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Cosmic radiation – from riddle to... riddles

Great discoveries often have humble beginnings. It was no different with cosmic radiation. When an electroscope is electrostatically charged, its leaves diverge. In 1875 the French physicist Charles Augustin de Coulomb pointed out only a seemingly obvious fact: after a certain time the leaves of a charged electroscope come back together on their own. Where and how does the electric charge accumulated on them disappear? In 1850, Italian researcher Cano Matteucci showed that the discharge time of an electroscope is extended in air with a reduced pressure. In the second half of the 19th century, after the discovery of radioactivity, there was a suggestion that the escape of electric charge from the electroscope's leaves was made possible by ionized paths created in the air by radiation emitted from the rocks of the Earth's crust. However, isolating electroscopes from the ground with layers of water or lead at best only slowed down the fall of the leaves. In 1901, British physicist Charles Wilson concluded that at least some of the radiation ionizing the air must come from outside the Earth.

In 1912, Austrian scientist Victor Hess, in his experiments with balloons, proved that the ionization of the atmosphere does not decrease with an increase in altitude (as one would expect if the radiation came from rocks), but it increases and five kilometres above the surface it is three times greater than just next to it. Confirmation of these results only came at the turn of 1932/33, when the American Carl Anderson discovered a new elementary particle of cosmic origin: the positron, i.e. the anti-material equivalent of the electron. In 1936 Hess and Anderson received the Nobel Prize for their achievements. Only two years later, Frenchmen Pierre Auger and Roland Maze showed that particles of cosmic radiation can have gigantic energies and, colliding with the Earth's atmosphere, initiate huge cascades of secondary particles in it.

Particles of cosmic radiation, hitting the vicinity of the Earth from outside the Solar System, are primary cosmic radiation. It probably fills the entire Universe. It consists mainly of protons and atomic nuclei from helium (i.e. alpha particles) to iron, and even as massive as lead and uranium. In primary cosmic radiation electrons, positrons, and even antiprotons are also registered, as well as photons and neutrinos with high energies. The mutual proportions between particular types of particles can change significantly depending on the energy interval.

Primary cosmic radiation does not reach the Earth’s surface. Its particles usually ‘die’ in collisions with atmospheric particles. Secondary particles are then formed, with smaller energies, moving in a direction similar to the direction of movement of the primary particle. In subsequent collisions these particles disintegrate into the next ones, with ever smaller energies. These cascades are called extensive air showers and form secondary cosmic radiation. When the cascade reaches the surface of our planet, it can cover an area even the size of a city.

The most energetic single particles of cosmic radiation carry energy that is roughly equivalent to the energy of a strongly hit tennis ball (for comparison: protons in the LHC accelerator reach energies a billion times smaller). Cascades initiated by single particles with energies over 1000 TeV (a million billion electron volts) consist mainly of photons, electrons and positrons, whose number at the surface of the Earth can reach even tens of billions. If the primary particle has an energy less than 1 TeV (one thousand billion electron volts), then only photons reach the surface (including Czerenkov radiation, which appears when a charged particle moves at a velocity greater than the velocity of light in air) and muons (about 200 times more massive equivalents of electrons, characterized by a short life time). It is assumed that an average of five such muons pass through the head of an adult human being every second. The muons of secondary cosmic radiation are so penetrating that they reach a depth of several hundred metres below the surface of our planet – and they are also observed there.

The origin of particles with the highest energies is not known. Their birth may be caused by galactic collisions, supermassive black holes in active galaxy nuclei (AGN), or the formation of black holes due to the gravitational collapse of massive stars. Other explanations link their existence to the remnants of the Big Bang or even the disintegration of yet unknown supermassive elementary particles. Solving the puzzle is hindered by the fact that with the exception of photons, all particles of primary cosmic radiation have electric charges. Intragalactic and intergalactic magnetic fields have curved their tracks for thousands and millions of years and this effectively makes it difficult to trace sources.

Cosmic radiation is a natural and surprisingly important element of the Earth's environment. The ionized channels it creates in the atmosphere are probably related to the formation of clouds as well as to the number of lightning discharges. Cosmic radiation thus influences our planet's climate. As the cause of at least some genetic mutations, it is also one of the driving forces of evolution. It may even perhaps have played a significant role in the development of the human species. Studies of the isotope of iron 60, produced by supernovae, suggest that about 2-3 million years ago there was an explosion of a nearby supernova. The increased amount of cosmic radiation reaching the Earth's vicinity at that time contributed to numerous lightning discharges, which resulted in more frequent forest fires. Faced with this threat, some species of monkeys could have chosen savannahs, which in a natural manner encouraged our ancestors to adopt a bipedal attitude. This in turn made it easier to use hands to perform more and more complex activities.

Cosmic radiation also affects the daily functioning of our entire civilisation, which is hard to imagine without electronics. Modern electronic circuits, especially computer memories, are so small and so complex that they become sensitive to interaction with single particles of cosmic radiation. It is a particular threat to electronic devices operating on board airplanes, probes and manned spacecraft. It obviously also affects the growing number of artificial satellites of the Earth, including orbiters responsible for fields as important for our daily lives as telecommunications or meteorology.