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° magnetic 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 superconductivity 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 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 $1/10^3$ to $1/100$ 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.

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


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 = $1.6 \cdot 10^{-12}$ erg = $1.6 \cdot 10^{-19}$ watt sec

1 BeV = one billion electron volt.