Scientific session of the Division of General Physics and Astronomy, USSR Academy of Sciences (26–27 February, 1975)

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A scientific session of the Division of General Physics and Astronomy was held on 26 and 27 February, 1975 at the conference hall of the P. N. Lebedev Physics Institute of the USSR Academy of Sciences. The following papers were delivered:

1. G. I. Petrov, The Nature of the Tungusska Meteorite.

2. G. E. Kocharov, Nuclear Reactions on the Sun.

3. L. F. Vereshchagin, E. N. Yakovlev, and Yu. A. Timofeev, The Possibility of a Hydrogen Transition to a Conductive State.

4. A. V. Gurevich, The Artificial Ionospheric Mirror.

We publish below brief contents of the papers.

G. I. Petrov. The Nature of the Tunguska Meteorite. The event of 30 June 1908 that is known as the "Tunguska Meteorite" is considered. The uncommon nature and scale of this phenomenon attracted a great deal of merited attention. An extensive literature has been devoted to its study.

The main peculiarity of the event was the fact that when the large body plunged into the earth's atmosphere, only the shock wave reached the surface. This wave felled trees over an area of about 2000 square kilometers and set fires in the taiga. Estimates of the energy released in the atmosphere yield values on the order of $10^{23}-10^{24}$ erg.

The effect has been analyzed with reference to the laws of mechanics and gasdynamics.

All aspects of the phenomenon can be explained rationally if the motion of the large body was strongly nonstationary and if the shock wave could separate from the body to distances considerably greater than its characteristic dimension. This is possible if the Strouhal number $\mathrm{Sh} = v/l\tau > 0.1$, where v is the velocity of the motion, l is the characteristic dimension of the body, and τ is the characteristic time of velocity change. For the deceleration of a body in a gas, $\mathrm{Sh} = k\rho_g/\rho_b$, where k is a coefficient determined by the geometry of the body. Thus the body that entered the earth's atmosphere had a density considerably below 0.1 g/cm^3.

The rapid disintegration of the moving body in the atmosphere is discussed, and estimates of the heat fluxes are given.

It is shown that at very high rates of vaporization, the rate of mass loss by the entire body is lower than the rate of mass loss by its solid phase, a factor that must be taken into account in computing the motion of the body.

Estimates of the kinetic energy lost by the body when it reached the surface of the planet are submitted.

It is shown that large bodies with an initial kinetic energy greater than 10^{24} erg at a density greater than 0.1 g/cm^3 retain much of their initial kinetic energy at the surface of the planet, even if the planet has an atmosphere like that of Venus; consequently, the steep-walled depressions with diameters of 50 to 100 km that have been observed on the surface of Venus may be impact craters (the energy required to form them exceeded 10^{30} erg).

In conclusion, the paper points out the inconsistencies of explanations involving shattering, thermal-explosion, annihilation, or thermonuclear-explosion hypotheses.

E. L. Krinov, Tungusskiĭ meteorit (The Tunguska Meteorite), USSR Academy of Sciences Press, 1949.

M. A. Tsikulin, Meteoritika, No. 20, USSR Academy of Sciences Press, 1961, p. 87.

E. M. Kolesnikov, A. K. Lavrukhina and A. V. Fisenko, Geokhimiya, No. 8 (1973).

V. P. Stulov, Doctoral Dissertation, Moscow State University, 1974.

G. E. Kocharov. Nuclear Reactions on the Sun. The numerous attempts to explain the results of solar-neutrino experiments can be classified into three groups:

a) Hypotheses are introduced to lower the temperature in the interior of the sun and, accordingly, the fluxes of high-energy neutrinos.

b) Attempts are made to lower the velocity of light in the neutrino experiment by lowering the rate of generation of high-energy neutrinos in the interior of the sun or by losing the "necessary" neutrinos on the path from the sun to the earth.

c) It is assumed that the temperature in the central part of the sun varies with time and that the temperature is at present below the average.

All of the hypotheses encounter difficulties associated with the need to modify established conceptions.

Experiment now gives the value $\xi \leq 1$ cent $= 10^{-36}$ reaction event per second with one Cl^{37} atom for the rate of the Pontecorvo reaction. Analysis of the background sources shows that $\xi = (0.3 \pm 0.6)$ cent. If it is found that $\xi \leq 0.3$ cent on a further reduction of the background, only five of the numerous current hypotheses will still stand. In group (a), only the hypothesis of G. E. Kocharov and Yu. N. Starbunov concerning the possible combustion of helium-3 in the interior of the sun will remain. According to this hypothesis, the presence of helium-3 with a content by weight of 0.1% in the central region of the sun would result in a Pontecorvo reaction rate of 0.1 cent. Remaining in the second group will be B. M. Pontecorvo's neutrino-oscillation hypothesis, the neutrino-radio-activity hypothesis of N. Bahcall, N. Cabibbo, and A. Jahil, and the hypothesis of G. E. Kocharov and D. Clayton with a nonmaxwellian velocity distribution of the ions in the region of the high-energy tail. In the third group, we presently have W. Fowler's hypothesis of jumpwise mixing of the interior of the sun, and it will remain at $\xi \leq 0.3$ cent. In any event, there is an acute need for experiments to register low-energy solar neutrinos. Along with the development of new methods in neutrino astrophysics, it is extremely important to study the various consequences that follow from the hypotheses under discussion for solar physics and solar astrophysics and concern external manifestations on the sun that can be investigated independently. Thus, for example, Fowler's hypothesis implies that the sun's luminosity varies in time. Several million years ago, the luminosity of the sun should have been 5% below the contemporary level, and this may have been responsible for the global ice age known in geology. It is also natural to expect within the framework of this hypothesis that the modulating action of the solar wind on cosmic-ray intensity would have been weaker in the past, and this should be reflected in the production rate of cosmogenic isotopes in the earth's atmosphere, in meteorites, and in the soil of the moon. Available experimental data on Al^{26} ($T_{1/2} = 0.74 \times 10^6$ yr), Mn^{53} (37×10^6 yr), and Be^{10} (2.5×10^6 yr) favor Fowler's hypothesis, but the accuracy is not adequate for final conclusions. An important consequence of the helium-3 and particle velocity distribution hypotheses may be enrichment of the solar corpuscular streams in helium-3. Analysis of experimental data on the isotope composition of solar cosmic rays indicates the presence of relatively large quantities of helium-3 in the regions of flares (as much as several percent at a content of 0.01% in the solar wind). But even in this case there are uncertainties that require special study.

2. The second part of the report discusses the results of study of solar neutrons and γ rays, helium isotopes, and hydrogen of flare origin. There have been flares in which the fluxes of helium-3 exceeded by considerable margins the values obtained by calculations using experimentally measured tritium and deuterium fluxes within the framework of generally accepted conceptions as to the features of the corresponding nuclear reactions. Two approaches are currently being developed to explain the anomalously large helium-3 fluxes. In one of them, it is assumed a priori that there is practically no helium-3 in the solar matter, whereas the other admits the presence of helium-3 and finds its content on the bases of experimentally measured ^3He fluxes. The first approach is being developed by R. Ramaty and R. Lingenfelter in the USA and the second by G. E. Kocharov and I. A. Ibragimov in the USSR.

In the former case, the thickness of matter that can be pierced by high-energy solar particles is increased by two assumptions:

(a) As compared with the helium-3 distribution, the angular distribution of the deuterons is more elongated in the direction of the sun and, accordingly, the helium-3 nuclei escaping from the sun are enriched as compared to the deuterons. As for the enrichment in helium-3 relative to tritium, it is explained as a result of stronger absorption of tritium in the solar matter.

(b) After production, secondary particles are subject to further acceleration.

Both hypotheses require detailed theoretical analysis and experimental verification, both in the laboratory by studying the kinematics of the corresponding nuclear reactions and in outer-space experiments. It is essential to note that even under such unusual hypotheses it is still impossible to explain all of the existing cases with elevated helium-3 fluxes. The question as to why the energy spectra of ^1H, ^3He, and ^4He are similar if ^3He is secondary and ^1H and ^4He are primary also remains unclear.

It seems more natural to us to explain the experimental data by the presence of ^3He in the flare region. In this case, the dynamic nature of the ^3He concentration is also explained: the helium-3 concentration is ~3% for the flare of 14 October 1969, 0.2% for the flare of 3 November 1969, and 0.2% for the flare of 6 November 1969. Since all of the flares occurred in the same active region, the ejection of ^3He from deep layers into the region of the flare may have occurred around 14 October 1969. On the assumption that ^3He is absent, the negative results of attempts to detect solar neutrons and gamma rays and the single positive result for the solar gamma quanta (August 1972) are interpreted as due to strong asymmetry of the escape of solar cosmic rays—fewer than 1% of the particles fly toward the sun. This conclusion is difficult to explain both from the standpoint of the nature of the asymmetry and in view of the established opinion that the energy of a flare in white light is the result of specific losses of solar cosmic rays in the matter of the sun.

If, on the other hand, we proceed from the helium-3 hypothesis, it becomes possible to explain the data, since ^3He is an extremely strong neutron absorber in the reaction $^3He(n, p)^3H$. The cross section of this reaction is 18 000 times greater than that of the reaction $^1H(n, \gamma)^2H$. At a 0.01% helium-3 concentration (as in the solar wind), these reactions have the same probability. But if $X_2 = 0.1\%$, the probability of the reaction $^3He(n, p)^3H$ is 10 times that of $^1H(n, \gamma)^2H$. This means that at a fixed value of the flux in the gamma line of deuterium, allowance for helium-3 increases the solar cosmic ray flux toward the sun. Concerning the 0.5, 4.4, and 6.1 MeV lines, Ramaty and Lingenfelter conduct the analysis on the assumption that the energy spectrum of the protons is exponential down to the very lowest energies in the region in which they are produced. On the other hand, the proton spectrum measured experimentally during the flare of 4 August 1972 indicates an intensity much lower than the extrapolation value in the range 20—30 MeV, where the generation cross section for these gamma lines is largest. In fact, the disagreement may be even wider if particles are accelerated in interplanetary space in the low-energy range. With consideration of the roles of helium-3 and the energy spectrum of the particles in their generation region, therefore, it becomes possible to explain the gamma-quantum results in their entirety with a simultaneous decrease in the asymmetry of escape of the solar cosmic rays.

Further experimental and theoretical studies of this complex of phenomena will aid in understanding the aggregate of processes in the interior of the sun and on its surface.

The paper was based on results published in the following papers:

G. E. Kocharov, Izv. Akad. Nauk SSSR, Ser. Fiz. **37**, 1228 (1973), **39**, 244 (1975); in: Trudy mezhdunarodnogo seminara "Solnechnye kosmicheskie luchi i ikh proniknovenie v magnitosfery zemli" (Proceedings on International Seminar on "Solar Cosmic Rays and Their Penetration into the Earth's Magnetosphere"), Izd. LIYaF Akad. Nauk SSSR, Leningrad, 1973, p. 7; USSR Academy of Sciences Physico-technical Institute Preprint No. 457, Leningrad, 1973; in: Proc. of 13th Intern. Conference on Cosmic Rays, Denver, USA, 1973, p. 1602.

G. E. Kocharov and Yu. N. Starbunov, ZhETF Pis. Red. **11**, 132 (1970) [JETP Lett. **11**, 81 (1970); in: Proc. of 12th Intern. Conference on Cosmic Rays, Vol. 7, Australia, 1971.

I. A. Ibragimov and G. E. Kocharov, USSR Academy of Sciences Physico-technical Institute Preprint No. 456, Leningrad, 1974; Izv. Akad. Nauk SSSR, Ser. Fiz. **39**, 287 (1975).

R. Ramaty and R. Lingenfelter, in: Trudy mezhdunarodnogo seminara "Uskorenie chastits i yadernye reaktsii v kosmose (Proceedings of International Seminar on "Particle Acceleration and Nuclear Reactions in Space"), USSR Academy of Sciences Physico-technical Institute Preprint, Leningrad 1974, p. 25.

R. Ramaty and W. Kozlowski, ibid., p. 58.

L. F. Vereshchagin, E. N. Yakovlev, and Yu. A. Timofeev. The Possibility of the Transition of Hydrogen to a Conductive State. The development of a process for the synthesis of polycrystalline diamonds of the carbonado type by the USSR Academy of Sciences Institute of High Pressure Physics opened new possibilities for the attainment of high pressures.

It was shown in earlier studies (made jointly with G. N. Stepanov, B. V. Vinogradov, K. Kh. Bibaev and T. I. Alaeva) that carbonado diamonds are capable of withstanding contact pressures up to 3 Mbar. These pressures are several times those presently attainable with the aid of hard alloys (0.5 Mbar).

Carbonado diamonds have been used to build miniature chambers for the study of dielectric-metal transitions. The high-pressure chamber consists of two anvils (one flat and one tapered with a blunted point), between which a layer of the dielectric is placed.

If the substance to be studied is a gas, the anvils are cooled to the appropriate temperature and the test substance is condensed on the anvil surfaces. To investigate hydrogen, the anvils were cooled to 4.2°K.

Among the solid dielectrics, the author investigated (jointly with V. P. Sakun) transitions in diamond, silica, corundum, and various other substances.

The appearance of a conductive phase is determined from the resistivity jump.

Resistivity jumps due to electric breakdown, to tunneling of carriers through the dielectric layer, or simply to contact were distinguished from jumps due to phase transitions by applying a special test. The latter is based on the effect of metastability that always accompanies first-order phase transitions in solids under pressure.

The metastable states are manifested in the form of a hysteresis that decreases as the temperature rises. The test developed consists in the fact that the substance heats up at forces near the direct and reverse transitions.

If heating in the dielectric state results in a stepwise decrease in resistivity (usually by a factor of 10^6—10^8) and heating in the conductive state brings about an increase (by a factor of 10^6—10^8), this corresponds to "unfreezing" of the metastable dielectric and conductive states. We take observation of the "unfreezing" effect as proof of the phase transition.

In addition to the test described above, there are various other criteria that can be used to confirm the phase transition. An example is the observation of two resistivity jumps in a mixture of powders of two dielectrics.

It was observed in a study of the resistivity of hydrogen that it decreases under pressure by a factor of at least 10^6. Heating of the hypothetical metastable conductive phase resulted in an increase of the resistivity to the original value (by a factor of 10^6).

This set of phenomena, which is analogous to that observed earlier in other dielectrics, served as a basis for the conclusion that a transition of hydrogen to a conductive phase is possible. These experiments yielded only an order-of-magnitude estimate of the transition pressure: $P \sim 1$ Mbar.

A. V. Gurevich. The Artificial Ionospheric Mirror. Considerable attention is being given to study of the phenomena that arise on artificial modification of the upper ionosphere under the action of powerful radio waves[1,2]. Large-scale layering of the disturbed region of the ionosphere [3], oscillations of a powerful pulsed signal reflected from the ionosphere[4], and intensive excitation of plasma and ion-acoustic oscillations[5] are among recent observations.

An interesting new phenomenon was recently discovered at Boulder, Colorado: the formation of an artificial ionospheric mirror that reflects radio waves in a broad frequency range, up to and beyond 100 MHz[6]. The reflections are caused by small-scale layering of the ionosphere. It was found that inhomogeneities with plasma-density fluctuations $\delta v = \delta N/N \sim 10^{-2}$ and strong elongation along the earth's magnetic field **H** appear under the action of the powerful wave. They are approximately 1 meter across and approximately 1 km long or longer. The inhomogeneities are formed on disturbance of the ionosphere by the ordinary wave, in the region of its reflection. The effective dimensions of the strongly disturbed zone are height 10—20 km, width 100—150 km. The extraordinary wave apparently does not cause such disturbances.

Radio waves of various frequencies can be scattered on these inhomogeneities. The scattering is sharply anisotropic because the inhomogeneities are strongly elongated along **H**. The scattering maximum lies on a cone whose axis is directed along **H**, while its generatrix form the same angle as the incident ray with the normal to **H**. It is as though the waves were reflected from slender specular rods oriented along **H**.