EXPERIENTIA

Vol. IV - Fasc. 2 | Pag. 41–80 | 15. II. 1948

Why are we studying Cosmic Rays?[1]

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In the last ten to twenty years a great amount of effort has been spent in studying the properties of a very faint radiation, which, coming from somewhere far away in the Universe, continuously bombards the earth. This radiation has been investigated in our laboratories, on mountain tops and at the bottom of deep lakes, and mines. Scientists have circled the globe to measure the intensity of this radiation at all latitudes, at the ground as well as at high altitudes. Instruments have been carried by balloons to the top of the atmosphere and now, every two months, at White Sands, New Mexico, a rocket is sent up a hundred miles, carrying in its warhead very elaborate apparatus for measuring the properties of this cosmic radiation outside the earth's atmosphere. The equipment, whose assembly requires just the two months between successive shots, is destroyed together with the rocket when the latter plunges back into the atmosphere; the information collected by the instruments is continuously telemetered to ground during the three-minute trip of the rocket in a region, where there is practically no air left overhead.

What are the reasons that justify the tremendous amount of effort spent for the study of cosmic rays? There is definitely no expectation of any immediate practical application of the results of cosmic ray research. In the following condensed report on the facts and problems of cosmic radiation it will be our purpose to point out the reasons, why we expect to learn more about "How Nature Works" from this field of investigation than maybe from any other particular domain of physics.

The cosmic radiation is a rather faint radiation: on the average only about one particle hits the top of the atmosphere per square centimeter every third second. Yet its total intensity is about equal to the overall amount of energy carried to the earth by the light of the fixed stars. Since our natural senses do not respond to them, the cosmic rays have been discovered only comparatively recently, at the beginning of the century, after sufficiently sensitive instruments of detection had been developed. The light of the stars consists of a tremendous number of very small energy quanta, or photons; the cosmic radiation of a very small number of very energetic particles. The energy we receive from the sun amounts to about two calories per minute per square centimeter (the "solar constant"); the energy from all the fixed stars is about a hundred million times smaller. From that one easily calculates that some billion[1] light quanta emitted by the fixed stars are received every second by every square centimeter of the earth's surface. Hence, since there is only one incoming cosmic ray particle per square centimeter every third second, the energy of these particles must be at least some billion times the energy of the photons of visible light. Actually the average energy of the cosmic ray particles is about $7 \cdot 10^9$ eV (at 50 °N geomagnetic latitude), whereas the energy of the photons emitted by the sun is 2·5 eV for the spectral region of maximum intensity. Cosmic ray particles go right through the human body at the rate of some thousands per minute.

Two questions arise at once: What are these particles which bombard the earth and where do they come from? These most obvious questions are the most difficult to answer. For the first a tentative answer has been found only very recently: the major fraction at least of the incoming cosmic ray particles are fast hydrogen nuclei or protons. The second question can not be answered at all and the origin of cosmic rays is still a "top secret" of Nature. We know only that they come from very far away in space and, since no effect of the position of the galaxy on the intensity of cosmic rays can be detected, they may come from outside even our galactic system of stars. About the mechanism of acceleration of the primary cosmic ray particles, for instance by high electric potential differences in interstellar space, nothing definite is known. One hypothesis is that cosmic rays not only come from very far away in space, but also from very far away in time; that they are "fossils" from a period, where there was neither earth nor sun.

All these questions are of course extremely interesting. There are a great number of extremely interesting

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[1] An American "billion" means 10^9, what is called in German "eine Milliarde".

phenomena in Physics which are still mysteries to us and await explanation: for instance the supraconductivity of certain metals, that is the disappearance of electrical resistance at low temperatures, or the superfluidity, the disappearance of viscosity of liquid helium below 2·18 °K. Yet these phenomena, mysterious as they still are, will doubtless find their explanation within the framework of our present day theories of the structure of matter. This is different with the

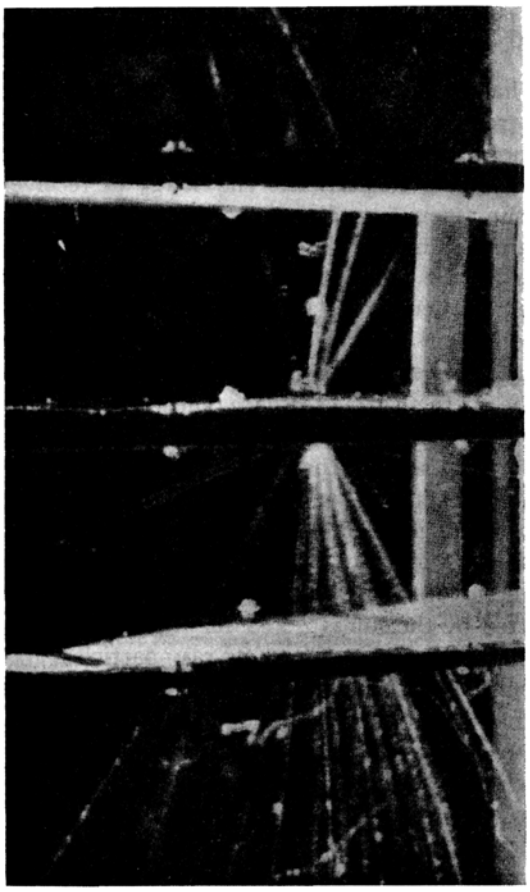

Fig. 1. *Nuclear explosion, observed in a cloud chamber.* Explosion shower, observed by L. FUSSELL, Harvard University, Boston, Mass. In addition to the tracks of heavy particles, some tracks of light particles coming from the center of the "star" are also to be seen[1].

phenomena we encounter in cosmic radiation. We have here to deal with particles, the energies of which are up to some billion times larger than the energies of single elementary particles involved in all other processes known, including conventional nuclear physics. And, as is well known, every time the energies of particles or quanta involved is increased by an order of magnitude, essentially new phenomena and unexpected qualities appear. From thermal energies of the order of $^1/_{10}$–$^1/_{100}$ eV[2] up to the energies of some million electron volts involved in nuclear reactions the jump on the energy scale amounts to a factor 100,000,000 or 10^8. The range of energies between these limits covers a tremendous amount of phenomena; chemistry, optics, X-rays, etc. In cosmic radiation particle energies up to 10,000,000,000,000,000 eV or 10^{16} eV have been observed. As compared to the energies of nuclear reactions this amounts to a jump by another factor of 10^8 on the energy scale. The cosmic ray particles travel most of the time with very nearly the maximum speed allowed by Nature, the absolute speed limit $c = 300{,}000$ km/sec, which is the velocity of light.

We will expect many new and strange events to occur in this vast energy domain and indeed, they do occur. Let us take an example: The most energetic reaction of conventional nuclear physics is the "fission" of heavy nuclei, the elementary process in the chain reacting pile. Here a nucleus, excited to internal vibrations by the capture of a neutron eventually splits into two parts. An energy of about 200 MeV (million electron volts) is liberated per fission. The cloud chamber picture of Fig. 1 shows what happens, if a cosmic ray neutron hits a nucleus. The nucleus is here literally smashed to pieces, a great number of its constituent particles being ejected. (In the cloud chamber picture of course only the proton tracks, not the neutron tracks are visible.) Would they differ only by their more drastic character from the ordinary exchange reactions of nuclear chemistry or the nuclear fission, these violent nuclear explosions would not be so particularly interesting. But in many of these violent nuclear explosions an event occurs which never happens in ordinary "low energy" nuclear reactions. New particles, which are not to be found as constituents of ordinary matter, are born: the *mesotrons*. These mesotrons are now the most exciting, because the most unknown, particles of physics.

On the logarithmic energy scale, the realm of cosmic radiation, involving energies of elementary particles from some hundred million to some hundred thousand trillion electron volts, is nearly as vast as the domain of the whole rest of physics and is still an essentially unexplored continent.

The Beginnings

The story of cosmic rays starts very modestly. At the end of the last century the early pioneers, ELSTER and GEITEL, C. T. R. WILSON and others, tried to find out, why ionization chambers still show a certain small amount of ionization indicated by a slow discharge of a connected sensitive electrometer, even after thick shields of lead have absorbed the radiations from radioactive materials in the ground, the walls of the building, etc. This fact was already known a long time and "explained" in a not at all unusual way: by giving a name, "residual" or even "spontaneous" ionization to this phenomenon.

[1] Reprod. from: W. GENTNER, H. MAIER-LEIBNITZ, and W. BOTHE, Atlas typ. Nebelkammerbilder (Springer-Verlag, Berlin, 1940), plate 74.

[2] The energy unit used in elementary particle physics, the "*electron volt*", is the kinetic energy gained by a particle of electronic charge, falling through a potential difference of one volt.
One electron volt = 1 eV = $1{\cdot}6 \cdot 10^{-12}$ erg = $1{\cdot}6 \cdot 10^{-19}$ wattsec
1 BeV = one billion electron volt.

There was still some doubt left whether this ionization might not be the effect of a very penetrating radiation from the ground, much more penetrating than the hard gamma rays of thorium or radium, the most penetrating type of radiation known at that time. So one thought of getting away from the ground in balloons. GOCKEL[1] was the first to try it in 1909 in

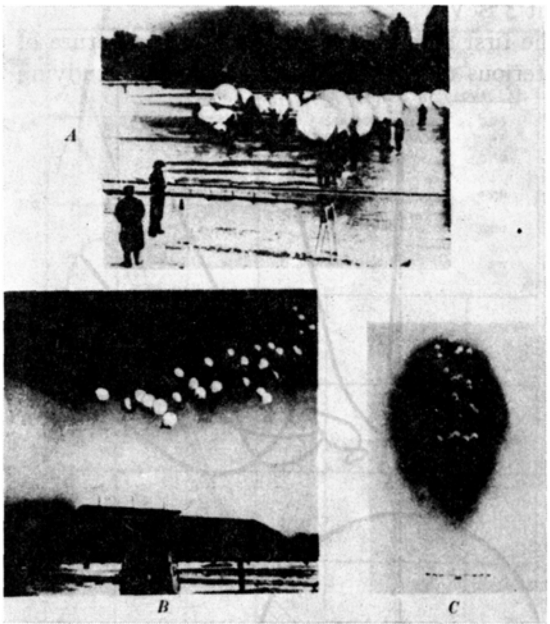

Fig. 2 a. *Balloon flights.* Balloon flight of january, 1943. Conducted by AUGER, SCHEIN, and ROGOSINSKY for the measurement o extensive (or AUGER-) showers in the stratosphere[2].

A The balloons are assembled on Stagg Field at the University of Chicago, Chicago, Illinois. In the foreground can be seen the long frame which was required for the wide separation of the cosmic ray counters.

B The large cluster of balloons as it is about to be released.

C The balloon train sails into the sky after its release. Suspended below the balloons is the frame supporting the counters and recording apparatus.

Zurich; the next year V. F. HESS went to considerably higher altitudes. The result was startling: instead of continuously decreasing with increasing distance from the ground, the ionization increased. KOLHOERSTER, who went up to an altitude of 9 km in a balloon, found a tenfold increase of the ionization at this altitude, as compared to the ionization at ground. The "residual" ionization had to be ascribed to a radiation coming from above, called "Höhenstrahlung" by HESS and later "Cosmic Radiation" by MILLIKAN and CAMERON. The ionization on the ground is indeed "residual" in the sense, that it is only the meager remainder, left after most of the radiation has been absorbed in the atmosphere (Fig. 2).

[1] A. GOCKEL, Physik. Z. *11*, 280 (1910).
[2] From: PIERRE AUGER, What are Cosmic Rays? (University of Chicago Press, 1945), plate 19.

The most astonishing feature of this "Höhenstrahlung" was its tremendous penetration power. It was found that under thick shields, at the bottom of lakes (MILLIKAN and CAMERON, 1928), in mines and tunnels the "Höhenstrahlung" can still be detected. The earth's atmosphere besides is in its mass equivalent to a layer of 10·3 m of water, a layer which would reduce the intensity of, for instance, gamma rays of thorium or radium to a completely negligible fraction of its initial value. The hypothesis seemed reasonable that the cosmic radiation might be some sort of an ultra-penetrating gamma radiation. Now, gamma rays, in contrast to charged particles, are not deflected by a magnetic field. So, in order to test the above hypothesis on the nature of cosmic rays, one had to find a sufficiently big magnet and then see, whether the

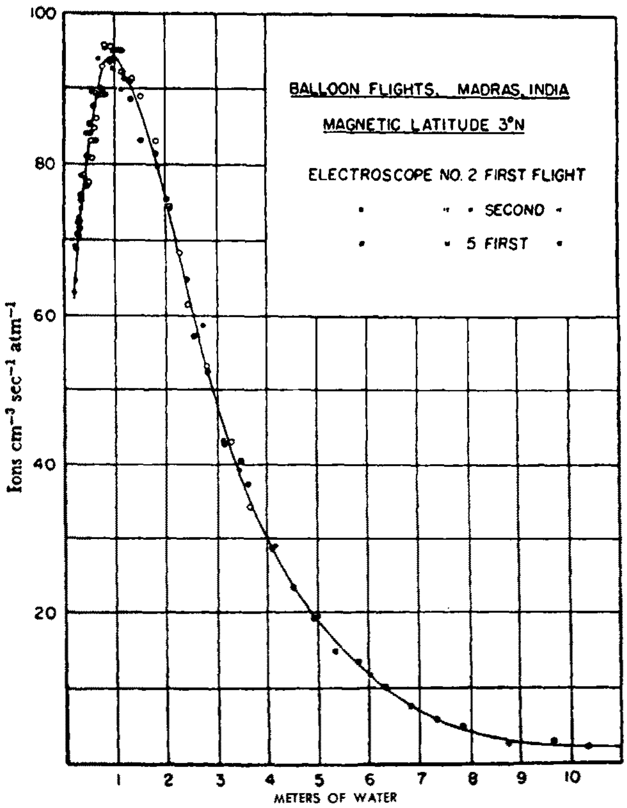

Fig. 2 b. Ionization as a function of depth, in equivalent meters of water, below the top of the atmosphere at Madras, India, magnetic latitude 3 °N [1].

cosmic rays are affected in passing through its field. There is only one magnetic field sufficiently extended to be useful: the magnetic field of the earth.

Geomagnetic Effects and the Nature of the Primary Cosmic Radiation

The magnetic field of the earth is weak, but it acts over an extremely large region and hence affects practically only the orbits of the particles outside the

[1] From: R. A. MILLIKAN, Electrons (+ and —) etc. (University of Chicago Press, 1947), fig. 92.

atmosphere (Fig. 3). Long before anybody thought of cosmic rays, Stoermer studied the paths of charged particles in the magnetic field of the earth in order to explain the northern lights (*aurora borealis*). It can easily be seen that charged particles cannot reach the earth at a given geomagnetic latitude and under a given zenith distance, if their energy is below a certain

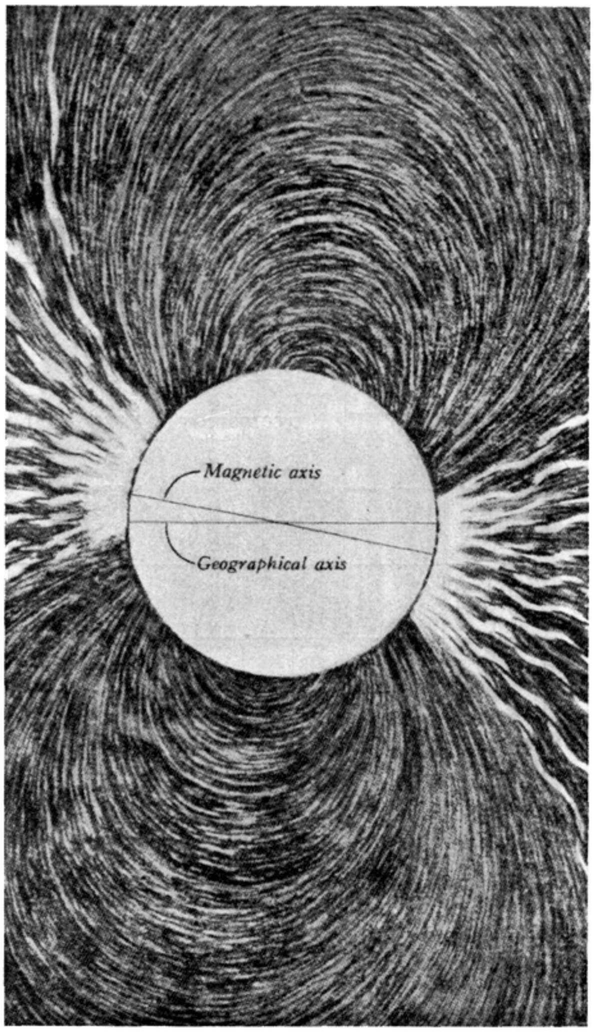

Fig. 3. *The earth's magnetic field.* The figure shows the shape of the field and the displacement of the magnetic from the geographical poles. The earth's atmosphere extends but a few hundred miles, at most, from the surface, but the magnetic field should be appreciable to a distance of 12,000 miles. At 4,000 miles its intensity is one-eighth as much as at the surface[1].

critical value E_c. Protons with energies below 9·3 BeV cannot reach the geomagnetic equator at all, protons with energies below 3·4 BeV cannot reach a goemagnetic latitude of 40⁰. If only particles falling on the earth from the zenith direction are recorded, then the critical energy necessary to penetrate the earth's

[1] Reproduced from: R. A. Millikan, Cosmic Rays (MacMillan Company, Cambridge University Press, 1939), fig. 20.

magnetic field is given as function of the geomagnetic latitude λ by the relation

$$E_c(\lambda) = 15 \cos^4 \lambda \text{ BeV}.$$

At the poles the magnetic field of the earth does not prevent even a low energy particle from coming to the top of the atmosphere (Fig. 4); but in order to produce effects at sea level, the energy must even then be about 3 BeV.

The first attempts to investigate the nature of the mysterious rays falling on the earth by studying the

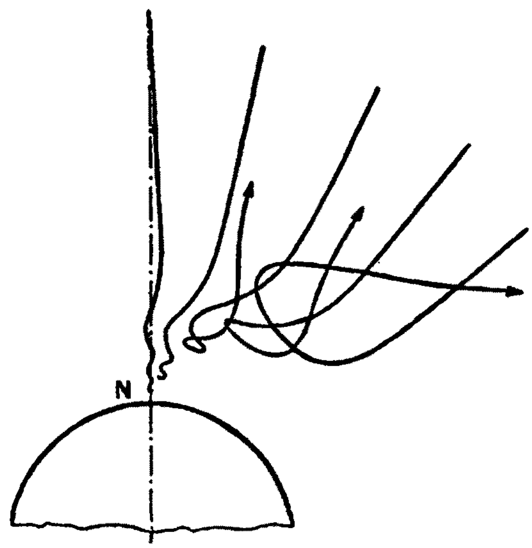

Fig. 4. *Various trajectories of electrons in the earth's magnetic field.* In the case of electrons with moderate energies, only those directed toward the polar regions can reach the earth.

variation of their intensity with geomagnetic latitude were made in 1925 by Millikan. In 1927, J. Clay, on a trip from Amsterdam to Batavia found a definite decrease of 15–20% between these points. Thus it was first established that the primary cosmic rays are affected by a magnetic field and hence that they are not of the nature of the most penetrating rays until then known: gamma rays. They must be charged particles. The variation of intensity with latitude, the "latitude effect", is rather small at sea level (Fig. 5), but this

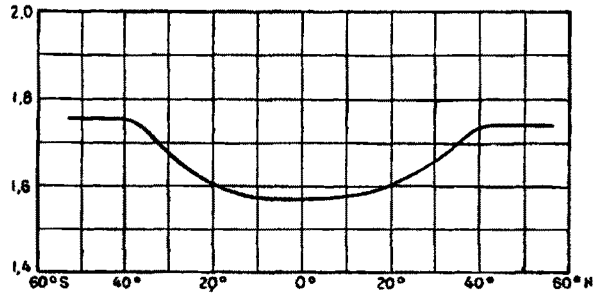

Fig. 5. Clay's *latitude curve*, showing the equatorial depression in cosmic ray intensity, and the two polar plateaus. (After Clay.)[1]

[1] Reproduced from: Pierre Auger, Die kosmischen Strahlen (Francke, Bern, 1946), fig. 5b and 7.

is to be expected, since only the most energetic particles, which are least deflected by the magnetic field, can be responsible for effects down here at sea level. At great altitudes the variation of cosmic ray intensity with latitude is quite large, as shown in Fig. 6, which represents the results of observations by MILLIKAN, NEHER, and PICKERING. In Saskatoon,

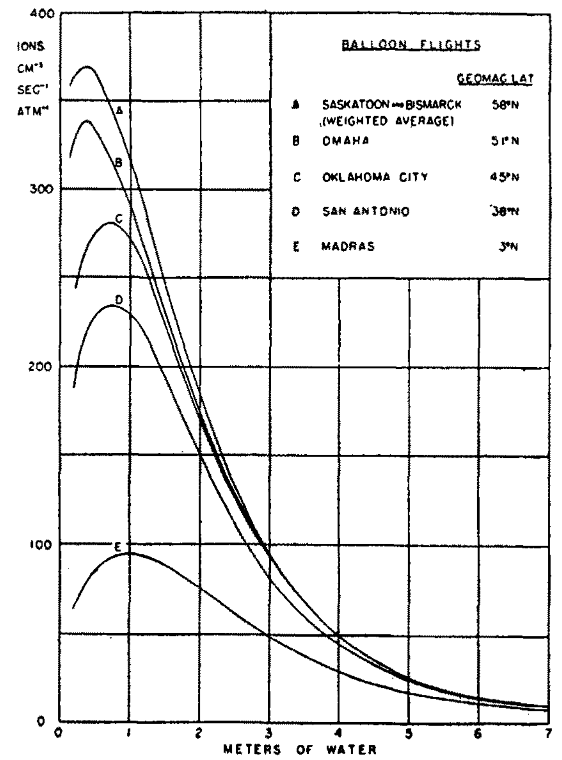

Fig. 6. *Total intensity of cosmic rays from all directions as a function of altitude measured at various magnetic latitudes*[1].

Ordinate: Total intensity in ions/cm^3·sec/atm.

Abscissa: Altitude in meter of water.

A Saskatoon and Bismarck	58 °N geomagnetic latitude
B Omaha	51 °N
C Oklahoma City	45 °N
D San Antonio	38 °N
E Madras	3 °N

Canada, at 60° N geomagnetic latitude, the total intensity near the maximum of ionization is four times as large as at Madras, India, at 3° N. Since the difference in the overall cosmic ray intensity for two different geomagnetic latitudes is due to primary particles, which can penetrate the earth's magnetic field at the higher latitude but not at the lower, it is obvious that an analysis of the curves of Fig. 6 gives some information on the energy spectrum of the primary cosmic ray particles. This energy spectrum falls off towards higher energies according to a power law: the number $N(E)$ of particles with energies greater than E is given by the relation:

$$N(E) = \frac{\text{const}}{E^{\gamma}}, \text{ where } \gamma \text{ is about } 1{\cdot}8 \pm 0{\cdot}2.$$

Once we know that the cosmic ray particles, falling on the earth, are charged, the next obvious question is: what is the sign of the charge? This question too can be decided with the earth's magnetic field used as a spectrograph, the experiments now being more delicate. Consider the equatorial plane of the earth's magnet: the magnetic field will skew positive particles to the right, so that they will fall on the earth coming from the western sky; negative particles will be deflected in the opposite direction, so that most of them will reach the earth coming from the eastern sky. Hence, in order to determine the sign of the particles' charge, one has to study the *East-West-asymmetry* near the geomagnetic equator. Experiments of this type have been performed by T. JOHNSON, by ALVAREZ and COMPTON, and others. Fig. 7 shows results on the East-West-asymmetry, obtained by VALLARTA, PERUSQUÍA, and OYARZÁBAL in Mexico. At least as far as the primaries responsible for the effects at sea level are concerned, there are definitely more particles coming from the West than from the East. Hence the primary cosmic rays responsible for the sea level effects must be, at least predominantly, positive. Actually, VAL-

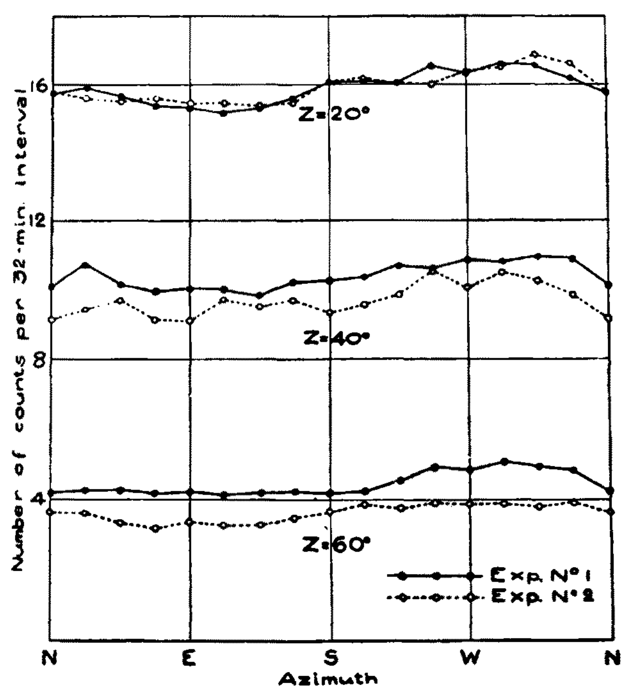

Fig. 7. *The East–West effect.* The intensity of cosmic rays is plotted as function of the azimuth for three different values of the zenith angle ϑ. The measurements were carried out in Mexico City at the altitude 2,242 m, geomagnetic latitude 29 °N with a counter telescope[1].

[1] Reproduced from: R. A. MILLIKAN, H. V. NEHER, and W. H. PICKERING, Physical Rev. *61*, 405 (1942), fig. 7.

[1] Reproduced from: M. S. VALLARTA, M. L. PERUSQUÍA, and J. DE OYARZÁBAL, Physical Rev. *71*, 393 (1947), fig. 1.

LARTA, PERUSQUÍA, and OYARZÁBAL conclude from their results, that probably all of them are *positive*.

On the following pages we will see other reasons, which, together with the fact that the charge of the primary cosmic ray particles has the positive sign, lead to the conclusion, that these particles probably are *protons*, the positively charged nuclei of hydrogen atoms. Protons and neutrons are the building blocks

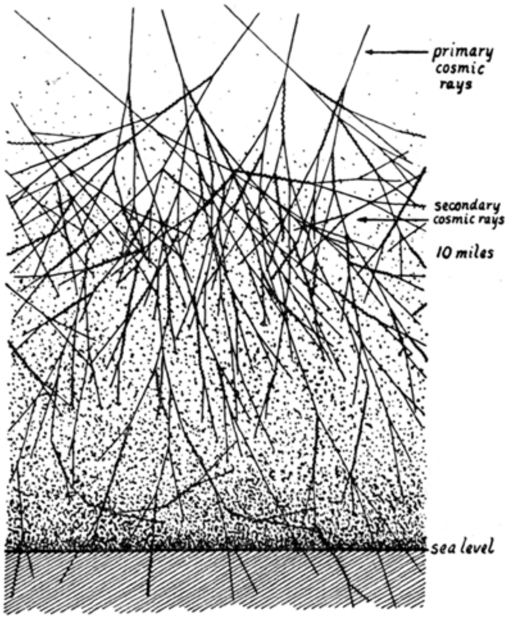

Fig. 8. *Schematic illustration of secondary cosmic rays produced from primaries entering the earth's atmosphere*[2].

of the atomic nuclei and are to be considered as two different states of the "nucleon" or heavy nuclear particle, the "charge variable" having the value zero for the neutron and the value one for the proton. Only the proton state of the free nucleon is stable; the free neutron is expected to be instable and to transform itself with a half-life of the order of 20 min into a proton through emission of an electron and a neutrino[1]. Neutrons then cannot be expected in the primary radiation. Hence we may say that *nucleons*, in the only stable state, the proton state, are thought to be the particles of the cosmic radiation, falling on the earth.

The conclusion that the primary cosmic rays probably are very fast protons has been the result of a very long and intense study of cosmic ray effects and has been reached only very recently (JOHNSON, 1938; SCHEIN, JESSE, and WOLLAN, 1941). The reason for this is that the particles we observe at sea level and even on the highest mountain peaks are not fast protons at all, but chiefly electrons, light quanta, mesotrons and slow protons and neutrons, ejected in nuclear explosions. What is observed even at great altitudes is not the primary radiation, coming to the earth as a messenger with a yet undeciphered code message from the outer fringes of space, but only the *secondary radiation*, produced by the primary radiation in the upper atmosphere. The primary protons are almost completely absorbed in the top layers of the atmosphere, at altitudes above ca. 20 km. After they penetrate into the atmosphere, their energy is rapidly transformed and carried over to the various secondary radiations (Fig. 8).

Showers

Particles which we observe frequently at sea level and especially at greater altitudes are the familiar *electrons*. But the cosmic ray electrons do not behave at all familiarly. This is most obvious from cloud chamber pictures like the one reproduced in Fig. 9, obtained with a counter-controlled cloud chamber (this

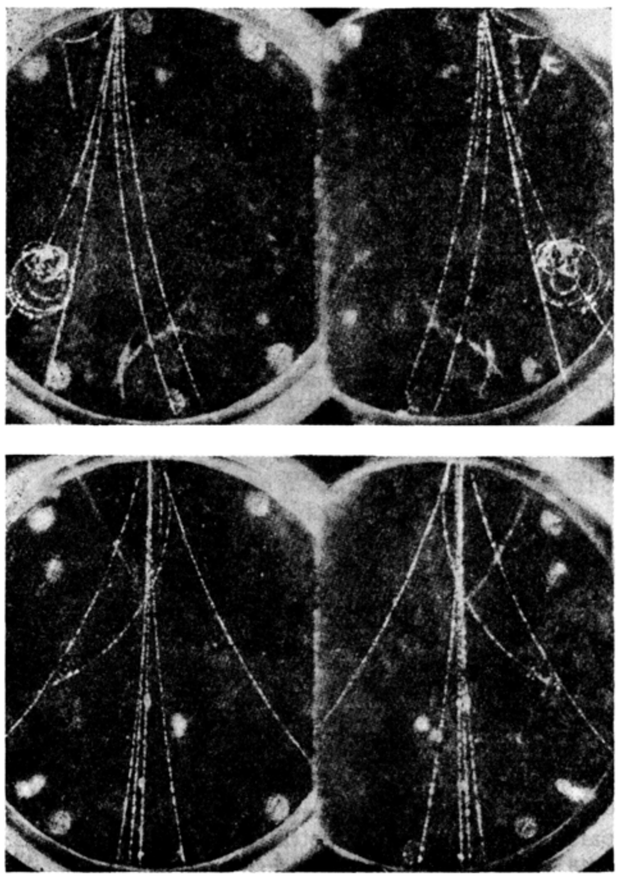

Fig. 9a. *Cascade showers*. Stereoscopic picture of an electron shower observed on Pikes Peak with a cloud chamber in a magnetic field (ANDERSON and NEDDERMEYER). The tracks of three positive and three negative electrons, with energies between 3·5 MeV and 190 MeV, are visible in the upper picture[1].

[1] The transformation of a neutron bound in a nucleus into a proton through emission of an electron and a neutrino is the well-known "beta decay". Experiments to observe the beta decay of the free neutron are now carried out; thus far no definite result has been obtained.

[2] Reproduced from: R. A. MILLIKAN, Cosmic Rays (MacMillan Company, Cambridge University Press, 1939).

[1] Reproduced from: PIERRE AUGER, Die kosmischen Strahlen (Francke, Bern, 1946), plate 2.

technique was introduced by Blackett and Occhialini). A fast electron, passing through the lead plate in the chamber, creates a *shower of electrons and photons.* The electrons of the shower cannot have been just knocked out of the lead plate by the incoming fast electron, because the curvature of the tracks in a magnetic field, applied perpendicularly to the cloud chamber, reveals that about half of the particles are positive electrons. Ordinary matter contains only negative electrons. The positive electrons must have been created in the lead plate.

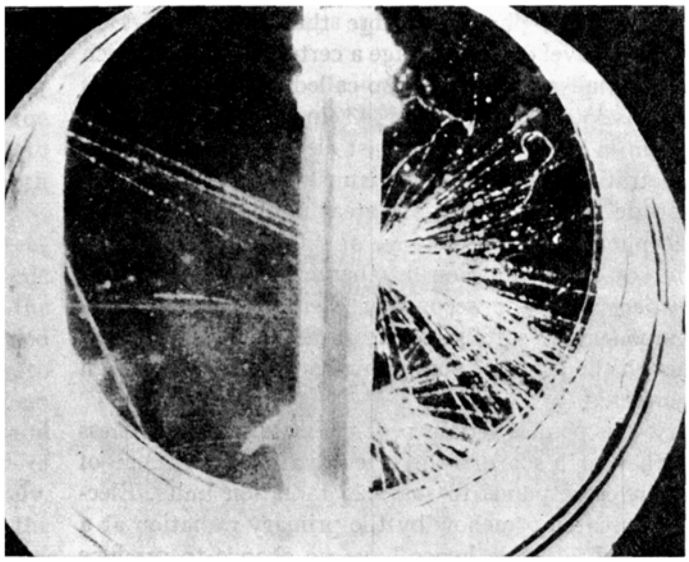

Fig. 9b. Production of a shower by an electron (top left) and a photon (bottern left) in a lead plate across the middle of a cloud chamber (Corson and Brode)[1].

Cosmic ray observations (Anderson; Rossi, 1933) first revealed this "creation of matter", a process unknown on the low energy scale. The reason is that, in order to create a pair of electrons (Fig. 10), the radiation must have at least the energy $h\nu = 2\,mc^2 = 1{\cdot}02$ MeV, the energy corresponding to the rest mass of the electron pair according to Einstein's relation $E = \mu c^2$. The inverse process of the pair creation is the annihilation of positive and negative electrons, if they collide with each other. Every positive electron created somehow on the earth is bound to be "annihilated" sooner or later in an encounter with an ordinary negative electron. From the older point of view, which considered matter and energy as two essentially different things, these are obviously very strange phenomena.

The mechanism of the cascade showers, which so strikingly demonstrate how different matter behaves at high energies, can be described as follows: Fast electrons, deflected by nuclei, lose part of their energy by emitting electromagnetic radiation (X-rays). If the energy of this radiation is sufficiently high, it can produce pairs of negative and positive electrons, which will again emit radiation when encountering atomic nuclei, this radiation again produces pairs and so on. In this cascade process, the initial high energy, concentrated on one electron, is more and more shared by many electrons and photons, created in the cascade. If the energy has been broken up so much that the now moderate energy of the individual electrons is furthermore lost mainly by the usual process of ionization, then the cascade has developed to its maximum and will then "die out", the electrons having lost their potency to produce progeniture (Fig. 11). Cascade showers are responsible for the maximum of total ionization occuring at an altitude, where about one-tenth of the atmosphere remains overhead (Fig. 2).

Both the high energy electrons, before they emit radia-

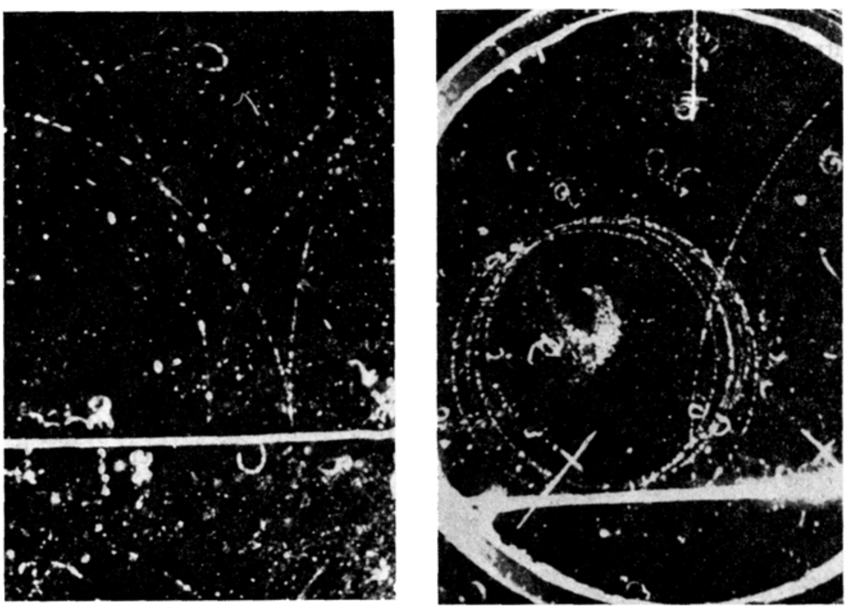

Fig. 10. *Creation of an electron–positron pair.* Gamma rays, coming from below produce electron–positron pairs in a lead foil (Fowler, Lauritsen, and Gaerttner). The left-hand picture shows the tracks of two pairs, which were created by two photons nearly simultaneously, that is within about 0·1 sec, the sensitive time of the cloud chamber[1].

[1] Reproduced from: W. Gentner, H. Maier-Leibniz, and W. Bothe, Atlas typischer Nebelkammerbilder (Springer, Berlin, 1940), plate 27.

[1] Reproduced from: Pierre Auger, What are Cosmic Rays? (Univ. of Chicago Press, 1945) (Plate IV).

tion, and the photons, before they create pairs in matter, travel on the average a certain distance, which is essentially given by the so-called ***radiation unit***; its value is 330 m in normal air, 43 cm in water, and about 0·5 cm in lead. Even very fast electrons are not very penetrating, because they transfer their energy by cascade multiplication to a great number of electrons and photons over a distance of a few radiation units. The cascade radiation is therefore called the *soft component* of the secondary cosmic radiation; this component is "soft", that means not very penetrating, though the particles composing it may have very high energies.

At this point a serious problem arises. The thickness of the earth's atmosphere, equivalent to 10·3 m of water, corresponds to some 25 radiation units. Electrons created somehow by the primary radiation at a very high altitude hence have no chance to produce any effects at sea level, unless their energies are exceedingly large, of the order of 10^{15} eV. They then produce the *large air showers* (P. AUGER, 1938), enormous showers with millions of particles, the initial direction of the electron, which started the shower at the top of the atmosphere being conserved in the axis of the shower. These large air showers have been studied intensely in the last years, since only through the study of these large air showers do we get information on the particles with the highest energies, up to at least 10^{16} eV, occuring in cosmic radiation. Yet the number of these particles with "record" energies is very small, since the energy spectrum of the primary cosmic rays falls off very rapidly towards the high energy side. The intensity of electrons at moderate altitudes or at sea level would be extremely small; that means the atmosphere would nearly completely shield the surface of the earth from cosmic rays, if there were no other particles involved.

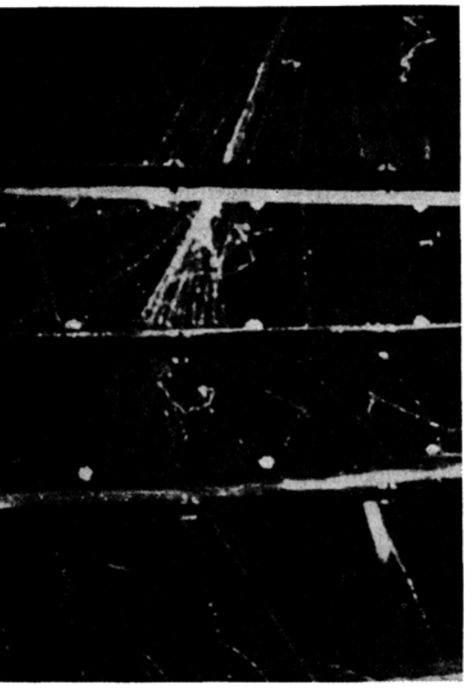

Fig. 11b. Final stage of a cascade shower.

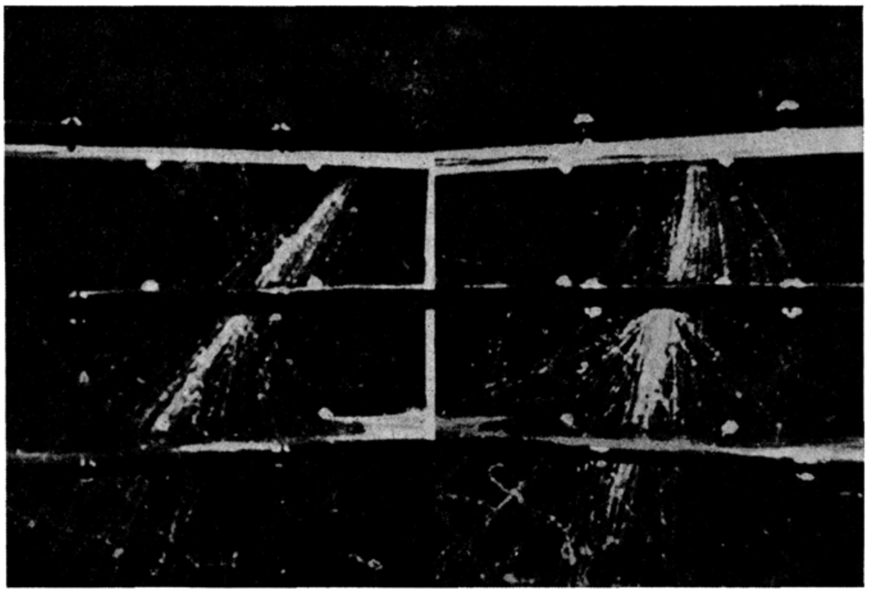

Fig. 11a. *Development c a cascade shower* (L. FUSSELL)[1]. Cascade shower, produced by a photon.

[1] Fig. 11a-d repoduced from W. GENTNER, H. MAIER-LEIBNIZ, and W. BOTHE, Atlas typischer Nebelkammerbilder (Springer, Berlin, 1940), plate 63, 64, 65, and 67.

Mesotrons

It is now about ten years ago that the ***mesotron***, a particle with a mass intermediate between the mass of the electron and the proton, was discovered in cosmic radiation[1]. According to the most recent determinations[2], the mass of the m.sotron is (202 ± 5) times greater than the mass of the electron. Because mesotrons are so much heavier than electrons they have a much smaller chance to emit radiation. The probability of emission of radiation, induced by the electromagnetic interaction of a charged particle with the electromagnetic field, is proportional to the square of the "classical particle radius" $r_0 = e^2/mc^2$ and hence decreases as the square of the rest mass of the particle. Mesotrons of high energy are hence very *penetrating*,

[1] C. D. ANDERSON and S. H. NEDDERMEYER, Physical. Rev. *54*, 88 (1938).
[2] W. B. FRETTER, Phys. Rev. *70*, 625 (1946).

since they lose their energy almost exclusively by ionization at a rate of about 2·5 MeV per cm H_2O equivalent. They constitute the main portion of the so-called *hard component* (Fig. 12), the penetrating part of the secondary radiation, which carries the energy of cosmic radiation down to sea level and to depths of at least 1,400 m of water, the greatest depth for which cosmic rays have thus far been observed.

Schein, Jesse, and Wollan measured the intensity of the hard (mesotron-)component of cosmic radiation with the counter telescope sketched in the right-hand side of the figure; the telescope was carried by balloons up to the very top of the atmosphere, to an altitude where the pressure was reduced to 2 cm Hg. Coincidences between the counters 1, 2, 3, 4 and 2, 3, 4, 5 respectively, measured the intensity of mesotrons traversing 4 and 6 cm Pb respectively. Simultaneous firing of counters 6 indicates that the passage of a particle through the telescope is accompanied by a shower.

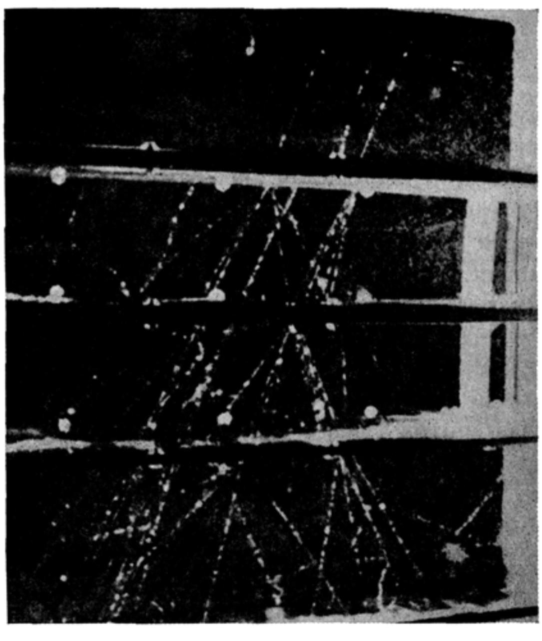

Fig. 11c. Parallel showers: The origin of the electron entering the cloud chamber is a shower originating far above the lead plates.

Curve *A* gives the intensity of the hard component as function of altitude for various lead absorber thicknesses; Curve *B* gives the intensity of the total ionization[1]. The intensity of the hard component is seen to increase still at altitudes where the total ionization, mainly due to electrons and photons, has already passed the maximum considerably. This indicates that the mesotrons of the hard component are not secondaries of the soft component. It was also observed that only a few per cent of all penetrating particles are accompanied by showers, and hence, that there are not many fast electrons at the highest altitudes reached,

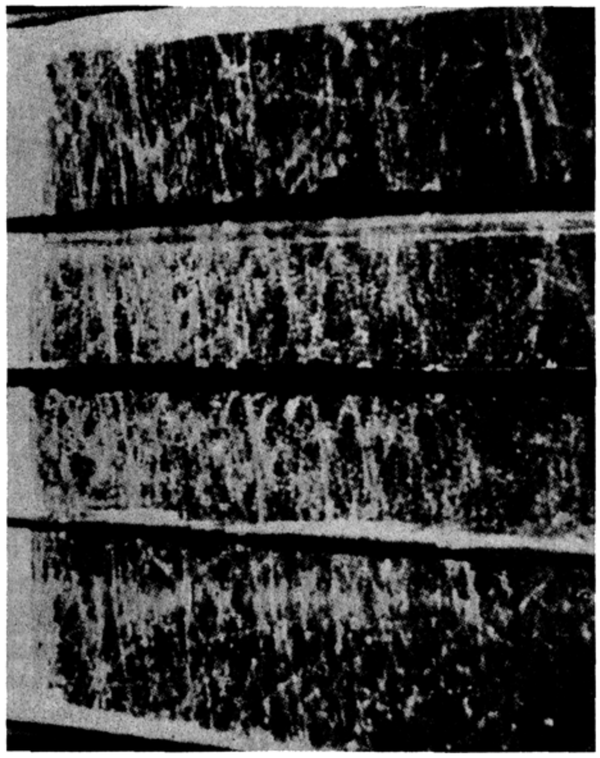

Fig. 11d. Part of a large air shower.

since fast electrons traversing the telescope would almost certainly produce showers in the interposed lead blocks. Schein, Jesse, and Wollan concluded from these important observations: "It is therefore

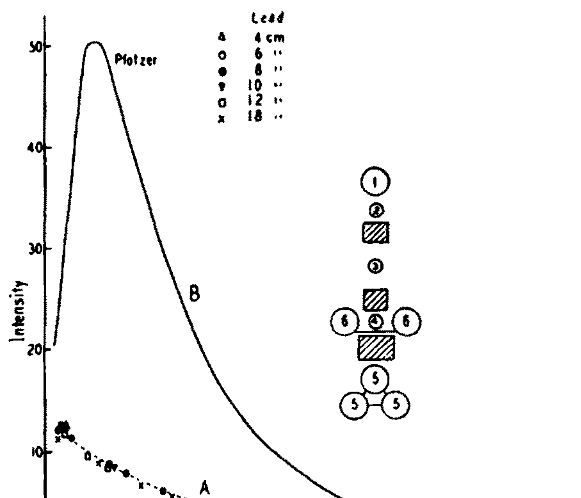

Fig. 12. *The variation of intensity of the hard component with altitude*[1].

[1] G. Pfotzer, Z. Physik *102*, 41 (1936).

[1] Reproduced from: M. Schein, W. P. Jesse, and E. O. Wollan, Physical Rev. *59*, 615 (1941), fig. 1.

probable that the incident cosmic rays consist of protons." That protons are the primaries for the creation of mesotrons has since been brought out by many other experiments.

We may ask why mesotrons are not found as a component of ordinary matter? The answer is that free mesotrons are *unstable* and decay with a life time of about two microseconds into an electron and, probably, a neutrino. Rasetti in 1941 and Nereson and Rossi[1] in 1943 have determined the life time of the mesotron by recording delayed coincidences between the pulse of a counter telescope, detecting mesotrons stopped in a block of material below the telescope, and the pulse of a set of counters detecting the decay electron. One method is to shift the pulse of the meson telescope by a variable time interval t with respect to the pulse from the decay electron counter set. Thus the probability that the passage of the mesotron through the telescope is followed after a time t by the decay electron, that is the radioactive decay law for the meson, can be most easily measured: Nereson and Rossi give for the half-life time of the free mesotron the value $\tau_0 = (2{\cdot}15 \pm 0{\cdot}07) \cdot 10^{-6}$ sec.

Mesotrons are produced in the upper atmosphere in collisions of the primary protons with the nitrogen and oxygen nuclei of the air. Very little is known about this extremely important process of mesotron production. There is good evidence that mesotrons are mainly produced in groups, some eight or ten together in one violent collision of the incoming nucleon (proton) against one of the nucleons bound in the nitrogen- or oxygen nuclei (Fig. 13 and 14). The cross section for the creation of mesotrons by the fast primary protons, due to nuclear interaction, is of the order of the geometrical nuclear cross section, $\sigma \approx \pi R^2 = 4 \cdot 10^{-25}$ cm^2. Hence the energy of the primary protons is transferred to mesons after traversal of on the average some 80–100 g/cm^2 of air, that is, one-tenth of the atmosphere. It is a very remarkable fact that to this high probability of mesotron production by nuclear collisions there does not correspond a similar strength of interaction of the cosmic ray mesotrons with nuclei, when they pass through matter. The observation of the scattering of cosmic ray mesotrons by nuclei has revealed that nearly all scattering processes are due to Coulomb interaction of the charges. Large angle scattering due to nuclear interaction is extremely rare and the corresponding cross section is certainly smaller than $^1/_{100}$ of the geometrical cross section.

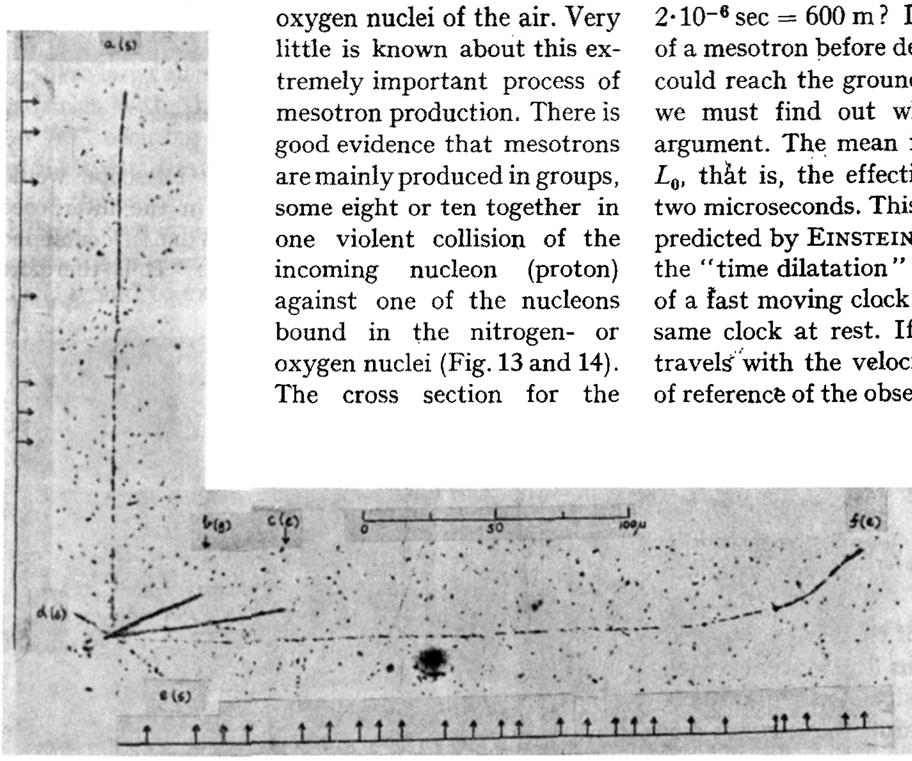

Fig. 13. *Emission of mesons in nuclear explosions.* One process assumed responsible for the creation of mesons in the upper atmosphere are nuclear explosions, initiated by fast protons or neutrons. The photographic "star", reproduced in this figure, shows a nuclear explosion, in which at least one meson, the track of which is $f(e)$, was created. From the range of this track f, which ends in the emulsion, and the grain count, the particle producing the track f was with certainty identified as a meson. Note the increase of grain density and scattering towards the end of the range[2].

We may at this point ask a rather obvious question. If the life time of a mesotron is only two microseconds, its velocity being not larger than $c = 3 \cdot 10^{10}$ cm/sec, how can it come down from its origin in the upper atmosphere, some 20 km above ground, down to sea level, since the average distance it can travel before decay seems to be only $L_0 = c \cdot \tau_0 = 3 \cdot 10^{10}$ cm/sec $\cdot$ $2 \cdot 10^{-6}$ sec $= 600$ m? If this were the mean free path of a mesotron before decay, then hardly any mesotrons could reach the ground. Since we know that they do, we must find out what is wrong with the above argument. The mean free path must be greater than L_0, that is, the effective life time much longer than two microseconds. This indeed is the result of an effect predicted by Einstein a long time ago, well known as the "time dilatation" of relativity theory. The period of a fast moving clock is longer than the period of the same clock at rest. If the latter is τ_0, and the clock travels with the velocity v with respect to the frame of reference of the observer, then the period is given by

$$\tau = \frac{\tau_0}{\sqrt{1 - \frac{v^2}{c^2}}} = \tau_0 \frac{E}{\mu c^2} ,$$

if E is the energy of the particle and its rest mass. The instable meson is a kind of clock and hence its life time, according to relativity theory, must be equal to the life time at rest $\tau_0 = 2{\cdot}2$ μsec, multiplied with the ratio of the meson energy E to its rest energy $E_0 = \mu c^2$. For a meson of energy $5 \cdot 10^9$ eV the life time is ca. 50 times

[1] N. Nereson and B. Rossi, Physical Rev. *64*, 199 (1943).

[2] Reprod. from: G. Lattes, H. Muirhead, S. Occhialini, C.F. Powell, Nature *159*, 694 (1947), fig. 3.

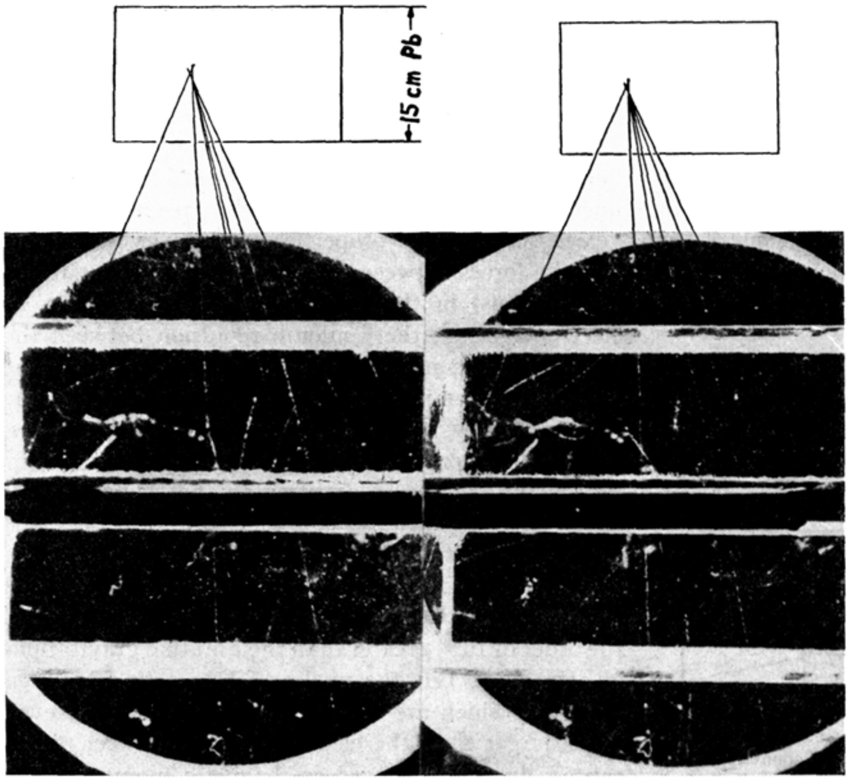

Fig. 14a. *Showers of mesotrons*[1]. A shower of six mesotrons produced near the center of a lead block 15 cm thick.

larger than the life time at rest, the mean free path hence about 30 km, greater than the height of the mesotron-producing layers of the atmosphere.

The mean free path before decay of mesotrons has been directly measured by comparing the "absorption" of the mesotron in a certain column of air with the absorption in a dense absorber of equivalent mass. The apparent absorption of the air is greater, since mesotrons will decay in an appreciable number on their long way through the column of air, whereas the probability of decay on the short way through the dense absorber will be negligibly small. The spontaneous decay of mesotrons was actually first observed in experiments of this type: mesotrons seemed to be absorbed not only by matter, but by space (or for that matter, time) too. A recent determination of the mean free path before decay has been carried out by COCCONI and TONGIORGI in Milan (Fig. 15). For $5 \cdot 10^9$ eV mesotrons the mean free path turns out to be $L = 39$ km. If we take the life time of the free mesotron at rest to be $\tau_0 = 2{\cdot}15 \cdot 10^{-6}$ sec, this result gives us for the rest energy of the mesotron the value

$\mu c^2 = \frac{c\tau_0}{L} E = 83$ MeV, or for the rest mass $\mu = 160\,\mathrm{m}_{electron}$ with an accuracy estimated to 10%. This experiment constitutes not only a very direct check of the fundamental "time dilatation" formula, but is also a good mass determination for the mesotron, the "scale" for weighing the mesotron being a stop-watch in this case. In principle a thermometer also could be used for the same purpose. The intensity of the cosmic radiation at sea level shows small fluctuations with temperature, of the order of 0,2% for 1 °C temperature change. This is due to the fact that for high temperatures, that is a low density of air, the mesotron-producing layer shifts to greater altitudes

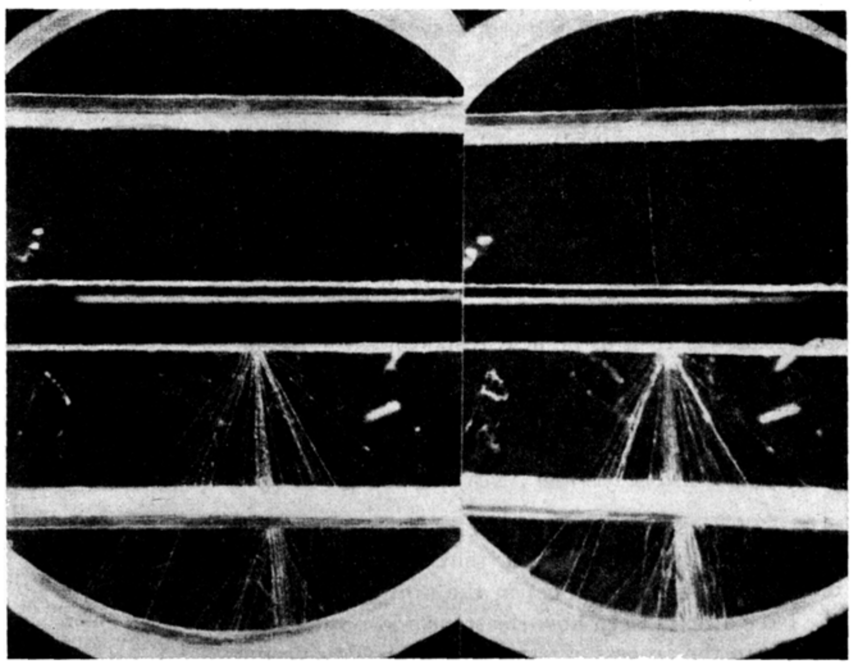

Fig. 14b. A shower containing possibly as many as 11 mesotrons produced in 5 cm of lead[1]. That the particles are mesotrons and not electrons is clearly shown by the fact, that they do not produce showers in the lead plates.

[1] Reproduced from: R. P. SHUTT, Physical Rev. *69*, 261 (1946), fig. 1 and 2.

and hence the mesotrons have a slightly greater chance to decay on their increased path before they reach us.

It was already mentioned that, without the relativistic time dilatation, practically no mesotrons would come down to sea level, because they would decay long before. But we would have hardly any electrons or photons either. Apart only from the electrons of the very large air showers, the electrons which are observed at sea level are either decay electrons of mesotrons, or

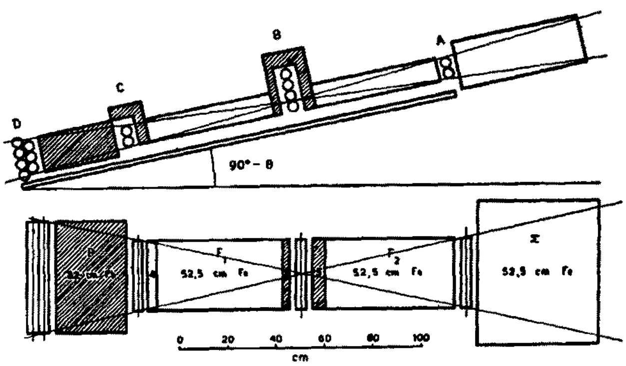

Fig. 15. *Counter telescope used to determine the mean free path of mesotrons before decay*[1]. Triple coincidences between counters A, B, C and quadruple coincidences between counters A, B, C, D are recorded. The difference gives the number of mesotrons passing through the telescope after having traversed the atmosphere and the absorbers F and Σ and being stopped in the lead block P. This way mesotrons of energy around $5 \cdot 10^9$ eV are selected. The zenith distance of the telescope is varied together with the thickness of the absorber Σ, so as to keep the total effective amount of absorbing mass (air and iron) traversed constant. The fact that the counting rate decreases with increasing zenith distance ϑ is then only due to the decay of the mesotrons on their path from the upper atmosphere, where they are produced, down to sea level, this path length obviously increasing with the zenith angle.

The mean free path of $5 \cdot 10^9$ eV mesotrons $L = c \cdot \tau = c \cdot \tau_0 \cdot \frac{E}{\mu c^2}$ has thus been determined by COCCONI and TONGIORGI to be 39 km. Hence $\frac{\tau_0}{\mu c^2} = (2{\cdot}6 \pm 0{,}3) \cdot 10^{-14}$ sec/eV. With the observed life time of the mesotron at rest (ROSSI and NERESON) of $\tau_0 = 2{\cdot}15 \cdot 10^{-6}$ sec we obtain for the rest mass of the mesotron the value $\mu = 160\, m_e \pm 10\%$.

else they are electrons knocked out of the shells of nitrogen—or oxygen—atoms by mesotrons. The "time dilatation" is then to be held responsible for the fact that we observe down here at sea level, or even greater depths, any cosmic radiation at all.

Mesotrons and Nuclear Forces

Mesotrons, since they are unstable, certainly do not fall on the earth from outside; they are created by the primary nucleons (protons) in the upper atmosphere. We have already seen how electrons and positrons are created in the process of pair production. Pair production of electrons and positrons results from the interactio nbetween the electronic charge and the electromagnetic field, an interaction described by MAXWELL's equations. For the production of mesotrons by protons colliding with nucleons another type of interaction between nucleons must be responsible.

The interaction of nucleons has been studied for a long time by the nuclear physicists. The study of nuclear binding energies and nuclear reactions has revealed some of the properties of the very strong attractive forces between the nuclear particles (neutrons and protons) in the nucleus. These forces are nonelectromagnetic: the Coulomb repulsion between the protons in the nucleus would violently disrupt the latter, were it not more than counterbalanced by the much stronger nuclear forces. These *nuclear forces*, holding the atomic nucleus together, represent a third type of interaction in addition to the *electromagnetic forces*, holding atoms and molecules and crystals together, and the *gravitation*, holding the planets in their orbits. The electrical forces between charged elementary particles are enormously (by a factor of the order of 10^{40}) greater than their mutual gravitational attraction. But the nuclear forces acting between nucleons, which are brought close together, are even much larger than the electrical forces between them, caused by their charges or magnetic moments. The study of these nuclear forces is one of the main concerns of contemporary physics; whereas the phenomena of gravitation and electromagnetism are rather throughly understood, we still know very little about nuclear forces. Probably much more basic information must be provided by fundamental experiments, before the elaboration of a consistent theory of nuclear forces, comparable to MAXWELL's theory of electromagnetism or NEWTON's, resp. EINSTEIN's theory of gravitation will be possible.

At this point we fall back on the mesotrons. Nuclear stability and creation of mesotrons both are the result of the interaction of nucleons with each other. It would therefore be very satisfactory if both nuclear forces and the interaction of mesotrons with nucleons could be understood as consequences of a unique type of interaction. Attempts in this direction have been made by the theoreticians in the last ten years, thus far with no definite success.

Let us compare electromagnetic and nuclear forces somewhat further. The importance of the field concept for the adequate description of electromagnetic phenomena is well known. In a similar way we have to imagine a nuclear force field. According to the principles of quantum theory, the field energy is quantized. The photons or light quanta for instance are the quanta of the electromagnetic field. The Coulomb force between electrons can be considered as a result of an exchange of photons between the interacting electrons. What properties then, may one ask, must the quanta of the nuclear force field possess in order to account for the fundamental properties of nuclear forces? The most

[1] Reproduced from: G. COCCONI and V. TONGIORGI (Milan), Physical Rev. *70*, 855 (1946), fig. 1.

characteristic difference between nuclear forces and forces of the $1/r^2$-law type is the fact that nuclear forces are *short range forces*, acting only over distances of the order of the nuclear radius $R \sim 2 \cdot 10^{-13}$ cm. The nuclear binding shows "saturation", similar to the homopolar chemical binding. Four nucleons, two protons and two neutrons, are very strongly bound together in an alpha particle, but an additional fifth nucleon is not bound at all to this strongly saturated alpha core. This behavior can be easily understood if the nuclear forces are *exchange forces*. The quanta of the nuclear force field, the exchange of which results in an interaction between nucleons, can carry one positive or negative unit charge or no charge at all, since we have nuclear attraction between neutron and proton as well as between two protons. In order that the nuclear force acts only over a certain range R, the quanta must possess a finite rest mass. This is easily shown by the following argument, given by G. C. WICK: If the force has a finite range R, then exchange of the field quanta occurs only within a distance R and takes an amount of time of the order of $\Delta t = R/c$, if c is the velocity of light. During this short time the energy balance is violated by at least the rest energy of the quantum, or $\Delta E \sim \mu c^2$. According to the uncertainty principle, the product of the life time of the intermediate state and the amount by which the energy balance is violated is of the order of PLANCK's quantum of action:

$$\Delta E \cdot \Delta t \sim \hbar \text{ or } \frac{R}{c} \mu c^2 \sim \hbar$$

$$\text{and hence } \mu \approx \frac{\hbar}{cR} .$$

The mass of the quantum of the nuclear force field must be greater than the electron mass by the factor

$$\frac{\mu}{m_e} = \frac{\Lambda_c}{R} = \frac{\hbar/mc}{R} ,$$

where Λ_c is the COMPTON wave-length of the electron, divided by 2π; its numerical value is $\Lambda_c = 4 \cdot 10^{-11}$ cm. Hence for a range of $2 \cdot 10^{-13}$ cm of the nuclear forces, we need a particle, the rest mass of which is ca. 200 times larger than the rest mass of the electron. For a smaller rest mass the range would become larger and would go to infinity if the rest mass goes to zero. This conclusion was reached by the Japanese physicist YUKAWA in 1935, who also expected that this particle, in order to account for the beta decay, is unstable and decays into an electron and a neutrino. From the experimental data of the beta decay he predicted the life time of the free particle to be of the order of a microsecond. Two years later a particle with just these properties was discovered in cosmic radiation. Hence, what was more natural than to identify the cosmic ray mesotron with the "YUKAWA particle", the quantum of the nuclear force field? This has been done, of course, and for ten years the theoretical physicists have been trying hard to develop a consistent theory of nuclear forces on this basis. The present "meson theory of nuclear forces"[1], though its basic ideas are supported by several striking facts, has thus far had only slight success in giving a quantitative account of the facts. One of its most radical and serious failures has been brought to light by the recent experiments of CONVERSI, PANCINI, and PICCIONI[2] of the University of Rome, whose results have been corroborated and extended by investigators at Princeton University and the Massachusetts Institute of Technology.

The great strength of nuclear forces, in the present meson theories, is the result of an extremely strong coupling between mesons and nucleons. This, as has first been pointed out by TOMONAGA and ARAKI, should give rise to a very different ultimate fate of positive and negative mesons, once they have lost their energy and are stopped in matter. The positive mesons, which are repelled by the positively charged atomic nuclei and thus cannot approach them if they have lost their energy, should decay, "die a natural death". The negative mesons, attracted by the nuclear Coulomb field, should be captured by the nucleons in the nuclei (Fig. 16), long before they have had a chance to decay. Because of the very strong coupling between mesons and nucleons, this fate of mesons is to be expected for all stopping matter, even the lightest one, hydrogen. CONVERSI, PANCINI, and PICCIONI have proved that for stopping material with not too low an atomic number, this indeed is actually what happens: the positive mesotrons decay, the negative mesotrons are captured. But for very low atomic number of the stopping material, as carbon for instance, also the negative mesotrons decay! This is in complete variance with the predictions of present "meson theory": the interaction of the cosmic ray mesotrons with nucleons seems to be a billion times smaller than would be expected by this theory, provided the cosmic ray mesotron actually is the quantum of the nuclear force field.

There is yet no indication how this difficulty will be solved. It has been suggested that the mesotrons normally observed in cosmic radiation are not the only particles of intermediate mass, and recent observations of mesotron tracks in photographic emulsions seem to support the view, that there is more than one type of "mesotrons". Obviously much more experimental information on the fundamental properties of mesotrons, their birth and death in matter, is needed before the relations between mesotrons and nuclear forces will become clearly understood.

[1] G. WENTZEL, Rev. Mod. Physics *19*, 1 (1947). – Following LEPRINCE-RINGUET we reserve the name "mesotron" for the particle actually observed in cosmic radiation, or the experimental "meson".

[2] M. CONVERSI, E. PANCINI, and O. PICCIONI, Physical Rev. *71*, 29 (1947).

Outlook

In the course of its long history, physics, in its attempt to understand the laws of Nature, has step by step analyzed the complexity of phenomena, until finally the structure of matter is described in terms of motion and rearrangement of *elementary particles*. In most phenomena, these particles, with the exception of photons, behave like indestructible, invariable units of mass, charge and energy. In the field of chemistry we have to deal with the arrangement of atoms in molecules, crystal lattices etc., in most nuclear reactions we substitute nuclear constituents one against another. If the elementary particles were such invariable, eternal and indestructible units as the "atoms" of LEUCIPPUS and DEMOCRITUS, then the analysis of natural phenomena would have reached a definite limit. But we know that elementary particles are very far from being such "hard" indestructible things as LEUCIPPUS "atoms". For photons, this is of course obvious, since photons are created and annihilated in the processes of light emission and absorption. There is no *energy threshold* for photon creation, because photons have the rest mass zero and hence photon creation, that is, emission of electromagnetic radiation, occurs all along the energy scale. This is precisely the reason why one somewhat hesitates at first to think of light quanta as of particles. But "ordinary" particles alike are created, annihilated and undergo transformations of all kinds, once sufficient energy is provided for these transformations.

In the radioactive beta transmutations, the so-called "beta decay", we observe the transformation of a neutron into a proton and vice versa through emission of negative resp. positive electrons and neutrinos, the light particles being created during this transformation. Instead of emitting a positive electron, the β^+-unstable nucleus can prefer to transform one of its protons into a neutron by capture of an orbital electron. If we have ordinary "beta decay"—a very misleading term!—then at least the rest energy $mc^2 = 0{\cdot}51$ MeV of the electron must be available. With two times this energy, $2\,mc^2 = 1{\cdot}02$ MeV, the threshold for the creation of electron pairs by electromagnetic radiation is reached.

These are only the well-known examples. We know very little about the processes generating mesotrons, besides the fact that they do occur. The results of M. SCHEIN's Chicago group seem to prove that there are at least two different reactions generating mesotrons: The first is the creation of mesotrons by gamma rays, in pairs or possibly also single, the threshold for the mesotron pair creation being $2\,\mu c^2 = 200$ MeV. The big accelerators—superbetatrons, synchrocyclotrons (Fig. 17) and synchrotrons—now under construction at many places, are in general designed to meet the energy requirement for mesotron pair production: 300 MeV seems to be a popular figure among the designers. Then there certainly occurs generation of mesotrons by nucleons: by the primary protons at the top of the atmosphere, probably also by neutrons, ejected in nuclear explosions at lower altitudes. Production of mesotrons in large showers (Fig. 14) seems to be frequent. The threshold for the shower production of mesotrons is unknown.

If we really would understand the nucleon, we certainly should be able to predict what happens, if two nucleons collide. At low energies, there will be mutual deflection, the probability of a certain deflection angle depending on the law of force, which is unknown. But if the energy is of the order of the rest

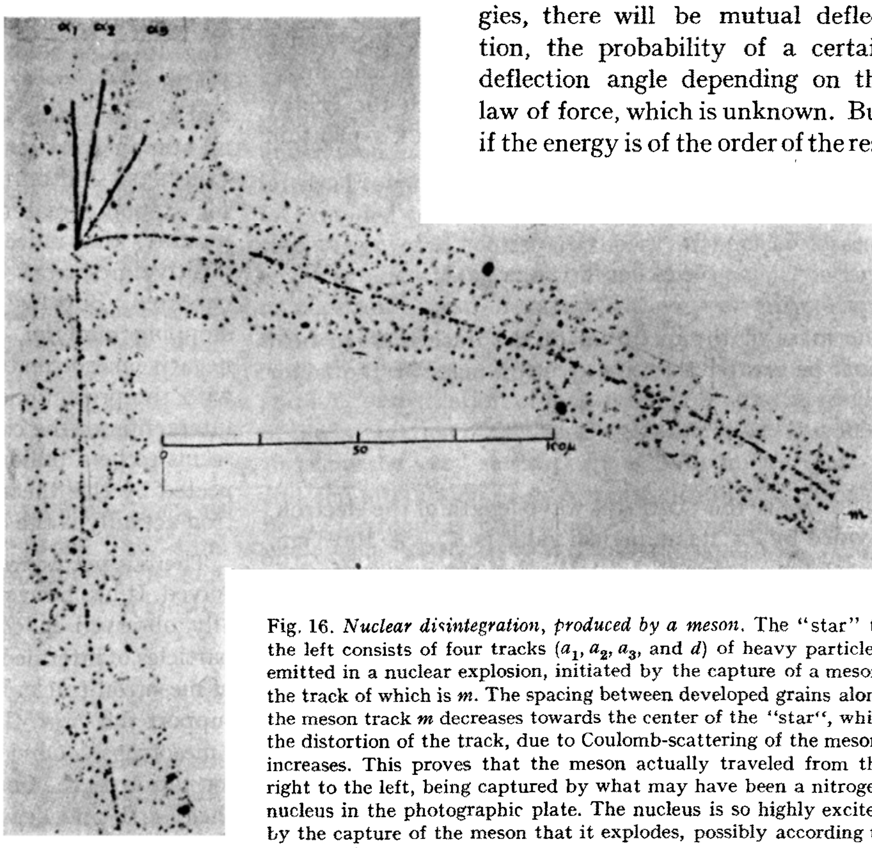

Fig. 16. *Nuclear disintegration, produced by a meson.* The "star" to the left consists of four tracks (a_1, a_2, a_3, and d) of heavy particles, emitted in a nuclear explosion, initiated by the capture of a meson, the track of which is m. The spacing between developed grains along the meson track m decreases towards the center of the "star", while the distortion of the track, due to Coulomb-scattering of the meson, increases. This proves that the meson actually traveled from the right to the left, being captured by what may have been a nitrogen nucleus in the photographic plate. The nucleus is so highly excited by the capture of the meson that it explodes, possibly according to the equation

$$N^{14}_{7} + \text{meson}(-) = 2\,He^{4}_{2} + 2\,H^{1}_{1} + 4\,n^{1}_{0}.$$

The tracks a_1, a_2 are tracks of alpha particles, the track a_3 a proton track; the track d, which does not end in the emulsion, may also be the track of a proton[1].

[1] Reproduced from: C. M. G. LATTES, H. MUIRHEAD, G. P. S. OCCHIALINI, and C. F. POWELL, Nature *159*, 694 (1947), fig. 4.

energy of the proton, in the billion electron volt range, anything may happen. We hardly know anything definite. Certainly, mesotron creation will occur. Will they be produced singly or in groups? (The observed mesotron showers may be explained in two different ways: all mesotrons may be created in a single act by the interaction of just two nucleons; they may be created one after another in the extremely short time, the bombarding nucleon needs to traverse an oxygen- or nitrogen nucleus, interacting with all nuclear constituents during this time.) What about neutral mesons, which thus far have not been observed, but the existençe of which is necessary in order to account for the complete symmetry of nuclear forces between proton and neutron on one side, proton and proton on the other? Will one nucleon altogether disappear in such a catastrophic collision? Will the internal state of the nucleons undergo a change, one proton for instance reversing the sign of its charge? What about negative protons, which, like neutral mesotrons, have not yet been observed, but which definitely should exist, since Nature is expected to be symmetric with respect to plus and minus. What about the neutrinos, about which we know only what follows from the conservation laws. They are constantly created, for instance in great number in the interior of the stars, but we hardly have any idea what their ultimate fate is bound to be.

So many questions, so many enigmas. The science of the *transformations of elementary particles* is new land. Where there seemed to be an ultimate limit, there actually is just a new frontier, beyond whichthere is a new and strange realm of phenomena, the explor ation of whichmight completely revolutionize our understanding of Nature. The theoreticians declare themselves unable to make predictions at our present state of knowledge. "The theory must be guided by experiment" says H. A. BETHE, and "Theory is still experimenting with ideas" is the opinion expressed by J. A. WHEELER: that means, let first the experimentalists provide us with some more facts. The relevant facts for the physics of elementary particles, this for the time being last frontier of physics, can be found in in the phenomena of cosmic radiations, because there is no threshold which is not expected to be small as compared to the highest energies, found among the particles of cosmic radiation. On the stage of cosmic radiation, the whole full program of the show of elementary particle transformations is played continuously, with no omissions. That is the reason why we are studying cosmic rays.

Résumé

L'auteur décrit tout d'abord les observations qu'on a pu faire sur les rayons cosmiques. Il insiste sur le fait qu'on trouve parmi ces rayons des particules ayant une énergie cent millions de fois plus grande que celle des particules naissant dans les machines atomiques. Ces dernières particules avaient déjà une énergie cent millions de fois plus grande que celle des atomes et molécules qui nous entourent. Dans ce domaine énergétique atomes-particules des machines atomiques se placent tous les phénomènes du monde sensible, chimie, optique, électricité, rayons X, radio-activité. Entre les particules des machines atomiques et les particules des rayons cosmiques, un domaine aussi étendu en énergie que le monde sensible que nous connaissons doit donc trouver place, un domaine dont nous ne savons rien. Des particules

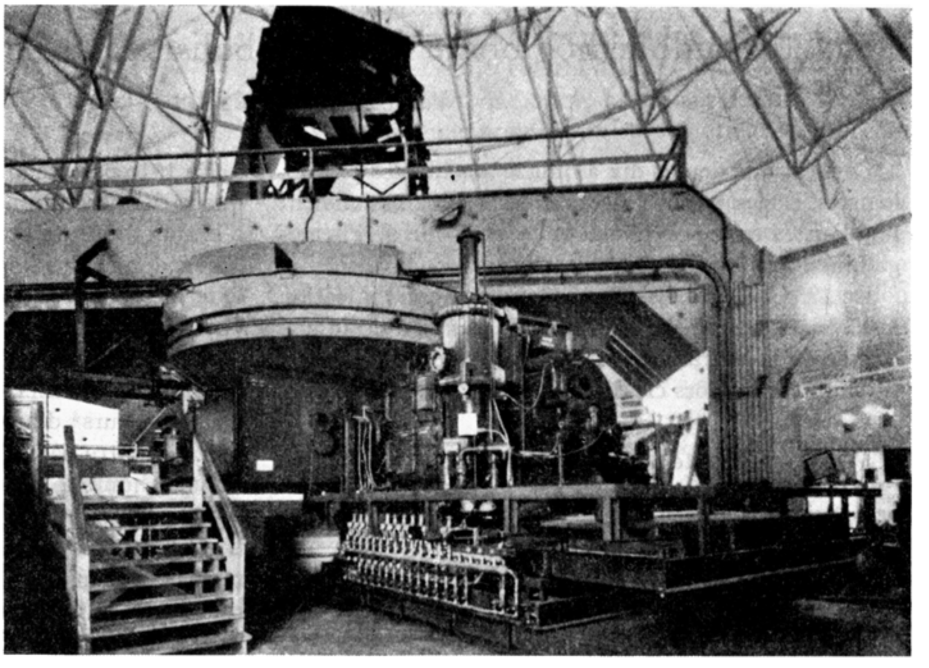

Fig. 17. *The giant 184-inch-cyclotron of the University of California, Berkeley.* This super-cyclotron, operating with frequency modulated R. F. voltage, is used for accelerating deuterons to 200 MeV, helium nuclei to 400 MeV. A well-collimated beam of 100 MeV neutrons has been produced by bombarding a beryllium target with 200 MeV deuterons: the deuteron breaks apart in the field of the beryllium nucleus, whereafter the neutron proceeds in the initial direction of the deuteron, the proton is stopped in the berryllium target. Phenomena, known before only from Cosmic Radiation, as for instance the production of nuclear explosions, have been observed with these 100 MeV neutrons[1].

[1] P. MORRISON, J. Applied Physics *18*, 142 (1947), fig. 9. – A report on the initial performance of the 184-inch-cyclotron is to be found in the Physical Rev. *71*, 449 (1947).

nouvelles d'une masse intermédiaire entre celle d'un électron et celle d'un proton ont été observées dans les rayons cosmiques; on leur a donné le nom de mésotrons. On ne sait presque rien sur les processus créant des mésotrons. Les résultats des études du groupe de M. Schein à Chicago semblent montrer que deux sortes de réactions peuvent créer des mésotrons:

a) Des rayons gamma peuvent créer des paires de mésotrons en se matérialisant, et il faut pour cela qu'ils aient une énergie minimum de deux cent millions d'électrons volts (200 MeV). C'est en partie pourquoi on construit un peu partout des machines capables de donner 300 MeV (bêtatrons, synchrocyclotrons, synchrotrons).

b) Des collisions entre noyaux d'atomes donnent aussi des mésotrons, en particulier les protons et les neutrons éjectés lors d'explosions de noyaux semblent créer des gerbes de mésotrons (l'énergie doit être alors de l'ordre de 5 milliards d'électrons volts [5 BeV]).

Si l'on connaissait vraiment les noyaux des atomes, on pourrait prédire ce qui arrive lors de leurs collisions, et cela nous ne le pouvons pas aussitôt que l'énergie est de l'ordre de la masse de repos du proton (1 BeV). Est-ce que des mésotrons neutres sont produits? Est-ce qu'un proton ou un neutron s'annihilera? Est-ce qu'un proton deviendra négatif? Qu'est-ce que les neutrinos?

Chacune de ces questions est une énigme. La science des *transformations des particules élémentaires* est un vaste domaine inexploré. Et il est possible que cette exploration ouvre des horizons entièrement nouveaux et nous oblige à revoir entièrement notre compréhension de la nature. Le spectacle des rayons cosmiques nous montre à chaque acte des *transformations de particules élémentaires*. C'est pourquoi nous les étudions.

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La pseudohémoglobine et le catabolisme des composés hémiques[1]

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Ce n'est que depuis dix à quinze ans que les physiologistes et les biochimistes se sont progressivement familiarisés avec le schéma de catabolisme de l'hémoglobine actuellement adopté.

En 1934 en effet, Duesberg[3] montra que l'injection intraveineuse d'hématine n'était pas suivie d'une hausse de la bilirubinémie: il fallait rejeter le schéma suivant, jusqu'alors classique:

Hémoglobine ↗ Globine
Hémoglobine ↘ Hématine → Protoporphyrine → Bilirubine

En fait, ce schéma n'avait jamais eu de soutien expérimental sérieux.

D'autre part, une série d'observations plus anciennes avaient déjà attiré l'attention sur l'existence de pigments verts dérivés de l'hémoglobine par oxydation et dont Fischer et Lindner[4] avaient déjà supposé qu'ils pourraient être intermédiaires entre l'hémoglobine et les pigments biliaires.

En 1916 par exemple, Asher et Ebnöth[1] signalèrent que la désintégration de l'hémoglobine par un mélange d'extraits de rate et de foie conduit à une substance qui ne donne plus les réactions du noyau hémique, mais le fer ne peut être décelé à l'état libre dans la solution obtenue.

A partir de 1930, Warburg et Negelein[2], Karrer, von Euler et Hellström[3] et surtout Lemberg et ses collaborateurs[4] d'une part, Fischer et ses collaborateurs[5] d'autre part étudièrent ces substances du point de vue chimique.

En se limitant tout d'abord aux produits d'oxydation des hémochromogènes, on peut résumer leurs recherches dans le tableau suivant où n'est représentée que la partie de l'hème avoisinant immédiatement le carbone α.

[1] Conférence principale, présentée à la Société suisse de biologie médicale lors de la 127me Assemblée générale de la Société helvétique des sciences naturelles à Genève, le 31 août 1947.

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