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PHYSICS OF COSMIC RAYS

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PHYSICS OF COSMIC RAYS *

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By G.D. Zhdanov

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An All-State Conference on Cosmic Rays took place in Moscow on October 4-10 1963, where 130 scientific reports were delivered by young scientists. In their reports they had spoken about various problems and achievements in the area of cosmic ray mastering. What are the last achievements? What is new direction for future study? All these questions aroused interest of most Soviet scientists. AUTHOR

I. NEW INSTRUMENTS AND METHODS

With further penetration into the depth of the atmosphere the cosmic ray flux is rapidly decreasing and at the same time its composition becomes more complex. Therefore, the penetration into open space depths is the main goal of cosmic ray studies. During last year this idea was materialized in the form of further development and building of new laboratories on top of high mountains in Armenia, Georgia, Kazakhstan, Uzbekkistan, in more frequent use of the Air Force (flights at altitudes of 6 - 12 km) and use of Cosmos-type scientific satellites.

In order to analyze the nature of cosmic particle interaction with atomic nuclei it is important to make a close comparison with the conditions

* FIZIKA KOSMICHESKIKH LUCHEY

[redacted]

of contemporary experiments by means of accelerators, having more or less precise data on energies of colliding particles and at the same time a broad energy range by comparison with the most powerful of all existing and even currently built accelerators.

That is why large-scale colorimetric installations are widely used today, for they allow to register all or part of cosmic particle energy on the basis of the cascade showers formed by cosmic particles inside thick filters divided by rows of ionization chambers.

A new feature in the field is the introduction for the first time of Čerenkov computers and the use of controlled photographic emulsion instead of ionization chambers.

In case of using photographic emulsion the arrangement must be as follows: Above certain rows of ionized chambers lie mosaic rugs consisting of a great number of photo emulsion blocks. Of these, only that under which a heavy cosmic particle shower has passed is subject to development and analysis.

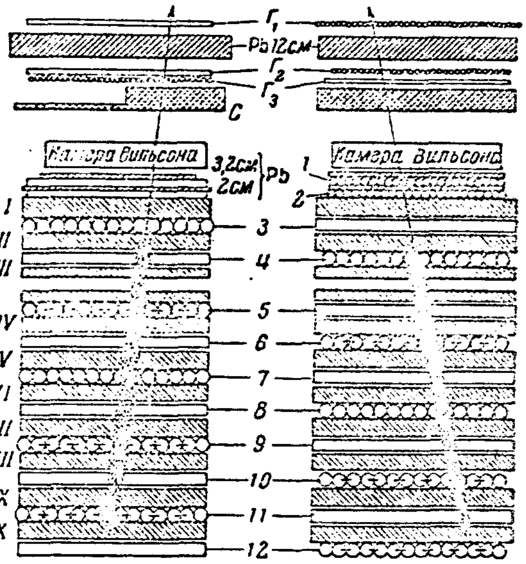

Fig.1.- One of the typical calorimetric installations for the study of high-energy nuclear interactions. are the rows of hodoscopic counters, 1 — 12 are rows of ionization chambers.

The application of these various complementary methods helped to achieve more accurate and reliable results. The first ones still are somewhat unreliable, but decidedly promising results were obtained by researchers having used spark chambers, of which some types were worked out at Moscow, Yerevan and Tbilisi laboratories. The most interesting achievements have been obtained with the aid of tracking spark chambers, in which it is possible to fix the precise spatial picture of the charged particle trail in the form of a chain of brightly glowing points.

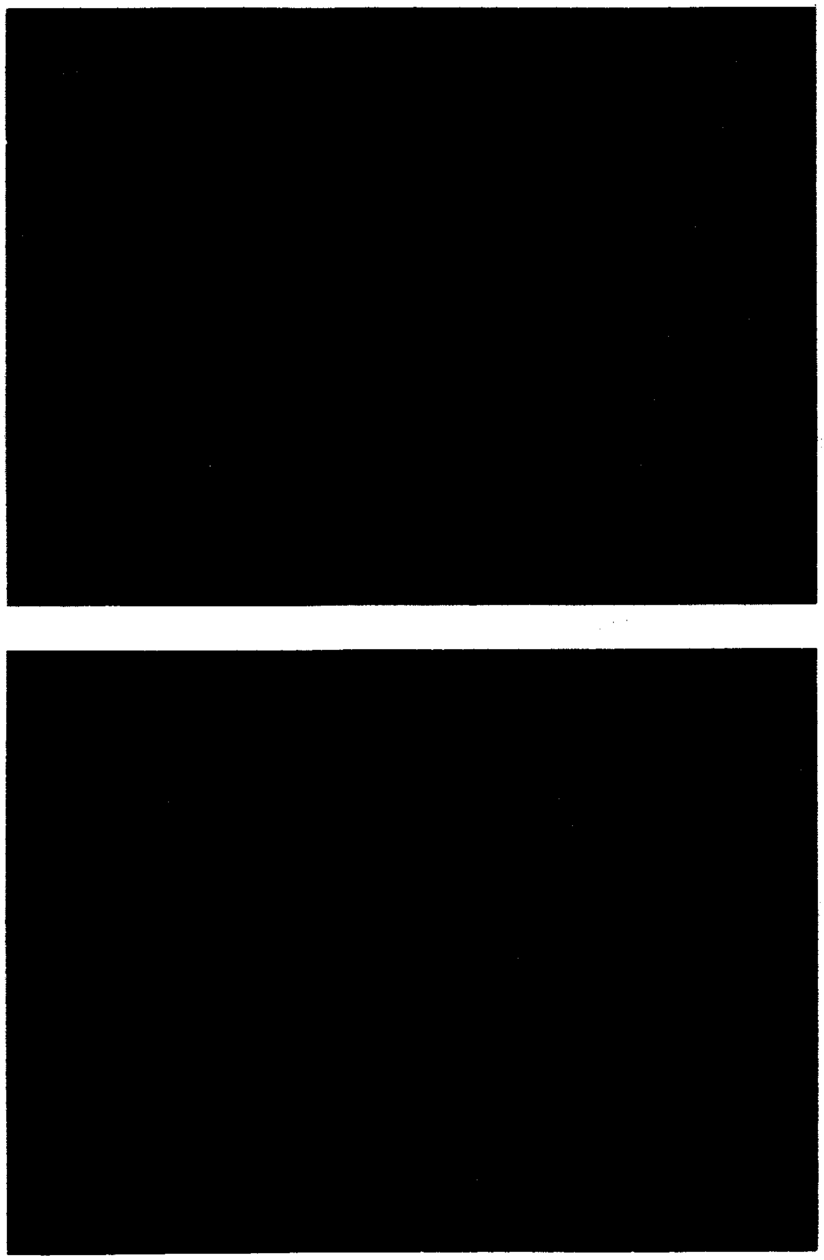

Fig. 2. - Wakes (Trails) of fast particles in the tracking spark chambers

The informations about the magnitude of a particle impulse can be obtained by applying a magnetic field to the spark chamber. The working material in sparking chamber was undistorted, contrary to what happened in the standard "Wilson Chamber". Therefore, the accuracy of the sparking chambers is much higher than that of the Wilson Chamber. There are very interesting perspectives for the apparatus developed in Yerevan and designed for a direct measurement of high-energy charged particles. This appartus is based on the registration of transitional emission inside stratified media with a periodically modulated index of refaction. The apparatus for complex study of broad atmospheric showers, which will also provide informations on each of them, has also been rapidly modernized.

A new variant of such installation, occupying an area of about 4 hectare (2,471 acres) has been created at Moscow University. The total working area of all gas-discharge counters is of 100 m^2 and their scintillation area is of 10 m^2.

SPACE PHYSICS AND COSMIC RAYS

During last years research in the field of space physics developed mainly in two directions; Mastering various processes of natural acceleration of particles and using these particles as an instrument for cosmic space soundings. The various experimental studies of charged particles flows above the Earth's atmosphere in combination with other geophysical, astrophysical researches, have helped to move toward the solution of this fundamental problem.

The next object of research in space nearest the Earth and very, important for many practical problems consists of Earth's radiation belts, which have been discovered less than 5 years ago. Up until now scientists have been using in the majority of cases only descriptive and not always reliable data about this most interesting phenomenon of the nature, and they were a long way from the creation of the quantitative theory of radiation belts.

Strict equations of particle flow inside the Earth's magnetic field could only be written recently taking into account the non-stationary processes, conditioned by comparatively slow variations of this field under the influence of solar corpuscular streams. Calculations have been made, which show how the slowly varying magnetic field determines simultaneously the acceleration of charged particles and their bilateral scattering. One of the scattering directions from space to Earth is connected with the capturing of solar corpuscular flux particles (solar wind) into the magnetosphere of the Earth (as a result of scattering, charged particles are completely trapped by the lines of force of the geomagnetic field). At the same time the interaction of two factors - diffusion of particles inside the magnetic field and their spreading on atoms of discharged gas of the outer atmosphere leads toward characteristic spatial distribution of the intensity of electrons inside the outer radiation belt.

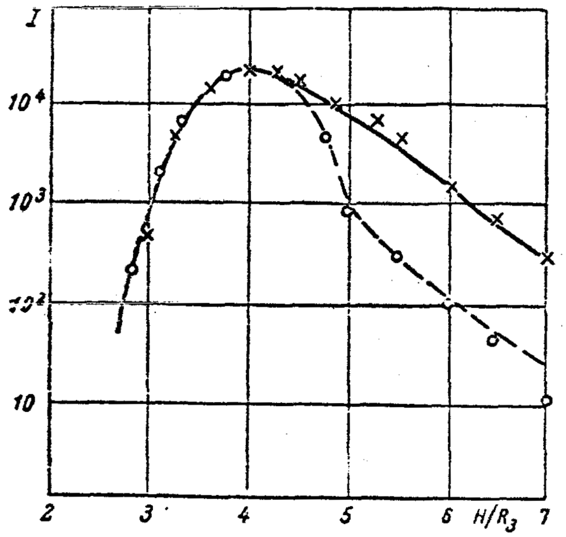

Fig. 4.- Dependence of radiation intensity on the height H (in relative units) for fast electrons of the outer radiation belt (in the Eaerth's equatorial plane). The solid line gives the computations by Tverskaya (1961) and the dashes — the days free*

The same theory permits the explanation of the cause for the appearance in this belt of protons with energy of about 10 million eV. It is interesting to point out that such a celestial accelerator, which is similar to these created by men (BETATRON) can probably use only 2% of energy carried to the Earth by the solar wind.

Similar calculations have explained how a relatively low altitudes the protons of higher energy (about 100 Mev), injected by cosmic rays from the Earth's atmosphere, can stay within the inner radiation belt during several years, while a great height (near the exterior border line of the outer blet) they escape into cosmic space after several days.

In parallel with the "breathing" of the outer Earth's radiation belt, two types of cosmic ray intensity variations, well studied for the past years, are also being used as sensitive indicators of the electromagnetic processes in cosmic space.

The first type of variation (the Forbush effect) consists in the decreasing intensity of emission because of scattering of charged particles along the non-homogeneous magnetic field in the area of encounter of the Sun's corpuscular streams with the magnetosphere of the Earth. The second

* [continuation of caption]... from magnetic storms (end of 1962). The corresponding experimental data are given by crosses and small circles. The height is given in Earth's radius units (R).

type (the cosmic ray intensity outbursts) are connected with the arrival on the Earth of fast-moving charged particles, dispersed inside the active areas of the Sun's corona and then coming under the influence of slow diffusion through the magnetized plasma clouds. The electromagnetic situation inside the interplanetary space is varying in accordance with the eleven year cycle of periodic variations of Sun's activity. During the years of maximum activity displacement of cosmic rays of galactic nature by the regular one but with more powerful corpuscular streams, whose influence can be observed even at such distances as the orbit of Mars.

During the years of the Quiet Sun the magnetized plasma clouds are dispersing and this leads on the one hand to an increasing (approximately twofold) of general galactic emission background, and to a more effective egress of the complementary emission, ejected from the Sun during chromospheric flares - on the other.

At substantionally larger scales of the whole Galaxy one can study the processes of cosmic ray diffusion through a non-homogeneous magnetized plasma with the aid of analysis of primary cosmic emission of higher energies (10^{15}eV), which induces inside the Earth's atmosphere gigantic showers, consisting of many millions even billions of particles. However, this analysis is, made more complex because of the possibility for cosmic rays to egress into the intergalaetic space, of which we know very little. It is nevertheless nearly taken for granted that the experimentally observed sharp break (toward the side of steeper energy drop) of the energy spectrum of broad atmospheric showers with energies of 10^{15} - 10^{16} eV is precisely related to the variation of the magnitude of the diffusive path of respective particles in the interstellar space.

NUCLEAR PHYSICS RESEARCH

During past several years theoretical and experimental physicists have been discussing the hypothesis of the "fire balls". These are highly activated, and highly unstable clusters of "pure" meson field moving for some time independently from the high energy (10^{12} eV) - nucleon having undergone a nuclear collision.

Although the new experimental data obtained in various laboratories are not coordinated as yet, they nevertheless compelled us to consider that the appearance of the mysterious "fire balls" is at least not the only way of generating high-energy particles.

One point of view on the subject is that, alongside the fire balls" the formation and the subsequent decay of the highly agitated nucleons — isobars of the different mass, have a decisive role in the generation of particles with high energy. This process must be less effective in relation to the number of newly formed particles (π - mesons) but it is very effective for transfering larger amounts of energy to the separate π - mesons. According to a second, more radical hypothesis, the fire balls are fiction, but in reality formation and decay of meson-nucleons resonant systems or "resonons", discovered during the last two years with the aid of accelerators, have been observed. Because of their increased mass, the resonons can differ from the directly formed π - mesons by greater energies and smaller angles of escape. Discovery of new, earlier unknown, processes of particle generation may still be used for the explanation of two more recently-revealed anomalies, the "behavior" of cosmic particles with high energy. At first it helps to explain the nature of γ - quantum formations, whose number is very difficult to correlate with the existing theory of birth directly through neutral π - mesons. Secondly, it has been discovered that in the flow of the nucleoactive component of cosmic rays, especially at low altitudes, the part of unstable particles (mainly charged mesons) is considerably larger than expected earlier and constitutes tens of percent at energies above $10^{11} - 10^{12}$ eV for a relatively high atmosphere density. Efforts of theoretical physicists have been directed toward the development of the quantitative theory of the peripheral nuclear collision, at which only a small part of the total mass and energy of the impinging partners has been taking part in the formation of new particles. A characteristic feature of such relations is the exchange of the impinging particles with one virtual meson. However, certain arguments have appeared in favor of the idea that besides characteristic for high energy peripheral interactions, the central type collision may take place, leading to simultaneous exchange with several virtual mesons and therefore with high efficiency for the utilization of kinetic energy of two impinging particles. Finally, experimentators have recently started the study of the particularities of particle interaction with complex nuclei in comparison with simple nucleon-nucleon collision processes. Experimenting with cosmic rays physicists have heretofore usually observed the processes which take place

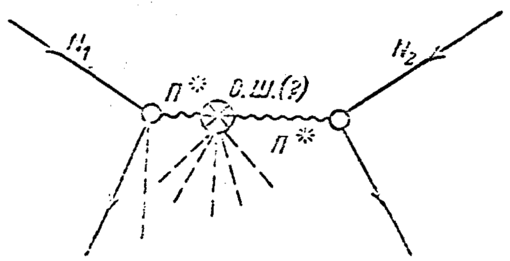

Fig. 3. - Scheme of peripheral interaction of high-energy nucleons (N_1,N_2 with participation of virtual mesons and of the fire ball. Dashes indicate the newly created particles.

in complex, although at times in light nuclei, without particular regard to their composition, and only recently the validity and the reliability of measurements have reached a level at which the results of collisions of separate nucleons with the complex nuclei could be compared quantitatively. Because of this, the conditions of the experiment become clearer.

PRIMARY SOURCES

What are the primary sources of cosmic rays? An accurate analysis of radioemissions of local sources (shells of the already exploded supernovae) has permitted to master the energetic spectrum of particles scattered by enlarging shells, and to evaluate the whole energy transmitted to charged particles (electrons) which become comparable with the total energy of the shell's magnetic field. It was also ascertained that the intensity of the total Galaxy radioemission (which is not connected with the remains of supernovae) is approximately 100 times greater than the cosmic emission, wandering in the Galaxy as a result of formation of secondary electrons. Therefore, there arises the problem of searching for direct sources of electrons and of high-energy γ - quanta (up to 10^{10} - 10^{11} eV). The recently discovered explosion of the nucleous of one of the distant Galaxies paves the way toward a new solution of the problem of cosmic ray sources in our Galaxy.

It is a fact that the power of such an explosion is millions of times greater than its effect on the average supernova. One such explosion can supply our Galaxy with cosmic rays for the next 50 - 100 million years. Calculations show that such hypothesis can even explain, with the help of additional assumptions, the cosmic rays energetic spectrum inside our Galaxy. However, it can do so again with the process of their diffusion through a non-uniformly magnetized interstellar plasma. Very interesting possibilities for verifying these various theories of the origin of cosmic rays arise from the analysis of the isotopic composition of the meteorite matter. This can in principle provide data on the intensity of cosmic rays at the remote periphery of our solar system and far back in its history, as well as that of the Galaxy as a whole.

* * THE END * *

Draft by N. A. Pirogov

Revised by ANDRE L. BRICHANT,

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