Letters to the Editor

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Communications should not in general exceed 600 words in length.

The Energy Spectrum of the Primary Cosmic Rays

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As it is impossible to send a cloud chamber to the top of the atmosphere, we cannot obtain the energy spectrum of primary cosmic rays as one can for secondaries at sea level. This important problem has been attacked by Bowen, Millikan and Neher[1] by indirect methods with some success. They calculated from their ionization-altitude curves obtained in 1936 and in 1937 the rough distribution of the energy carried into the atmosphere per cm^2 per sec. by the primaries of energy E, and concluded a sharp band structure of the primary cosmic rays. For many purposes, a knowledge of the number of primaries as a function of their energy is very desirable. This induces the author to make the following calculation.

Let the number of primaries of energy between E and $E+dE$ be $N(E)dE$. Bowen, Millikan and Neher found the values of the areas $\int_{E_1}^{E_2} N(E)EdE$ to be 0.11, 0.44, 0.87 and 0.94 billion ev per cm^2 per sec. for the limits E_1 and E_2 set at 1.4 and 2.9, 2.9 and 6.7, 6.7 and 17, and 17 and 40 billion ev, respectively. Dividing the areas by the average and by the difference of the corresponding energy limits, we obtain the average numbers per billion ev energy range of primaries having energies lying between E_1 and E_2. From this we get the solid circles shown in Fig. 1.

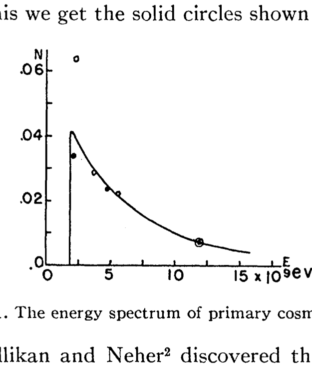

FIG. 1. The energy spectrum of primary cosmic rays.

Later Millikan and Neher[2] discovered that the ionization-altitude curve at one place changes with time. This introduces considerable ambiguity in the result. The curves obtained in 1938 were added in the new analysis. They found then the areas $\int_{E_1}^{E_2} N(E)EdE$ to be 0.14, 0.16, 0.28 and 0.87 billion ev per cm^2 per sec. for the energy intervals from 2 to 2.9, from 2.9 to 4.5, from 4.5 to 6.7, and from 6.7 to 17 billion ev, respectively. Using these data and making the above calculation again, we get the open circles shown in the figure.

Although the accuracy is low, the curve in the figure probably represents the energy spectrum of primary cosmic rays. The sudden cut-off at the low energy end ($\sim 2\times 10^9$ ev) is exceedingly remarkable. This is very likely to be due to the blocking effect of the solar magnetic field. The curve in the figure is well represented by the exponential equation

$$N = Ae^{-\alpha E}$$

with $\alpha \doteqdot 0.176$, but it is to be noticed that the primaries contain both electrons and protons, as most of us believe, and the energy distribution may be different for electron and proton primaries.

[1] I. S. Bowen, R. A. Millikan and H. V. Neher, Phys. Rev. **53**, 855 (1938).
[2] R. A. Millikan and H. V. Neher, Proc. Am. Phil. Soc. **83**, 409 (1940).

Latitude Effect and the Decay of Mesotrons

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DATA on the latitude effect reported in a paper in 1937[1] give some additional information on the decay of the mesotron. In that paper are given measurements with an ionization chamber on cosmic-ray intensities within 20° of the vertical under shielding thicknesses up to 19.4 cm Pb at altitudes corresponding to 76, 51 and 45 cm Hg barometric pressure at geomagnetic latitudes of about 50°N and 1°S. It was pointed out that whereas the latitude ratios I_N/I_E of the northern to the equatorial intensities decrease from 1.30 to 1.16 as the thickness of the atmosphere increases from 45 to 76 cm Hg, the ratio at a given altitude is independent of thickness of lead up to 20 cm. At that time we could give no adequate explanation of this phenomenon. It can now be explained by the decay of the mesotron. The decay of mesotrons is given by the relation: $dn/dz = n\mu_0/p\tau_0$ where dn/dz is the loss of mesotrons per cm of path due to spontaneous disintegration, n the number of mesotrons at a depth z below the top of the atmosphere, μ_0 the rest mass, p the momentum and τ_0 the "proper" lifetime of the mesotron. According to this relation the loss of mesotrons due to spontaneous disintegration is inversely proportional to their momentum. Since the average energy of the radiation getting through the blocking effect of the earth's magnetic field is greater at the equator than in higher latitudes we should expect that the decrease of intensity of the cosmic radiation due to spontaneous decay of the mesotron should be less at the equator than at higher latitudes. This is borne out by the facts quoted above. Interposition of equal masses of lead at both latitudes reduces the radiation in exactly the same way, but interposition of equal masses of air reduces the radiation more strongly in northern latitudes than at the equator.

Integration of the equation for mesotron decay gives $\log n_2/n_1=\mu_0(z_2-z_1)/p\tau_0$ where n_2 and n_1 are the numbers of mesotrons at depths z_2 and z_1 below the top of the atmosphere. The term p, held constant in the integration, must be interpreted as the "effective" momentum between the depths considered. An expression for p is given by Rossi and Hall.[2] The ratio of the effective momenta for the two latitudes is: $p_E/p_N=\log(n_2/n_1)_N/\log(n_2/n_1)_E$. This ratio is independent of the values taken for the mass or the lifetime of the mesotron. A method of separating the penetrating component from the secondary component is described in reference 1. It was found that under 19.4 cm Pb at northern latitudes about 80 percent of the radiation at sea level, and 50 percent at 51 cm Hg was due to the penetrating component. Since the absorption curves are similar at both latitudes the same percentages may be applied to the equatorial data. Using the data of Table III, reference 1, we obtain:

$$p_E/p_N=\log(0.74/1.62)/\log(0.64/0.80)=1.5.$$

For the energy ranges involved the momenta can be considered proportional to the energies. The ratio of the energies corresponding to these momenta is thus approximately 1.5. The ratio of the minimum energies required for primary electrons at the vertical to break through the earth's magnetic field is $E_E/E_N=4.5$; for protons, 6.5. The variation of energy of mesotrons which penetrate the earth's atmosphere between 51 and 76 cm Hg barometric pressure and have residual ranges greater than 19.4 cm Pb is hence much less than the variation of the lower cut-off of the energy spectrum of the primary radiation which arrives at the earth.

[1] R. T. Young, Jr. and J. C. Street, Phys. Rev. **52**, 552 (1937).
[2] Bruno Rossi and David B. Hall, Phys. Rev. **59**, 223 (1941).

An Explanation of the Diminished Acoustic Velocity in Fluids at High Frequencies

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THE existence of dispersion of acoustic velocity with frequency in gases and the accompanying anomalous damping of high frequency acoustic waves have been definitely established. A satisfactory theory has also been worked out to explain these two phenomena in gases.

In the case of liquids, however, the anomalous damping of ultrasonic waves of high frequency was the first to be observed. A search has been made by a number of investigators to find the accompanying dispersion of acoustic velocity with frequency. So far, in the ultrasonic region at any rate, the experimental results have been inconclusive for the reason that the expected changes in the ultrasonic velocity, a couple of meters per second, are of the same order of magnitude as the errors due to changes in the temperature of the liquid during the course of the experiment.

Early in 1937[1] and subsequently in 1938,[2] one of us experimentally established the dispersion of acoustic velocity in liquids, carbon tetrachloride and acetone, in the hypersonic region. It is now known that it is only at such high frequencies that one should expect measurable changes in the velocity of liquids, a fact subsequently mentioned by Kneser,[3] Bergmann,[4] and others.

What appeared surprising at that time was the fact that in the case of carbon tetrachloride the hypersonic velocity was greater than the ultrasonic velocity, while the reverse was the case in acetone. On a comparison with similar phenomena in gases it is easy to understand the result in the case of carbon tetrachloride. But until now the case of acetone where the hypersonic velocity was less than the ultrasonic velocity required explanation. Further work[5] by interferometric examination of light scattered by liquids in the manner already mentioned has shown that a few other liquids behave similar to acetone in this respect.

In looking for an explanation of the result, one has to consider the effect of high frequency acoustic wave propagation on the liquid medium. Usually the reason for applying Laplace's formula in preference to Newton's in calculating the acoustic velocity in liquids and gases is that the pressure changes in the medium are so rapid that they are taken to be adiabatic. But a closer examination will show, as envisaged by Herzfeld and Rice[6] and by Condon,[7] that this assumption becomes less and less justifiable as the acoustic wave-length approaches 10^{-5} cm for gases and 10^{-8} cm for liquids. In the case of any given fluid the pressure changes due to acoustic wave propagation can be considered completely adiabatic over a range starting from a minimum frequency up to a certain high frequency. Above this, the acoustic velocity begins to diminish due to the enhancement of heat conduction at such high frequencies.

From the relation $\nu=v^2\rho s/4\pi k$ where v is the acoustic velocity, ρ the density, s the specific heat and k the coefficient of thermal conductivity, one can calculate ν the frequency of acoustic waves, at which the departure of the pressure changes in the medium due to acoustic wave propagation from the adiabatic state is a maximum and the corresponding velocity a minimum. But at precisely what frequency of the acoustic wave the adiabatic formula does not hold can at present only be determined by experiment. From the work of one of us on the determination of acoustic velocity in the hypersonic region and from the work of Richardson[8] on the acoustic velocity in gases we get evidence for diminished velocity at a frequency of 10^9 cycles per sec. for liquids and 10^6 for gases under the conditions of the experiment.

This new point of view put forward to account for the diminished acoustic velocity in liquids in the hypersonic region, satisfactorily accounts for the results of Richardson with CO_2 and N_2O where he finds evidence for diminished velocity at a frequency of 10^6 cycles per sec.

[1] B. V. Raghavendra Rao, Nature **139**, 885 (1937).
[2] B. V. Raghavendra Rao, Proc. Ind. Acad. Sci. **A7**, 163 (1938).
[3] H. O. Kneser, Physik. Zeits. **39**, 800 (1938).
[4] L. Bergmann, *Ultrasonics* (John Wiley & Sons, New York, 1938). English translation, p. 137.
[5] B. V. Raghavendra Rao, work in course of publication.
[6] K. F. Herzfeld and F. O. Rice, Phys. Rev. **31**, 691 (1928).
[7] E. U. Condon, Am. Phys. Teacher **1**, 18 (1933).
[8] E. G. Richardson, Proc. Roy. Soc. **A146**, 56 (1934).