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A. Vibert Douglas "Cosmic Rays: Messages from Space" Publication

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Cosmic Rays: Messages from Space.

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The study of rays emitted from the depths of space has recently given rise to new ideas about the creation of the universe. The work of Professor Millikan, already noted in "Discovery," is here dealt with in particular, although a solution of the problem has yet to be found.

It is always of special interest to watch the way in which an advance in knowledge in one branch of science may provide the solution of an apparently hopeless problem in another branch. This has happened time and again in astronomy and physics, until to-day their problems are so interwoven that the physicist in his laboratory and the astronomer in his observatory may be in very truth searching for the same thing.

An Astronomer's Problem.

Penetrating radiation is just such a problem—groped after by the astronomer, detected by the physicist, partly understood, and then so amplified by further experiment as to be again a source of great mystification; further discoveries raising it to a position of primary cosmical importance.

When first the astronomer realized that the Andromeda nebula was a spiral aggregation of myriad stars, far out in space beyond the utmost limits of the Milky Way, and estimated its mass to be one thousand million suns, he was mystified by the fact that its total output of light was only one three-thousandth of what was to be expected from so much matter. Why is Andromeda nebula so faint? was the problem to which no answer was immediately forthcoming. And so the astronomer quietly put this problem away upon the shelf of his memory and turned his attention to other matters.

About the year 1902 at McGill University, Montreal, Sir Ernest Rutherford was beginning to feel his way into the innermost recesses of the atom in his early researches in radioactivity. He was led to suspect that anywhere and everywhere on the surface of the earth there could be detected a very penetrating radiation which would pass through a considerable thickness of lead. One of his associates, H. L. Cooke, confirmed this suspicion experimentally, detecting beyond all doubt the influence of this penetrating radiation. Somewhat similar investigations had been carried on independently at Toronto by Dr. J. C. McLennan. Following up this discovery, Dr. A. S. Eve, at McGill University, calculated the intensity gradient of the penetrating radiation, that is to say, the rate at which its intensity diminished as one ascended above the surface of the earth.

Some time later two continental physicists Kohlhörster and Hess, making use of balloons to attain greater altitudes, discovered that although the penetrating radiation decreased with height until a certain altitude was attained, it then began to increase again. This was of great importance, pointing for the first time to a source of penetrating radiation external to the earth. Thus there were seen to be the two sources—the radioactive elements in the crust of the earth emitting a constant supply of *gamma* rays more penetrating than the hardest known X-rays, and an unknown source outside the earth from which penetrating radiation is poured into our atmosphere continually.

The next step in this tale of discovery was made by Dr. Kohlhörster, when he ascended the Jungfrau and set up his instruments in an ice cave. Here he detected radiation more penetrating than any known *gamma* ray and found furthermore that this cosmic radiation was most intense when the Milky Way was crossing the zenith.

A Physicist's Explanation.

About this time Dr. R. A. Millikan began similar observations in the Rocky Mountains. His results seemed to indicate very little diurnal or seasonal change in intensity. Another series of observations pointed to an increased intensity when the Great Nebula in Andromeda was on the meridian, and no sooner was this announced than the astronomer seized upon it as the explanation of his old problem—why is Andromeda nebula so faint?

The explanation seemed self-evident. The energy which is generated, just how we need not now specify, in a star or in a nebula meets with many vicissitudes on its way out into empty space. In getting to the surface of a star, it encounters millions upon millions of atoms, being absorbed and radiated again, emerging after each encounter slightly longer in wave-length because of the slight loss of energy consequent to each encounter. Thus, what was originally very penetrating radiation is frittered down to light waves and heat waves by the time it escapes from a star. In escaping from a nebula, however, the density and opacity are so low that a large proportion of the radiant energy leaves the nebula in its original highly penetrating form, and much less of the energy has been reduced to the range of wave-lengths of visible light. Thus the nebula appears faint because a large proportion of its radiant energy is invisible.

One astronomer, basing his judgment upon the results obtained by Kohlhörster, concludes that the source of the cosmic rays is within our Galaxy, emanating probably from the nebulous matter in interstellar space, this diffuse matter being chiefly found near the galactic plane, that is to say, in the Milky Way. Another astronomer, influenced more by Millikan's results, comes to the conclusion that the spiral nebulae are the source, and as they are believed to be fairly uniformly distributed over the entire celestial sphere, this would agree well with the observed constancy of intensity.

The Latest Study.

This is how the problem stood a short time ago, but during the last six months Millikan has published an account of his latest study of cosmic rays and the inferences which he draws from the new facts obtained. In order to understand the line of argument, a word must be said about his method. The intensity of radiation can be measured by the rate of discharge of an electroscope, the penetrating power of the radiation being found by screening off the electroscope and finding how much of the radiation is absorbed by the screen. The more penetrating the radiation the greater the thickness of the screen through which it passes, and the lower will be the "absorption coefficient." Now Millikan used water as his absorbing screen. The absorption caused by the earth's atmosphere is equal to that which would be caused by a water screen ten metres thick. Millikan enclosed his instrument in a watertight case and lowered it beneath the surface of a lake high up in the Rocky Mountains, taking readings down to a depth of 200 feet. Cosmic rays reaching to this depth are of such penetrating power that they would go through 18 feet of lead.

The results were most interesting, indicating that the cosmic rays fall into three distinct groups having different absorption coefficients; for the softest group, 0.35; for the second group, 0.08; and for the most penetrating group of rays, 0.04. What can this signify? Millikan's first conclusion is that evidently the rays do not come from the annihilation of matter nor from the upbuilding of matter into more complex atoms within a star or nebula, but from the process of atom-building in interstellar space.

Let us consider what are the most common elements in nature and how much energy would be set free as radiation if these elements are being synthesized, atom by atom, from the simplest atom of all—the hydrogen atom—which is composed of one proton and one electron, the two ultimate charges of positive and negative electricity.

Stellar Chemistry.

The hottest stars tell us that they contain a great deal of helium; cooler stars like Capella, Polaris, Arcturus, and our sun tell us of the abundance of iron and silicon in the stellar make-up; yet cooler stars tell of carbon atoms and molecules, while the gaseous nebulae record oxygen and nitrogen until recently unrecognized as such and called nebulium. Apart from this spectroscopic evidence, we have the analyses of many meteorites—54 per cent oxygen, 15 per cent silicon, 13 per cent iron, 13 per cent magnesium; and of the earth's crust (a chance fragment of a quite typical star)—55 per cent oxygen, 16 per cent silicon, 5 per cent aluminium, and lesser percentages of other elements, while the earth's core is undoubtedly chiefly composed of iron.

Now assume that somewhere in space four hydrogen atoms come together, rearranging their protons and electrons into the compact atom called a helium atom. The relative weights of a hydrogen and a helium atom are 1.00778 and 4.0, whereas one would expect the helium atom to weigh 4×1.00778 or 4.03112, since it contains four protons and four electrons while the hydrogen atom has only one of each. Where has the extra mass gone? Evidently the closer packing of the electric charges in the nucleus of the helium atom results in less energy content or mass, so that the excess energy represented by the figure 0.03112 is dissipated into space as radiation. It is always possible to evaluate the mass of a body as ergs of energy and to calculate the frequency of the radiation to which this energy would give rise, by means of a relation due to Einstein and to Planck:—

$$mc^2 = E = h\nu$$

where m is the mass expressed in grams, c is the velocity of light, E the energy in ergs, ν the frequency of the radiation and h a numerical factor known as Planck's constant. Knowing thus the frequency and therefore the wave-length of the radiation, it is possible to calculate its absorption coefficient by means of a somewhat complicate formula due to Dirac.

Millikan carries out these calculations and finds that the synthesis of helium from hydrogen would be accompanied by an emission of a radiation having an absorption coefficient 0.30 in very fair agreement with his experimental value, 0.35. Encouraged by this, he passes on to consider the synthesis of an oxygen atom and a nitrogen atom from 16 hydrogen atoms and from 14 hydrogen atoms respectively. The one process leads to a cosmic ray with absorption coefficient 0.074, the other to 0.086 or averaging the two, 0.080 as found experimentally. Carbon, another of the abundant elements being equivalent to 12 hydrogen atoms, would give rise to a radiation falling alongside of the oxygen-nitrogen group.

It takes 28 hydrogen atoms to build one silicon atom, and here again the absorption coefficient of the resulting radiation agrees closely with the experimental value—0.041 and 0.040. Not very different would be the radiation accompanying the synthesis of each magnesium atom from 24 hydrogens.

But what of iron, perhaps the most abundant of all the elements? If 56 hydrogen atoms unite suddenly to form one iron atom, a radiation would be emitted even more penetrating. This radiation, however, has not been detected. Nevertheless, one cannot but be impressed by the close agreement between theory and observation in the other cases.

Eddington's View.

It should not be supposed that this is the first time that synthesis of the atoms of other elements from the hydrogen atoms has been suggested as a source of radiant energy—far from it. As soon as relative atomic weights were accurately established and the relation between mass and energy known, this hypothesis arose quite naturally, but following the lead of Professor Eddington most people looked to the interior regions of the giant stars as the places where this upbuilding was taking place. The stars became in our thoughts the crucibles of nature in which the successively heavier atoms were being evolved, as in a fiery furnace of Nebuchadnezzar seven times heated. Not but that this picture had its attendant difficulties. The centre of a great star may be at a temperature of twenty million degrees or more, but is that hot enough? Professor Eddington's famous reply to such critics is well known, being briefly a courteous invitation to "go and find a hotter place."*

Professor Millikan declines that invitation and says, in effect, that it is not a hotter but a colder place that is needed. It is in the regions of lowest material density and most nearly at the absolute zero of temperature where the hydrogen atoms are so quiescent that their kinetic energy is almost reduced to nothing—it is there that the synthesis of the elements will occur.

Which of these two views is correct? It is well, perhaps, to reserve our judgment until further and more convincing evidence is forthcoming. The latter hypothesis like the former has its difficulties which we must not ignore. Imagine all the matter in a great galaxy of a thousand million stars suddenly ceasing to exist as matter, its equivalent energy being all of the form of radiation traversing and retraversing without loss the same vast volume of space as the galaxy had occupied. Then in every 400 cubic feet there would be just enough radiant energy to form one hydrogen atom if it could all be concentrated into the material form of one proton and one electron. Imagining this miracle to have been accomplished, our galactic volume is now filled with hydrogen atoms, the density being one atom to each 400 cubic feet. Next picture the chance coming together of four of these atoms to combine as a helium atom, or 16 of them to form an oxygen atom, or 56 of them to form an iron atom, and so on. It is not an easy flight of the imagination, nor is it rendered less difficult by assuming it to take place very gradually during aeons of time.

A further criticism comes from Queen's University, Canada, where Dr. J. A. Gray claims that Millikan overlooks the effects of the secondary or scattered radiations in calculating the wave-lengths, which are actually shorter than those derived by Millikan.

The problem of the source of the penetrating radiation is thus not yet solved, but it has brought us face to face with alternative theories of atom building and of the annihilation of matter, the transformation of the energy of matter to the energy of radiation, and *vice versa*.

A Philosopher's Answer.

Possibly it is not too much to hope that the further study of the cosmic rays may yet throw light upon the vast cosmical processes. Are they indeed irreversible, or is Millikan right in regarding them as reversible? Most physicists would give the affirmative answer to the former question. Perhaps the reader, turning disappointed from this ebb-tide picture of the universe, will find comfort in the words of the philosopher, Dr. A. N. Whitehead, who states his belief in a universe "physically wasting," it is true, but "spiritually ascending" whatever that may mean to him, to you, or to me. *Quot homines tot sententiae.*

* See "Stars and Atoms" (Clarendon Press), 1927, p. 102.

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