Measurement of the Nuclear Absorption of Electrons by the Atmosphere up to about 10^{10} Electron-Volts

ACCURATE observations on cosmic ray intensities as measured by Neher electroscopes have been made in the equatorial belt (Madras, India, mag. lat. 3° N.) and in San Antonio, Texas (mag. lat. 38·5° N.) up to between 98 and 99 per cent of the way to the top of the atmosphere. The most significant results of these measurements may be summarized as follows:

(1) Cosmic rays, whatever their nature, are so rapidly absorbed as a whole in the outer layers of the atmosphere that even in the equatorial belt, where the effect of the earth's magnetic field upon them is a maximum, they get into equilibrium with their secondaries and produce their maximum ionization before they have penetrated through the first tenth of the atmosphere. (This effect was suggested as a possibility by Millikan and Cameron in 1927[1] in their report made at the Leeds meeting of the British Association on their first voyage (1926) made from Los Angeles to Peru to look for the effect of the earth's magnetic field on incoming electrons. The words then used were: "If the northern hemisphere and the southern hemisphere curves [of ionization with altitude] coincided, it would go a long way toward eliminating the possibility that the rays are generated by the incidence of high-speed beta rays on the very outer layers of the atmosphere. . . . For such beta rays would be expected to be influenced by the earth's magnetic field so as to generate stronger radiation over the poles than over the equator". This is precisely what the present experiments show to be the case for the whole field-sensitive portion of the cosmic rays.)

(2) From that point on, they fall off exceedingly rapidly in intensity, following an exponential equation, their law of absorption being like that of X-rays and not like that of particles that exhibit range phenomena such as low-energy beta rays, proton rays or alpha rays.

(3) The depth beneath the top of the atmosphere at which the maximum ionization is attained, always less than a tenth of an atmosphere, changes but slightly in going from San Antonio, where no electrons of energy less than 6×10^9 electron volts can get vertically through the blocking effect of the earth's magnetic field, to Madras where no electron-rays of energy less than 17×10^9 electron-volts can similarly get through.

(4) The difference between the San Antonio and the Madras curves makes possible for the first time the determination of the complete curve of ionization produced in the atmosphere by incoming charged particles contained within a sharply limited band of energies having a weighted mean value of 10×10^9 electron-volts.

(5) Down to a depth of a third of an atmosphere from the top (3 metres of water) this curve is in good agreement with the Bethe-Heitler theory of nuclear electron absorption as recently extended by Carlson and Oppenheimer as well as by Bhabha and Heitler.

(6) The exceedingly rapid absorption of this latitude-sensitive radiation, with an absorption coefficient which is nearly constant and independent of incident energy, qualitatively justifies the 'shower theory' of Millikan and Cameron as the main cause of the ionization of the atmosphere produced by incoming electrons even of this huge energy.

(7) The latitude-sensitive part of the cosmic ray ionization found in the *lower* part of the atmosphere is considerably more penetrating than is predicted by the foregoing extended Bethe-Heitler theory of electron absorption; nevertheless, while at a distance of one twentieth of an atmosphere from the top, these 10×10^9 electron volt field-sensitive rays are producing 160 ions per c.c. per sec., *at sea-level* their total ionizing influence has fallen to but 0·3 ion per c.c. per sec., that is to less than 1/500 of its value near the top of the atmosphere.

(8) The two foregoing results in (7) show that the process of nuclear absorption of electrons is more complicated and involves the production of more penetrating secondaries than is pictured in the simple physical assumptions underlying the Bethe-Heitler theory, but, at the same time, that the whole progeny of secondaries, whatever their nature, has been reduced almost to zero by the time sea-level has been reached, not more than about one tenth of the sea-level ionization being accounted for by field-sensitive rays at all.

(9) The latitude-sensitive part of the cosmic ray ionization found in the lower atmosphere is practically all due to the *secondary* effects of varied nature resulting from the absorption of the incoming electrons in the upper tenth of the atmosphere.

(10) The *apparent* absorption coefficient, namely, 0·54 per metre of water, of the actual curve representing the whole progeny of secondary influences resulting down to sea-level from the absorption of incoming electrons in the very top layers of the atmosphere is approximately the same as that found by Johnson and by Neher for the east-west effect, thus proving that the particles causing the latitude and the east-west effect are of the same type. Both absorption coefficients are such as to suggest that these particles are electrons (predominantly positive), not protons.

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Longitude Effect and the Asymmetry of Cosmic Radiation.

IN a recent letter, Dr. M. S. Vallarta[1] has emphasized the discrepancy which arises from the comparison of the variation of intensity of the cosmic rays along the magnetic equator (longitude effect) and the position of the magnetic centre of the earth as determined from magnetic observations. According to Hoerlin, the longitude of the magnetic centre as determined by cosmic rays should be 100° E. instead of 160° E. as found directly.

The theory according to which the cosmic ray observations are interpreted is that the angle of opening of the cone $\pi/2 + \theta$ must be computed by Störmer's formula

$$\sin \theta = \frac{2}{r} - \frac{1}{r^2},$$

with a value of $r = r_0(1 - \rho \cos L + \ldots)$ proportional to the distance to the magnetic centre and therefore dependent on the eccentricity ρ of the dipole and on the difference of longitude L reckoned from the dipole (positive towards the east).

It should be noted that the angle θ in Störmer's formula is reckoned, not from the vertical of the place

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