The Difference in the Absorption of Cosmic Rays in Air and Water and the Instability of the Barytron

Ehmert[1] and Auger, Ehrenfest, Freon and Fournier[2] have found that the intensity of the cosmic radiation depends not only upon the quantity of a given kind of matter traversed by the rays, but that it is a function of the distribution of that matter as well, the denser matter appearing to absorb the rays less. As an interpretation of these results Kulenkampf and Euler and Heisenberg[3] have pointed out that the instability of the barytron, predicted by Yukawa,[4] should give rise to a lower intensity when the time required for the secondary barytrons produced in the upper atmosphere to reach the apparatus is greater. The mean life predicted by Yukawa for the barytron at rest is $\tau_0=0.5\times10^{-6}$ sec., and because of the relativity transformation the stability appears to increase in proportion to the energy for energies large compared with the rest energy μc^2. A recent comparison of the cosmic-ray intensities and zenith angle distributions at two elevations by Ehrenfest and Freon[5] enabled these authors to compute a rest life of the order of 4×10^{-6} sec., or about ten times that predicted by Yukawa.

W. F. G. Swann has recently had erected at the Bartol Laboratory a cylindrical water tower three meters in diameter and 8.9 meters deep, with a room beneath for experimentation. He has generously placed this at our disposal for a similar investigation in which we have had the advantage of making all measurements under favorable laboratory conditions at a single location. In these experiments the counting rate of a quadruple coincidence counter train of large area but small angular aperture was recorded, first when it was directed vertically upwards through the 8.9 meters of water and the equivalent 10 meters of atmosphere, and then when it was inclined at the zenith angle $\zeta=\sec.^{-1}(1.89)=58°$. Lead plates for eliminating the soft component were stacked between counters to a thickness of 17 cm and 38 cm, respectively, in two independent experiments. In both instances the counting rates in the inclined position were less than those in the vertical; if j_ζ and j_v designate the respective intensities the experiments gave

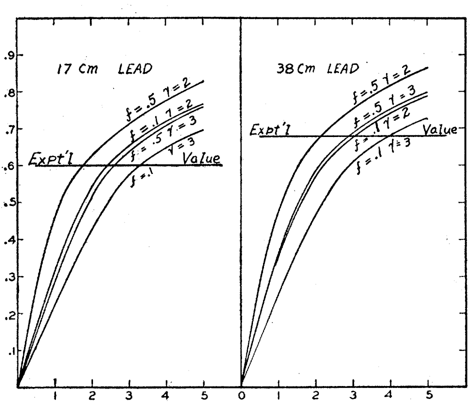

FIG. 1. Ordinates: calculated values of j_ζ/j_v. Abscissae: the rest life τ_0 in microseconds.

$$j_\zeta/j_v=0.60\pm0.02 \text{ with 17 cm lead}$$
or
$$=0.68\pm0.02 \text{ with 38 cm lead.}$$

In order to evaluate the mean life of the barytron from these data we have used two types of calculation, both of which involve assumptions which must be regarded as more or less arbitrary in the present state of our knowledge. Barytrons incident at zenith angle ζ are assumed to have originated as secondaries at an atmospheric depth $h=fH\cos\zeta$ where H is the depth of the homogeneous atmosphere ($=8\times10^5$ cm) and f is a fraction of the order of 1/10; the actual height above sea level, corresponding to this depth, is $x=H\log(\sec.\zeta/f)$. The mean life of barytrons of energy $\epsilon\mu c^2$ is $\tau_0\epsilon$, and if a ray loses energy by ionization at the constant rate $i\mu c^2$ per cm in normal air, the probability of a ray of initial energy $\epsilon\mu c^2$ reaching sea level without disintegrating is given by

$$P(\epsilon,\zeta)=\exp -[(H\sec.\zeta/c\tau_0\epsilon) \times\log(\epsilon/ifH-1)/(\epsilon/iH\sec.\zeta-1)]. \quad (1)$$

In the first calculation we let $j(\epsilon)d\epsilon$ represent the number of barytrons per cm² per sec. per unit solid angle whose initial energies lie between $\epsilon\mu c^2$ and $(\epsilon+d\epsilon)\mu c^2$, a function which may be supposed independent of the direction, so that the number of rays of these initial energies which reach sea level in the vertical direction is $j(\epsilon)P(\epsilon, 0)$. The experiments of Ehmert[1] and Wilson[6] show the latter function to be of the form $A/(\epsilon-iH(1-f))^\gamma$ where $2<\gamma<3$. If $\alpha\mu c^2$ is the energy required to penetrate the lead shield, the intensity in the vertical direction under 8.9 meters of water and the atmosphere may be expressed by

$$j_v=\int_{iH(1.89-f)+\alpha}^{\infty} j(\epsilon)P(\epsilon,0)d\epsilon = A/(\gamma-1)(\alpha+0.89iH)^{\gamma-1}, \quad (2)$$

whereas that in the inclined position is given by

$$j_\zeta=\int_{iH(\sec.\zeta-f)+\alpha}^{\infty} j(\epsilon)P(\epsilon,\zeta)d\epsilon. \quad (3)$$

We have chosen as a value of the rest mass of the barytron one-tenth of the proton mass, and with the rate of loss of energy by ionization proportional to the inverse square of the velocity we find $\alpha=3.6$ for 17 cm lead, 6.4 for 38 cm lead, and $iH=20$. The values of j_ζ/j_v calculated for various values of τ_0, for the cases where $f=0.1$ and 0.5 and $\gamma=2$ and 3, are shown in Fig. 1. Agreement with our measured values occurs for values of τ_0 between 2 and 4×10^{-6} sec.

The second calculation is concerned with the disintegrations of rays whose energies lie within the narrow band of energies which penetrate the 17-cm lead absorber, but fail to pass through the 38-cm shield; this calculation is independent of the energy distribution and applies to only those rays whose initial energy is given by

$$\epsilon_1=iH(1.89-f)+\bar{\alpha},$$

where $\bar{\alpha}$ is the average of the minimum energies for penetration of the two thicknesses of lead. In this calculation τ_0 is obtained from the equation

$$\eta\equiv\frac{j_v(17)-j_v(38)}{j_\zeta(17)-j_\zeta(38)}=P(\epsilon_1,0)/P(\epsilon_1,\zeta). \quad (4)$$

The order of runs in these experiments was not arranged to give an accurate value of η, but we can give $\eta=0.40$ as a preliminary value from which we calculate $\tau_0=2.6\times10^{-6}$ sec. with $f=1/10$ or $=2.4\times10^{-6}$ sec. with $f=0.5$. The result is insensitive to the choice of f.

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The Bartol Research Foundation of the Franklin Institute,
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December 8, 1938.

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Ferromagnetism of Semi-Conductors

A theory of ferromagnetism of semi-conductors has been proposed on the basis of Wilson's model of semi-conductors[1] and Slater's model of ferromagnetic substances[2] in which ferromagnetism appears in crystals having very large exchange integrals.

The outline of our theory is as follows: We assume that in semi-conductors there are two near energy bands, and at absolute zero temperature the lower band in which a very large exchange integral exists between two electrons is entirely filled up, while the higher band in which the exchange integral is small is entirely empty.

In a suitable temperature range several electrons are excited to the higher band, and thereby make positive holes in the lower band. Then ferromagnetism can appear.

The number of positive holes $2n$ at T°K is

$$2n=2\varphi_1(T)\nu\exp(-\Delta B/2kT),$$

where $\varphi_1(T)$ is a function related with the shape of the lower (magnetic) band, ν is the total number of ferromagnetic atoms in the crystal, and ΔB is the width of the forbidden region.

Then the magnetic moment M_s of one mole of the crystal is given by the following formulae:

$$M_s=M_\infty\exp(-\Delta B/2kT)\tanh(\alpha+M_s\theta/M_\infty T),$$
$$M_\infty=2\mu L\varphi_1(T),$$
$$\alpha=\mu H/kT,$$
$$\theta=J\varphi_1(T)/k,$$

where L is the number of atoms of one mole, k the Boltzmann's constant, J the exchange integral in the free atom, H the magnetic field, μ the Bohr magneton and T the temperature on absolute scale.

If we assume $\varphi_1(T)$ is a constant b, and the magnetic field is weak, we can calculate M_s numerically as the function of absolute temperature for the different values of γ, where $\gamma=\frac{1}{2}\Delta B/Jb$.

Ferromagnetism can not appear in every temperature when $\gamma>1/e$.

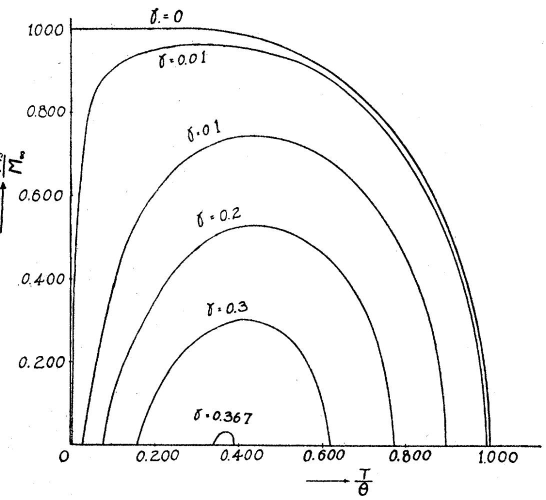

FIG. 1. Ferromagnetism of semi-conductors.

The results are different from those calculated by the ordinary Weiss-Heisenberg theory.

Our results are illustrated in Fig. 1. It is specially interesting to note that at very low temperature ferromagnetism vanishes.

This result will be useful for the interpretation of experimental facts on magnetite,[3] pyrrhotite[4] and chromium sulphide.[5] Further experiment which is necessary for the verification of our theory is now in progress.

The detailed account of the above theory will be published at a later date.

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Mesotron as the Name of the New Particle

After reading Professor Bohr's address at the British Association last September in which he tentatively suggested the name "yucon" for the newly discovered particle, I wrote to him incidently mentioning the fact than Anderson and Neddermeyer had suggested the name "mesotron" (intermediate particle) as the most appropriate name. I have just received Bohr's reply to this letter in which he says:

"I take pleasure in telling you that every one at a small conference on cosmic-ray problems, including Auger, Blackett, Fermi, Heisenberg, and Rossi, which we have just held in Copenhagen, was in complete agreement with Anderson's proposal of the name 'mesotron' for the penetrating cosmic-ray particles."

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California Institute of Technology,
Pasadena, California,
December 7, 1938.