# Development of physics in Dagestan

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Dagestan is currently a flowering autonomous Soviet Socialist Republic with a highly developed culture and industry, which is a member of the Russian Federation. The population of Dagestan exceeds 1.7 million people. The territory of the republic, which covers an area of 53,000 square kilometers, ranging from the glaciers and high-mountain alpine meadows in the mountainous part of Dagestan to the sandy deserts of the lowlands of the Caspian Sea, with a water area with a shoreline up to 500 km long, is distinguished by variety and contains all bioclimatic zones.

Dagestan is multinational. The crest of the Dagestan Autonomous SSR is framed by 11 banners, representing the number of its basic nationalities, in whose languages the newspapers and magazines are published and in which radio broadcasts are made. There are a total of 33 basic nationalities in Dagestan. Dagestan contains more than 20 scientific research institutions and institutions of higher learning. More than 1500 Candidates and Doctors of Science work in these institutions. None of this existed before the great October socialist revolution.

In Dagestan, as in most regions of the northern Caucasus, there was a theocratic system of government, under which even glimmerings of secular power were suppressed by the clergy. It is only due to the attention and concern of the great party of Lenin and of the Soviet government that Dagestan embarked upon its present path of development and progress and attained what it now has within the historically short period of 60 years.

I shall now proceed to the theme of my report on the development of physics research in the Dagestan Autonomous SSR.

In 1950, Academician Abram Fedorovich Ioffe conducted the 7th All-Union Conference on the Physics of semiconductors in Kiev. It was at that time that the question of my transfer from the Academy of Sciences of the Azerbaĭdzhan SSR to the Dagestan Affiliate of the USSR Academy of Sciences was decided.

In his review of the status of and prospects for scientific research in the physics of semiconductors in the USSR, Avram Fedorovich first mentioned the name of the city of Makhachkala and spoke kindly of the work on the thermal properties of semiconductors which was being planned at the Dagestan Affiliate of the USSR Academy of Sciences.[1] The foundations of this work were laid even earlier at the Institute of Physics of the Academy of Sciences of the Azerbaĭdzhan SSR,[2] and the results of this work were reported at the preceding 5th and 6th conferences on semiconductors.[3,4] At the conference in Kiev, new recent results were examined and a program was instituted for continuing this research (see the minutes of the meeting).[5-7]

The apparatus, specially developed for studying the thermal properties of semiconductors, was approved (semiconducting heat meter and adiabatic calorimeter), but the possibility of practical application of the phenomenon of thermal asymmetry of electrical conductivity for rectifying an alternating current was received critically and this problem was successfully solved only now, more than 25 years later (I shall say more about this below).

In accordance with the program, the first candidate's dissertation was defended in the physics of semiconductors by a candidate from Dagestan, A. A. Babaev,[8] and the first paper published based on the subject of the dissertation concerned the physics of semiconductors in a magnetic field. The result of these investigations was the first observation of a significant change in the thermal conductivity of semiconductors in a magnetic field.[9] Interest in the thermal conductivity of semiconductors in a magnetic field remains even now, since in a number of semiconducting compounds (narrow-band and gapless), the thermo-emf increases with decreasing temperature, and if the thermal conductivity in a magnetic field decreases, then the so-called $Q$-factor of the semiconducting thermoelement will increase.

Subsequent investigations of the effect of a magnetic field on the thermal conductivity of semiconductors, performed by physicists at the Dagestan Affiliate of the USSR Academy of Sciences, showed that data on the electronic thermal conductivity in a magnetic field, measured in a complex with thermo-emf and galvanomagnetic effects can be used to analyze the band structure of solids, mechanisms of scattering of charge carriers, values of the effective mass, and the influence of phonon drag effects.[10]

To clarify the complicated mechanism of heat conduction in semiconductors, in addition to the study of the influence of a magnetic field, the thermal conductivity of complex semiconducting compounds with different phase transitions was investigated at the Institute of Physics of the Dagestan Affiliate of the USSR Academy of Sciences as a function of the pressure, temperature, radiation emission, and other physical factors.

The influence of the structural disorder on different mechanisms of heat conduction in semiconductors was explained for the first time from the results of these investigations.[11] The mechanism of thermal and electrical conductivity of a large group of chalcogenide glassy semiconductors in the region of softening of the

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glasses and in the liquid state was investigated for the first time.[11]

The process of metallization of the melts of some chalcogenide semiconductors was observed for the first time from data on the temperature dependences of the bipolar fraction of the thermal and electrical conductivities.[12]

An investigation of the mechanisms responsible for heat and charge transport over a wide range of temperatures showed that the semiconducting properties remain even after melting in the liquid state in a large group of complex binary and ternary semiconducting compounds.[12,13]

The study of the dependences of the thermal conductivity of semiconductors on the hydrostatic pressure, initiated at the Institute of Physics, had great theoretical and practical significance.

To solve many problems in geophysics and geology, in particular, to estimate the magnitude of the heat flow emanating from the deep interior of the earth, the study of the thermal conductivity of rocks and minerals making up the earth's crust, taking into account the enormous pressures and high temperatures in its deep interior, is of great significance. Semiconductors are encountered in the earth's crust much more often and in a much greater variety than it is possible to obtain them by artificial means in laboratories. Starting from this, we were the first to investigate the effect of hydrostatic pressure on the thermal conductivity of a number of semiconductors at different temperatures. These investigations established that the phonon fraction of the thermal conductivity, whose magnitudes and temperature dependence is greatly affected by the pressure dependence of the elastic constants of the semiconductor lattice, is subjected to considerable variation under the conditions of hydrostatic compression. The investigation of the influence of bulk compression and elastic anisotropy on the temperature dependence of the phonon thermal conductivity and the mechanism of scattering of phonons at high temperatures is of special interest.

The complex investigation of hydrostatic pressure on different mechanisms for transporting heat and charge and on a number of galvano- and thermo-magnetic phenomena gave a more accurate picture of the band structure of some ternary semiconducting compounds and clarified the contribution of additional subbands in the conduction and valence bands to transport phenomena.[15]

Later, investigations of the thermomagnetic Nernst-Ettinghausen effect in semiconductors were begun at the Dagestan Affiliate of the USSR Academy of Sciences. These investigations initiated the widespread use of thermomagnetic effects in laboratories as a possible method for obtaining information on the mechanisms of scattering of charge carriers.[16] The results of the investigations were published in numerous papers, generalized in dissertations of staff members of the affiliate and in the monograph by I. M. Tsidil'kovskiĭ entitled "Thermomagnetic Phenomena in Semiconductors."

Further delivery of precision physical apparatus to the Dagestan Affiliate of the USSR Academy of Sciences, organization of graduate studies in physics in the Affiliate itself, and strengthening of the physics staff of the Affiliate made it possible to raise the question of organizing a Physics Institute at the Dagestan Affiliate of the USSR Academy of Sciences. L. A. Artsimovich, Academician-Secretary of the Division, was very sympathetic to this and in 1957, by a declaration of the Division of General Physics and Astronomy, the Physics Institute of the Dagestan Affiliate of the USSR Academy of Sciences was organized.

Lev Andreevich, continuing to watch over the Physics Institute both in the "turbulent period" at the end of the 1950s and at beginning of the 1960s, when scientific institutions were either closed or thrown from one government department to another, sent a commission headed by V. S. Vavilov to the Dagestan Affiliate, and then he himself later came to Dagestan and helped to retain not only the Physics Institute but also the Dagestan Affiliate in the system of the USSR Academy of Sciences.

In subsequent years, the Division of General Physics and Astronomy, directed by Academician A. M. Prokhorov, continued to support the development of physics in Dagestan. Academicians N. A. Devyatkov and B. M. Vul and Corresponding Member K. A. Valiev were assigned to become acquainted with and to help the Physics Institute of the Dagestan Affiliate, which was of great significance to the development of science. I want to especially note the help provided by B. M. Vul, who participated in the work of the Dagestan Affiliate itself, agreeing to become a member of its presidium.

Up to the time that the Physics Institute was organized, the physics staff at the Affiliate was also systematically enlarged. A. F. Ioffe sent the well-known physicist V. P. Zhuze to the Affiliate and some young physicists came to the Institute as well: É. V. Matizen, R. I. Bashirov, I. M. Tsidil'kovskiĭ, and others. The staff was strengthened by the graduation of specialists from Dagestan University: the young physicists B. G. Alibekov, A. P Adamov, L. K. Anokhina, A. S. Batyrmurzaev, D. I. Vikhrov, Ya. V. Magomedov, A. Yu. Mollaev, N. G. Polikhronidi, G. V. Stepanova, and others.

The assimilation of cryogenic technology had great significance for the further development of research in the physics of semiconductors. At the end of the 1950s, installations for liquifying hydrogen and then helium as well were started up at the Dagestan Affiliate of the USSR Academy of Sciences with the collaboration of the Department of Low Temperatures at Moscow University.

During the same years, investigations of kinetic phenomena in semiconductors in superstrong pulsed magnetic fields at helium temperatures were begun for the first time by staff members of the Physics Institute. These pioneering works in 1962[17] led to the discovery of spin splitting of quantum oscillations in transport

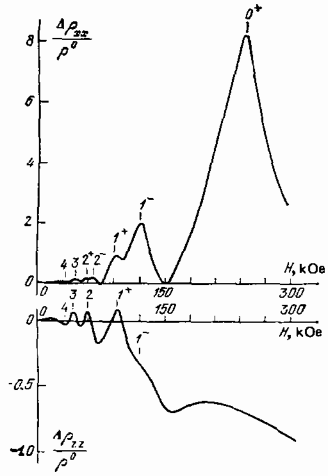


FIG. 1. Spin splitting in quantum oscillations of mercury telluride. $T=4.2$ K, $n$ =HgTe, $n=3.5\cdot10^{17}$ cm$^{-3}$.

phenomena (Fig. 1). The observation of spin splitting gave one more possibility of measuring the effective mass of charge carriers and the spectroscopic splitting factor, the most important characteristics of the band structure of semiconductors, and obtaining information on spin-lattice interaction. These experiments, initiated in Makhachkala, were then supported in Leningrad, and the staff of the Institute of Semiconductors of the USSR Academy of Sciences made a great contribution to the development of this research. In recent years, this effect has been widely used in laboratories in this country and abroad.

In the period from 1960 to 1970, the magnetophonon resonance, magnetoresistance in the quantum limit, negative longitudinal magnetoresistance due to scattering by a screened Coulomb potential, and the magnetic freezing out were investigated at the Physics Institute in magnetic fields with intensities up to 300–350 kOe in semiconductors of the group $A_3B_5$. The results of the investigations were published in the form of numerous papers in national and international publications, and they were reported practically at all All-Union conferences on low-temperature physics in the 1960s, at conferences on strong magnetic fields, etc.[17]

In the first part of my report, I said that at the 7th All-Union Conference on Semiconductors, the possibility of applying thermal rectification for practical purposes gave rise to great doubt, but in 1975, work being performed at the Physics Institute of the Affiliate demonstrated that under certain conditions thermal rectification could reach a magnitude of practical interest.

The nonlinearity of the current in an electron-hole germanium plasma with nonuniform temperature was discovered at the Physics Institute in 1975.[18] In later years, the Institute's staff developed new methods and apparatus for rectifying alternating current without using an electron-hole junction. Some of the inventions are now being patented abroad. In the future, this fundamentally new method for rectifying alternating current could find application in dc transmission lines.

Investigations of breakdown in silicon electron-hole junctions permitted the staff members of the Physics Institute to develop together with the manufacturers, silicon voltage multipliers and high-voltage rectifying columns and use them to replace insufficiently reliable selenium parts.

Extensive research in the physics of semiconductors and solid-state physics is being conducted at the Dagestan Order of Frienship Among Peoples V. I. Lenin State University. Under the direction of Professor A. Z. Éfendiev (1968), research is being conducted on electrical breakdown in different semiconductors, insulators, and gases in the presence of ionizing radiation (ultraviolet rays, gamma-neutron fluxes) and strong magnetic fields up to 400 kOe.

The magnetic properties of solids and the physical properties of alloys of metals and films of semiconducting compounds are being studied in the Department of Solid State physics under the direction of Professor I. K. Kamilov (1975). Physicists in the Department of Physics of the Dagestan Pedagogical Institute, under the direction of Professor G. B. Bagduev, are investigating the dislocation structure and its effect on the kinetic properties of semiconductors.

Apparatus designed to study the thermophysical properties of semiconductors was approved at the 7th Conference on Semiconductors, but it has found even greater applications in thermoenergetics: for studying the thermophysical properties of technologically important liquids, vapors, and gases. At that time, Academician M. V. Kirpichev became interested in this apparatus and scheduled my report in the seminar conducted by Corresponding Member of the USSR Academy of Sciences A. M. Mikheev; Academician M. A. Styrikovich was present at this seminar. The thermal conductivity of water with high values of the parameters encompassing the region of the critical state was studied for the first time using this apparatus. Data from this investigation were examined at many international congresses and conferences and entered into the international "framework" on thermal conductivity.[19]

Figure 2 shows seven isobars of thermal conductivity, covering all measurements of thermal conductivity of water, contained in the literature, with superhigh values of the state parameters. Investigations of the thermal conductivity of carbon dioxide in the critical state with different gap sizes (Fig. 3) established that

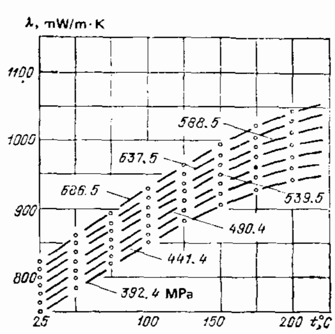


FIG. 2. Thermal conductivity of water.

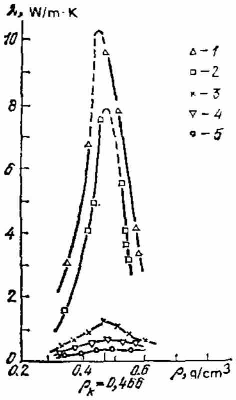

FIG. 3. Dependence of the thermal conductivity of $CO_2$ on density. $l$ (mm) = 12 (1), 5 (2), 1.5 (3), 0.51 (4), and 0.32 (5).

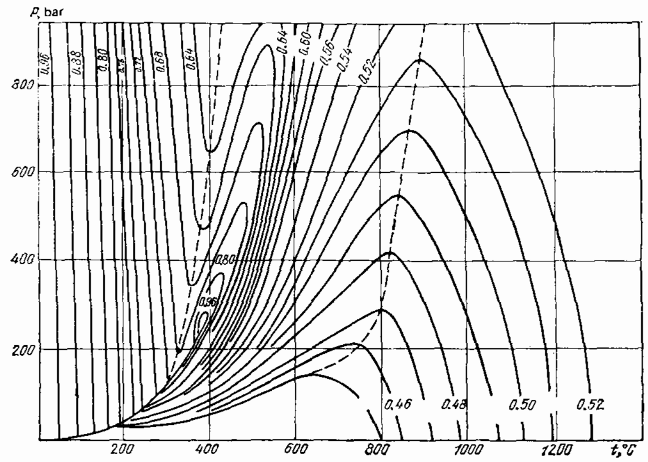

FIG. 4. Lines of constant isochoric heat capacity of water and steam.

the maximum of the thermal conductivity decreases with decreasing gap width. However, investigations of the isochoric heat capacity of water and other technically important liquids especially attracted energy specialists. These investigations were first conducted at the Dagestan Affiliate of the USSR Academy of Sciences.[20]

The investigations of the isochoric heat capacity of water and steam were performed up to 800 °C and 1000 atm. The result of this work is the monograph entitled "Isochoric Heat Capacity of Water and Steam" which was reprinted in the USA by the National Bureau of Standards.[21]

Extensive investigations of normal alkanes are generalized in the monograph "Isochoric Heat Capacity and Other Caloric Properties of Hydrocarbons of the Methane Series."[22]

Extensive experimental data has been obtained on the isochoric heat capacity of heavy water, carbonic acid, aliphatic alcohols, nitrogen tetraoxide, and aqueous solutions of salts and alkalis. The results of investigations in critical and supercritical regions are of great interest.

Figure 4 shows a diagram of the curves of constant isochoric heat capacity of water and steam. The dashed line separates the region of the critical state of the substance (so-called incoherent phase), representing a state that is intermediate between a liquid and a gas which encompasses a considerable part of the diagram of states. It was not possible to obtain this in the past using other methods. The measurements of the isobaric heat capacity did not yield a distinct picture, since the work of expansion in it presented an interference.

Investigations are being conducted at the direction of the State Committee of Standards of the USSR and the Presidium of the USSR Academy of Sciences and are included in the national economic plan for providing the country with reliable thermophysical data.

All-Union seminars on methods for investigating the isochoric heat capacity, organized by the state Bureau of Standards of the USSR and the USSR Academy of Sciences were conducted in Makhachkala in 1977 and 1982 and it has now been decided to conduct the next seminar in Makhachkala as well.

The Physics Institute of the Dagestan Affiliate of the USSR Academy of Sciences presents scientific reports in three divisions of the USSR Academy of Sciences: the Division of General Physics and Astronomy, Division of Energy, and the Division of Geology. The reason for this is that in the early years of the buildup of physics in Dagestan, the physicists at the Affiliate had to conduct scientific-research work in other areas of science adjacent to physics. Thus, for example, in 1952–54, I was the co-organizer and one of the directors of the northern-Caucasus complex geological petroleum expedition of the USSR Academy of Sciences, based at the Dagestan Affiliate of the USSR Academy of Sciences (the director of the expedition was Professor I. S. Brod), I organized and directed the Geological Institute of the Dagestan Affiliate of the USSR Academy of Sciences (1956–1957), I conducted work on thermal prospecting for minerals, I participated in work on geothermal power and earthquake forecasting, etc.

However, the most laborious work, which gave significant scientific and practical results, was the development, at the Dagestan Affiliate of the USSR Academy of Sciences, of a fast mass-spectrometrical method for determining the absolute age of minerals and rocks from radioactive transformation of potassium-40 into argon-40. This work was begun by Academician D. I. Shcherbakov, who, on behalf of the Presidium of the USSR Academy of Sciences, proposed to the Affiliate the development of a mass spectrometrical method for determining radiogenic argon in the well-known potassium-argon method of determining the absolute age, proposed in its time by Academician V. G. Khlopin and Professor É. K. Gerling. This method consisted of determining the age of rocks by the so-called volume method, in which the content of potassium (source product) and argon (daughter product) was determined by a chemical method. The main disadvantage of this method, aside from the time required to perform the measurements, was that the total argon, which may not be radiogenic, in the rock was determined. D. I. Shcherbakov sent to the Affiliate Candidate of Technical Sciences I. G. Gurvich and later Candidate of Technical Sciences S. B. Brandt was invited. Together with physicists at the Dagestan Affiliate of the USSR Academy of Sciences, they were the first to develop a mass-spectrometric method, distinguished by its rapidity, in which the age was determined according to radiogenic argon-40.[32] In the preface to the monograph "Determination of the Absolute Age of Minerals and Rocks"[23] D. I. Shcherbakov wrote: "Mass-spectrometrical analysis was not, of course, assimilated immediately and the criteria for argon retention in minerals and rocks were determined. The first successful steps in this direction have already been taken. A large quantity of numbers has been obtained, whose reliability has been checked, on the one hand, by parallel control analyses of other radioactive minerals and on the other by comparing with data on the stratigraphic positions of the specimens investigated.

The honor for this great achievement belongs to physicists at the Dagestan Affiliate of the USSR Academy of Sciences, who as a result of persistent organizational work and labor developed the foundations of the method as well as the apparatus and organized an outstanding age laboratory in their Affiliate."

The greatest achievement of the physicists at the Dagestan Affiliate of the USSR Academy of Sciences in this work was that they were the first to use the mass-spectrometric method of isotopic dilution, in which they used argon with a natural isotopic composition as a standard, to determine radiogenic argon in minerals. The basic idea was that since the object of the measurements is the monoisotope argon-40, i.e., a substance whose isotopic composition differs from the natural composition, the reference for the isotopic dilution can have a natural isotopic composition.. Thus the first rapid method in the world was created for determining the absolute age of minerals from the radioactive transformation of $^{40}K$ into $^{40}Ar$, which has universal application in the USSR and abroad.[23-25]

A novel apparatus was also created: a reactor for separating and purifying radiogenic argon from rocks and minerals.[23,26]

The mass spectrometric method developed at the Dagestan Affiliate of the USSR Academy of Sciences differed advantageously from the previously developed volume method by its reliability, high sensitivity, accuracy, and speed and, for this reason, it permitted determining for the first time the absolute age of entire geological regions, such as India, Sudan, China, Mongolia, Northern Caucasus, Kazakhstan, and others. Later, however, as the potassium-argon ages were accumulated, disagreements between the radiological data and stratigraphic determinations appeared in many minerals and rocks. Minerals such as sylvites and feldspars, indicated ages that were clearly too low. The investigators, proposed two possible reasons for this decrease in age of the indicated minerals: losses of radiogenic argon from the structure of the mineral over geological time or influx of calcium with retention of argon. For purposes of retaining the mass-spectrometric method developed, further physical investigations of these minerals were required for argon and calcium retention and, as a result of multiyear investigations from 1956 to 1960, a new method was developed, which involved thermal activation of minerals and permitted studying transport of radiogenic argon in crystalline structures of minerals.

The thermal activation method permitted interpreting for the first time, based on experimental diffusion parameters (D and E) of argon, the discordant K–Ar ages and obtaining the "true" ages.[26-28]

Based on diffusion experiments, in 1958–1965, it was established that argon and potassium are found in many minerals in two energy positions: stable (volume) and unstable (surface). It turned out that argon migrates out of the stable zone beginning at 500 °C and diffusion is accompanied with an activation energy of 40–70 kcal/mole, while argon leaves the unstable zone in the temperature range 100–400 °C and the separation process conforms to the kinetics of physical adsorption with energies of 2–6 kcal/mole. To correct the discordant K–Ar ages, it was necessary to introduce corrections to the unstable fraction of argon and potassium.

Thus a procedure was developed for the first time for correcting the discordant K–Ar ages by age-hardening the stable zones of both argon and potassium. The essence of the method reduced to the following: mineral specimens were subjected to isothermal annealing in the atmosphere; after annealing, the content of the remaining argon was measured in separate specimens by the mass-spectrometric method.

To determine the unstable potassium fraction, the experiment is conducted under conditions of high pressure and temperature. The specimen is enclosed in a thick-walled cylinder and the cylinder is filled with a solution of thallium nitrate (later, the thallium nitrate solution was reported by twice-distilled water). The volume of the cylinder is sealed with a steel cone and heated in a muffle furnace. When the isothermal annealing is completed, the potassium separated into the solution is determined by the method of flame photometry.

To calculate the corrected age from the total amounts of argon and potassium, the unstable fraction is subtracted out. The corrected age is calculated from the ratio $^{40}Ar_{stable}/K_{stable}$. The results obtained in this manner agree well with the data obtained using other radiological methods.[26-28,31,32]

Speaking about the importance of this method, Professor P. E. Daimon of the University of Arizona (USA) wrote: "Amirkhanov and his colleagues observed in a number of brilliant experimental investigations that the onset of appreciable diffusion of argon in feldspars under laboratory conditions coincides with the break in the curve of the specific heat capacity, indicating the onset of restructuring in the crystalline structure.

From here follows the conclusion that such changes can occur gradually over the course of geological time at comparatively low temperatures, creating interfaces on which some part of radiogenic argon is localized. This part of the argon in the so-called unstable zone is easily desorbed under heating for two to three hours at temperatures of 350–400 °C. In addition, these researchers established that a limited part of the potassium can be removed as a result of catiogenic exchange with thallium. Apparently, this potassium was also bound with argon in the unstable zone. In any case, after eliminating the easily desorbable argon and potassium capable of exchange, the disagreement in the age between micas and these potassium-containing feldspars disappeared and the mica and feldspar ages coincided well with one another. "[29]

In 1966, a new neutron activation $^{39}Ar-^{40}Ar$ method for determining the absolute age was developed abroad.[30]

Beginning in 1980, the data for the K–Ar ages of minerals, obtained using the technique of age-hardening stable potassium and argon zones developed at the Dagestan Affiliate of the USSR Academy of Sciences were compared with the ages obtained by the $^{39}Ar-^{40}Ar$ method. Analysis of the data showed that the $^{39}Ar-^{40}Ar$ method is essentially identical to the determination of the absolute age according to stable zones using the K–Ar method. In other words, both the Dagestan Affiliate method and the $^{39}Ar-^{40}Ar$ method leads to the same result for the corrected ages relative to the daughter and source elements in the most preserved parts of the crystalline lattice. The difference lies only in that in the classical K–Ar method, the stable K and $^{40}Ar$ zones are revealed by experiments at high pressures and temperatures, while in the $^{39}Ar-^{40}Ar$ method, they are revealed by neutron irradiation. The presence of such a relation is likewise indicated by the values of the diffusion parameters of $^{39}Ar$ and K. Thus it may be assumed that the discovery of unstable zones of $^{40}Ar$ and K was a precursor to the creation of the $^{40}Ar-^{39}Ar$ method. Undoubtedly, both the K–Ar and the $^{39}Ar-^{40}Ar$ methods must function in geochronological laboratories together, especially since the entire theory of the K–Ar method is applicable to the $^{39}Ar-^{40}Ar$ method.

In 1965, investigations to determine the mechanisms of migration of lead, helium, rubidium, and strontium isotopes were begun for the first time at the Physics Institute in order to interpret the discordant ages of minerals containing uranium, thorium, radium, and rubidium. The results of these investigations permitted determining the presence of stable and unstable zones of lead, helium, rubidium, and strontium isotopes in many minerals.[33] It turned out that the application of the method of age-hardening of stable zones of lead, rubidium and strontium isotopes is not only applicable to correction of discordant ages of minerals obtained by lead-lead and rubidium-strontium methods, but it is even more necessary in this case than in the potassium-argon method.

From 1953 to 1982, the laboratory published the following: five monographs with a total length of 2.4 million ens, of which one was translated abroad (People's Republic of China); two topical symposia with a total length of 600,000 ens; one article in the USA ("Annals of the New York Academy of Sciences"); and about 200 papers in specialized journals. Two monographs are currently being prepared for publication with total length of 1.2 million ens.

At the suggestion of the Presidium of the USSR Academy of Sciences and of the Commission for determining the absolute age of geological formations in the Division of geology, geography, and geophysics, the XIXth session of the Commission on Determining Absolute Age was held at the Physics Institute of the Dagestan Affiliate of the USSR Academy of Sciences in 1975.

Since 1964, a new direction has been developing in the Dagestan Affiliate: determination of the absolute age of rocks and minerals by the method of nuclear gamma-resonance spectroscopy. The main achievement in this research was the discovery, at the Physics Institute of the Dagestan Affiliate, of a functional relation between the Mössbauer parameters of iron-57 atoms and the age of the mineral, which can be explained by the fact that in the mineral lattice, iron ions play the role of "tagged" atoms and carry information on acts of radioactive decay and accumulation of daughter elements in the mineral over geological history. The functional dependence of the Mössbauer parameters on time forms the foundation for a new graphic method for determining the absolute age of minerals.[34]

As a result of the study of Mössbauer spectra of minerals of different age, it turned out that time "leaves an imprint" on the shape of the spectral lines.

Thus, for example, Fig. 5 shows the Mössbauer spectra of two biotites: in Fig. 5a, the biotite is a dated cenozoic soil (17 million years) and in Fig. 5b, it is a dated precambrian soil (1760 million years). The difference between the spectra according to the external appearance and according to the Mössbauer parameters is due to the redistribution of cations over nonequivalent positions, which occurs in the structure of the mineral over geological time.

Figure 6 shows the experimentally found redistribution of iron ions over cis- and trans- positions. The

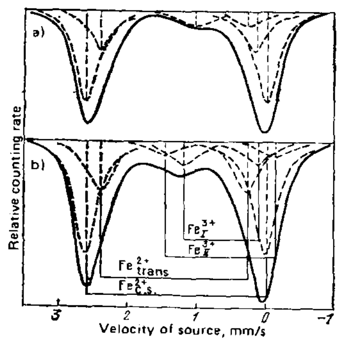


FIG. 5. Mössbauer spectra of biotite with an age of 17 million years (a) and 1760 million years (b).

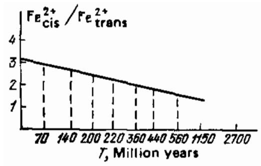


FIG. 6. Graph of the change in the magnitude of the ratio $Fe^{2+}_{cis}/Fe^{2+}_{trans}$ with age.

magnitude of the ratio $Fe^{2+}_{cis}/Fe^{2+}_{trans}$ for biotites and phlogopites decreases from cenozoic to precambrian.

Based on the functional dependence found between the age of the mineral and the ratio of cis- and trans-positions, a new method was developed at the Dagestan Affiliate of the USSR Academy of Sciences for determining the absolute age, which is now gaining "strength" by means of statistical accumulation of measurements and estimates of their applicability in geochronology. More than 40 papers with detailed descriptions of the results of the determination of the absolute age with the help of the Mössbauer effect have already been published in different journals in this country and abroad.

In addition to this practical fruition of the functional dependence between the age of a mineral and the Mössbauer parameters, this work also had other great fundamental scientific success, raising the curtain on the problem of the genesis of the earth in geological time.

As is well known, historical geology, which describes the time of existence of our planet, divides the earth's lifetime of ~5 billion years into a series of epochs and periods, characterized by sharp stratigraphical and facial changes in the earth's crust, often related with different stresses on biological life over this time. Up to now, this division was made by studying many geological parameters in combination with the biological processes occurring during these periods on earth.

Comparison of the parameters of the Mössbauer spectra of iron according to their quadrupole splitting in minerals of different ages led the authors to the discovery of a new phenomenon: the "tagged" iron atom $^{57}Fe$ itself marks all geological periods according to the difference in the quadrupolar splitting.

Figure 7 shows the earth's geochronological scale, marked by the "tagged" iron-57 atoms according to the magnitude of the quadrupolar splitting in minerals of different ages. Thus the "tagged" iron atom $^{57}Fe$ not only "ages" together with the mineral, but it also participates in all other processes leading to the division of the earth's age into geological periods.[35] These processes in the $^{57}Fe$ nucleus are recorded forever. The problem now facing physicists at the Dagestan Affiliate of the USSR Academy of Sciences, naturally, includes the observations of these periods or, more precisely, their manifestation. Work is now being conducted on selecting analogous actions on the iron atom $^{57}Fe$, to which it could have been subjected in the distant geological past. For this purpose, investigations are being conducted at the Physics Institute on the action of electrical and magnetic fields, pressure, high and low temperatures, radiation, etc., on the $^{57}Fe$ atom.

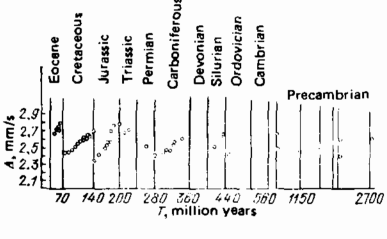


FIG. 7. Secular variations of the quadrupole splitting of iron on a geochronological scale.

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