dmitriyevich with his very strong immunity against "pride" and "ideas" placed above human rights and needs and, essentially, above life. And there was never anything proud in him, not even a glimmer of a vain feeling from recognizing the exceptional position that he occupied in the world. But there was a sense of responsibility and the importance of his words and actions. "It turned out that my name does not belong only to me, and I must take this into account," he said once in the mid-seventies, simply stating an objective reality.

* * * *

On 2 July 1983, on the eve of the publication in IZVESTIYA of the not-unknown letter of four academicians (a reaction to Sakharov's letter to S. Drell), I received a letter from Sakharov. Here is an excerpt from it:

"With regard to compactification, this hope has not become senselessly fashionable....It occurs to me that the compactification radius is possibly established at some constant value with an allowance for quantum effects, like the radius of a hydrogen atom. I certainly do not know how to solve the problem of the Λ-member (supersummetry?)...."

The letter speaks of unified geometric models in which space-time is not four-dimensional but has a greater number of dimensions. But the "extra" dimensions are not observed. No contradictions of experience arise in the case where the space in these additional directions is closed (compactified) in a sphere with a very small radius. By what is the compactification radius fixed. The theory still does not have an answer for this question. Andrey Dmitriyevich advanced the interesting idea (as far as I know, no one has yet implemented it) of applying the laws of quantum theory to the problem, i.e., examining everything within the framework of quantum cosmology. At the end of the letter was the following about his health and the hopelessness of the situation: "If things could but be different, perhaps." Everything turned out awfully, especially after chapters of N. N. Yakovlev's book appeared in the journal SMENA. And things got worse and worse....

From the moment Sakharov began his involvement in social activity they tried to silence him. But why they did not "shoot" both Sakharov and the entire human rights campaign immediately? Here evidently was a "violation of the law of conservation of energy" about which physicists whispered without understanding that the course of the entire process might depend on the personal initiative and actions of one individual man.

On the stone face of the sovereign
Marching forward without a hitch
Down the steep proud road of glory
Are unnoticed Pockmarks.
(A. D. Sakharov, Gorkiy, Shcherbinki microrayon.)

[Note: The last line of this poem contains a play on the word Shcherbinki, which could refer to both pockmarks and residents of Shcherbinka.]

"On May 25-27 they used the most agonizing and humiliating barbaric method. Again they threw me down on my back on the bed and tied my hands and feet. They put a tight clamp on my nose so that I could only breathe through my mouth....So that I could not spit up the food mixture, they clamped my mouth until I swallowed it. In spite of it all I was still often able to spit out the mixture, but that only drew out the feeding."[6]

Was this an absurd obsession or a sensible fight against a completely real and far-from-fairy tale "evil force"? Such matters are decided not by reason but by some sixth sense and higher knowledge.

The opinion exists that he went hungry and beat his head against the wall, after which M. S. Gorbachev arrived, began perestroyka, and everything resolved itself. The hidden psychological motives of such discussions are entirely understandable. It is the position of a "small man" who is certain that nothing depends on him. Future historians may perhaps still explain what happened—all these improbable and life-saving transformations called "perestroyka" began. I am always trying to prove that Sakharov not only anticipated events but also created a new reality. Truly, this is precisely why the first reaction to his speeches or actions was "Sakharov is not taking reality into consideration." Even many compassionate and thinking people often thought that way early on. Such, for example, was the attitude to his proposal regarding a 50 percent reduction in the army (at a meeting of the forum "For a Nuclear-Free World, for the Survival of Mankind" in 1987) and his calls to replace the sixth article of the constitution (June 1989) and a political strike (December 1989), etc. But Sakharov knew that it was no longer "early," that the situation was exploding, and he made thought work by fighting stereotypes.

Moreover, he knew how to calculate time. I never remember him hurrying or worrying that it was getting late. He simply stopped his conversation at the necessary moment, excused himself, and began to leave. He could see ahead in both everyday life and in more serious matters. Without difficulty he assessed a situation overall, all its participants, and the numerous influencing factors. In essence, this explains the high effectiveness of his actions. It was the same in science. His colleagues recall that, after thinking for several minutes, he could sketch a graph that was later calculated for several months or would immediately come up with the results of very long calculations. In a word, thinking was easy for him.

* * * *

In April 1984 on the eve of the tragic May hunger strike, Sakharov sent a fundamental work entitled "Cosmologic Transitions With a Change in Metric Signature" to the ZHETF that was published in August of the same year.

This work merits special discussion. Its main idea was the possibility of the existence of additional dimensions besides space and time and regions in space-time with a different number of "times." In the eighties several new directions in physics arose that Sakharov considered truly revolutionary. One was the theory of strings (or superstrings)—a unified theory of all interactions, including gravitation. Another was the rebirth of the old (60 years old) idea of Kaluza and Klein regarding the possibility of the existence of additional, albeit very small in size, dimensions. The authors of numerous works on such types of unified geometric models always introduced "extra" spatial dimensions but used only one time dimension—our conventional one. Sakharov hypothesized that the additional compactified dimensions could also be timelike. In subsequent years this type of model was examined increasingly frequently, and the number of references to Sakharov's articles have increased.

In this article Sakharov terms the number of "times" (time coordinates) a "signature" and designates it with the letter σ. In the universe observed by us $\sigma = 1$, but he also hypothesizes the existence of areas that are purely spatial in which there is no time at all, i.e., $\sigma = 0$. For them, Sakharov introduces special designations:

Let us arbitrarily use the letter U (from Universe) to designate the regions of the space-time continuum with $\sigma = 1$; purely spatial regions with $\sigma = 0$ will be designated by a P from the name of the ancient Greek philosopher Parmenides who discussed a world without motion (from Pushkin: "There is no motion said the bearded wise man...."). Andrey Dmitriyevich loved to quote lines of verse.

Quantum transitions, i.e., tunnel transitions with a change in the number of time coordinates that are not described by classical gravitational field equations, are possible between areas with different signatures. In quantum theory any dynamic quantity fluctuates. In quantum gravitation, the metric tensor, which describes (according to Einstein) a gravitation field and the geometry of space-time, is such a quantity. If the fluctuations of a metric are small, changes in both the signature and topology of the Riemann variety are possible, as is the formation of a set of different universes that, generally speaking, are different from ours. Imagine a room filled with soap bubbles ("universes"), a part of which are connected by thin connecting tubes and some having "little arms," i.e., tubes beginning and ending in the same "universe." This is the two-dimensional analogy of what quantum cosmology examines in four or more dimensions. In quantum gravitation it is necessary to consider all possible configurations of this type. Andrey Dmitriyevich proposed also examining tunnel transitions with a change in signature, i.e., with a change in the number of time coordinates.

One of the main parameters of the universe is the energy of a vacuum, or the cosmology constant Λ. In our universe Λ is very small (or equal to zero). Theory is still unable to explain why this is so. There are also other important parameters whose numerical values require explanation. In this matter Sakharov adheres to the anthropy principle, the essence of which he explains in the introduction to his article:

"In 1950-1970 several authors independently hypothesized that, besides the observed universe, there exist an infinite number of "other" universes. Many of them have characteristics and properties very different from "our" universe, because of which structures (atoms, molecules, stars and planet systems, etc.) can arise that support the development of life and reason. This hypothesis eliminates many questions of the type "Why is the world structured exactly the way it is and not differently?" because of the hypothesis that there are differently structured worlds even though they cannot be observed at present. Some authors consider the anthropy principle unproductive and even not conforming to the scientific method. I disagree. I will note, specifically, that the requirement of the applicability of the fundamental laws of nature under conditions that are significantly different from those in our universe may have a heuristic significance for finding such laws. Back in 1917 P. Ehrenfest noted that the fact that the number of dimensions of observable space equals three may possibly be explained by the fact that the power index in Coulomb's law changes in the case of a different number of dimensions and the existence of atoms is impossible. This is certainly an argument in the spirit of the anthropic principle."

Sakharov insisted on the validity of the anthropy principle, although like always, trying to be precise and objective, he noted that not all physicists agree with this. In an alternative approach that arose at the end of 1988 and is still popular and undergoing intense development (the so-called Big Fix, i.e., fixation of the values of all fundamental world constants), all worlds ("soap bubbles") are connected by an infinite number of tubes (mole holes[7]), thanks to which the values of Λ and other fundamental constants are identical in all universes. This approach naturally arises within the framework of quantum cosmology and is based on the existence of several exact solutions of gravitation theory equations. Despite its attractiveness, this approach encounters great difficulties, the main one being the absence of a specific positive result. It has still not been possible to derive a numerical value for one fundamental constant. (The initial "bang" arose from the "prediction" $\Lambda = 0$, but in subsequent works this result is disputed.) The Big Fix thus still remains a dream. Andrey Dmitriyevich, despite his improbable business, was in the flow of events and became interested in this theme.

But let us return to his 1984 work. I will present several concluding paragraphs:

As is known, either the cosmological constant $\Lambda = 0$, or else it is anomalously small (in which case it is surprisingly not in an internally symmetrical state of a "false" vacuum but rather in a state of a "true" vacuum with violated symmetries. The infinitesimality or equality to zero of Λ is one of the main factors ensuring that the universe has existed long enough for the development of life and reason. It is therefore natural to try to introduce the anthropy principle in order to solve the problem of the cosmological constant.

If the small value of the cosmological constant is determined by "anthropologic sampling," it is the result of discrete parameters. In this case, Λ is either exactly equal to zero in some variation or else is extremely small. In the latter case it is necessary to assume that the number of variations of the set of discrete parameters is rather large so that the spectrum of values of Λ in the small of the point Λ = 0 is rather "dense." This obviously requires a large value for the dimensionality K of a compactified space and/or the presence of a complex topological structure (like a large number of "arms") in certain topological cofactors.

In conclusion, we will note that in the space P (let us recall Parmenides, B. A.) it is necessary to examine an infinite number of U-inclusions (for the entire set of trajectories or even for one trajectory). The parameters of an infinite number of them may be as close as possible to the parameters of the observable universe. It may therefore be hypothesized that the number [of universes] [brackets as received] similar to our universe in which structures, life, and reason are possible is infinite. This does not exclude the fact that life and reason are also possible in an infinite number of significantly different universes forming a finite or infinite number of classes and "similar" universes, including universes with a signature different than that of our own universe."

This work was sent to the ZHETF in April 1984, and by May 11 Sakharov was force-fed a preparation that caused him a microinsult. And psychotropic drugs were evidently injected all summer. For nearly a month after his release from the hospital (September 8) he could not and did not want to work, did not approach his desk, and was not interested in the fresh preprints. He later recovered, but from April 16 on there was another hunger strike until October 1985.

* * * *

I will skip that year, a period during which almost nothing was known about Sakharov. In that time theoreticians visited him in Gorkiy twice, in November 1984 and February 1985. Unfortunately, this did little to change the situation. In spring 1985 the United Nations declared Sakharov "missing." At the end of October 1985 the blockade was broken, and Yelena Georgiyevna was finally permitted to travel to the United States for treatment. For half a year Andrey Dmitriyevich lived alone, but afterward in June 1986 Yelena Georgiyevna returned to Gorkiy, and they again were together under conditions of nearly complete isolation. And so it continued until that famed December.

But this was no longer such isolation. Correspondence became possible. (Although Andrey Dmitriyevich later said that a portion of his personal letters in which he wrote of the Chernobyl catastrophe in the summer of 1986 did not reach their addresses.) In that period Sakharov's colleagues traveled to him four times: in December 1985 and in January, April, and May 1986. Andrey Dmitriyevich renewed his scientific work. In 1986 he published an article in ZHETF entitled "Vaporization of Black Miniholes and High-Energy Physics," and in January and March I received two long letters from him:

"...I am very glad that you are in the flow and stream of the great events of our time—superstrings, Kaluza-Klein, etc. With great difficulty I am trying to enter the course of these matters—but my receptivity is no longer the same, and the gaps in my education are terrible. And authors, in a hurry to 'get their ideas on paper' write for the reader who is himself working in this field and knows everything besides the given article. They did not write this way before (I want to say 'in our time' but in reality what is our time?). It seems that the works of the Poles on the string and the subsequent works of Fradkin and Tseytlin are very important, but a great deal is unclear to me because of illiteracy. To me, Witten is almost inaccessible because of difficulties. There is a good selection in the August issue of UFN (six articles), but even there not everything is clear to me, and I cannot read these articles easily, alas...."

Next come very special formulas—Andrey Dmitriyevich often set forth an idea in a purely geometric method of writing the functional of an effect for a superstring. I then showed this letter to Ye. S. Fradkin and A. A. Tseytlin, and as far as I know, the discussions were continued during the theoreticians' visits to Gorkiy.

At the end of the letter, in total "Sakharov" style, he discusses "from scratch" the possibility of describing a two-dimension surface with an arbitrary topology (spheres with arms) by using correct polyhedra on a Lobachevskiy surface, the opposite sides of which are mirror images.

"It seems to me that similar surfaces can arise during compactification...and help (with a large number of arms) realize my idea of the "anthropic" zeroization of the cosmological constant...."

The second letter (dated 9 March 1986) was written after Yelena Georgiyevna had already had her operation. Most of it was devoted to one idea of the spontaneous violation of CP- (so-called "combined") and T-invariance in models of three complex scalar fields. Sakharov then told me about his report "Baryon Asymmetry of the Universe," which he presented at the International Conference Dedicated to the 100th Birthday of A. A. Fridman held in Leningrad in June 1988.

* * * *

After returning to Moscow, he began a tempestuous life that would have been difficult even for someone in good physical condition. I remember how in February 1987 he arrived at the seminar at the Physics Institute imeni P. N. Lebedev looking terribly pale. I asked what happened. "Nothing; I simply did not sleep last night. I was writing my speech for the forum.[8] It is good and calm at night. In the daytime I cannot work no matter what," were the approximate words Sakharov used to explain. "And now there will be no time at all," stated Andrey Dmitriyevich in March 1989 when he was selected a people's deputy. And he was right. But Andrey Dmitriyevich did not shirk the responsibility. He did not try to lighten his life. He continued to participate in scientific conferences and seminars, interested to the end in fundamental problems of physics, and did not want his social loads to sidetrack him from the curb of science.

These notes are not a chronicle. I am writing about how Sakharov was misunderstood and about how his actions and speeches continually revolutionized the situation, leading it out of dangerous "stagnation," destroying the myths, and (as usually happens in such cases) causing doubt or resentment. At the risk of repeating myself, I will recall several known facts of this type related to 1989. There was the speech published in MOSKOVSKIYE NOVOSTI entitled "In the Academy or Nowhere" (February), the interview in Canada regarding "Measures to Prevent Capture in Afghanistan" (February), the series of speeches during the summer tour in Western Europe about the danger of subsidizing the Soviet economy without perestroyka and about falling into euphoria too soon because the USSR is on the brink of civil war, the speech at the second session of the Supreme Soviet of the USSR about the need for a multiparty system (October), and finally the call for a 2-hour political strike (December).

There is yet another illustration of the fact that Sakharov was misunderstood and continues to be misunderstood as well as an illustration of the persistence with which he tried to live in the manner he felt necessary. The key words of the problem were Chernobyl, nuclear power generation, and underground location. Back in Gorkiy in the summer of 1986 Andrey Dmitriyevich wrote a long letter to G. I. Marchuk, president of the USSR Academy of Sciences, in which he insisted specifically on radical reassessment of the entire program for constructing nuclear power plants in order to reorient it toward locating reactors underground. Sakharov's main arguments were that the probability of large accidents cannot be calculated based on probability theory and that they always occur unpredictably. A Chernobyl-type maximum accident must never be repeated anywhere. Recognition of this is the main lesson of Chernobyl. The sole reliable guarantee against a "fool" or terrorist or destruction during an earthquake or war is to locate reactors underground. Andrey Dmitriyevich made an excellent study of the special literature on this problem and knew well the respective financial and engineering problems. But he continued to insist. However, his speeches continued to be unnoticed, and he well understood why. Too many billions had already been invested, and changing the entire program obviously contradicts departmental interests. "The problem of constructing underground nuclear power plants can only be solved on a political level. Specialized departments cannot solve it in principle," so he explained the essence of the problem. And I heard him say this more than once.

Sakharov did not speak out against nuclear power generation. Rejecting it today would mean even greater pollution of the atmosphere by the emissions of conventional electric power plants, intensification of the greenhouse effect, etc. He proposed the only possible way out. But very little time remains to resolve the "power generation-pollution" dilemma:

"The Five-Year-Plan for nuclear power generation must nevertheless be thrown into the trash. True, this is a blow to all of the themes on which I myself worked in nuclear power plant construction. The legacy for the future has already been created, and these are multibillion dollar expenditures....I feel that there should be an international law banning above-ground construction of nuclear reactors.[9] Once again, "re-education" comes with great difficulty. "Revolutions in consciousness" are generally difficult.

And so what is the "miracle of Sakharov"? How would Andrey Dmitriyevich himself have assessed it all?

"My destiny was in a certain sense exceptional. Not from false modesty, but from a desire to be precise, I will comment that my destiny turned out to be larger than my personality. I only tried to be on the level of destiny proper."

"And do you believe in destiny in general?"

"I believe in almost nothing except some general perception of the inner sense of the course of events—the course of events not only in the life of humanity but in the universal world in general. I do not believe in destiny as fate. I believe that the future is unpredictable and not determined. We create it ourselves—step by step—in our infinitely complex interaction. But freedom of choice remains for man. That is why the role of the personality to which destiny has provided certain key points in history is great."[10]

Footnotes

1. For more detail see "'Hot Spots' of Cosmology," PRIRODA, No 7, 1989, p 17.

2. Dosier "LG," Jan 1990.

3. He was forced to refrain from contact with his colleagues for a year and a half, understanding that the authorities were actively using even the very fact of their visits against him.

4. A pioneer in this direction, A. Golfand, a doctor of physical and mathematical sciences, was restored to his work at the Physics Institute imeni P. N. Lebedev in March 1980 by the very same high decision that allowed

Sakharov to work at this institute. This occurred as the result of an extensive protest campaign by foreign scholars.

5. From the family archives of Ye. R. and G. R. Galinskiy.

6. From a letter to A. P. Aleksandrov, president of the USSR Academy of Sciences. 15 Oct 1984, ZNAMYA, No 2, 1990, p 5.

7. For more detail see "'Hot Spots' of Cosmology," pp 15-16.

8. At this meeting of the forum "For a Nuclear-Free World, for the Survival of Mankind" Sakharov introduced a number of very important proposals, the main one being the need to reject the principle of the "package" linking progress in Soviet-American talks on nuclear disarmament with the American program SDI. As is known, this "package" blocked high-level talks in Reykjavik. Sakharov's idea was later accepted, and the rockets began to be destroyed.

9. ISKUSSTVO KINO, No 8, 1989.

10. MOLODEZH ESTONII, 11 Oct 1988.

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On Free Thought

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[Text of a roundtable session organized by I. N. Arutyunyan and G. M. Lvovskiy with Vitaliy Vladimirovich Zhurkin, Sergey Adamovich Kovalev, Merab Konstantinovich Mamardashvili, Boris Nikolayevich Topornin, and Leonid Aleksandrovich Shelepin participating; first paragraph is PRIRODA introduction]

[Text] They began talking about Andrey Dmitriyevich Sakharov aloud, and what is more, made it possible to speak to him himself only several years ago. Nevertheless, his influence was felt much earlier. Even those who were not acquainted with his scientific works and did not read his works on humanitarian problems knew that there was a man in this country that always said what he thought. This alone changed people, perhaps more or less and not always consciously, but it did nevertheless change them. Andrey Dmitriyevich's death made many start to think and try to make sense of the role that he played in our life. But since only history will give a final account of this role, today we can only talk of our own understanding of the significance of the sociopolitical activity of the academician Sakharov. On this theme our journal held a roundtable discussion with the following individuals: Vitaliy Vladimirovich Zhurkin, corresponding member of the USSR Academy of Sciences and director of the European Institute of the USSR Academy of Sciences; Sergey Adamovich Kovalev, candidate in biological sciences and people's deputy of the RSFSR; Merab Konstantinovich Mamardashvili, doctor of philosophical sciences and department heat at the Philosophy Institute of the GSSR Academy of Sciences; Boris Nikolayevich Topornin, corresponding member of the USSR Academy of Sciences and director of the Institute of State and Law of the USSR Academy of Sciences; and Leonid Aleksandrovich Shelepin, doctor of physical and mathematical sciences and lead scientific associate of the Physics Institute imeni P. N. Lebedev of the USSR Academy of Sciences.

Politician or Prophet?

[Moderator] Speaking at Andrey Dmitriyevich's funeral, D. S. Likhachev said that Sakharov was a prophet in the ancient age-old meaning of the word. This would seem to be a very high assessment. But many extract a quite negative meaning from it. Even among people who got along well with him, there was the opinion that Sakharov was a very honorable and sincere man but not a politician and that the proposals he set forth could not be realized in real life. To some degree, these views are still held now. According to the viewpoint representing the other extreme, Sakharov was, on the contrary, a marvelous politician, and he calculated all versions of events' developments with such great precision that it was therefore necessary to follow his every word rigorously.

Which of these two positions is closer to the truth? To make the question as pointed as possible, was Sakharov a politician or a prophet?

[V. V. Zhurkin] I do not know whether it is possible to say unequivocally that Andrey Dmitriyevich was a politician, but it is indisputable that, along with a scientific approach, his thought process also manifested a political approach. I will present an example—an excerpt from an open letter to American physicist S. Drell:

"I understand, of course, that in trying not to lag behind a potential enemy in any way, we are throwing ourselves into the weapons race—a tragic race in a world where there are so many vital problems that cannot brook delay. But the main danger is to creep toward all-out thermonuclear war. If the likelihood of such an outcome can be reduced at the price of even 10 or 15 years of the weapons race, perhaps this price should be paid with simultaneous diplomatic, economic, ideological, political, cultural, and social efforts to prevent the possibility of the occurrence of war."[1]

These are indeed not the judgments of a preacher who is calling upon the world solely to disarm, ease tension, and solve their problems by means of talks, although it was just such humanism and the priority of the humanitarian that were characteristic for the political concept of the academician Sakharov. But nevertheless, what distinguishes a politician? It seems to me that it is the capability to combine the nobility of one's purposes with realism when selecting ways of achieving them. And if, for example, you take his analysis of the strategic situation or his approaches to different scenarios of using nuclear weaponry, it is clear that a very constructively thinking politician in the highest sense of the word is speaking here.

[S. A. Kovalev] Andrey Dmitriyevich constantly felt his own personal responsibility for what was happening and tried to examine a problem he considered important as professionally as he could. And after this, he did not digress from his conclusions or worry what others thought. And it is with such responsibility and fundamentality that he approached today's disarmament discussions. In fact, calculations show that too rapid and too complete a disarmament would not reduce the risk of military confrontation using nuclear weaponry but would instead increase it. This is easy to show in a first approximation. Imagine that total nuclear disarmament occurred. However, the technology for producing nuclear weaponry already exists, and the risk that some country or simply a small criminal group could use this weaponry would increase against a background of general nuclear disarmament. This is a rough model, but there is logic in it. Sakharov's responsibility here led him to realism. Indeed, unlike many peace movements, he did not call for quick and total disarmament but rather looked at things in a balanced manner.

[L. A. Shelepin] In my view, Andrey Dmitriyevich was neither a politician nor prophet—he was a scholar above all. And his "Razmyshleniya o progresse, mirnom sosushchestvovanii i intellektualnoy svobode" [Thoughts on Progress, Peaceful Coexistence, and Intellectual Freedom] began precisely with the thesis that scientific methods should be introduced into both politics and the social sciences. This was very difficult, however. Even back in the times of Stalin there was a sharp division: physics had its own laws, biology had its own, and the social sciences had their own. The different disciplines were divided by their own Great Wall of China. This is why the social sciences did not have any of the methods used in the exact sciences. In fact the social sciences ceased being sciences—they became dogmas. We are still encountering this difficulty today. Not only in our country but in the West as well, the social sciences largely lack the very structure of the sciences. The word "teaching" is usually used idly: the teaching of Marx, the teaching of Galbraith, etc. What is needed is a unified science about society, to which Marx has made some contribution and other scholars have made other contributions, and where each principle has known bounds of applicability, the dynamics of social processes are studied, and the hierarchy of the characteristic times is considered. In other words, for a science about society to become a full-fledged science, the entire set of methods developed in other disciplines—cybernetic methods and synergetic methods—must be introduced into it. The world is not divided into cells—they all interact in it, and therefore the social sciences must not be examined in and of themselves.

If scientific methods are introduced, it will be possible to predict society's development scientifically, and this will be of fundamental importance. Of course, we are speaking not of mathematical prediction, for mathematics is the ideal. Even Mendeleyev said that science cannot be termed science if quantitative relationships are not introduced into it. This means that our task (and it is possible) is ultimately to introduce quantitative relationships into the social sciences, even for the characteristics of social consciousness. But the main thing for now is examining the structure of these sciences. How should they be structured? What we term dialectic and historical materialism is essentially metascience. It should also be examined. We must renounce this teaching or that.

Moreover, as far as I can judge, dialogue is one important feature of Andrey Dmitriyevich's approach. You could argue with him or disagree with him, but he never tied his views down. He could change or modify them in the course of a discussion. Such was his analysis method—also the scientific method. He was not afraid to reassess his views, and this distinguished him from many politicians who, once having said something, never changed their stand. And in this respect his was a scientific approach.

[V. V. Zhurkin] But nevertheless, if you are talking about Andrey Dmitriyevich's sociopolitical views, they are set forth not so much in scientific reports as in the speeches of a politician or, we might say, a politician-scholar. What characterizes his approach? First, the highest professionalism. This is evident, above all, in the very logic of this thoughts on themes determining the fate of mankind at the end of the 20th and beginning of the 21st centuries, themes such as global nuclear war, local nuclear war, conventional wars, disarmament,.... This professionalism was also manifested in small details, his precision, and the precision of his formulations. They were uncommonly correct formulas even though he spoke of the most complex problems in very simple and very clear language. I will give only one example. Academician Sakharov was speaking about the nuclear arsenals of the USSR and United States and analyzing their specifics. He then compared the capabilities of their missiles and bombers, which in reality are very different from one another, and suddenly pointed out:

"The mass penetration of aircraft into the depths of the territory of the USSR is doubtful—this last remark should be refined with an allowance for the capabilities of winged missiles; they could likely overcome the enemy's antiaircraft defense."[2]

Behind this phrase, which is so simple on the outside, stands exact knowledge of the specific features of the Soviet Union's antiaircraft defense and the U. S. antiaircraft defense. Such professionalism is certainly explained, above all, by his unusual conscientiousness. Nevertheless, in my view, the mind of a scholar is such that it generally assimilates such nuances from the sphere of strategic thinking and the social sciences exceptionally quickly. It seems to me that in Andrey Dmitriyevich Sakharov this distinction appeared especially clearly.

Second, he was distinguished by his clear political stand based on solid ethical and moral principles. Third, he was distinguished by his realism. Many in our society have formed the opinion that Academician Sakharov is a maximalist of noble intentions. However, his works on matters of nuclear strategy or military and political problems are not maximalistic but exceedingly realistic works. Proceeding from humanistic priorities, virtually everywhere he takes the possibility of a constructive solution to this or that problem to the limit but as a rule does not cross the boundary beyond which the solution would become unrealistic. And it seems to me that this is the greatest virtue of a politician—an extraordinary and outstanding politician.

[S. A. Kovalev] You know, I was just thinking about how Andrey Dmitriyevich would react to what we are now discussing. It seems to me that he himself never asked the question of whether he is a scholar, politician, or social activist. For him the beginning of such social efforts was determined by a moral impulse. This means that one must speak about the relationship between morality and science because, both by virtue of genetics and by virtue of all his own efforts, he was a scholar and remained one until the end of his life.

Generally speaking, the natural sciences do not have any relation to morality. In any case, this is generally assumed because no moral judgments are applicable to the results of, let us say, physics. If, however, one asks the question of what relationship science has to morality in principle, it is possible to perceive a deeper link. In my opinion, the sole moral basis of science is the dispassionate, unselfish, and intrepid search for truth (and this applies not only to science but to creative thought in general). But unselfish and intrepid also mean extremely responsible. And this was the starting position for him. When he understood the full measure of his responsibility (his own personal responsibility, for he never shared it with anyone, and for him, his own responsibility was always greater than any collective responsibility), all his actions thereafter were determined by the structure of his personality as a thinker and scholar. It is as if there are two contradictory traits: constructiveness and realisticness. On the one hand, there was his tendency to pointed formulations of a question and, on the other hand, a tendency toward far-reaching formulations. For instance, several times in his publications he was not afraid to pose the remote and nonpragmatic question of a world government. The question is not new, but now we all prefer not to talk about it. Andrey Dmitriyevich not only talked about it, but he also wrote it into his draft of the constitution. At the same time there was a feeling of responsibility that determined his psychology as a scholar and made his other developments very pragmatic. He therefore seemed entirely unprincipled to some. For example, when we were developing the draft bill about a most important policy, in accordance with today's international law standards, we indicated strictly that no extreme circumstances could be considered justification of such a measure as internment. Andrey Dmitriyevich basically approved the plan but added the following because of that point, "Understand that all circumstances may come about. This must be considered." "But what for?" I asked. "Indeed the Congress of the United States discussed this problem heatedly for 2 years and finally apologized to the Japanese who were interned during wartime." To this Andrey Dmitriyevich replied, "Yes, they apologized, but 30 years after the war and then only after 2 years of discussions. But would they have made the apology if the Japanese had landed in U. S. territory or if there really could have been a threat?"

It seems to me that these are the dispassionate thoughts and lack of bias that flow from the moral foundations of science. And his professionalism, which was just mentioned, was of the same origin. If you abandon independence of thinking, if you undertake some task, then please do it the way it should be done. I remember how, in the beginning of the seventies when the Sakharov committee was formed (in the beginning it included Sakharov, Chalidze, and Tverdokhlebov, but later it grew, and its make-up was changed), Andrey Dmitriyevich was worried by the theoretical legal direction of the actions of this committee. Indeed the committee set about consulting everyone, the government included, on matters of law. Sakharov had great respect for Chalidze's legal knowledge but nevertheless doubted that the committee had the right to pretend to the role that it had taken upon itself. This was by no means modesty—when the problem at hand concerned thought-out matters, Andrey Dmitriyevich was not distinguished by any special modesty. He simply said what he thought. This was instead the concern of a professional and a manifestation of his deep sense of responsibility. He understood that amateurs must undertake these problems because they could not be left to the professionals alone—especially not to the Soviet professionals of the time in the field of law. But on the other hand, there exists an extensive literature and a set of well-educated and intelligent people who have thought and written about these problems before us—should not their experience be considered.

[M. K. Mamardashvili] I cannot accept the very formulation of the question. I cannot understand in general what politics is let alone what politicians call politics, or what, at their suggestion, we then perceive as politics. It seems to politicians that they make politics. I think that Sakharov's entire life and activity proves that they are wrong. Indeed politics exists where open and articulated social opinion, or more precisely social understanding, i.e., an understanding of society that has not been borrowed from science departments but that instead that lives and develops in the heads of the subjects of social life, rather than an understanding that comes from studying science, economics, or something else. This understanding is, in and of itself, already political. And professional politicians either believe this if they are intelligent or do not believe it if they are stupid.

Sakharov is advocating thought rather than science. When he says that there is not enough science guiding politics, economics, art, education, and military matters, one must understand that in reality he does not mean the methods of science as they are presented in the departments (modeling, mathematical processing, or something along these lines). What he had in mind was one fundamental question: Can reason and common sense reign in social, political, military, and other matters. The reality of the 20th century, especially reality in the Soviet Union, showed him that the role of reason in these matters is minimal.

And if we say that society must be directed by means of science, we are simply repeating the starry-eyed delusions of the early Enlightenment. They say that some system-controlling thought is possible (we have still not abandoned the dream that it can be developed either in an individual head or in a set of different heads) and that this though will control politics, economics, art, education, and military affairs. Above all, this is in radical contradiction to the scientific style of the 20th century. Such ideas were possible in the 18th and 19th centuries, but not in the 20th century when the properties of self-regulation and self-organization of living processes are explicitly taken into account everywhere, including in the strictest sciences, mathematics and physics (and politics is a living process, as are economics, education, and art). Are we supposed to forget the entire experience of modern physics, cosmology, quantum mechanics, economic science and again begin to dream of an ordered rank or unified systems engineering that appears to have insufficient scientific control? What is lacking is thought and reason. Because the system of science is itself charged with an irrational force, all models and all calculations may turn out to be an unstoppable stream of nonsense. And then there is conversation about scientific planning—kafkaesque delirium in general. For us a plan is an noneconomic mechanism of forcing labor. During such conversations, I feel like I am seeing people who are carrying on a conversation on a stairwell and agreeing to drop in on one another, not noticing that the stairs have accidentally been built outside the house.

A good example is the activity of the former Ministry of Land Reclamation and Water Resources. All of the plans for hydroelectric power stations and all the irrigation plans were very complex scientific plans that were certainly calculated in accordance with models. Was it really possible to correct them by using the same methods used to derive them—to improve the models and refine the calculations? Is this really what Sakharov had in mind? But no, he did not mean that the mass behavior of people who seemed to be reasonable people individually is characterized by irrationality and impermeability to thought. But a thought (every scholar understands this) is always tied to a root that lies in a person's personal worth and his intellectual honesty. A certain measure of truth is contained in the very act of thought.

In my opinion, Sakharov's "disorderly conduct" was a reconquest of those qualities that, ousted to the basement, are inseparable from thought itself regardless of whether it is in strict natural science attire or in freer sociohumanitarian garb. I would say that he helped us understand two basic things. First, politics cannot be entrusted entirely to the politicians, just like military matters cannot be entrusted entirely to military personnel. And thus discussing how much of a politician Sakharov was and how of a scholar he was means proceeding from an idea that politicians instill in us, namely, that they make politics. I assert that this is not so, at least not in the developed European society. Politics only becomes a professional area of activity when it is consciously in the civil life of all members of society, no matter what their occupation. The second thing is the illegitimacy of the strict professional separation and "classification" of people. Let us say you are involved in politics. Does this mean in Russia? You were **assigned** to be involved in politics. Are you a scholar? You wish to work in science, and you are **assigned** to work in it. It is not difficult to imagine that a man, perceiving himself to be the bearer of thought, may one fine day rise up against this situation. Not against this specific political decision or that (although possibly against it also) but against such predeterminism itself.

[Moderator] But this type of division is frequently made by education or professionalization.

[M. K. Mamardashvili] This is entirely true. But when speaking of civil thought—and scientific thought is syncretically present in it—or art and many other areas, we are speaking of a method of orienting modern man in the world. And then we of course understand that every "assignment" is an archaic residue of serfdom in Russia. It is not without reason that this is disguised in terms of other problems, let us say, professionalization. The question is very simple. From the time of the Gospel and the Word, there has been nothing that does not have some relationship to me, and there has been no delegation of thought or delegation of responsibility. Such is the primary evangelical meaning of christianity. And that is why a scholar is not **planted** in the laboratory. He is involved in science because it interests him. And the thoughts of any member of a society regarding what is happening in it, including those of a man in a laboratory, are important to that society. He is a personality, and what he thinks about what is happening, including what he thinks about what politicians are trying to declare by their monopoly, is important. No such monopoly exists in the modern interconnected world.

[V. V. Zhurkin] I agree with Merab Konstantinovich's assessment. Nevertheless, in every specific area, particularly in the area of military politics or disarmament, this is some world level of evolved sets of ideas and professional approaches that politicians must deal with, whether they want to or not. True, they frequently do not deal with them; nevertheless, objective reality compels them to continuously make corrections and restructure. Thus, Academician Sakharov's speeches did not simply conform to this level but raised it unalterably. Most of his works were written at a time when monolithic thinking dominated us and when there was one line in the big strategic issues. If there was discussion, it was so closed that, on the surface in real politics, everything followed one line. In view of this monostructure the conditions for a social polemic on the most acute questions touching all of mankind and each person did not exist, and alternative versions were not examined. But now, under conditions of pluralism, we understand that much of the things A. D. Sakharov wrote are the most marvelous alternative versions that are needed to develop realistic politics. And that is why I hold fast to my opinion. I am not prepared to judge whether Andrey Dmitriyevich was a prophet, but since his works are permeated with political thinking in the best sense of the word, i.e., dynamic, realistic, directed toward finding solutions that are not only constructive but also ethically justified and morally grounded, I nevertheless think that we can speak of the academician Sakharov as a politician. Although, of course, he would not be among those politicians about which Merab Konstantinovich speaks.

[M. K. Mamardashvili] To the question of whether he was a prophet, I would answer as follows. Sakharov was a man who did not wish to be a prophet. He did not want to because the status of a prophet is an archaic status completely contradictory to modern society. This status, even in the Gospel, is subject to doubt. Unfortunately, in Russia it is associated with Christianity. The New Testament states (and this thought is presented twice): "Until John it was the law and the prophets; since then, there is the good news of the Kingdom of God, and everyone forces his way in" (Luke 16:16). What this means is that the Law and prophets represent the archaic status of spirituality and thought in a world in which there is a Law that can function completely automatically and there is only one counterbalance to it—the outcry of the prophet. And the Gospel says that nothing is foretold by either the Law or the prophet but by your own efforts, and your efforts are connected to everything.

[S. A. Kovalev] I would like to support Merab Konstantinovich in his, if one can use the term, evangelical analogies. It seems to me that Christianity, proceeding from the idea that everything down to the smallest details can and should be regulated, imposed a terrifying and sometimes back-breaking task on people—to make a choice at each step. Several basic principles are proposed, but no recipes for how to proceed in one case or another are given. In my mind, Andrey Dmitriyevich realized the full measure of responsibility, and this determined a great deal in his life.

[M. K. Mamardashvili] When the question of prophets and whether or not to respect them was discussed in Rus, it was immediately transformed into a question of everyone who was state serf property being the master of his own affairs. And that is why he could mind his own business, do a ballet step, and make scientific discoveries (that will be state property just as he himself is), but at any moment when the master wants, i.e., those very same politicians, they could order him to the stable. That is the problem of every man of free thought in our country, which has inherited completely the serfdom structure from 19th century Russian society. And this structure itself leads people like Sakharov to sociopolitical activity because the dignity of a scholar cannot be reconciled with this. This is a continuation of the tradition that I call the tragedy of Vernadskiy.

Vernadskiy used to repeat that if there is no freedom of thought there will be a grave and candles for modern society. By free thought he did not simply mean freedom from censorship but also the presence of thought in all things—the victory of intellectual force as he called it. And it was also absence in control of the economy, art, education, and military affairs. By that time, an appalling break between the mind of the controllers and the mind that was accumulating in society had formed. That is why a sad internal note is always heard in Vernadskiy's articles and his diaries. And following after him, Sakharov showed the controllers—feeble-minded and immoral men—how outraged thinking could have merit.

Sakharov was a phenomenon of the self-merit of thought not needing to lean against anything—not foreign authorities or the domestic authority or the collective. His words were addressed to the "authority" of free inner thought. No, he was not a prophet because he rejected the very "designation" itself—be a prophet. It is as if a prophet brings the voices of reality, justice, and measure to the powers that be. He thereby speaks for all others. But Sakharov felt that each person can and must speak.

Dialogue With Humanity

[Moderator] That is how he himself acted. He spoke or rather, he thought aloud. Indeed Sakharov was not a tribune in the usual sense of the word, although many remember him just that way. This was, however, preceded by a long evolution process—from a scholar whose power of thought the state needed to a man of free thought who turned out to be unclaimed by the state. And now, when speaking of the results of this evolution, one must not fail to think about its main states or fail to try to penetrate to the motives that guided him in his activities. Specifically, his attitude to his own participation in the creation of thermonuclear weaponry was an enigma to many.

[S. A. Kovalev] A. Adamovich spoke with him on this topic and until this day is surprised by Sakharov's answers. He does not agree with them and feels that after several years Sakharov would have perhaps answered differently. There is the following popular model: Sakharov made the bomb, was then horrified that it was his creation, and his conscience compelled him to atone for his former sins. Sakharov himself did not take it so lightly and persistently disputed such an interpretation. He said that he did not regret his participation in these developments even though he understood that the results fell into hands that were not at all clean and that the consequences could be terrifying. But nevertheless, if he had to live his life over and make the same choice, he likely would again participate in developing nuclear weaponry. And again he would later protest against its use. As far as I remember he felt that it was necessary at the time. It was not a simple decision, Nevertheless, thinking about it very recently, he came to the conclusion that he made the correct choice—not irreproachable morally but nevertheless correct. History, he felt, would show the correctness of this choice because in recent years peace had been maintained precisely thanks to a balance of forces. We are balancing at the edge, but have been balancing for tens of years now.

[V. V. Zhurkin] Sakharov's fully developed moral stand was of course formulated over the course of time. It seems to me, however, that it had always been present in principle. And how he morally justified his work on creating nuclear weaponry is a question that he himself never answers in his works. Personally, I think that latent in them is the thought that any nuclear monopoly is dangerous and some balance is necessary. The very idea of a balance of forces or parity was born later. When the nuclear arms race was underway, no one thought about it—each side tried to produce the next new type of weapon as quickly as possible. And I am certain that the understanding that nuclear weaponry should not be in the hands of one government, that it has changed everything in our world, and that it will never be as before could become not just a justification for but rather a normal logical and moral basis for participation in developments of nuclear weaponry.

[Moderator] However, when an approximate balance of forces was achieved and Andrey Dmitriyevich thought about the feasibility of further nuclear weapons tests he straightened N. S. Khrushchev out. Here is how Andrey Dmitriyevich himself later wrote about it:

"I remember the summer of 1961 meeting of atomic scientists and scholars with Council of Ministers Chairman Khrushchev. He explained that he needed to prepare for a series of tests that should support the new USSR policy on the German matter (the Berlin wall). I wrote a note to N. S. Khrushchev: 'The renewal of tests after a 3-year moratorium will turn the talks about halting tests and disarmament upside down and will lead to a new round in the arms race, particularly in the area of intercontinental missiles and antimissile defense,' and I passed it along to him. Khrushchev put the note in his breast pocket and invited those present to have dinner. At the set table he gave an improvised speech that I found memorable for its sincerity, reflecting not only his personal position. He said approximately the following. Sakharov is a good scholar, but let us—the specialists in this intricate matter—make foreign policy. Only force, only disorientation of the enemy. We cannot say aloud that we are conducting a policy from a position of force, but it must be so. I would be a ditherer instead of Chairman of the Council of Ministers if I listened to people like Sakharov."[3]

But how are nuclear weapons tests a policy tool? It would seem that who besides scholars should decide whether it is necessary to test weaponry or not?

[V. V. Zhurkin] I would not agree with the fact that nuclear weapons tests can be a political tool. A moratorium on tests or an agreement to halt them is certainly politics. International society presses for it. It seems to me that in the sphere of nuclear weapons tests and their technical aspects there is a constant war of two forces: the growing number of scholars proving that the need for nuclear weapons tests has long passed and the militaries of all countries that, for the most diverse motives, insist on regular verification and modification of the arsenal. And in this sense Khrushchev's intervention was absolutely incorrect. The argument should be waged among professionals who know all the complexities of the effect of nuclear weaponry's mechanisms (incidentally, at the Moscow forum in February 1987 the academician Sakharov spoke of the main sets of such mechanisms) and other professionals who in case of war would have to use this weaponry. Of course, it is easy to look into history from today's vantage point and judge, but all of Khrushchev's positions in his argument with Sakharov seem to me to be at least alogical.

[L. A. Shelepin] In my view, Andrey Dmitriyevich's ideas about our society and ways of developing it underwent a no-less-interesting and complex evolution. In "Razmyshleniya...," for example, he speaks of socialism, its moral foundations, and its advantages. He never returned to this theme by the middle and end of the seventies, but then the government also subjected his actions to sharp criticism. And there is no contradiction here because, at the beginning of the seventies in our country, there was a phase transition, as the physicists would say. Of what did it consist? Up until the beginning of the seventies, the economy developed, and sober-minded self-assessment was possible (specifically, there were reliable statistics). What happened next was as follows. Statistics were replaced by continuous upward distortions. It is no wonder that serious economists only use statistical data before 1972. Money-grubbing and careerism acquired a state scale. On this scale, various mafia-like structures began to form. In short, a qualitative change in our government occurred. And Andrey Dmitriyevich caught this. Therefore, there are no contradictions in his position. The evolution of his view is linked to the evolution of society. In the sixties our country could still turn to the path that he indicated relatively painlessly. We could have avoiding sailing to a crisis. But the warning was not valued or understood. It was a voice singing in the desert. And the state did not take the necessary steps.

[M. K. Mamardashvili] The "epoch of the smell of steak," as I call it, began. Earlier fear gripped people.

Then fear was replaced by the smell of steak, and it turned out to be a more reliable way of filling socialist space.

[S. A. Kovalev] As far as Andrey Dmitriyevich's first work "Razmyshleniya..." is concerned, I must say that he vacillated about whether to include it in his book "Trevoga i nadezhda" [Alarm and Hope]. He said that much there was the fruit of immature and naive ideas but then decided: what can you do—he wrote that way once, so let it be published without revisions. In any case, I am certain that his discussions about socialism did not contain any elements of a tactical maneuver. He wrote the way he thought.

I want to make one hypothesis. The idea of socialism and social justice is a wonderful idea that has played a significant role in history: it corrected narrow-minded and selfish capitalism. Alas, as it seems to me, realization of this idea is impossible. It simply contradicts human nature and certain economic laws that cannot be circumvented. There is direct evidence of the fruitful contribution of this idea, but unfortunately not in the country that was the first to call itself socialist. The socialist idea immediately bore fruit in the capitalist West. There, where it was prescribed and where by virtue of democracy and freedom of society it was able to be realized, of course, not in the ideal, but in a form close to it. What I have in mind are guaranteed minimum wages, unemployment benefits, and a well-developed social insurance system. So my hypothesis is that Andrey Dmitriyevich would today have come to approximately the same conclusions regarding socialism and capitalism. Moreover, the germs of these thoughts are already in his first work, where he discusses convergence.

[Moderator] When speaking of capitalism, one generally means Sweden, the FRG, and the United States. But there is also Uruguay or India. Does this mean that the capitalist idea alone is enough for prosperity?

[L. A. Shelepin] There is a fundamental difference between capitalism in weakly developed and advanced countries. While the structure in the former is reminiscent of early capitalism, in the latter a new formation—postindustrial society—has arisen. It incorporates the laws of both early capitalism and socialism. Its fundamental difference is that surplus value appears thanks to science. The basis of the prosperity of such a society is not large enterprises or their intensified operation but the use of scientific-technical progress, rapid introduction of leading-edge technologies, and quick reaction to market changes. This is the new society. In my view, Andrey Dmitriyevich was the prophet of such a new society for us—his pluralism, freedom of thought, respect for science.... We could have switched to a new formation, but the tragedy was that our society did not become socialist from its own foundations. Instead it began to approach a society in early capitalism.

[M. K. Mamardashvili] Of course, Sakharov's activity had the very same motive as that of the small number of government officials who were the so-called initiators of perestroyka. This motive was a deep recognition of the incompatibility of the existing economic and social structures with scientific progress and an understanding of the fact that in the modern world the weight of a superpower is fully determined by its scientific-technical potential. I am not simply speaking about machines but rather about the capability of doing anything, including waging war. Modern war contains elements of logistics and the highest technologies, and the Soviet Union would lose such a war no matter what form it took. The pressure of reality enlightens one's consciousness and makes one thin: what will Russia be like at the beginning of the next century, what presence will it have before the face of history?

Therein lie the sources of what is called perestroyka. It naturally becomes necessary to examine teaching about formations and all "formation" terminology: feudalism, capitalism, socialism. One simple thing must be learned. The language in which we formulate these problems is a European language, and the "formation" terms are borrowed translations of words that arose in Europe. The trouble is that for us all these words are simple linguistic "pseudomorphs," as O. Spangler called terms that designate nonexistent phenomena and are constructed on the basis of formal linguistic laws rather than born from experience. There is no internal equivalent for one of them in our reality, and the very principle of the formation of these words was not in existence. Perhaps, in view of this, socialism was truly constructed in Russia in the direct sense of the word. We can use the word "socialism" in that sense, but not in the same as the sense understood by European tradition. What happened in our country is frequently linked to the tragic incorrectness of Marx's thinking, specifically, with regard to the fact that Russian socialists transformed the theory of formations from the sphere of scientific thought into a means of manipulating the masses.

There exists a European civil society that was formulated on the basis of industrial urban democracies. Capitalism, if it is understood as the maximum extraction of profit based on large industry, presupposing the division of labor and mass production of goods, is one of the phenomena of this society that links it with others. Other phenomena arose on different foundations and are in no way permeated by the capitalist principle but rather interact with capitalism as with a particular phenomenon. If we look at reality in that way, we will understand that European civil society should be described not in terms of a capitalist formation but rather in other, much broader terms. To me, this is obvious. But if capitalism does not exist as a formation, then socialism exists. It may be shown that in our country socialist principles are a core penetrating all social institutions.

So what happened to capitalism? All other phenomena of civil society, including such traditional phenomena as religion and parliamentarianism, interacted with it and assimilated it. It found a specific spot—as did the socialist idea that belonged to that same civil society and that had a real equivalent in it. But this did not happen in the Soviet Union. Here it was still necessary for a civil society to arise that would assimilate socialism and transform into into one of a number of phenomena, in particular scientific-technical progress, that would dilute it in civil society. Therefore, when we speak of Uruguay, we must realize the extent of the development of civil society there and will then discover archaic layers that do not conform to any civil society. We must then examine the interaction of capitalism with these archaic layers, etc. By comparing socialism and capitalism as European ideas with the pseudomorphs "socialism" and "capitalism" in the Soviet Union, we will immediately refine the problem instead of banging our heads.

It seems to me that all of Sakharov's thoughts and remarks were formulated in pragmatic socialist terms. Such terms are the products of observation, and the very act of observation serves as their internal equivalent and the root of the occurrence and use of the words. It is therefore, for example, that Sakharov got the idea of convergence. He never proceeded from these words. And it turns out that when you do not proceed from these words, you understand something. But when you do proceed from these words, you will not understand it.

[Moderator] There is yet another example of even more distant, it would appear, world outlooks: Japan and Western Europe. In Japan the linguistic estrangement is even stronger, and their system of moral values is very different from the European. Two different world outlooks, and yet they have achieved very similar results today. Is there no contradiction here?

[M. K. Mamardashvili] The answer is simple: they never had any pseudomorphs, they had something else. Here is an example for the social sphere. Lawlessness may be corrected by the idea of law or by law as such. In other words, cultures in which the idea of law is lacking altogether may assimilate this idea and create legal structures. But can law correct "antilaw" in the strict sense of the word? In Russia the pseudomorph "law" already exists, i.e., there is an imitation of law, and no true law can penetrate it.

[Moderator] Certainly, this is precisely why Andrey Dmitriyevich devoted so much effort to his human rights activity—to fighting the imitation of law. What distinguished his approach and how did the academician Sakharov's involvement in the human rights movement change it?

[S. A. Kovalev] Usually, when this topic is discussed, the isolation of his position, his authority, and finally his three Hero's stars are recalled. In 1970, for example, we traveled to Kaluga where Pimenov and Vayl were being tried. They would not let anyone into the courtroom, but they let Andrey Dmitriyevich in (true, the "rage of democracy" later began and they stopped letting him in as well). All this is important, but it is not the main thing. The main thing is that he introduced the constructive approach, he shook the human rights activists' intuitive aversion to politics. In this sense he was nevertheless a politician.

Before Sakharov, the human rights activists acted simply: say what you think, and do not worry about the result—there is something to denounce. Andrey Dmitriyevich constructed the ideal, but he did not lose his constructiveness or realism in the process. He was not afraid to make his own proposals in spite of their apparent fantasticalness. He extended his hand to the authorities in cooperation, and even though this hand was rejected, he never tired of extending it.

[M. K. Mamardashvili] That is, he proposed that the authorities do something and told the opposition to accept it despite the fact that it would have been done by the hands of power?

[S. A. Kovalev] Yes, precisely so. There is sufficient proof: many of his specific proposals are now being proclaimed from all rostrums. But then these were hardly the first—how many there were I cannot judge—examples of proposals that were clear and ready for realization. It seems to me that this is a significant contribution.

This approach was rather quickly seized by the human rights activists. True, Sakharov not only found supporters among them, but very sharp opponents as well. The sharpness of the criticism grew until his very death, and alas this criticism was not always honest. He remained calm in the face of all reproaches and maintained his independence, for indeed the position "always against" is not real independence. Moreover, in the beginning there were no opponents—there were only those who revered him. But opponents, and very sharp ones, appeared much later, when he returned from Gorkiy. There were publications that were no longer on the edge but rather over the edge of propriety, saying that Sakharov had abandoned his own principles.

Understand, the human rights movement is a rather complex thing. It looked unified but was never so. For many who (in my view, without grounds) considered themselves politicians, legal appeal was simply a method of criticism. It was clear to everyone that criticizing the authorities precisely for violating the law was more effective than entering into an open political struggle with them, if only because violation of the law could be proved. But the nucleus of the human rights movement consisted of people who did not think this way at all. For them, observing legal standards was in fact their goal. They did not hide behind the law as behind a convenient method of criticism.

As long as law remained the sole root of the problem (for some, the tactical root, but for others, the true root), the movement looked monolithic. When it became noticeably freer, the nonuniformity appeared very quickly. Those who continued to stand on legal positions, Sakharov included, began to be subjected to criticism. They says they are talking about the law, but there is no law in this country, and there never will be. Why pretend that any legal improvements are possible? The system must be changed radically.

The system does in fact need to be changed. Legal modifications are in fact not the only way and, undoubtedly, are not the cardinal way. But Sakharov was a very responsible man. From the moment when he could somehow see the result of an action (and such a moment came in the eighties), Andrey Dmitriyevich tried very hard to calculate it. The simplicity of our position in the sixties lay in the fact that it was not necessary to calculate the result—there was nothing to think about. Now the result may be foreseen, and responsibility has increased a hundredfold. The opponents feel that the worse, the better. If the system must be pulled down, let it collapse as soon as possible, and how and on whom is a small point. We will forcibly destroy the entire world to the foundations and then....The question "And what then?" was always put off to the future. Andrey Dmitriyevich did not think that way. He continually felt responsibility. Throughout the last year of his life this was especially evident.

[Moderator] I am afraid that someone will see a contradiction in your words. What does "calculate the result" mean in human rights activity and is it morally justified? Indeed you yourself said that in the sixties it was not necessary to hope for a result. However, this did not stop a great many, including Andrey Dmitriyevich.

[S. A. Kovalev] When it was a matter of individual fates, the question of a result or of what could and could not be accomplished was, for Andrey Dmitriyevich, in second if not in fifth place. Every time he had sufficient reliable information to be certain of an injustice, he took some steps. He had a surprising ability to feel another's trouble or another's pain with his own skin. I can confirm this because many times I observed him at a moment when news arrived about someone's arrest, pain, or acute hunger in a camp, or sometimes even a threat against someone's life.

But if you a speaking about a method of reacting, then it seems to me that Sakharov calculated it. The question of the justification of his hunger strikes, for example, the one with the demand that Ye. Alekseyevna be permitted to travel abroad to her fiancee, was often raised. Certainly, Andrey Dmitriyevich calculated well that he was in a condition to secure Liza's departure. On the other hand, his Gorkiy hunger strike in connection with Yelena Georgiyevna's treatment was not as calculated or practical. It is likely that he completely ignored the possibility of his own injury but could not act differently. Incidentally, it was the same way with Sakharov's very first hunger strike during President Nixon's 1972 visit to Moscow—a hunger strike with a simultaneous appeal to Nixon and Brezhnev. I cannot imagine that Andrey Dmitriyevich did not understand its futility in the practical sense of the word. Because the demands were entirely general: political amnesty, examination of the question of human rights in the USSR. I think that he did not doubt for a moment that his demands would not be met. However, he took that symbolic step, and as a result, world public opinion was turned to the problem of human rights in our country. That he set out to achieve, and that he did achieve.

He frequently used other methods as well—an open letter or participation in such a letter, protest, or address to correspondents.

[Moderator] Undoubtedly, such extreme forms of protest as a hunger strike become necessary only when resounding lawlessness reigns in a country. In civilized society, the state itself in the face of its organs of justice should be the guarantor of citizens' rights. And that is why creating a rule-of-law state is perhaps the most cardinal form of human rights activity. But a rule-of-law state needs an perfected and actually functioning constitution. We know that, by developing a draft constitution, Andrey Dmitriyevich helped solve this problem too.

[S. A. Kovalev] To me, the draft constitution is a very clear document. Perhaps it should still be translated into special legal language, although it seems to me that this will change little.

The history of its creation is very simple. It was done as a standard scientific work. Andrey Dmitriyevich sat down and started writing, and he wrote for many months in a row. And then he handed the text over for discussion—first to a very narrow circle of individuals and then to a wider circle. In the narrow circle the text did not evoke any special discussions. But it is difficult to judge about the wider circle because the draft has not yet been subjected to public discussion. Andrey Dmitriyevich only gave his possession rather wide-scale glasnost shortly before his death. Understandably, Sakharov's death stopped the discussions, even though he himself did not consider it the final version.

[B. N. Topornin] Sergey Adamovich had the fortunate opportunity to be a direct witness to and even a participant in work on the Sakharov draft of the constitution. I also had something to do with the document itself. True, after the meeting of the constitution commission, already on the way out, I struck up an acquaintance with Andrey Dmitriyevich and a general conversation. At the time those of us at the USSR Academy of Sciences Institute of State and Law had prepared a concept for a constitution and wanted to acquaint Sakharov with it. I remember that Andrey Dmitriyevich spoke about the importance of alternative drafts and comparing them. However, a meeting at the institute was not destined to take place.

Today we have come rather far in preparations for the constitution. There is the initial conception that, incidentally, was discussed at the meeting of the Presidium of the USSR Academy of Sciences, and there are versions of the structure of its sections, etc. However, just as Andrey Dmitriyevich thought, even the draft that was disseminated to the members of the constitution commission at M. S. Gorbachev's suggestion turned out not to be the final one. Andrey Dmitriyevich continued his work on it and made some rather significant revisions and additions. In many of its initial ideas, and especially in its humanistic approach, the Sakharov draft is up-to-date and significant by the strictest standards.

I remember that the Sakharov draft was very short. It took little more than 10 typed pages. It was more a statement of a general platform, a system of views, and a list of fundamental principles. From the standpoint of a professional jurist it was striking for its lack of implementing the positions proclaimed. But it seems to me that it is just such a draft that best expresses Sakharov's spirit and termperament. As far as the legal material is concerned, it would undoubtedly be woven in later.

The new constitution should—and of this I am certain—differ from the currently existing one by virtue of at least three qualities. First, it should proceed from the degovernmentalization of our society, especially in the sphere of economics, social development, science, and culture. I am essentially speaking about freeing "civil society" from the government. Second, man and his freedom, independence, and protection should be at the center of the constitution's attention. Third, the constitution should become the basis for a fundamentally new union of republics and just solution of the most pressing international problems. Not only does the Sakharov draft give these problems a serious place, it also contains bold and decisive innovations and a departure form the normal stereotypes of thought.

[Moderator] We have been speaking here about Andrey Dmitriyevich's human rights activity. Do you, as a professional jurist, see it reflected in the draft constitution that he created?

[B. N. Topornin] One can argue about what to call Sakharov—a scholar, politician, or social activist. Only this is indisputable: in all of his roles he was above all a great humanist. And if you please, it is precisely this side of his personality that appears most clearly in his draft constitution.

In the very beginning of the document, which is written like any constitution in solemn language, the goal of the people and all of their organs of authority is written: "happy, meaningful life, material and spiritual freedom, well-being, peace, and safety for the country's citizens and for all people on earth regardless of their race, nationality, sex, age, and social status."[4] And further on, in the fifth article: "All people have the right to life, liberty, and happiness."[5] (I do not recall where else the right to happiness would be established constitutionally!) The principles of pluralism and patience were postulated by Sakharov as the foundation of society's political, cultural, and ideological life. Its draft guarantees broad civil rights and bans any discrimination. And this is far from all the theses characterizing Sakharov's humanistic approach in constructing a rule-of-law model of society.

Undoubtedly, jurists might say that Andrey Dmitriyevich is proclaiming the common humanitarian doctrines of good and justice and personal freedom that it is entirely unnecessary to write down in a constitution, which should contain only the strict legal prescriptions guaranteed by the state. This is partly true. But at the same time one must not fail to mention that the traces of the battles that Sakharov waged on the human rights front are visible in the text of the draft. And here he is specific, proposing that guarantees against unlawful arrest and medically unfounded psychiatric hospitalization be secured by legislation and establishing in detail that "no one may be subjected to criminal punishment for actions related to convictions if they do not contain violence, calls for violence, or other infringement on the rights of other people or high treason."[6]

I will pause on a moment that in my view is very significant. A paternalistic approach to relations between state and citizen is rooted in our previous constitutions. It turned out that by virtue of its good will, the state cares for its citizens by giving them various benefits out of its generosity. The obligations of the state and its responsibility to society and individual citizens were placed in the background. The state could only ask but not demand. Civil servants of all ranges, permeated with a feeling of superiority over all other people, had the capability of manipulating them freely. All of this generated social passivity and apathy in society.

It is now important not only to criticize the idea of paternalism but also to turn decisively away from these principles in legislation. At the same time, under modern conditions, it is easy to fall into another extreme—proclaiming broad human rights and freedoms and forgetting about responsibilities. This is nevertheless a mandatory component of a person's constitutional status. Even back in the 1948 General Declaration of Human Rights the following is written: "Each person has a responsibility to society. Only in it is the free and complete development of his personality possible." The manifestation of a lack of discipline and personal egoism and violations of law contradict peoples' interests. It must be said that Andrey Dmitriyevich saw the problem of man's constitutional status in its full measure and focused attention on the fact that "execution of a person's rights must not contradict the rights of other people or the interests of society as a whole."[7]

[Moderator] But between each individual person and society as a whole, at least in our country, there are communities of people, such as nations and peoples. In our times, the problems of the sovereignty of nations and international relations have become especially acute, and the solutions proposed by the current constitution do not eliminate the tension. In many republics national movements with the most diverse trends are being activated.

[M. K. Mamardashvili] Above all, one must understand what the national movement in the Soviet Union is. In my view, it is simply the form in which the rebirth of civil society is occurring—some social structuralization independent of the state and existing alongside it as an autonomous force. And the national problems are, above all, problems of civil freedoms and civil society expressed in national form.

They say that private property is inalienable, and this is the basis of civil society. Consequently, authority and property are separate in such a society. The soviet structure is a total mixing of authority and property, and every attempt to separate them is an attempt to revive the phenomenon or private or civil society. The life of a nation is a particular case of privacy. A nation may be defined in terms of the unity of some set of people before fate and history. It then becomes clear that a nation is a product of the constitutional process. Therefore, a national movement always includes people standing on constitutional principles and understanding that a nation is not an ethnic group but rather a product of the operation of a constitution in the body of an ethnic group. It seems to me that, above all, the intelligentsia should introduce the rule-of-law constitutional approach into the national movements.

Any totalitarian state is, by definition, mononational. And the main enemy to whose destruction the totalitarian state devotes its own life is that civil society that is of course polynational. That is why its revival or appearance takes the form of national movements.

[B. N. Topornin] All of us today are directing the edges of our critical analysis to the past and present. And this is understandable. It is not possible to go forward without having uncovered the dimensions and causes of the deformations, miscalculations, and mistakes that led our union to crisis. Diseases can only be treated successfully if the physician has all the necessary information. But besides that, it is extremely important to determine how the union must be restructured so that it does not respond to dogmas, schemes, or subjectivistic goals but rather to the real interests of the Soviet people that are dictated by life itself. Andrey Dmitriyevich tried to the find the answer to this question, which he considered one of the most fundamental.

Above all, he supported the idea of a union agreement that had already been set forth in a number of republics. Today this idea seems obvious and urgent, but it should be borne in mind that back then it encountered strong resistance. It was assumed that the principles of the 1922 union agreement that was then entered into the text of the 1924 constitution were adopted and developed by subsequent constitutions. Consequently, it is possible today to manage with a regular examination of constitutional legislation on the national-state configuration of our country. But Sakharov felt that a new union agreement is, above all, useful because our union is in a certain sense being created anew.

Quite recently the Supreme Soviet of the USSR adopted a number of new laws reflecting the idea of differentiation of the relationships of the union republics with the USSR. In this context, one must not fail to mention that in his draft Andrey Dmitriyevich agreed to the possibility of including the republics in the union under additional conditions with the formulation of a special protocol. As is evident, he divined the general developmental trend. Undoubtedly, more than a few complex problems, specifically the relationship between the common and additional conditions, must be solved. It may be proposed that the minimum conditions mandatory for the existence of the union and common for all republics be included in the updated union and that, in addition, each republic itself decide what it will do independently, what it will do together with certain other republics, and what it will relinquish to the USSR.

It is still early to close the discussion of the Sakharov draft—we in the professional arena will take it farther, if only for the simple reason that it is directly linked to the development of human civilization and belongs to the arsenal of great scientific ideas and developments.

It is entirely natural that all of Sakharov's positions are by no means unequivocally accepted. The draft also contains disputed ideas, including very fundamental ones. For example, one can hardly agree with a concept of separation of powers that would call for something like all the branches—the legislative (Council of People's Deputies), executive (Council of Ministers), and judicial (Supreme Court)—but would have them be united by the concept of a central government and would have a head of state, i.e., the president of the USSR, be appointed. And the very idea of a conference may be deemed obsolete. As I have already said, the draft is interesting in its common humanist concepts but is less developed from a judicial standpoint. But here it might have been possible to argue with Andrey Dmitriyevich, especially since he, like every real scholar, willingly entered into arguments and discussions and did not leave his opponent without an answer.

Gift of Freedom

[Moderator] When we were already in the full heat of working on this issue, the editorial staff received a letter from the associates at the Zhitomir Museum of Local Lore. Our readers, presented with the suggestion that a "separate issue of PRIRODA be entirely devoted to the scientific and social legacy of A. D. Sakharov," emphasized the need for an in-depth and honest analysis of his ideas. "It is insulting and sad to sometimes see and hear recollection of the name Sakharov in vain, out of place and out of time," they wrote.

We admit that this often happens after the death of great people. In 1911 a similar situation was beautifully described in L. Andreyev's story "Death of Gulliver":

"The news of the death of a Mountain of a Man shrouded the entire country of Lilliput in deep mourning. His numerous enemies and those who envied him, having judged him too large and of a height that was harmful to the state, fell silent, satisfied by his death; quite the contrary, everyone remembers his strength and gentleness with pleasure. And a small group of friends, initially very small, grew noticeably with each day until finally the entire people of Lilliput was transformed into a sincere, loudly crying friend of Gulliver."[8]

Perhaps the agitation around the name of A. D. Sakharov is completely natural. But nevertheless, does not the swift transformation of Andrey Dmitriyevich's image into an icon trouble you?

[S. A. Kovalev] It is even more troubling that not one icon painting has been created but rather a hundred, and certainly each has been created "in its own image" for its own purposes. Many no longer care what kind of man Sakharov really was. His rank must be raised quick so that, God forbid, he does not end up without his image on a banner. Who only now would not fight for this name! Some orthodox figures say that an icon is wonderful, and Sakharov should become an icon, and even certain geometric considerations are presented in corroboration. They say an icon must be made and carried to the gonfalon, to the gonfalon. In my opinion, Leskov spoke on this theme more successfully than anyone else. Generally, by proverb, if you can't say anything good about the dead, you don't say anything. But Leskov said, "The truth must be told about the dead, just like about the living."

[Moderator] But will Andrey Dmitriyevich's image only end up on gonfalons, or will people nevertheless be able to penetrate his wisdom, patience, and honor? Are we ready to really grasp his ideas in depth?

[S. A. Kovalev] I am a pessimist in this respect and do not hold a great deal of hope for general in-depth understanding. People sometimes ask: what would have been if parliament only consisted of Sakharovs? In my opinion, it would have been wonderful because these 500 Sakharovs would not have turned out to be like-minded at all but instead would have been honest to the limit as was Andrey Dmitriyevich. Many now speak about the new political thinking and emphasize that it distinguished Sakharov. But I do not understand (it seems to me that he did not understand either: What does this mean? Does it mean new? Does it mean political?

[M. K. Mamardashvili] There is no new thinking. Either there is thought or there is not.

[S. A. Kovalev] And therein lies the point. And had 500 people similar to Andrey Dmitriyevich been elected to parliament, everything would have been all right. Because they would have been as responsible, wise, patient, and would also have not understood what new and specifically political thinking means. There are still not enough such people, and it is felt.

When a zone is turned entirely into an empty camp, everyone goes off watch, and then the experienced convicts know that someone will start a quick run. They will run to the headquarters to get the keys from the breadcutters, baths, barbers, laundry, and other such vitally important points. Something similar is observed when new people come to power. It is similar to the tactics that sometimes predominate in a very hurried political struggle. The constitution and foundations of various laws come later, later. But the main thing is the options. One must must gain the victory for them, and then after that the fundamental questions can be tackled, but for the present it is better to sacrifice them. This problem scares some constituents, and that one scares others. What is important now is that no one be scared—we do not have the right to lose.

There is some logic in this, but there is also a terrible risk: the mask sticks. For example, how do the young and unconscientious scientific associate reason? In his student years he says, "I will write a slapdash degree thesis to begin work on my candidate's dissertation more quickly." Then he says, "Agreed, my candidate's dissertation has been done carelessly, but I will do the doctor's dissertation as it should be done. I have to get opportunities for work!" But he never does begin work because he shows the same reasoning about his doctor's dissertation and election to the academy—indeed the possibilities for research increase with each degree. And he, of course, suggests that he will push forward hard on science as soon as he manages to move up high enough. Alas, experience shows that scientific potentialities end before all of the necessary degrees have been achieved. Science is only really accomplished by the one who worked on science while still a student rather than on his potentialities.

This does not mean that questions of tactics should be ignored. I am very much afraid that everyone will stop there. In my opinion, Andrey Dmitriyevich also feared this. S. Stankevich told about how a future interregional group gathered before the first Congress of USSR People's Deputies. The young energetic people spoke many intelligent works about politics and about how to act to achieve this or that result. At first Andrey Dmitriyevich was apparently daydreaming, but then he rose and said, "Certainly everything you say is correct. But I do not understand any of it. In my opinion, once we are given the rostrum we should say what we think. In any case, I myself intend to do so!" You remember the congress—how he conducted himself. And remember the results. At the time it seemed that everything had been lost, but it is now clear that that was really not the case. You see, the question of the sixth article of the constitution has now been resolved. True, Sakharov was not its author, but it is agreed that this is not important. Perhaps it is now necessary to make sure that the necessary conclusions follow from the changes in the sixth article and are achieved by the same direct method.

[Moderator] That ability of Andrey Dmitriyevich not to throw up his hands even in the most hopeless situation but to find solutions that at some time, even in the distant future, will yield a result seems amazing to many. Two years ago you, Merab Konstantinovich, published an article in PRIRODA in which you wrote about an absurd situation in which "it is always already late" and could not be understood from within or corrected.[9]

Andrey Dmitriyevich began active sociopolitical activity in a situation that should be considered absurd. What helped him get out of it?

[M. K. Mamardashvili] This is really a fatal question: what can be done in a situation where it is always too late? There is only one thing: change the very coordinates of the problem and the very soil on which the node "always later" arises. And Sakharov's activity was precisely such. Marcel Proust said, "The mind does not know dead-end situations." It does not know in the sense that the phenomenon of the mind is a resolution of a dead-end situation—there is no way out of the dead-end, so change all of the data of the problem. Since the situation is irresolvable from within, can one not remove himself from it and create other soil on which similar situations would not arise—only this will be sensible activity.

[S. A. Kovalev] To the question of what to do when no solution is evident, Andrey Dmitriyevich answered completely directly and unequivocally. One must make fundamental decisions because in the existing system of relationships you cannot do anything anyway. And he held to this. There is the famous interview that he gave in Gorkiy. They asked him whether he hoped for a change in the overall situation in the foreseeable future. Andrey Dmitriyevich answered that he held no such hopes. What can be done under such conditions? Construct an ideal, he said, because that is all the intelligentsia ever did. But then he also noted: however, the mole of history burrows unnoticed. And, recalling the conversation about the prophet, there is an element of prophecy here too.

[M. K. Mamardashvili] In the situation of the absurd, what is important is the very fact of its public discussion. We repeat the elements of a situation by the act of discussion—we do not change the situation but repeat it. Perhaps some secret work of history occurs in this repetition. Perhaps the mole of history that Sakharov had in mind is working during this time.

[S. A. Kovalev] Yes, not the one that is already on the surface but another that has yet to appear.

[M. K. Mamardashvili] God's millstone grinds very slowly but thoroughly. One must therefore construct some ideal without expecting that it will be realized in his lifetime. Incidentally, this is a very old note in Russian culture. In his time, Chaadayev proposed rejecting one of the three christian virtues—love, faith, and hope. He proposed rejecting hope (let God forgive us) since any action in the mire of a situation will only sink us deeper into that mire. And only free, sober-minded thought can save us.

Sakharov was a modern professional thinker to whom thought was subject only to the laws of thought itself—a matter of its merit and honor proper. He was a singular type not characteristic of the Russian intelligentsia, which was in fact a cross-bearing order of radicalism. That type arose in the beginning of the century alongside the radical intelligentsia—it is no accident that I recalled Vernadskiy. And it seems to me that Sakharov continued the tradition. From the portrait drawn by Sergey Adamovich emerges the face of an antinihilist, and this is a very significant figure in Russian history. It is a pleasant exception against the background of all-out nihilism, specifically legal nihilism. I would say that Sakharov was an uncompromising advocate of compromise, i.e., a man capable of laboring together with the existing authorities and not intensifying the gulf between it and society. But his striving to cooperate never made him pervert his thought or make it obliging. Here is a remarkable example that is especially needed in today's state of affairs, which vividly recalls the situation of Russia in the 1900's. The very same combinations of political forces and platforms are being revived, and consequently, the same results may also be reproduced.

The abyss of nihilism is again gaping before us. Reigning in society is a mood that, first, blames the authorities for everything, second, says that we do not want anything from the hands of power whether it be good or bad, and third, if we do want something, we want it all right now and not slowly. This is a classical case of nihilism. The gulf between the authorities and society is even more dangerous in that a third party always steps into the void. Once upon a time the bolsheviks stepped into the void. They made immediate use of the nihilistic state of society that arose when the natural development of the Russian empire was interrupted in 1914. (This is more exact than naming the year 1917. A historical description as an act of blaming some individuals, let us say the Bolsheviks, is not necessary; in such form it would be simply stupid. Speaking in Berdyayev's terms, a cosmic catastrophe took place. Is it worth looking for specific individuals who were to blame?)

Unfortunately, today, like before, there are very few people capable of occupying a position similar to the one Sakharov occupied. And we are again encountering the risk of the treachery of the intelligentsia. Such treachery already took place once—in the 1900's. I am referring to the treachery of its failing to fulfill its function, which was to think, and their failure to care about the people and sow the reasonable, good, and eternal. There is not a single civil society in which the irresolvable problem of the "people and the intelligentsia" does not exist, and intellectuals do not dispute what it is they should do for the people. Thought is not produced for anyone's sake; thought is produced for the sake of thought.

[S. A. Kovalev] Independence must be preserved because without independence there is no thought. And those Russians to whom the term "intelligentsia" initially referred always selected one side of the fence and ultimately turned out to be engaged and dependent. What a thought!

Thought is something that is followed by a result. If the decision comes before the thought, there is no place left for thought. The Russian intelligentsia always made the decision before having the thought, uttering lofty words about justice, the offended, oppressed, and abused. Merab Konstantinovich is entirely correct: the intelligentsia automatically separated itself from the people. It could acknowledge its fault before the people but did not know how or want to feel for the people. And since it was guilty of this before the people, it should have helped the people and only then decide which side of the fence to choose. But that was all that the Russian intelligentsia occupied itself with. Of course, not the entire intelligentsia, but let us say, the legal movement of the 1900's died out because of again choosing a side of the fence. The advocates of law turned out to be in the minority and were branded by both sides precisely for their attempts to preserve their independence.

[Moderator] Even when maintaining independence of thought, it is sometimes very difficult to make the right decision. Indeed, on the one hand, one must not reject ideals; on the other hand, one must act realistically and responsibly. But Andrey Dmitriyevich's ability to construct an ideal while simultaneously setting forth constructive proposals cannot, I fear, be taught. It is, like a Gospel moral, a life principle and not a set of recipes.

[M. K. Mamardashvili] I cannot agree with this. Real ideals presuppose a keen realization of human imperfection and, consequently, help make politics pragmatic, i.e., not constructed on human idealization. And this is realism. For example, the U. S. Constitution is based on a simple thing—an understanding of human evil is built into it, and social balances and counterbalances compensating one evil with another have been developed. The Europeans, and even more so the Americans, know how to clothe ideals in the fabric of a sober-minded understanding of man. The Russian tradition, on the other hand, is a proclamation of the idealness of man and counts on it. If we reject this, we will be able to act in Sakharov's spirit. This will naturally happen.

The idea of creating a new man and constructing communism on this basis is no longer poplar, but its residues have become firmly entrenched within us so that it still runs our innermost recesses and crannies. This is an antichristian idea. Almost all the disciples in the Gospel belong to the so-called historic section of christianity, and only two are in the nonhistoric section. And both of them indulge man. They bequeathed us two things: eternal life and freedom, the insufferable gift of freedom. There are no other behests.

[Moderator] And accepting this gift, we can, following after Andrey Dmitriyevich, look for support only in independent thought, absolute honor, responsibility to others, and love of life and those who have not yet been born. Perhaps this is the main message that all of Academician Sakharov's life and deeds holds for us?

Footnotes

1. Sakharov, A. D., "Trevoga i nadezhda" [Alarm and Hope], Moscow, 1990, p 221.

2. Ibid., p 213.

3. Sakharov, A., "Mir, progress, prava cheloveka. Stati i vystupleniya" [Peace, Progress, and Human Rights. Articles and Speeches], Leningrad, 1990, pp 5-6.

4. Sakharov, A. D., "Trevoga i nadezhda," p. 266.

5. Ibid., p 267.

6. Ibid.

7. Ibid.

8. From Andreyev, L., "Izbrannoye" [Selected Works], Moscow, pp 348-358. We thank one of the authors of this issue, B. M. Bolotovskiy, who called our attention to this story.

9. Mamardashvili, M. K., "Consciousness and Civilization," PRIRODA, No 11, 1988, pp 57-65.

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Edges of Talent

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[Article by D. A. Kirzhints, corresponding member USSR Academy of Sciences, Physics Institute imeni P. N. Lebedev, USSR Academy of Sciences]

[Text] These comments, which are rather subjective and fragmentary, are based on impressions that I have accumulated in 20 years of joint work with Andrey Dmitriyevich at the Physics Institute imeni P. N. Lebedev. Their purpose is to add several lines to the portrait of Sakharov the physicist without pretending to reveal the inner depths of his creative personality. That requires a serious and lengthy work involving specialists writing about the science of men of letters, which should be preceded by a "revelation" of even a portion of Sakharov's closed works, the reminiscences of his comrades in work, and of course publication of the memoirs and autobiographical works of Andrey Dmitriyevich himself. Moreover, it is the conviction of the author of these lines that it is difficult to penetrate the image of Sakharov the scholar apart from analyzing his social activity—and it was there that he manifested one of those traits of his unrepeatable personality. Indeed, the larger an external impression, the more deceptive it is (who, for example, could, without knowing Andrey Dmitriyevich, imagine that behind his soft intelligent exterior lay the iron character of an inflexible champion fighter.) You think about all this when you look at the present I received from Sakharov and his wife—two spheres that were absolutely indistinguishable from the outside but one of which bounced from the floor and the other "stuck" to it.

Each person who had scientific contact with Andrey Dmitriyevich felt, to one degree or another, the distinctive features that distinguished his creative personality. Above all, this includes the most unusual breadth of his scientific interests. If there is anything that links the extremely diverse problems on which he worked it was their global nature. I mean global in essence (the theory of the structure and evolution of the universe as a whole) or in their significance to all of humanity (the problem of using the energy of nuclear synthesis or his last works on safe nuclear power generation and on preventing earthquakes). People often ask what attracted Andrey Dmitriyevich's soul most—basic or applied problems. I think that it was more likely the latter. In any case, when Andrey Dmitriyevich was away from applied works and had the opportunity to concentrate on basic activity, he tried to get involved in work on laser thermonuclear synthesis, which promised mankind a new source of energy. One must think this was a manifestation of not only the storehouse of his creative personality but also his social stand—his desire to be of direct and visible use to people.

It is important to note that while working on global problems, Andrey Dmitriyevich did not limit himself to expressing general ideas and leaving it to others to embody them in specific form. In this sense he did not suffer from far-sightedness or near-sightedness—the trees did not hide the forest from him, nor did the forest hide the trees. According to the confirmation of his colleagues, he knew how to reduce a problem to numbers at least as good as anybody else could and had a taste for this work. But, really, do we not also see this very same absence of "aristocratism" in Andrey Dmitriyevich's social activity, in which he not only created such documents of our epoch as the memorandum "Razmyshleniya o progresse, mirnom sosushchestvovanii i intellektualnoy svobode" [Thoughts About Progress, Peaceful Coexistence, and Intellectual Freedom], or a draft for the new constitution but also personally "fought" for closed trials or a tribune of parliament?

Sakharov the scholar was distinguished by the amazing independence and originality of his physics thinking. His teacher I. Ye. Tamm recalled that from the time Sakharov began graduate studies, he stuck the examiners with his nonstandard approach to the most simple and, apparently, obvious things. Those listening to a report by Andrey Dmitriyevich or discussing something with him were struck by the thought that he had his own, more direct path from premise to consequence aas well by how quickly he grasped the long-range consequences of the statement being discussed. Sakharov's ideas were often amazing in their unexpected simplicity and obviousness (becoming clear, of course, only after he had stated them), as if Andrey Dmitriyevich dug up a mushroom growing at the very side of the road along which he was walking, dismissing all the others as conventional specimens. One must think that the independence of Andrey Dmitriyevich's thinking had as its source his inherent internal freedom and organic nonconformity, which were so visible in his social activity.

The power of his physical intuition[1] was one of the characteristic traits of Andrey Dmitriyevich's personality. Possessing a splendid mastery of the apparatus of theoretical physics, he was highly endowed with the capability of foreseeing results before any calculations (his colleagues in his applications activities swear that he often foretold even the value of numerical coefficients). Sometimes, after being struck by Andrey Dmitriyevich's ability to present the details of the behavior of an electron or nucleon with ultimate clarity, it was difficult to shake the feeling that he knows how to reincarnate himself in these particles, as if feeling with his very skin what had fallen to their lot. Was it not a similar ability to reincarnate a feeling of compassion in his pores that led him to defend persecuted human rights activists and to fight for a better lot for our unfortunate people?

Thinking in images is closely linked with phsyical intuition. I am not trying to say that Andrey Dmitriyevich possessed symmetry of left- and right-hemisphere activity, although we used to joke about just that, but I was spellbound when I observed how, while writing a line during a report, he switched to chalk into his left hand and continued writing the line just as freely. In any case, during our visits to Gorkiy, Andrey Dmitriyevich listened to the news attentively while continuously drawing small figures on sheets of paper (that I later stole): rogues with big mustaches, sphinxes, etc. Perhaps these facts will say something to psychologists if they lend their ideas to these lines.

Yet one more distinguishing trait of Sakharov the scholar was his scientific boldness. In reality, what words can characterize the prophetic idea of the decay of a proton that went against the then-existing ideas about the microworld or the hypothesis about the fact that during the process of the universe's evolution the direction of time changed and there was a stage when all motion was absent (the world of Parmenides, to use Andrey Dmitriyevich's terminology)? Moreover, no one is now surprised by the combination of words "Sakharov" and "fearlessness."

And in conclusion, here are several unforgettable episodes that, I hope, will add additional lines to the portrait of Sakharov the scholar. After one of Andrey Dmitriyevich's reports, there spoke a young self-assured theoretician who, clearly studying the presenter, announced that while he said that one result could be obtained by a stricter method, Yu. Shvinger had yet another, etc. Expecting that the one giving the report would simply wave this criticism away, we were quite more than a bit surprised when, after the seminar, Andrey Dmitriyevich approached his none-too-tactful opponent and, sitting with him for a long time afterward, discussed the details of the report. Andrey Dmitriyevich evidently sensed a specialist in him, and all the rest was meaningless.

Another episode relates my visit to Gorkiy along with one of my associates (who was noticeably shorter and smaller than Andrey Dmitriyevich). When we sat at the table and began working, Andrey Dmitriyevich said, "I am a little cold, I will go and put on a jacket. When he returned, I noticed that the jacket looked strange on

Andrey Dmitriyevich. After several hours of intense work, when we were getting ready to leave, my colleague asked, "Andrey Dmitriyevich, could you please return my jacket?" During the process of working Andrey Dmitriyevich was unaware of any physical discomforts.

Here is yet another fact. It characterizes Andrey Dmitriyevich as a man who was scrupulous with respect to references to others' works. It must be said that the respective moral standards are not too high: far from everyone cites work that has been done independently and close in time, and hardly anyone does so if it contain mistakes to boot. But here is a quotation from a letter Andrey Dmitriyevich sent from Gorkiy to A. D. Linde and me: "I looked at Vilenkin's article just the other day. I did not hurry because Andrey said that the article was in error. It turned out that the author's main idea is the same as my basic idea....If, even in the future, an author makes some mistake, that is not the main thing. I could not therefore not cite Vilenkin in the most serious manner...."

There is a legend that Sakharov's path in science was determined by a chance meeting between Tamm and Andrey Dmitriyevich's father, the physicist D. I. Sakharov, who was said to state, "Igor Yevgenyevich, I have a son Andryusha, he is of course not I. I. [not further identified], but nevertheless talk with him, sense will suddenly come out of him." Whether this is true or not, A. D. eventually became Tamm's pupil and, consequently, as a theoretical physicist belonged to the Mandelshtam-Tamm school and in many ways (and perhaps it no wonder how many) Andrey Dmitriyevich conformed to the scientific, human, and civil principles of that school, even though in many respects he stepped far beyond its bounds by embodying these principles in his life.

Footnote

1. If you please, one of the most striking examples of the manifestation of physical intuition was the feat of Russian pilot K. K. Artseulov during World War I (and Andrey Dmitriyevich agreed with this assessment after hearing my story about it). Artseulov placed his own life on the line in checking the correctness of his intuitive ideas regarding the mechanism of spin and a way of getting out of it. He sensed that this required somthing directly opposite to what the instinct of self-preservation and piloting experience at the time dictated—rather than steering off the course that led to the spin, it was necessary to in fact steer into it even harder. It was in that way and only in that way that control of the airplane, the loss of which generally led to the pilot's death, could be maintained. Artseulov was the first in the history of aviation to consciously guide his plane into a spin and luckily get out of it, thus creating a method that has saved many pilots' lives. And only after tens of years have aerodynamics scholars substantiated his method.

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My Schoolmate

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[Article by A. M. Yaglom, doctor of physical and mathematical sciences, Institute of Atmospheric Physics, USSR Academy of Sciences, Moscow]

[Text] I have never written any reminiscences, but I know that I must break this habit. The point is that I evidently knew Andrey Dmitriyevich Sakharov longer than all of the others with whom he continued to meet until the end of his life. This fact, together with the certainty that everything related to Sakharov must be preserved, compelled me to pick up the pen.

I became acquainted with Andrey Sakharov in the eighth class at the end of 1935 and beginning of 1936. Before that (together with my twin brother who is alas now dead), I studied in a 7-year school. After completing it, those of us who intended to study further were forced to switch to a different school. Upon the advice of acquaintances, my brother and I submitted an application to school No 114 on Bolshaya Gruzinskaya Street; however, some pupils of our class selected school No 113 on 2 Brestskaya Street.

In the seventh class my brother and I were considered the best mathematicians, and one of my friends from school No 113 informed us that there was also a strong mathematician, Andryusha Sakharov, in his new class. So we met Andrey Sakharov (we never called him Andryusha). At the time of our first meeting, we spoke mainly about mathematics (my brother and I spoke more than Andrey, who was never very talkative), and we seemed to like one another—in any case, we exchanged phone numbers and agreed to meet. We immediately told our new friend about the mathematics circle affiliated with Moscow State University that we visited and about the university's Sunday lectures for schoolchildren. Andrey listened with interest but did not express any desire to join us.

Nevertheless, we began meeting rather often. We told Andrey what we learned at the meetings of the mathematical circle and from the journals MATEMATIKA V SHKOLE [Mathematics in School] and MATEMATICHESKOYE PROSVESHCHENIYE [Mathematics Education], which we read regularly. He was interested in it and often surprised us with unexpected comments illuminating the mathematical problem under discussion with a side that was new for us. Several times he tried to propose physics problems for us, but we did not show any enthusiasm: in those years the school course in physics did not include any problems except for the most trivial exercises, and so we did not have any taste for solving physics problems. It seems that in spring of 1936 we talked Andrey into accompanying us to the Sunday mathematics lecture at Moscow State University, but what the lecture was on and what impression it made on Andrey I do not remember. Neither do I remember what else we talked about besides mathematics and physics during our meetings. I only remember that we agreed to go together to the section meetings of the mathematics circle at Moscow State University until the next school year.

And indeed, upon entering the ninth class, Andrey Sakharov began visiting one of the mathematics circle sections at Moscow State University together with us. We took our classes on a specific day of the week in the evenings in one of the mechanics and mathematics auditoriums in the old university building on Kokhovaya and generally continued for about 2 hours. The classes include a short communication from the section director, a student from the senior class or a graduate student. A number of problems were proposed in passing. Next began an analysis of the solutions, which were sometimes proposed by the participants right there but more often found at home. The discussion of the solutions often was transformed into a long report, but Andrey Sakharov seldom stepped forward with long communications. He clearly preferred problems on construction or the combinatorial problems that were popular in school circles and that required finding an answer over problems proving theorems. He was often the first to show the correct solution, but his explanations of it were often incomprehensible to the others without additional commentary by the circle director, and sometimes even he had difficulty.

I automatically recalled this when, much later during the course of one of my conversations with Sakharov (that probably occurred at the beginning of the 1970's), I complained that I was writing an article very slowly and with great difficulty. In response I heard that he is never able to write long articles at all because over the course of a number of years he had grown accustomed to confining himself to short formulas and predictions of results—he never had to give detailed explanations for them.

My brother and I were carried away with the mathematics circle, but when, at the beginning of the 10th class, we phoned Andrey and suggested that we go to Moscow State University together, we heard that he had decided not to attend the mathematics circle that year. He added, "If the university had a school physics circle, I would attend it without fail." Moscow State University organized such a circle only 2 years later, but it seems to me that in 1937-1938 mathematics was much more popular among Moscow pupils than was physics. The conversation with Andrey was therefore surprising. We even thought that he did not like the fact that so much of the time in the classes was devoted to strict proofs of theorems.

In summer 1938 Andrey Sakharov, my brother, and I finished school and entered Moscow University. Large competitions did not exist at the time, and getting in was not difficult. Andrey naturally selected the physics department. I also entered it, but my brother entered the department of mechanics and mathematics (we agreed to study in both departments in parallel). Sakharov had classmates at the university. Luckily, he had many, but I think that for the first years at least I was closer to Andrey than the others (we did know each other back in our school years). I cannot say, however, that I was a close friend of his. It seems to me that in those years he had no close friends at all. Possibly because of his intensive inner life, it was as if he shut himself off from others for a long time. He was always good-natured. There was never anyone in our class who would not have been fond of him, but he did not let anyone get close to him.

He studied well but did not shine. It seems to me that his teachers did not always understand him completely. In addition, when taking examinations he usually spoke slowly and as if uncertainly. Therefore his gradebook contained a great many 4's along with the 5's. He did particularly poorly in the social disciplines. They were evidently a world away from him, and had absolutely no ability to discuss general topics smoothly and superficially. For that reason, in the social disciplines he also had 3's, and once had to retake one of those examinations. When, at the end of the sixties, I read Sakharov's beautifully written "Razmyshleniya o progresse, mirnom sosushchestvovanii i intellektualnoy svobode" [Thoughts on Progress, Peaceful Coexistence, and Intellectual Freedom], I was, it seemed, stunned—it seemed to have been written by another man rather than the Andrey that I knew, who had dismissed everything that was not physics. And indeed at the end of his life the entire country did not leave their televisions but instead followed Sakharov's speeches with emotion. A brilliant orator he never became, but he spoke with maximum distinctness and clarity, strikingly able to say what is most important in several words. It seems to me that he developed internally throughout his entire life, slowly but as thoroughly as possible, thinking everything out to the end, unlike other types of people who mature quickly but stop on the level they reach early.

But let me return to our university years. Sakharov did not study brilliantly. From a purely formal standpoint, I or, for example, M. L. Levin were considered the better students in the class than Sakharov. But, following the convention of school years, we often spoke with him "about science," and I became certain that he was stronger than me—he understood what was inaccessible to me. I will present a well-remembered example. In the third course in the mathematical physics lectures we learned about the Bessel function and the connection between the nulls of a zero-order Bessel function with the free-running frequencies of the oscillations of a round membrane. Soon Andrey told me about a method that he had thought of for estimating the nulls of a zero-order Bessel function. As had happened earlier, it was hard to understand to the end (it frequently seemed to me that Andrey omitted some very simple logical steps that seemed obvious to him, which was possibly related to his dislike of long logically irreproachable proofs of theorems), but I kept the impression that "there is something here." To check, I suggested that he take a sheet of paper and calculate several of the first nulls. He agreed and after a short time brought the results of the calculations. We went to the university library and found a reference book. It turned out that the values of the first three or four nulls that he found were virtually the same as specified in the table. I perceived this as a miracle (it seemed to me that his theory could not be very rough) and remembered it my entire life. But Andrey did not feel any special satisfaction—he was completely sure of the result.

Unfortunately, the third course in the physics department was the last in which Sakharov and I studied together. The war began in the summer of 1941. In the early days many of us hurried to enlist in the army (none of those who were able to returned from the war), but in July-August 1941 were were sent to the Smolensk Oblast to construct defensive fortifications (I do not remember why, but Andrey was not there). In September all the students in the course were called to the Air Force Academy, but Andrey and I did not pass the medical commission. On 16 October Moscow State University had to be evacuated to Tashkent. The last time in autumn 1941 I saw Sakharov was 2 days before the proposed evacuation when he helped my brother and me bring things to the physics department from where they were to be taken to Tashkent. But the evacuation did not take place on 16 October. Early in the morning the Sovinformbyuro [Soviet Information Office] broadcast the terrible report by radio. A panic began in Moscow, the students were informed that the university was closed, and it was recommended that all proceed by foot to the east along the railroad lines. Many did so. I stayed in Moscow with my parents. On 20 October in subway cars our family was taken to Sverdlovsk together with the rest of the Narkomchermet, where my father worked. By the 20th the university had already begin functioning, and after several days Andrey and a large group of students, graduate students, and teachers were evacuated, but to Ashkhabad rather than Tashkent.

My next meeting with Sakharov took place in Moscow in 1945. He returned from Ulyanovsk, where he had worked in a military plant and married after completing the university. I also finished the university and, after working for a year and a half at the scientific institute in Sverdlovsk, began graduate studies in Moscow at the Mathematics Institute of the USSR Academy of Sciences. I was very interested in theoretical physics and regularly attended the seminar at the theoretical department of the Physics Institute imeni P. N. Lebedev directed by I. Ye. Tamm. Andrey dreamed of graduate studies at the Physics Institute imeni P. N. Lebedev. At his request, my classmate P. Ye. Kunin (at the time, one of Tamm's graduate students) and I brought him to the Physics Institute imeni P. N. Lebedev and introduced him to Igor Yevgenyevich. (Later I found out that Dmitriy Ivanovich Sakharov, Andrey's father, had send some scientific manuscript to Tam after his son's trip to Moscow by way of A. M. Lopshits, a mathematician who worked at the Pedagogical Institute and was a long-time acquaintance of Igor Yevgenyevich.) Tam informed Andrey that to begin graduate studies he would have to take an entrance examination in the form of a report at the theoretical department seminar. An entrant could either select his own report topic or ask that one be assigned to him. Andrey selected his theme himself (something about the diffraction of electromagnetic waves on solid bodies). Kunin and I were at the report and simultaneously decided that he was very unsuccessful, but Igor Yevgenyevich found the report remarkable and announced on the spot that he was accepting Andrey for graduate studies.

In the years of our graduate studies and in the first years after completing it, I often met Andrey and spoke with him a great deal. The conversations on physics themes were always interesting, but I often had to later think more about everything I had heard. One summer I got a summer cottage on the Moscow-Volga canal not far from Vodnika Station, where the laboratory in which I was working was measuring the characteristics of atmospheric turbulence that very same year. At the time I got to know his first wife Klavdiya Alekseyevna better and introduced him to to my Laboratory head A. M. Obukhov and his wife, with whom Andrey and Klava quickly became friendly. Later Andrey dropped out of sight for a long time. He was working intensely outside Moscow and was practically inaccessible.

After Andrey's return to Moscow, I met with him occasionally. I remember in 1971 (2 years after Klava's death) that I was strolling in Peredelkina with my wife and met Andrey with his second wife Yelena Georgeyevna (Lyusya) Bonner, whom I did not know before then. At the time Sakharov was gathering signatures for a letter about abolishing capital punishment. I said that in my opinion abolishing capital punishment was not the first thing that should be accomplished in the USSR during those years and that, besides, capital punishment for terrorist acts should be maintained so as not to increase the capture of hostages for the purpose of freeing arrested terrorists. Softly, as if convincing himself, Andrey retorted, "No, there cannot be a law requiring the killing of people. And have you thought about those who will carry out the capital punishment?" (I am certain that everything he said had been thought out long ago, but at scientific conferences he frequently gave the impression that he was thinking during the course of the report.) We never returned to this question again. Of course, at the time he was right and not I. I also remember that during the stroll we were all enjoying the woods, grass, and sun, and Lyusya said that it was remarkable because until meeting Andrey she had never walked in the woods.

In autumn of the next year my wife and I met Andrey and Lyusya at the buffet at a hotel in Tbilisi where we had gone for several days. Two of my Georgian graduate students offered to drive us in cars to Mtskheta and to the Atena and Kintsvissi temples, which have very interesting 12th century frescoes, over the next couple of days. I invited Andrey and Lyusya to go to. The trip was amazing. My wife's sister and her husband at the time

Yura Tuvin, who also came to like Andrey Dmitriyevich and who touchingly cared for him and Lyusya in Moscow, helping as much as he could, also came along.

Thanks to my friendship with Tuvin, I unexpectedly turned out to be a witness to Andrey's finding out that he had been awarded the Nobel Peace Prize in 1975. In the autumn, when Lyusya went to the West for treatment, Andrey Dmitriyevich agreed to visit Yura some evening. When the date of the visit was made definite, Yura called me and suggested that we spend the evening in good company (but he did not say who would be there, at the time it was preferred not to mention the name Sakharov on the phone). It unexpectedly turned out that that was precisely the day when the awarding of the Nobel Prize to Sakharov was announced in Oslo. Many journalists tried to contact the new laureate, but no one answered his telephone, and no one knew where to look for him. Finally, in response to an ordinary phone call from abroad, one of Sakharov's friends (it seems, Lidiya Korneyevna Chukovskaya) said that Sakharov might be at the home of Yu. Tuvin and gave his phone number and address. Suspecting nothing, I went to Yura's at the very moment when a crowd of foreign journalists and human rights activists connected with Sakharov poured into the apartment. I recall the evening well—it was very joyous (Andrey, it seems, was the least joyful), but naturally nothing came of Yura's idea to spend a cozy evening in close company.

The next day Yura and I went again to Ckalov Street to congratulate Andrey Dmitriyevich on being awarded the prize. Many of our acquaintances were there. The telephone never stopped ringing, L. Z. Kopelev, who knows several foreign languages well, answered all the calls from abroad, but when he left and another call came from abroad, Yura turned to me and said, "Take the phone, you can speak English!" I do not know whether Sakharov could tell that I was disturbed or simply guessed that I could find it unpleasant, but he intervened, "No, you do not need to talk for me on the phone." (I really did not want to speak on a telephone that could be heard from abroad; I was certain that such a conversation would have to attract the attention of the KGB.)

Between 1975 and Sakharov's exile to Gorkiy at the beginning of 1980 I only saw Andrey a couple of times. During one of the meetings (I think back before 1975) I asked whether it disturbed him that his scientific work was connected with the creation of a superbomb intended to destroy people. (I was especially interested in this question because I myself, after completing graduate studies at the end of 1946 and being very much captivated with theoretical physics nevertheless declined to go to work at the Physics Institute imeni P. N. Lebedev since part of the time I would have had to work on an applied theme related to work on the atom bomb). Andrey listened to me attentively and, after thinking, answered, "No, you know, at the time I did not think about it; it was very interesting to explain whether all that we had thought of would work." I know Andrey sometimes answered the same question differently—he considered the presence of the bomb on both sides the best guarantee that it would never be used. Nevertheless it seems to me that the answer he gave me is interesting. I am certain that both answers are true (Sakharov could not lie in general), but both considerations likely were decisive for him. Possibly the first reflects his feelings at the beginning of his work more precisely, and the second refers to the later stage—indeed Sakharov was always in the process of development, and his views underwent many changes.

After Sakharov's return from the Gorkiy exile, I immediately phoned him to congratulate him on his arrival. I very much wanted to see him, but he kept putting off the meeting, saying that he was busy. Nevertheless I phoned him rather often and always heard, "It is good that you phoned, phone again." I do not know whether this was a manifestation of his rare delicacy and softness or whether he really was always glad to hear from such an old friend despite how incredibly busy he was.

In summer 1988 we met at the Leningrad conference dedicated to the 100th birthday of A. A. Fridman, where Sakharov presented a very interesting report (evidently the last of his life) and somehow seemed childishly glad to have the opportunity to talk with physicists about physics. Specifically, with a feeling of deep pity and delight he told me about his conversation with S. Hawking, the eminent English scholar who was nearly completely paralyzed as the result of a rare disease. Speaking about Fridman in response to my comment that it was as if Fridman himself perceived the exact solution he found to Einstein's equation (it later turned out to agree beautifully with observational data, which Fridman did not live to see) as a purely mathematical exercise, Andrey objected that he did not believe it, "Each physicist, upon finding a new beautiful solution, immediately begins to look for that in nature to which the solution should correspond."

Andrey and I met several times at the meetings of the Moscow Tribunal and, alas, at funerals. In spring 1988 he came to my brother's funeral. At the beginning of December 1989, not long before his death, he attended the funeral of A. M. Obukhov, director of our Institute of Atmospheric Physics. The following fact serves as a commentary. The point is that Obukhov, who was on friendly terms with Andrey at home, signed the famed letter of 40 academicians against Sakharov. After some time our director tried to justify his deed and carefully quoted detestable remarks about Sakharov made by several high academic officers but soon fell silent. In conversations with me he expressed sorrow for Sakharov and as far as the reason for his own signature he said that he "got caught up in the unpleasant affair": it turns out that he was not on the initial list of those on whom it was incumbent to sign the letter and but that he was dragged in at the last minute instead of someone who could not be found. In one of our conversations I recalled Obukhov, and Sakharov said the same thing: "I understand that Keldysh pressured him, but he could have refused; I do not bear him any grudge for it" (it seems he never bore a grudge against those who caused harm to him personally). I was therefore not surprised to see him at Obukhov's funeral. Later I found out that he calmly said to his daughter: "Tell your mom that I must write her a long letter." Unfortunately, he did not have time to do so.

A day later was the funeral of the lawyer S. V. Kallistratovaya, who for many years had defended all who were unjustly accused and was a long-time friend of our family. Seeing Andrey there, I said to him, "How I wish I had half an hour to talk somewhere other than at a funeral." He answered very seriously, "You know I have no time at all, but you absolutely must call." Possibly, under the influence of this conversation after S. V. Kallistratova's burial service at the church, he walked up to me and said, "Lyusya and I are waiting for a car—let us give you a lift home." I answered that I could not not go to the cemetery. We spoke for a couple of minutes, and Andrey said that he likes the procedure of church burial ("it is somehow human"), after which he recalled my brother's funeral where my brother's son and his friends read European prayers over the grave. We kissed in farewell, and a week later the news came that Sakharov was no more.

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"Nothing Will Ever Come of This Andrey!"

917F0007R Moscow PRIRODA in Russian No 8, Aug 90 pp 111-114

[Article by I. S. Shklovskiy]

[Text] (Autumn 1941. The evacuation to Ashkhabad) ...To my left on plank beds lay a 20-year-old fellow with a completely different frame of mind, hardly taking part in our seminary pastime. He was rather tall and thin, with deeply sunken eyes, and fairly ragged but who had let himself go (if speaking about his dress). He was hardly heard. He diligently performed the black, dirty work so plentiful in echelon life. It was evident that the whirlwind of ware had torn the boy form an intelligent family without having had time to singe him. Moreover, there were more than a few such as he in our echelon, among its "mire." But once this boy turned to me with a request that seemed completely wild, "Do you have something to read on physics?" he asked his "senior comrade," i.e., me, respectfully. It must be said that most of the children addressed me informally, and I made a wry face at my neighbor's [formal] address. My first wish in the BAM [Baykal-Amur Railroad] language was to send this mama's boy packing with his stupid request. "You have found the time, you little fool—" but at the last minute an evil thought occurred to me. I remembered that in the very bottom of my backpack, taken during the rather hurried evacuation from Moscow on 26 October 1941 lay Heitler's "Kvantovay teoriya izlucheniya" [Quantum Theory of Radiation)....

I remember well that I had bought Heitler's monograph, which had just been translated into Russian, in April 1940 in a bookstand in Moscow at the entrance to the old building of Moscow State University. The book seduced me with the possibility of immediately immersing myself into the depths of a high theory and thereby being "at its level." Alas, I was quickly grinding my teeth: I did not get farther than the preface and very first paragraph (a discussion of first-order processes). I remember how oppressed I was with this fact. Of course it meant that I was not to be a theoretical physicist! How was I to know that this book is simply very difficult, not to mention the fact that it is written in a heavy "German" style. But nevertheless, why had I placed it in by backpack?

"I'll play a good joke on him, by giving the boy Heitler," I thought. And almost immediately I forgot about the strange youth on whom I often fixed by glance unconsciously: in the weak, flickering light of the oil lamp, against the background of songs and gay tunes the of the boys, he lay quietly on the plank bed and read something. And only when we had reached Ashkhabad did I understand that he had been reading my Heitler. "Thanks," he said, giving me back the book in a black, very dirty binding. "What, you read it?" I asked uncertainly. "Yes, what did you think?" Thunderstruck, I remained silent. "It was a difficult book, but very deep and full of substance. Thanks a lot," concluded the boy.

I was beside myself. Judge for yourself. Here I was, a graduate student who, despite all my desire, could not even read the first section of this damned Heitler, while a boy—a student in the third class—not only read it but read and understood it (I remembered that he wrote something while reading it), and under such, to put it mildly, extreme conditions no less! But the bitterness passed quickly and was followed by surprise for our completely fantastic, happy, and hungry Ashkhabad life that was unlike anything else....

I often saw the fellow that struck my imagination as ragged and hungry as we all were. It seems that he sometimes worked as a odd-job man in the dining room or, as we called it, "soup station" (there were yet other words for it: soup-tropics [a pun on the word "subtropics"], i.e., Ashkhabad, suopo-stat [a pun on the word "adversary"], i.e., the man standing in line for soup in front of you, etc.)....

In April 1943—an early bird!—I returned from the evacuation to Moscow, which was completely empty. At the end of 1944 my graduate studies chief, the very dear Nikolay Nikolayevich Pariyskiy, returned from the evacuation. We met joyfully—indeed we had not seen anyone for 3 years! There were arguments and big and small pieces of news. "And where is X? And where is the family Y?" Who could you not remember? Every one had his end, and the list of common friends and acquaintances was after a (no short!) time practically exhausted. And then the conversation shifted to topics that were not the most vitally important. N. N. said incidentally, "And Igor Yevgenyevich (Tamm, the old friend of N.N., I. Sh.)

had gotten a completely extraordinary graduate student. There has not been another like him, even V. L. [Ginzburg] is not fit to hold a candle to him!" "What is his name?" "Wait, wait, it is such a simple name, it is always turning in my head—the devil take it: I have become a complete sclerotic!" Well, this was so typical for Nikolay Nikolayevich, who was legendary in the astronomy world for his absent-mindedness. And then I thought, "All the graduates from the physics passed before me in the Ashkhabad echelon. Where was this outstanding graduate student?" And at that moment I found him: he could only be my neighbor on the plank beds in the shelter who had surprised me by having studied Heitler. "Is it Andrey Sakharov?" I asked Nikolay Nikolayevich. "That's it, that's it, such a simple name, and it jumped out of my head!"

I did not see him after Ashkhabad for 24 years. In 1966 on the day of my 50th birthday, I was elected (on the fifth attempt) as a corresponding member of the USSR Academy of Sciences. At the next autumn meeting of the academy, Yakov Borisovich Zeldovich said to me, "Would you like me to introduce you to Sakharov?" Hardly elbowing his way through the thick crowd gathered in the foyer of the House of Scholars, Ya. B. introduced me to Andrey. "But we have known each other for a long time," he said. I recognized him immediately—only his eyes were more sunken. It is strange, but baldness did not at all spoil his noble face.

At the end of May 1971 on the day of Andrey Dmitriyevich's 50th birthday, I miraculously gave him that same exemplary copy of Heitler's "Quantum Theory of Radiation."

[January 1967, United States] ...It was already 6:55 when I entered the luxurious light-filled cottage of the famous physicist who was the "father of the American hydrogen bomb." The American scientific elite was present at the reception at Teller's. There were at least six Nobel laureates....To my extreme embarrassment, Teller threw himself at me as soon as I entered the room and began to elicit what I thought about these incomprehensible quasars. In so doing, he placed me in the center of attention. By the way even though it had been my intention to just listen. This attempt continued for no less than a quarter of an hour. And then I decided to extract myself from it in some unexpected way. Without any link to the problem of quasars, I said, "And do you know Mister Teller that several years ago your name was extremely popular in our country!" Teller was very interested in my announcement. What I had in mind was the famed "lower half of the page" in LITERATURNAYA GAZETA [Literary Newspaper] that was garishly headed "Cannibal Teller." In trying to explain the content of this article to my host in his home, to my horror, I forgot how to translate the word "cannibal" into English. I stood in contemplation for a number of seconds and then, remembering that Teller was a Hungarian Jew and that his native language was German, I said, "Menschenfresser." "Oh," Edward groaned with glee, "cannibal! And how do you say it in Russian?" "Lyu-do-yed" I said separating the syllables. Teller took out his notebook and wrote down the easily pronouncable Russian word. "Tomorrow I am lecturing students at Berkley and I will tell them that I am a lyu-do-led! [Note: "led" means ice as opposed to the root "yed," which means "eater"]...I castled myself in a corner of the veranda. I had time to think about Teller's reaction to being accused of cannibalism.

Six years after my conversation with Teller, while lying in the hospital at the Academy of Sciences, I asked Andrey Dmitriyevich, who was often in my ward, whether he suffers from the Eatherly complex.[1] "Certainly not," answered one of the most outstanding humanists of our planet.

[November 1973. Hospital at the USSR Academy of Sciences] ...While lying in my separate ward I gradually began to establish contacts with the outside world through my small Sony receiver. For several hours a day I listened to a different type of "enemy voice." At the time these "voices" devoted a great deal of attention to Andrey Dmitriyevich Sakharov and his spouse, who was long known to me by the name Lyusya even though the name on her passport was Yelena. She was always being dragged to the prosecutor comrade Malyarov for interrogation. Each day the academic couple informed foreign journalists of the entire peripeteia of its complex relations with the authorities so that I was in the flow of events.

Once, having heard the regular portion of a similar type of news, I fell into a semidream state. When I opened my eyes because of some noise, I understood that I was no longer in this world. Judge for yourself, whether I could have thought differently. In the empty ward alongside my cot stood the very person of the academician Sakharov and his spouse! When it finally dawned on me that this was not a delusion, I was naturally glad to see this couple who had been known to me for so long. Then the reason for their appearance at the academy hospital was explained. It was not a bad idea—save themselves from comrade Malyarov in the aforesaid hospital. And then yesterday on Friday evening, like snow on the head, they fell down on the duty officer in the reception room. One could of course feel sorry for this duty officer. He had to decide a complex problem. In the end, after consultation with the hospital authorities the Solomon-like decision was made: the academician in the separate deluxe ward (there is nothing to be done: the law is the law!) and his wife should be sent to the general ward! Indignant at this arbitrary decision, the spouses came to me (somehow they found out that I was in the hospital) as to an "old-timer" of these places to get advice as to how to deal with this outrage. "Just don't hold a press conference," I said. "On off days there are no authorities. Wait 2 more days, and on Monday they will unite you." And so it turned out.

A new and very bright stage of my hospital life began. In the haste of their flight from comrade Malyarov, the spouses, like ancient Jews running form the tribe of

Egyptians, forgot one important thing. While the aforementioned Jews forgot the yeast, the academic couple forgot their transistor receiver. For this reason, each evening after supper Andrey Dmitriyevich, either alone or else with his wife, came to my ward to hear any type of "voice." It was touching to watch them while, sitting at my bed and listening to the radio, they constantly held hands. Even newlyweds do not sit that way....It was fun to listen along with them as the BBC said that the academician Sakharov was forcefully placed into the hospital and that the Moscow progressive society was seriously upset with this fact....

My hospital life grew much more complicated because of the visits of Andrey and Lyusya. Immediately, there was a sudden dramatic increase in the number of visits to my ward by all sorts of guests. Before this, I had not seen many of them for long years. The visits were mainly in the evening—somehow they coincided with the time when the famed married couple visited my ward. Very often, when we listened to the radio in the evening, the door opened unexpectedly, and some completely unfamiliar and very unsympathetic physiognomy leaned out. The guests told me that in anticipation of Sakharov's arrival at my room the ambulatory patients—the main contingent of the academic hospital—sat along the entire corridor. Long before the academician and his spouse followed along the corridor to my ward, this contingent occupied the best spots (they came with their chairs) and patiently awaited the "phenomenon" since they had enough free time. As a result of this lifestyle saturated with vivid impressions, during the evening rounds my blood pressure jumped by 20 points.

Despite all these complications, the every-evening conversations with one of the most remarkable people of our time gave me enormous gratification. They gave me a great deal and enabled me to better understand my amazing partner in conversation. We spoke a great deal about science, the ethics of a scholar, and the "climate" of scientific research. I recalled his remarkable sentence: "You astronomers are lucky people: you have still kept the poetry of facts!" How true it is! And how one's understanding of the spirit of a field of knowledge that is in essence so far from his own interests must be in order to give such an assessment of the situation!

I was struck by Andrey Dmitriyevich's scrupulous objectivity and unlimited benevolence in his remarks about his colleagues—the eminent physicists....Sakharov's kindness, benevolence, and strict objectivity emerged clearly during these conversations.

Of course, we not only spoke about science. Once I asked Andrey: "Do you believe that you can accomplish anything with your social activity in this country?" Without pausing to think, he answered, "No." "So why do you behave the way you do?" "I cannot act any differently," he cut in. In general, the combination of unbending firmness and childlike directness, kindness, and even naivete were the distinctive traits of his character.

[1972, Moscow] ...My mood was absolutely awful. The next round of painful tests was beginning. For a couple of months before that, in the beginning of February on the day before my scheduled departure to Maleyevka, Andrey Dmitriyevich Sakharov literally grabbed me and asked if, along with him, I would sign a paper addressed to the USSR prosecutor. The paper contained a request to allow us to familiarize ourselves with the matter of some Kronid Lyubarskiy and study the possibility of releasing him on bail until his trial because of poor health. "Oh well—such is my fate!" I answered momentarily immediately. Andrey convinced me that we are acting in strict accordance with the conventional procedural code. And for some reason he needed two signatures, "something like two orientations of an electron's spin," joked the academician not entirely appropriately. "One signature is mine, and the second will naturally be yours. Indeed, he is an astrophysicist, your colleague.!" What could I say, Andrey is a great expert on the law. I knew this Lyubarskiy slightly, he was working in a semiamateur manner on the planets in the marxian astrobotanical sector of G. A. Tikhov in Alma-Ata. I would never again have respected my self until the end of my days had I not placed my signature alongside the signature of this man whom I respected highly. And, clearly understanding that I was making a mistake, I signed (I simply could not do otherwise). "Nothing will come of this, Andrey!" "I don't think so either," he answered rather calmly. Neither before nor after that, did Andrey Dmitriyevich ever come to me with similar requests.

Footnote

1. Claude Eatherly was the American army colonel who dropped the first atomic bomb on Hiroshima from a B-29 bomber. Sometime afterward, the weak-nerved lieutenant, tortured with guilt, fell into a deep depression and ended his days in a psychiatric hospital.

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Criminal Affair

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[Article by B. M. Bolotovskiy, doctor of physical and mathematical sciences, Moscow]

[Text] In 1948, several months after Andrey Dmitriyevich Sakharov was included in the scientific research group developing thermonuclear weaponry that Igor Yevgenyevich Tamm headed, the famed August session of the All-Union Academy of Agricultural Sciences imeni V. I. Lenin [VASKhNIL] sadly took place in Moscow. Intense top-secret work took Sakharov and Tamm away from the outside world. But events in biology that carried with them the total devastation of genetics could not escape their attention. And it may certainly be said that Tamm's opinion on this matter at the time was of decisive significance for the young Sakharov.

Several decades later Andrey Dmitriyevich remembers the years of his work at the "facility" as follows: "After the workday I went to Igor Yevgenyevich's cottage, and we talked our hearts out. And thus we spent three years, after which he was allowed to return to science. And that was correct, he was the most capable. But I remained because very dramatic events in the development of our products still lie ahead. I did not visit Moscow often, but each time I went to see Igor Yevgenyevich. Our relationship remained close, although over the course of time I somehow evolved farther."[1]

Sakharov went much farther than Tamm as a social activist, but at the time in question, Tamm was Sakharov's teacher in many respects.

For Igor Yevgenyevich biology was a kindred element. He had been interested in it since his days as a university student and perhaps even since his gymnasium days. In 1918-1920 he was close to A. G. Gurvich, the renowned researcher of the physiology of cell division, and he followed his works intently. Igor Yevgenyevich was interested in the problem of life as a physicist. In his reminiscences about Ya. I. Frenkel he recalled that in the years of their joint work in Tavricheskiy (now Simferopolsk) University they discussed more than once the problems of the thermodynamics of living systems, which Yakov Ilich was studying at the time.

Having found out about the VASKhNIL session, Tamm assessed its results unequivocally. Since Igor Yevgenyevich was in the habit and even felt the necessity of discussing all of the more or less important news, there could be no doubt that his conversations with Andrey Dmitriyevich included more than a little discussion of "weismanism-morganism" and "Michurinite biology." This suggestion is touched lightly in Sakharov's story: "In my opinion, it is entirely right to say that all of us were very happy that Igor Yevgenyevich turned out to be right alongside us. Without him, much would have turned out differently—on business, scientific, and psychological planes. During the evening stroll, Igor Yevgenyevich was our senior comrade, a little tired and silent, breathing in the damp smells of the forest along with us. Over a cup up tea, however, we discussed all matters, and Igor Yevgenyevich told a great deal of his own life and simply what he knew and heard (and he knew a great deal). At the board in the service room, we received a lesson in the methodology of theoretical work. At a meeting with the head we received a lesson in adherence to business, human, and scientific principles. And in all situations we received a lesson in conscientiousness, love of work, and profound thinking."[2]

History of One Legend

Recalling the first tests of the hydrogen bomb (August 1953), Sakharov said that no one had imagined exactly how it would all look. There were reasons to fear radioactive fallout, but the scholars did not put a lot of stock in that. A great deal of courage and effort was required from Tamm and Kurchatov in order to be able to insist on an expensive evacuation of the public from the adjacent regions. It later turned out that this was not necessary.

After the successful tests, Tamm and Sakharov were awarded medals and became academicians in the next election. Tamm had been nominated earlier, but the matter did not come to a vote—the all-powerful authorities rejected his candidacy because he was considered little-reliable. But this time he was elected together with his pupil.

But in Sakharov's mind a break had fully evolved. "Once," said Andrey Dmitriyevich, "I admitted to Igor Yevgenyevich how hard and agonizing it was to realize what a terrible thing we were working on. He perceived my words distinctly, although they were very unexpected by him. Indeed we were captured by a feeling of the scale and grandiosity of the matter on which we were working."[3]

Enormous human and physical resources were involved in the work at the "facility." The understanding that they were performing work of colossal importance gave those doing the work strength. But Sakharov developed new worries.

Around the Physics Institute imeni P. N. Lebedev there are many stories about Andrey Dmitriyevich that were perceived as legends. It later became clear that they were generally well-founded. At the end of the fifties I heard that 2 weeks before each test explosion Sakharov would lock himself into his office and begin to calculate how many cripples and monsters would appear on earth as a result of the radioactive contamination of the atmosphere. (They were speaking about explosions at significant altitude over the earth.)

The details of a legend are unimportant. What is important is that they reflect a real situation. In the second half of the fifties Sakharov moved from a recognition of the threat that nuclear weaponry poses to mankind to attempts to estimate it quantitatively. Consequently, his knowledge of genetics at the time was not bad.

Here is what he wrote later: "Beginning in 1957 (without the influence of the remarks on this theme throughout the world by such people as A. Schweitzer, L. Pauling, and several others), I felt myself responsible for the problem of radioactive contamination during nuclear tests. As is known, the absorption of radioactive products of nuclear explosions by billions of people populating the earth leads to an increase in the frequency of a number of diseases and congenital deformations (on account of so-called no-threshold biological effects, for example, on account of damage to DNA molecules, which are the carriers of heredity). When the radioactive products of an explosion fall into the atmosphere, each megaton of power from the nuclear explosion brings with it thousands of innocent victims. And indeed, each series of nuclear weapons tests (whether in the United States, the USSR, Great Britain, or China and France) means tens of megatons, i.e., tens of thousands of victims."[4]

After Stalin's death, the strict ban placed on genetics began to be eased. This was explained by a certain liberalization of society and, specifically, by the expansion of work with radioactive substances and the need to explain their effect on human heredity. Radiation genetics began to develop. Genetics laboratories were opened at a number of physics institutes. A biology seminar under Tamm's direction began work at the Physics Institute imeni P. N. Lebedev. But Lysenko and his advocates held on to the high command.

I remember how, during those years, Igor Yevgenyevich said, "Geneticists have now received an opportunity to work. They are not longer persecuted, they are setting down to work, they themselves can determine the theme of their research, and the results of their work are published. But many cannot now work to their full capacity. They see their main task as finally giving a fundamental evaluation of the madness that Lysenko and his advocates created."

And so it turned out that Andrey Dmitriyevich was one of the first to give an honest and merciless assessment of the results of the sadly renowned session of the VASKhNIL.

In 1964 academic elections were held. Lysenko nominated his closest associate N. I. Nuzhdin. During the voting in the biology department the Lysenko majority snapped into action. In that stage Nuzhdin passed (having received four yes votes and two no votes). Confirmation in the academy's general assembly lay ahead. But there the blow was given—not actually to Nuzhdin but rather to Lysenko. Andrey Dmitriyevich actively participated in the "battle activities." He and Tamm stepped forward. I heard him tell about it, and I wrote it down.

Tamm's Story

Engelgardt came to me and said that the biology department had nominated Nuzhdin as a candidate and that in elections in the department he was approved for the academy. This man was an opponent of formal genetics, and the worst thing was not his scientific convictions but considerations of a different sort. I knew about this before by conversation with Engelgardt. One biologist told me of his meeting with Nuzhdin not long before the VASKhNIL session in August 1948. Nuzhdin asked what that biologist (I did not write down his name at the time and now forget, B. B.) was working on at the time. He began to tell of his study of the mutations in some object. Nuzhdin listened, listened, and then placed his hand on the other's shoulder and said, "You're not climbing on that horse, are you?" Do you understand? He was in on everything, and he knew that they would impose a ban on genetics.

I asked Engelgardt what could be done. He answered that it was necessary to speak out against Nuzhdin at the general assembly. I said that I could but that it would be difficult for me if the biologists keep silent. If even one of them would say his piece, I would also be ready.

Engelgardt thought but still did not make any decision. Not long before the meeting, Vladimir Aleksandrovich informed me that he would speak out. I began to get ready.

I came into the hall. They got to the confirmation. The first word was from the chairman of the general assembly's party group. He announced that the party group had examined the results of the departmental elections and decided to vote for all those selected. Well, I thought, things are bad, Nuzhdin will pass. But I nevertheless decided to speak. When they got to Nuzhdin, Engelgardt spoke. Then came Andrey Dmitriyevich. I also said a little something. It was very short and without any sharpness. I said that, proceeding from the state interests, biological science must create all the conditions for development. Specifically, the things that biology is developing must be supported in every way, and anyone who impedes this development should be fought. Proceeding from such issues, I would vote against Nuzhdin. The discussion heated up. By an overwhelming majority Nuzhdin was defeated.

After the vote the meeting participants came up to me, shook my hand, and thanked me for my speech. I said to one of them, "You are a member of the party group. How did you come to decide to vote in favor of those previously elected in the departments?" And he answered, "We did not know what was explained to us here. Thank you for your speech."

From Words of Syrovatskiy

Then I heard a more detailed story about the same affair from Sergey Ivanovich Syrovatskiy, who is now deceased but who at the time was one of the associates at the theoretical department of the Physics Institute imeni P. N. Lebedev. He too was at the meeting, and he described it very colorfully.

First spoke Engelgardt. He said approximately the following. In the past few years not one article by Nuzhdin has appeared in any journals, and no other authors cite his works. There are no acknowledgments of his advise or discussions. This means that he himself has not worked, has not had any pupils, and has had no effect on the course of scientific development. In addition, he defended a doctorate dissertation in formal genetics and was elected a corresponding member of the academy for works on Michurinite biology. He was evidently nominated into the academy based on the set of these mutually exclusive works. Proceeding from these considerations, Engelgardt announced that he would vote against Nuzhdin.

Then Sakharov presented a word. Sergey Ivanovich repeated the content of his speech rather precisely. But let us use the text of the transcript.

"I will speak very briefly," said Andrey Dmitriyevich. "We all recognize and we all know that the scientific reputation of an academician of the Soviet Academy of Sciences should be irreproachable. And here, while speaking on Nuzhdin's candidacy, we must approach the question very attentively. The document that we have been given contains the following words: 'N. I. Nuzhdin has also devoted a great deal of attention to the problems of fighting anti-Michurinite distortions in biological science, always criticizing idealistic theories in the field of the study of heredity and variability. His general philosophical works linked to the further development of the materialistic teaching of I. V. Michurin and other leading figures of biological science are widely known not only in our country but abroad.' The matter of the scientific conscience of each of those academicians that will vote is, as I understand it, to determine what is really hidden behind this struggle with anti-Michurinite distortions and the philosophical works of other leading figures of biological science, etc. I will not read this excerpt a second time.

As far as I am concerned, I call upon all those academicians present to vote such that the only yes votes will be by those individuals who, together with Nuzhdin and together with Lysenko, bear responsibility for those scandalous and dark pages in the development of Soviet science that are currently, fortunately, coming to an end (applause!)."

It is interesting that Syrovatskiy's story is somewhat different from the content of the transcript. Specifically, he said, and I remember well, that in his speech Sakharov recalled the thousands of geneticists who, after the VASKhNIL session, were dismissed from their work and how many of them were subjected to persecution. And in Syrovatskiy's words, Sakharov closed his speech with the words, "Let those whose hands are stained with the blood of Soviet biology vote for Nuzhdin."

These words are not in the transcript. There is suspicion that they were softened. Sakharov's sharpest comments were not presented. This is indirectly confirmed by the story of Tamm, who several times stresses that he Tamm "told it correctly." I then understood why Igor Yevgenyevich emphasized this. Finally, we came to Sakharov's direct remark, which he made on 8 July 1988 in a conversation with B. L. Altshuler. "The phrases deciphering what the scandalous and dark pages in the history of Soviet sciences constitute, namely, the disintegration of Soviet genetics and the physical annihilation of scholars, are absent in the transcript of my speech."

Andrey Dmitriyevich also said that he knew of the agreement between Tamm and Engelgardt but spoke regardless—on his own initiative.

When Sakharov finished, Lysenko asked to speak from his seat. The chair (M. V. Keldysh, president of the USSR Academy of Sciences) answered that Tamm was scheduled next and that Lysenko could have a word after him.

We know what Tamm said. But Syrovatskiy remembered his story in curious detail. When Sakharov returned to his seat, he discovered that he was sitting not far from Lysenko. He did not know him by sight previously. So while Tamm spoke and Lysenko was waiting for his turn, he nervously shook his hand several times, saying "A criminal case!"

Stepping up to the rostrum, Lysenko called Sakharov's words slander and said so several times in different ways. Then, he demanded that the president and presidium specify their attitude to Sakharov's speech. Keldysh announced initially that the presidium would not assume responsibility for Sakharov's point of view. But Lysenko was not satisfied with such an answer. Then Keldysh said that he did not share Sakharov's point of view and also thought that the presidium did not share it either. It was evident that Keldysh related to Lysenko with apprehension, and it was also evident that Lysenko still remained dissatisfied with Keldysh.

Ya. B. Zeldovich spoke last. For the occasion he had put on all three of his Hero's stars and had a simple-minded and stupid expression on his face (which was not easy). He said that, not being a specialist in biology, he had to draw his conclusions by proceeding from the discussions that took place. Three persons had spoken out against Nuzhdin's candidacy—Engelgardt, Sakharov, and Tamm. They had expressed a number of reasons why they intended to vote against the confirmation. Lysenko spoke in Nuzhdin's defense. But he essentially criticized Sakharov and did not answer the objections raised against Nuzhdin. Zeldovich emphasized that all the objections remained unanswered. And he announced that he would therefore vote against Nuzhdin.

Nuzhdin was not approved. The results of the vote were as follows: of 137 academicians taking part, 23 voted yes and the rest voted no. Since the party group of the general assembly numbered approximately 80-90 persons, it turned out that it had voted against its resolution.

According to general opinion, Sakharov's speech played a decisive role. It was his first civic speech, which could be considered the beginning of his fight against the violation of rights, honor, and conscience. It was remarkable in another respect. "That was the first time," he recalled, "my name appeared in the Soviet press in an article by the president of the Academy of Agricultural Sciences that contained the most unpardonable attacks on me."[5] But Andrey Dmitriyevich could be assured these would not be the most unpardonable attacks.

Footnote

1. Interview in the newspaper MOLODEZH ESTONII, 11 October 1988.

2. From the manuscript text of A. D. Sakharov, "Pamyati I. Ye. Tamma" [In Memory of I. Ye. Tamm], the original remains with Ye. G. Bonner.

3. See [1].

4. Sakharov, A., "Mir, progress, prava cheloveka. Stati i vystupleniya" [Peace, Progress, Human Rights. Articles and Speeches], Leningrad, 1990, p 5.

5. Ibid., p 7. Andrey Dmitriyevich meant the article by M. Olshanskiy "Against Disinformation and Slander" (SELSKAYA ZHIZN, 29 Aug 1964) in which, among other things, there is the following passage: "At one of the meetings of the USSR Academy of Sciences academician A. D. Sakharov, an engineer by specialty, presented in his public report (which was very remote from science) an abusive attack against Michurinite scholars in the style of anonymous letters...."

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Letter From A. D. Sakharov to Editor of IZVESTIYA Science Department

917F0007T Moscow PRIRODA in Russian No 8, Aug 90 pp 117-118

[Article by A. D. Sakharov; text in italics is underlined in the source text]

[Text] Being a regular reader of IZVESTIYA, I address you in reference to an article published in SELSKAYA ZHIZN on 29 August 1964 that was written by Olshanskiy and that contains intolerable distortions of the truth not only in relation to me personally but in relation to fundamental questions of the development of Soviet science. The latter fact requires the publication in the Soviet press of information shedding more light on the matter. I recommend the publication of an article by the renowned geneticist-scholar V. P. Efroimson, who is also mentioned in Olshanksiy's article (and again concealing the truth).

Briefly about me and my relationship to the biological sciences. I am a physicist by education and a pupil of the academician I. Ye. Tamm, although not only in matters of science. For 16 years I worked in a large collective of people who devoted their live to engineering problems important to our motherland. We are all deeply convinced that, for a scholar, there is nothing more important than absolute scientific and practical objectivity. My personal interests, scientific surroundings, and work on problems of the effect of nuclear charges on human health (two articles have been published) have given me a good knowledge of the situation in biological science, which is so tragically different from that in the physics, engineering, and mathematical sciences.

A pseudoscientific group arose in the thirties and was finally formulated in 1948. With the help of demagogy, falsification of facts, false promises, political provocation, intimidation, and repressions, it captured key posts in Soviet biology. It must, unfortunately, be stated that this group that arose during the years of the cult of personality sunk roots into all of the most important party and state organs that were so deep that its deception-based existence has continued for many years after the 20th CPSU congress and it has inflicted enormous harm on our agriculture, on medicine, and on the international authority of our motherland.

This group has stepped forth under the false banner of Michurinite biology but in fact represents an unprincipled union around Lysenko that is based on career considerations and based on different forms of pressure. It is therefore known as "lysenkoism."

Lysenkoism is characterized by the following traits:

1. Scientific unsoundness. In a century of progress in chemical genetics, which promises unforeseen supremacy over nature, lysenkoism is leading Soviets away from darwinism to the idealistic views of Lamarck. Countless anecdotal stories are contained in the "works" of Lysenko and his followers; dozens of them have received a life annuity from the Higher Certification Commission, for example, for work about the spontaneous transformation of species under the influence of the environment.

2. Political provocation and false information at all levels, including the CPSU Central Committee....

3. Economic adventurism (analyzed in detail in Efroimson's article) that has cost us billions.

4. Destruction of the system of training scientific personnel, scientific traditions, and scientific propaganda. Even the textbook for the ninth class is impregnated with lysenkoism.

5. Deprivation of the opportunity for differently minded persons to engage in productive work, which incidentally leads to a situation wherein many less courageous but capable people (some of them were recalled by Olshanskiy) serve as a false advertisement for the group even though they do not share its methods. *But the main consequence of this peculiarity is an intolerable lag of Soviet science and enormous economic and moral harm.*

All these points may be confirmed by extensive documentation and scientific material.

Knowing all these facts, I do not feel right to keep silent but add my voice to the voices of those honest Soviet biologist-scholars who, under difficult conditions, wage a battle for the triumph of scientific truth in the interests of our motherland.

A. Sakharov

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Letter From A. D. Sakharov to N. S. Khrushchev

917F0007U Moscow PRIRODA in Russian No 8, Aug 90 p 118

[Letter to Nikita Sergeyevich Khrushchev from A. Sakharov dated 30 Jul 64]

[Text] Dear Nikita Sergeyevich!

The mention of may name at the CPSU Central Committee plenum gave me the boldness to direct several explanations to Your address.

I have recently been accused of slander (by the "wounded" Lysenko) and incompetence.

About the "incompetence." Biology is being increasingly penetrated by the latest ideas of the exact sciences. And, if you please, the physicist is in a better position than a narrower specialist to follow the Soviet and foreign popular science literature in the field of biology. The author of this letter came to be acquainted with the problem of radiation genetics in more than just a speculative way. I know the tragically nonstandard position in Soviet biology well and cannot be silent about it. No special competence but rather only general science skills are required to differentiate a productive scientific theory (the chromosomal biochemical theory of heredity) from helpless babble about the influence of the environment, intraspecies help, spontaneous transformation of oats into wild oats, etc....Even less special knowledge is required to differentiate honest scholars from falsifiers and demagogues.

About the "slander." I only said that Lysenko bears responsibility for the darkest and most scandalous period in the history of Soviet science (this is only a small fraction of what I think of him). The votes of 114 academicians (out of 137) against the candidacy of Lysenko's true "comrade-in-arms" N. I. Nuzhdin showed that no one was shocked by this accusation. The speeches of the academicians Engelgardt, Tamm, and myself were met with applause. And so, for 114 academicians the matter was clear.

But overall the legs of our science are still in the fetters of lysenkoism.....

We know the greatness of the practical progress in genetics, the production of new breeds of animals and new strains of plants in the field of hybrid strains and breeds, the production of new productive microorganisms for commercial microbiology by radiogenetics methods, etc., abroad. There is no doubt that analogous progress could be made here were it not for lysenkoism.

1) The amount of work in the field of molecular biology, i.e., the most important theoretical research, is scandalously small. Here, because of a lack of personnel, equipment, reagents, and allocations, we are dragging behind world science, and this is creating the threat of a catastrophic lag. With respect to those areas of science that are already yielding practical results today, the situation is even worse.

2) All of the key policies that make it possible to formulate expensive tests or to introduce them into practice, all strain-testing stations, and most scientific institutions yielding practical results are under the control of the lysenkoites.

It is in this context that I focus Your attention on the interested manuscript of comrade Zh. Medvedev, which is based on the study of a large amount of documentary material.

In their time, Ioffe, Kurchatov, Mandelshtam, and S. I. Vavilov shouldered the burden of responsibility for entire branches of physics. In the biological sciences, one of the directors on this scale was the great scholar and patriot of our Motherland N. I. Vavilov....His death, the death of dozens of other outstanding scholars, and the removal of thousands of honorable scholars from their work is an indelible spot on lysenkoism. Over the course of almost 30 years the training of our youth was disorganized, and this can hardly be corrected immediately....The adventurism of irresponsible false scholars (yarovization, sowing on stubble, dogmatic grasslands on a countrywide scale, cluster forest plantings, and much else) has done our country great harm. All these "great discoveries" were pushed along by falsified tests and demagogy, and failures were bid farewell—indeed Lysenko was his own man. Many important beginnings were slowed down if they crossed the dogma (hybrid corn based on self-pollinating lines, works on artificial multiple pregnancies in sheep, works on mutagens, works on medical genetics, and much more). Lysenko and his advocates, having penetrated many key posts of the party and state apparatus, constitute a group from which scientific objectivity cannot be expected since that would contradict their self-preservation. The demagogy of lysenkoism does not fool those who know its scandalous history. Unfortunately, open discussion of matters of the history of biological science in the USSR in the press is encountering ever-increasing problems. Even many leading party workers do not know this history. But I am convinced that the general improvement in the health of political life in our country means the inevitable and swift end of lysenkoism.

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Three Episodes

917F0007V Moscow PRIRODA in Russian No 8, Aug 90 p 119

[Article by L. B. Okun, corresponding member USSR Academy of Sciences, Institute of Experimental and Theoretical Physics, Moscow]

[Text] The international seminar "Partons and Quarks" took place in November 1974 in the Moscow House of Scholars. In the break between reports, I told Andrey Dmitriyevich about a work that M. B. Voloshin, I. Yu. Kobzarev, and I had just sent to a journal. The essence of the work was that a vacuum may be unstable. In our world, for example, it is capable of spontaneously changing into another, more stable state by under-barrier quantum mechanical formation of a microscopic bubble within which a new vacuum is formed and outside which the old one remains. Having been generated, the bubble begins to expand quickly, its shell, which has supernuclear density, acquires a speed approaching that of light, and our whole world will be destroyed to its foundation....

When I first thought that such a bubble could be generated in an elementary particle accelerator in the place where a bundle of particles encounters the target or another bundle, chills ran down my spine.

At that point Andrey Dmitriyevich interrupted me, "Such theoretical research should be banned." I objected that accelerators operate independently of such theoretical research and, moreover, if the universe ever had an unstable vacuum it had been replaced by a stable one long ago because all possible collisions had occurred in it during its early stage. "But back then no one hit a lead nucleus against a lead nucleus," parried Andrey Dmitriyevich. This conversation took place in the White Hall of the House of Scholars under the portrait of its first director M. F. Andreyev.

On 21 July 1976 we were at the Aragvi restaurant in Tbilisi where a ceremonial supper was being held for the participants in the International Conference on High-Energy Physics (the 18th in the series of so-called Rochester conferences). There were many long tables. At one of them, I ended up close to Andrey Dmitriyevich. The general conversation changed direction stochastically. At some point they began talking about problems for a quick wit. I then posed the problem of a pet dog in ideal rubber to Andrey Dmitriyevich. Its essence is as follows.

One end of a 1-km-long rubber cord is attached to a wall and you have the other end in your hand. The dog begins to crawl along the cord from the wall to you at a speed of 1 cm/s. When he crawls the first centimeter, you lengthen the rubber by 1 km, when he craws another centimeter, you lengthen it another kilometer, and so on every second. Ask yourself, will the dog crawl to you, and if so, how long will it take?

Both before and after that supper I posed the problem to different people. Some took about an hour to solve it, others took days, and a third group remained firmly convinced that the dog would not reach you. The question about time was only asked to leave a false trail.

Andrey Dmitriyevich asked for the conditions of the problem again and asked for a piece of paper. I gave him my invitation to the banquet and on it, without comment, he wrote the solution to the problem on the back. In all, it took about a minute.

On 23 May 1978 only about two or three foreign participants attended the International Seminar on Field Calibration Theories, which was held in the conference hall of the Institute of Control Problems of the USSR Academy of Sciences on Profsoyuznaya Street in Moscow. Most of those invited refused to come because of protests over dissidents and especially as a sign of protect against the arrest of Yu. F. Orlov in February 1977. That was the beginning of the boycott that lasted many years and turned into a nearly global boycott after the beginning of our war in Afghanistan and the exile of A. D. Sakharov to Gorkiy.

A minute to 10 before the meeting began, Andrey Dmitriyevich approached the board and, standing at the rostrum and carefully drawing his letters, wrote "We thank all those who, by their absence at this seminar expressed their solidarity and support of our struggle for freedom." I recall the general sense well, but cannot guarantee that these are the exact words.

The inscription remained for 5 minutes. Then some man with whom I was not acquainted approached the board and carefully erased everything. The moist glittering traces remained on the blackboard.

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On One of A. D. Sakharov's Scientific Reports

917F0007W Moscow PRIRODA in Russian No 8, Aug 90 pp 120-121

[Article by G. I. Barenblatt, doctor of physical and mathematical sciences, Oceanology Institute imeni P. P. Shirshov, USSR Academy of Sciences, Moscow]

[Text] The Soviet-American seminar "Nonlinear Systems in Earthquake Forecasting" was held from 10 to 14 October 1988 in Leningrad in the academy of sciences' history building. It had been convened by the U. S. National Academy of Sciences and the USSR Academy of Sciences. The idea of the seminar, as conceived by its main organizers V. I. Keylis-Borok (USSR) and L. Knopov (United States), was to gather together the prominent specialists in the field now termed nonlinear science and "brainstorm" the problem. In the conception of its organizers, such a brainstorm would make it possible to propose fundamentally new ideas and move significantly forward in the critical area of forecasting earthquakes.

The difficulty of forecasting earthquakes is apparently connected, above all, with the dependence of this phenomenon on a very large number of different factors. Long ago, I. M. Gelfand (who also took part in the seminar) expressed the viewpoint that mathematics adequate for biology has not yet been created precisely because of the multifactoral nature of these problems. Perhaps, in this sense, the problem of earthquakes echoes biological problems?

On Friday 14 October, on the last day of the seminar's work, its participants, who had arrived at the academy building from the hotel, saw A. D. Sakharov in the corridor in front of the hall. The schedule of reports had been shifted: ADS [Andrey Dimitriyevich Sakharov] expressed a desire to present a report and warned that he was in a great hurry in connection with other matters.

ADS expressed the opinion that earthquakes could be caused artificially by using a nuclear explosion at a great depth as the initiation mechanism. The problem of predicting earthquakes, he noted, remains unsolved, and the purpose of such an effect would be to discharge the energy that had accumulated before it became critical and thus avoid great losses. ADS emphasized that he was not a specialist in seismology but an outsider; nevertheless, he knew the problem of large explosions and wanted to present this proposal at the seminar.

In the words of ADS, a nuclear explosion was selected because the conventional TNT equivalent required for such an explosion would be far greater and the technical problems entailed in implementing it should be much greater. Back in 1961 a 100-megaton charge had been tested, and it had been rather simple to implement an even stronger explosion. The explosion would have to be implemented at a great depth owing to safety considerations and considerations of the efficiency of an explosion as mechanism of initiating an earthquake. It was possible to speak realistically about a depth of many kilometers, but a depth of 5 km seemed sufficient. A blasthole on the order of a meter in diameter (this is technically possible and relatively inexpensive) should be drilled and the charges placed one on top of the other, after which the blast hole should be reliably insulated. The flow of stratal fluids in porous strata is a rather slow process so that the radioactivity of the thermonuclear explosion products would attenuate during the time of their flow. This would be all the more true since the cavity that would arise during the explosion would be covered with a glasslike cork. The cracks that could be expected to form during an underground expression are a serious problem (ADS placed special emphasis on this when answering the question of U. Neuman, United States). The transfer of radioactive products would occur much more rapidly along the cracks; however, this problem was evidently surmountable.

To determine the safe explosion energy E (in megatons) at a depth h (in kilometers), ADS proposed the formula

$$E = Ah^4 + Bh^3,$$

where he gave an estimate of 0.1 to 0.01 for the coefficient A. ADS estimated the cost of the plan between 10 and 100 million rubles, considering an even distribution of this sum between the cost of the charge and that of the blasthole optimal. ADS estimated the total energy of the explosion at 10^{23} to 10^{24} erg (10 to 100 megatons). At the end of the report he presented a qualitative graph of the ratio of the energy E_1 released during the earthquake to the energy E_0 of the initial explosion as a function of the time calculated from the moment of a spontaneous earthquake t_0. In the opinion of ADS, the interval of time from the year to the month to the spontaneous earthquake was of greatest interest.

After the report there was an interesting discussion. Some Americans grumbled, "Who would allow his bomb in California on the San Andreas fault where the main earthquake foci are nested?" I gathered the transparent films that ADS used for illustrations and, with full approval of the other participants, asked him to sign one of them.

I knew ADS for many years and had grown accustomed to the fact that any thought of his, no matter how paradoxical and unrealistic it may have seemed initially, should be carefully studied and preserved. The present publication is intended to do just that.

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They Are Expecting a Good Program From Us

917F0007X Moscow PRIRODA in Russian No 8, Aug 90 pp 121-123

[Article by M. Yu. Khlopov, doctor of physical and mathematical sciences, Scientific Council of the Integrated Problem Cosmology and Microphysics, USSR Academy of Sciences, Moscow]

[Text] I want to talk about a matter in which Andrey Dmitriyevich had to fulfill a scientific-organization function that sickened him deeply. But recognizing that he, by the will of circumstances, was the only person capable of doing so, in the last 2 years of his life he assumed the burden of worrying about the creation of the Scientific Council on the Integrated Problem of Cosmology and Microphysics of the Presidium of the USSR Academy of Sciences. My close contact with Sakharov in this work gave me the opportunity of adding several lines to his portrait.

By the second half of the eighties, it was becoming increasingly obvious that the process of the interpenetration of cosmology and microphysics should result in the establishment of a unified science uniting physics and astronomy. As one of the founders of this science from the very beginning, Sakharov seemed to be the only figure capable of ensuring its scientific-organization formulation and development. But when the question of creating such a council arose in spring 1987, Andrey Dmitriyevich had just returned from exile and declined the suggestion that he head it, citing among other reasons that Ya. B. Zeldovich was working in the field much more actively. Besides, asserted Sakharov, he was more inclined to be simply an "individual theoretician" studying questions at the junction of cosmology and the theory of elementary particles rather than the organizer of scientific research in this direction. But in December 1987, when Zeldovich died and the council had thus not been formed, it became clear that only Andrey Dmitriyevich's authority could overcome the interdisciplinary barriers and unify the efforts of scholars of the most diverse directions. This was also becoming increasingly obvious to Sakharov who, with difficulty, came to the conclusion that "this cup would not pass him by."

Zeldovich once compared our scholars with a runner bound at the hands and feet who had, however, received the assignment of achieving the world record in a race with hurdles. The numb system that has evolved in science has piled barriers that must be surmounted on the path to any matter of the mind.

Andrey Dmitriyevich's consent to continue what Zeldovich had begun initially seemed to many to be nothing more than a noble but symbolic gesture. "Develop a program connecting laboratory, cosmic, and astronomy research is a very difficult task requiring efforts and time," Andrey Dmitriyevich was warned. "But it is indeed necessary," he replied and, despite how very busy he was, he tried to delve into the essence of the individual plans and into the specifics of the problems connected with implementing them. Quite soon it became clear that his role in creating the council could not be purely nominal. Passes through the debris of official corridors required singular knowledge and skills (and how many times the debris was impassable!). But in the history of the creation of the council on cosmomicrophysics, like in a tiny fragment of a mirror, the course of the process was reflected as the living personification of of what Sakharov was. At the end of 1988 the General Assembly of the USSR Academy of Sciences elected him a member of the Presidium, and unexpectedly all of the barriers were broken.

As Sakharov told me, the first words with which he was met as a member of the Presidium by the president of the academy were "Andrey Dmitriyevich, you head our greatest scientific council. We are expecting a good, big program from you." To remind him about the organizational problems at that moment was, in Sakharov's opinion, out of place: "they expect a good program from us, and we must prepare it." And the work began.

Andrey Dmitriyevich immediately sent the VESTNIK AN SSSR [Bulletin of the USSR Academy of Sciences] material with an analysis of the causes of and circumstances surrounding the occurrence of a new science, cosmomicrophysics, and a discussion of its tasks and the prospects for its development in the USSR[1] that had been prepared by a group of enthusiasts. This publication was prefaced by an introduction written by Sakharov himself that reflected his attitude toward the problem. It must be said that Andrey Dmitriyevich had a very cautious attitude toward the authority of some ideas and plans or others and did not consider himself capable, even to a small degree, to rise above their direct authors and executors. He was just as attentive to Zeldovich's legacy when formulating the scientific council: he made organizational changes in its structure and make-up only when they were clearly necessary.

On 12 September 1989, after Sakharov's report, the Presidium of the USSR Academy of Sciences approved the structure and make-up of the Scientific Council on the Integrated Problem of Cosmology and Microphysics. And his task was formulated—create a unionwide program of research at the junction of the theory of elementary particles and cosmology.

When preparing the first session of the council, Sakharov found it necessary to separate the large long-term projects and the small tasks that could be accomplished in the next few years. "We must begin with the small projects—those that are minimal from a cost standpoint and maximal from the standpoint of results. Then the matter will work out," he said, determining the agenda for the day of the session and explaining the main ideas of each announced speech in a most overly particular way.

On 29 September 1989 the council convened its first meeting. The astronomers and physicists and engineers and mathematicians who filled the conference hall of the State Astronomy Institute imeni P. K. Shternberg were largely little acquainted with one another. It was possible to count on one's fingers those who knew the other council members personally. And this constituted one of the difficulties in his future work. The chairman of the council should not only know each member but should also present the specifics of his work. Understanding this, Andrey Dmitriyevich literally actively filled the gaps in his knowledge right before everyone's eyes. Rejecting any chairman's elevation in principle, he took a place in the first row and listened tirelessly to the alternating physics and astronomy reports. Most of the draft proposals related to areas that were not in the sphere of Sakharov's own scientific interests, but he had to understand them, and so he asked questions, grasping the overall idea very quickly and discussing the details of its implementation.

Having courageously held a more-than-4-hour meeting, Andrey Dmitriyevich was not fully satisfied with it. A great deal still seemed to him to be incompletely developed and raw.

More than two and a half months remained for him to live, and certainly in the context of all that he left unfinished, his work on the council on cosmomicrophysics may seem a digression from the mainstream. Nevertheless. his sense of responsibility and his ethical standards, which were so simple but yet hard to come by, were reflected in this matter that was far from the most important to him.

Footnote

1. Sakharov, A. D., "Cosmomicrophysics—Interdisciplinary Problem," VESTN. AN SSSR, No 4, 1989.

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From Sakharov Lectures (Gorkiy, 27 Jan 1990)

917F0007Y Moscow PRIRODA in Russian No 8, Aug 90 pp 123-126

[Speeches by A. V. Gaponov-Grekhov, academician, Institute of Applied Physics, USSR Academy of Sciences, and M. L. Levin, doctor of physical and mathematical sciences, Moscow Radio Engineering Institute, USSR Academy of Sciences, presented at the Sakharov lectures on 27 January 1990 in Gorkiy]

[Text]

[Academician A. V. Gaponov-Grekhov, Institute of Applied Physics, USSR Academy of Sciences]

The opening of the Gorkiy Sakharov lectures is, for me (and possibly for many of us), associated with contradictory feelings.

There is a feeling of shame for the role that I was given in the life of this great man and for the role our city played, and there is a feeling of guilt for the alienation and dismissal to which Andrey Dmitriyevich was subjected for many tortuous years. But there is also a feeling of immeasurable wonder and admiration of his entire life, which was rich in creativity, successes, and struggle and at the same time clear, pure, and to the end surrendered to mankind. And of course, there is the involuntary comparison with the sad fate of many Russian talents who were unrecognized and persecuted in their strange Fatherland in that anxious time of troubles.

I did not know Andrey Dmitriyevich well—certainly we did not have more than 10 meetings in 2 decades. But each left those traits of his remarkable personality in my memory that (as you will realize later) turned out to be entirely nontrivial. Even our first serious conversation showed Andrey Dmitriyevich's patience and benevolence coupled with the strictest adherence to principle. It was back in 1972 when, if you recall, he prepared two petitions to the government: one with a request for amnesty for political prisoners and the other about abolition of capital punishment. When we met he asked me to sign these letters. I signed the request for amnesty but did not sign the petition about abolishing capital punishment. Now, I would certainly have put my signature to both petitions—not because I have come to respect Andrey Dmitriyevich but simply because my views have changed. At the time abolishing capital punishment seemed premature to me. Andrey Dmitriyevich did not begin to try to judge me or change my mind but listened to my opinion with a respect and patience that I realized were a virtue much later.

In general, I was certain it is difficult, or rather, simply impossible to cram him into an ordinary human frame. People—and of course I mean strong, talented people—generally appear either in creativity or else in practical work or else in organizational and social life and politics. Possibly, this is not a completely successful definition. To put it more precisely and correctly albeit concisely—all people are either creators or builders or fighters. But these qualities with their diverse essences are never combined in one man: some make revolutions, others build, and the third group create, sitting in their "ivory towers." There are few, even among the most great, who manage to achieve success in even two of these three types of human activity, because they in fact contradict one another.

Andrey Dmitriyevich's absolute exceptionalness lies in his being equally great in all of his postures: as a scholar, engineer, and social activist. His significance far exceeds the capabilities of a single man. Hence the automatic analogy with Pushkin. According to Sinyavskiy, he stood over good and evil, with his inherent uncompromising nature, but with infinite patience and benevolence.

However, Andrey Dmitriyevich's untimely death showed that he was not without suffering, but that he felt the fate of our people, the fate of all mankind, and the fate of each individual man very close to his heart.

It is not worth it to weigh each of the sides of his activity. Perhaps the main thing is that we, having known Andrey Dmitriyevich and having lived alongside him, will always remember that in the times of difficulty for our people—the times when mediocrity, conformism, and stagnation reigned—he gave us the standard Man combining absolute honor, highest intellect, and total fearlessness.

These are the qualities that provide true spiritual freedom.

[Speech by M. L. Levin, doctor of physical and mathematical sciences, Moscow Radio Engineering Institute, USSR Academy of Sciences]

My speech in the very beginning of the lectures is justified only by the fact that I am the only one sitting in the room who knew Andrey Dmitriyevich since his youth.

And there is more. Among those present, I am evidently the only physicist who, during the 7 years of his stay in Gorkiy, was with him not because of formal necessity, not on an out-of-town assignment, not at the order of the institute, but just by myself. And perhaps that is why I saw him, so to say, in a free state, not bound by formal constraints.

Great people are not often born on earth. When Mayakovskiy died, there were blunders at the funeral, and the militiaman reassured the writers—don't work, next time everything will be in order. He did not know that great poets are not born and do not die so often.

I will begin from Andrey Dmitriyevich's young years, but I want to warn you right away: there is a danger of creating a myth. It already began during his life and is continuing after his death, and I would not want to be a part of it. Although, you yourselves understand that to create a myth about a young genius who was immediately perceived as a genius is very easy. One can also run to the other extreme—that he was a "numbskull with low grades" who suddenly became a remarkable scholar.

Andrey Dmitriyevich was neither a "numbskull" nor the most brilliant student in our course. Teachers and students alike quickly understood his most unusual strength, but they did not understand him himself or his method of reasoning. They did not understand that his "logical steps" are much greater than those of ordinary people. Let us say that later, after I was a grown man and had read about the remarkable mathematicians Galois and Ramunaijan, who were not understood by their contemporaries either, it occurred to me that they were somehow commensurate with Andrey Dmitriyevich. In relation to us—and we had a strong class—he was about in the same position that you and I are in relation to a philosopher who has become accustomed to reasoning based on the laws of formal logic. Thus, the phrase "Peter is dead" is obvious to us, but a philosopher needs "steps": Peter is a man, people die, and consequently Peter is dead.

I would not want to be a part of yet another myth—that I was a close friend of Andrey Dmitriyevich. I was not, and I had the feeling that in both his young and middle years he had no close friends. He had comrades at work and, in his last years, in his great work. But as far as a real close friend, I know of only one—that was his wife.

For him, I was (this very precise definition belongs to him himself and was stated to the all-powerful KGB with whom we came into contact during our first meeting on the streets of Gorkiy) his oldest comrade from the university. In fact, this is no little thing. Old university comrades, especially if they later work together, while not cooked in any workplace "boiler" in an academic-culinary or simply culinary sense, still remain dear comrades because each loves his youth and university friends bear a mark of this. I do not want to compare us with the lyceum students of the past century, but there is something similar. I think that this is precisely what explains the joy I felt when I paid him visits: we met four times in Gorkiy, and some personification of his returned youth was somehow associated with this.

Let me return to what I started with. Andrey was really difficult to understand, and he remained so long into his university years. Thus, his results and conclusions were always correct, and he solved problems correctly and gave the correct answers to questions—but it was difficult to understand him. And this continued for a long time. But when we saw each other after a large break (we studied together 3 years before the war and met again after the 20th party congress), I suddenly noticed that he expressed his thoughts clearly. He explained, "Yes, I learned how, I came to have business with the chiefs in the general's shoulder straps, and to explain things to them I learned how to speak their language."

And now the newspapers sometimes write that he stumbled over his words. Certainly, he "stumbled over his words" in his youth. However, it was not stumbling but rather great steps that he took in his discourse and with which no one else could keep up.

I can present yet another example. When he and I met and I became acquainted with his first wife Klavdiya Alekseyevna, she told me with pride that they had met at the end of the war and that she was perhaps the only woman in the country to whom a hand and heart had been proposed in writing. He wrote it not out of shyness but because otherwise she simply would have been unable to understand what he was talking about.

He later learned to speak, in my mind, with the clarity of expression with absolutely no pretensions.

And now about Gorkiy. For me the entire history of Andrey Dmitriyevich's stay in that city is an unhealed wound. When he was sent to Gorkiy 10 years ago, everyone was outraged. But for me at the time there was some comfort in finding out that it was indeed to Gorkiy: I very much like this city. I spent 6 years of my life here, and my initial conditions were also not simple. I came to Gorkiy with a license to teach at the university and to live at Bora, and although it was a stern and difficult time, things went very well for me in Gorkiy. There was a feeling of liberty after Butyrka and the "charade" [sharaga]. Friends and pupils appeared and, ignoring the external distress, I was left with bright impressions of life in Gorkiy. I therefore felt that, once in Gorkiy with so many outstanding physicist and so many real people, he would be well.

I do not know what happened, but on 22 January 1980, the day of his exile, by a wonderful (I think accidental) coincidence, a note on the 95th anniversary of Korolenko's exile to Nizhniy [the area below a town] in the newspaper GORKOVSKIY RABOCHIY. It told of how, in 1885, after a long exile in Yakutsk, Korolenko was there and about how he was received in Nizhniy.

Korolenko ended up in Nizhniy Novogorod [the area below Novgorod], and the leading intelligentsia immediately started gathering around him. There were students from the gymnasium, students from the seminary, civil servants, physicians, and lawyers, and a intellectual nucleus immediately formed around Korolenko. Gorkiy, who received Korolenko's blessings precisely in Nizhniy Novogorod, spoke of it best. His words and their meaning are presented in a note—one can speak of the epoch of Korolenko in Nizhniy.

I cannot vouch for the exactness of these words. Perhaps it was not the epoch but rather the era of Korolenko in the history of Nizhniy Novgorod. But here is what I want to remember: in the year 1885, 4 years after the murder of Aleksandr II and 3 years before the last unsuccessful attempt on Aleksandr III, so that you can imagine what the atmosphere in the country was like. But it was nevertheless the Korolenko epoch in Nizhniy.

But there was no Sakharov epoch in Gorkiy. They were the Gorkiy years in Sakharov's life.

At the time I unconsciously hoped that something analogous would occur 100 years later....The Gorkiy intelligentsia, and above all the intelligentsia of physics....Indeed it is a rare and unique opportunity to have so outstanding a physicist—and a theoretician and incomparable specialist in applied physics no less—in one's midst. I held that hope for some time until it became clear that things would not be so.

It is hard to remember this, and even harder to remember how the "best representatives of the academy" signed "letters of censure"—this was, of course, repulsive, but it did not hurt me personally.

During the first hunger strike, when there was talk about Liza Alekseyevna, great agitation was observed in the corridors of the Presidium of the Academy of Sciences. Various people wandered there, but one thought dominated—if Andrey Dmitriyevich dies, no one will offer us a hand abroad. There will be nothing for us to do there. That is what worried everybody!

But indeed, not all of them were that way! There were real people whom I love and respect there. What made them accept the extreme conditions established by the authorities? I still cannot understand it. I understand that to live in a collective means to howl like a wolf—that "one must mind his own business" and, as they say, it is the tsar and not the huntsman who bestows...and one must "rejoice in Christ" [khristoradnichat] (excuse the pun). But, in the end, was it worth it to try?...

I again became hopeful when, in the middle of Andrey Dmitriyevich's Gorkiy period, in front of the entire world, the president of the Academy of Sciences announced how humanely our government had acted by sending Andrey Dmitriyevich to Gorkiy, where the conditions are wonderful, there are many academic institutes, and the academy-rank scholars there are by no means trying to abandon Gorkiy.

All of this was said in an interview with the journal NEWSWEEK, and in that famed interview it was asserted that Andrey Dmitriyevich had undergone a serious psychiatric shift. The announcement by the president of the academy regarding the paradise-like conditions in Gorkiy was repeated more than once by scholars on "professional trips" abroad, where they were asked how things were with Sakharov?

It was precisely then that it had to be tried: invite Andrey Dmitriyevich to a conference and travel to him for a scientific consultation. It was not necessary to read between the lines to understand what the authorities meant and to proceed with the wise Shveykovskiy's bluntness and act in accordance with the president's published statement.

Unfortunately, nothing like that happened. And this still torments me to this day.

Today I was at the opening of the memorial board, and I listened to all of the speeches attentively. I am afraid that an incorrect picture justifying the incomprehensible behavior of Gorkiy's residents has been created. They say that Andrey Dmitriyevich was here in such a deep siege that it was hard to penetrate to him, so what could we do?

It seems to me that this was not the case. The "hard pressing" was mainly intended for the Moscow dissidents. They really tried to reach Andrey Dmitriyevich, and it was hard for them to break through. True, the fact that Moscow knew when they started out to see him did play some role. It was hard to restrain oneself and not speak even to one's closest friends. Even I knew that a certain person was going. But the first three times I was in Gorkiy was by prearranged plan, but I did not tell anyone about it previously.

The first time, moreover, I made a mistake. I did not consider that I could be doing my Gorkiy hosts a bad turn. I was invited to a conference and met with Andrey Dmitriyevich as it was nearing an end. This occurred 2 months after his exile. Then the conference organizers, by their words, were "stuck" and were warned that if anything like that every happened again—I don't remember the exact words—not only would they not permit any Muscovites but they would close down the conference. After that I never went to see Andrey Dmitriyevich, only during a break period, and I never brought anyone.

As far as I know, the most unpleasant thing that happened to most of those who visited Andrey Dmitriyevich or tried to visit him was to be sent back to Moscow and sometimes even free of charge. Such preventive punishment could hardly threaten the inhabitants of Gorkiy.

It went more simply with me. Having convinced them that I was not the emissary of this group or that but was really, as Andrey Dmitriyevich said, an old friend from the university, they did not drive me away, but let me leave myself. Afterwards, no one ever kept me from communicating with him on any other occasions. True, they used up a lot of photographic and movie film without feeling sorry about it.

In conclusion, I will tell you about the surprising intersection of two events occurring at different times about which I did not have time to ask Sakharov.

The last time I spoke with Andrey Dmitriyevich was 8 December, 6 days before his death at the funeral of S. V. Kallistratovaya.[1] A civil ceremony was conducted at the law college on Pushkinskaya, and a burial service was read for her in Obydensiaya Alley around the Kropotkinskaya metro station. We rode there together by car and traveled through the region of our common youth. And in that car memories of those places arose. Specifically, we spoke of the 110th school. And then Andrey said that the mythicizing was beginning. He had not studied long in that school and clearly did not know or remember anyone there. But already they had found pupils who "remembered" how genial Andrey Sakharov was and how all of the teachers worshipped him, how the girls admired him, and how the boys envied him.

And so he gave me something on the order of a warning not to get involved in mythicizing, and I, on my own, will refrain from doing so.

Before the war they taught us astronomy very seriously at the university. Now they do not teach it in the physics department at all. But we took a course, attended seminars, and did practical work at Shternberg's institute. A remarkable observer guided it, M. S. Zverev. He later departed to Pulkovo.

Once we were sitting in the observatory for a rather long time, waiting for the sky to clear. And one of the girls complained that she could never remember the order of Draper's temperature spectrum classes. They follow the sequence O, B, A, F, G, K, M, and N. It was difficult to remember but the examiners required it. Zverev said that when he studied at the university in the twenties they had a mnemonic phrase that, true, did not make a great deal of sense, but did contain the three necessary groups of letters in one word: O bozhe, AFGanistan! Kuda My Nesemsya? [O, God, Afghanistan! Where are we going?]

And in the evening on 8 December, after returning home, I suddenly remembered this phrase that, 40 years later, had a hopelessly clear meaning that was closely linked with Andrey Dmitriyevich's exile to Gorkiy.

Footnote

1. Five days before this came the death of Aleksandr Mikhaylovich Obukhov, director of the Institute of Atmospheric Physics, who was once a friend of Andrey Dmitriyevich. He later signed the famed "Letter of 40." Well naturally, Andrey Dmitriyevich felt a sense of disappointment and chagrin. But he was at Obukhov's funeral. During Kallistratovaya's funeral there was a conversation about the betrayal of friends, and I asked, "How was it for you at Obukhov's funeral?" He said, "You know, for me now the name Obukhov is associated only with one man—a doctor from Gorkiy. When they fed me artificially and tied me down there, I understood for the first time what the slaves of Ancient Rome felt when they were crucified." [Editor's note: From a shorthand record.]

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Sad Humor in Era of Confrontation

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[Article by G. A. Askaryan, Institute of General Physics, USSR Academy of Sciences]

[Text] Before the pain I had few direct scientific contacts with Andrey Dmitriyevich. There were only two or three brief discussions on the supercompression of magnetic fields by an explosion in regard to laser flashes for controlled thermonuclear synthesis (in the 1970's) and a preliminary attempt to discuss with him the harmful ecological consequences of microwave discharges in the stratosphere (1988). I remember being struck by how quickly he entered into the course of a matter and how critical his conclusions were. I got the feeling that Andrey Dmitriyevich yearned for the argumentative confrontation in a scientific dispute. In any case, I immediately sensed the neutrality and force of his logical thinking.

Since I was an associate of the Physics Institute imeni P. N. Lebedev at the time, I had the opportunity to observe Andrey Dmitriyevich's behavior over the course of many difficult years and the attitude of those around him toward his leniency to the weaknesses of human character.

I will try to recreate the atmosphere of the benevolent but sad humor with which Andrey Dmitriyevich and the associates at the Physics Institute imeni P. N. Lebedev tried to soften and diffuse the tense circumstances.

Happy Birthday

It was the period of the beginning of the confrontation. Sakharov's memorandum was sent by "voice"; our press was waging unbridled criticism with accusations of antisoviet propaganda.

At the theoretical department seminar dedicated to him on his birthday they were congratulating him and giving him a radio receiver.

Andrey Dmitriyevich thanked them with embarrassment and added, "True, many now felt that a radio transmitter would be more suited for me."

The Most Grateful Audience

We were standing at the entrance of the door to the Physics Institute imeni P. N. Lebedev. A taxi rolled up with Andrey Dmitriyevich inside, but he did not get out and showed something to the driver with the meter running. We fixed the time—40 minutes. Finally, Andrey Dmitriyevich finished his lecture. The driver switched off the meter and lit the green light. Looking at the meter with horror, Andrey Dmitriyevich paid the driver, crawled out, and said farewell to him. Someone noted deep in thought that the driver could have turned off the meter.

"Now I understand why he showed such interest in my theory of convergence," responded Andrey Dmitriyevich with a smile.

And Always About His Own

At a seminar dedicated to the jubilee of V. L. Ginzburg, D. A. Kirzhnits presented a joking report focusing the audience's attention on the fact that 10 kilotons of paper had been used for the articles and books of the productive V. L. Ginzburg, for which thousands of hectares of forest were destroyed.

Thinking about his own works, Andrey Dmitriyevich dropped the retort: "Ten kilotons could not kill that much forest."

Never Waste Anything Around the House

After the seminar, Andrey Dmitriyevich walked out of the Physics Institute imeni P. N. Lebedev. A crowd of institute people went with him. The academy Volga rolled to the gates. Behind it was yet another car. (An escort? A shadow? A guard? At the time, contacts with Andrey Dmitriyevich were monitored and cut off.) Andrey Dmitriyevich got in the first car and suggested that everyone get in. "And whoever cannot fit, can get in the second car," he added, pointing to the "escort" car with his hand. Two similar faces looked out of it sullenly. The scene was mute.

There are several more sketches characterizing the behavior of the associates at the Physics Institute imeni P. N. Lebedev in connection with Andrey Dmitriyevich's situation.

B. M. Bolotovskiy, the theoretical department's party organizer who was charged with Andrey Dmitriyevich's "re-education," explained the ineffectiveness of his mission to the party committee in the following way: Everything Andrey Dmitriyevich tells me seems too logical, and I cannot express myself with so much weight—indeed, he is an academician, and I am simply a professor. But if you made me an academician, my voice would be much more authoritative."

I want to mention that even in the most difficult years, scientific references to Andrey Dmitriyevich's works, at least in my articles, were not thrown out. References about him at jubilees and informal skits also passed.

Here are two examples.

The jubilee of P. L. Kapitsa took place during the years of the "sharpening of the confrontation," when Andrey Dmitriyevich announced his protest hunger strike. I stepped forward at the skits and read a "letter" from the administration of the Tretyakovskiy Gallery with a suggestion to organize opposing pay picture exhibitions: the academician Kapitsa would be placed in Tretyakovka guarding Kustodiyev's "Young Kapitsa and Semenov at the Still" in his personal collection, and for exhibit in the Academy of Sciences Presidium the Tretyakovskiy Gallery would have Shishkin's "Oaks Illuminated by the Sun" and Surikov's "Boyarina Morozova." Having understood the weak joke, the speakers lost all interest in me, but after the next phrase—"Give your day's earnings to the fund to help the families of the starving academicians"—a squall of applause in the packed hall of the Institute of Physics Problems merged with the joyful exclamation of P. L. Kapitsa himself.

At V. L. Ginzburg's jubilee seminar I read what was supposed to be a radio broadcast papal encyclic about the enormous encyclic of Ginzburg and his seminar and uniting believing christians and concluded with a sentence about the great physicist: "And, cutting off the warhead of the Serpent Gorynych with his sword, Andrey the First saved the Russian land from the foe...." In both cases there were no consequences. The party committee did not call, did not have any conversations, and did not issue any warnings. Perhaps this was because at the time I was in a scientific quarrel with the Physics Institute imeni P. N. Lebedev party committee secretary, was not speaking to him, and did not even say hello to him. Or perhaps it was because I did not have to be discussed by the party committee because I did not travel abroad, was not preparing to defend a doctorate dissertation, etc.

I will not forge Andrey Dmitriyevich's consideration for those around him: even in the very heat of the persecution, when access to him was limited and monitored, Andrey Dmitriyevich stopped even saying hello to many people so that he would not inflict any "political harm" on them. I was even hurt when he stopped paying attention to me. But after returning from Gorkiy, he again recognized all of his old acquaintances.

All these fragments of a large mirror that has been broken by time do not remove our growing feeling of guilt: we really could not have helped this great man because we were tangled in the web of apparent well-being and had a duty to our families and relatives that could not be broken easily. And therefore we tried to convince ourselves that Andrey Dmitriyevich was being a Don Quixote, that he was not a politician, that he believed in castles in the sky and the unity of mankind, and that it was easier for him to act that way in view of his unique position and great merits. But he turned out to be a prophet, messiah, and strategist of humanism, and he passed through our life almost alone, sad of smile, awkward, clumsy, and stumbling over his words, but with a proudly raised head. And so the hero went to the scaffold.

And I am beginning to understand that, for us, our little jokes were were only an imitation of support in a form that was almost painless for us. He accepted this game and sometimes took part in it, but also (and only) for us so that we would not be so sad and ashamed for our lack of participation in his great deed.

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