by Bloch and Gentile,[21] the explanation is probably that the arrangement of atoms in the hexagonal gratings does not deviate too greatly from cubic form. With strict cubic symmetry, the expression (53) would vanish, and with hexagonal the various members of (53) may nearly cancel, so that Ω_6 is considerably smaller than NC in magnitude. There is no corresponding cancellation in the fourth-order coefficient, which one should thus expect to be of about the same order 10^6 ergs/cm^3 as the cubic anisotropy coefficient K_2 in (1). This is indeed what is found experimentally in cobalt,[35] as at room temperatures K'' is 2.2×10^6 ergs/cm^3, or about one-half as large as $K'=5.1\times10^6$. The two terms of (51) are thus comparable even though they involve the spin-orbit parameter A to different powers (*viz.* the second and fourth).

It must be mentioned that the "one-atom model" of Bloch and Gentile described in Section 7 may have some significance for hexagonal crystals, since with only axial symmetry the crystalline field can lift the degeneracy if $S>\frac{1}{2}$. In fact the effective magneton number and g-factor can be different in different directions. Conceivably this fact has some connection with the anomalous behavior of pyrrhotite, which is ferromagnetic along certain axes but only paramagnetic along others.

The writer wishes to express his thanks to Dr. R. M. Bozorth and Professor F. Bitter for helpful comments.

[35] These values of K', K'' are calculated in unpublished work of Bozorth, from the data of Honda and Masamuto, Sci. Rep. Tohoku Univ. **20**, 323 (1931). Gans obtained $K'=1.1\times10^6$, $K''=4.4\times10^6$ from previous work by Kaya, Sci. Rep. Tohoku Univ. **17**, 1157 (1928). Dr. Bozorth asks me to record the following errata in the discussion of cobalt in his recent paper (J. App. Phys. **8**, 575 (1937)). The statement on p. 585 that the higher power term K_2 in his formula $E=K_0+K_1S_1^2+K_2S_1^4$ is negligible is incorrect, as vanishing K_2 is not required by the absence of anisotropy in the plane perpendicular to the hexagonal axis. The ordinate of Fig. 18 is K_1+K_2 rather than K_1. Bozorth's K_0, K_1, K_2 for cobalt are the same as our $F_0+K'+K''$, $-K'-2K''$, and K'' respectively since his S_1^2 is $1-\sin^2\varphi$.

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On the Nature of Cosmic-Ray Particles

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Various authors[1] have taken the view that cosmic-ray particles consist of two or more kinds of corpuscles. According to Compton and Bethe, and Auger,[1] the soft component near sea level is thus composed of electrons and the penetrating one of protons. Assuming the theory of showers by Bhabha and Heitler[2] and by Oppenheimer and Carlson[3] to be correct, we ought to be able to distinguish cosmic-ray electrons from protons, if they exist at all, by observing whether or not the particles suffer a large loss of energy and often produce showers on colliding with a lead plate of a suitable thickness.

We carried out such experiments with a lead bar 1.5 cm thick mounted in the middle of a Wilson chamber 40 cm in diameter, which is placed in a magnetic field of about 17,000 oersteds. The operation of the chamber is actuated by the coincidence of two Geiger-Müller tube counters mounted above the chamber, the distance between the counters being about 50 cm. The results showed that at sea level near Tokyo (geomag. lat. 25.4°N) about 10 to 20 percent of cosmic-ray particles of energies, high enough to produce coincidence in the strong magnetic field and pass through the Wilson chamber, consist of electrons and positrons, the rest being heavy particles, since they do not produce showers nor suffer much loss of energy in passing through the lead bar. Among the latter, however, we were

[1] A. H. Compton and H. A. Bethe, Nature **134**, 734 (1934); P. Auger, J. de phys. **6**, 226 (1935); C. D. Anderson and S. H. Neddermeyer, Int. Conf. on Physics, London **1**, 182 (1934); Phys. Rev. **50**, 268 (1936); J. Clay, Physica **3**, 338 (1936); L. Leprince-Ringuet, J. de phys. **7**, 70 (1936); J. Crussard and L. Leprince-Ringuet, Comptes rendus **204**, 240 (1937).

[2] H. J. Bhabha and W. Heitler, Proc. Roy. Soc. **A159**, 432 (1937).

[3] J. F. Carlson and J. R. Oppenheimer, Phys. Rev. **51**, 220 (1937).

surprised to find that there are some particles of both signs, which have much greater penetrating power for lead than protons of the same momentum ($H\rho$) would have. The specific ionization of some tracks is also much smaller than that of protons of the observed $H\rho$. These results can most naturally be explained, if one assumes the existence of new particles of a mass heavier than that of an electron and lighter than that of a proton. At about this time we received the paper of Street and Stevenson[4] and then that of Anderson and Neddermeyer[5] and saw that these authors had obtained similar results. Crussard and Leprince-Ringuet[6] also recognized the existence of particles, which lose less energy through matter than expected for electrons on the theory of showers and produce smaller specific ionization than protons of the same $H\rho$.

We have since then been trying to find a more exact value of the mass of the new particle. Since this seems hardly to radiate in collision with matter, we may for the moment assume that the loss of its energy in passing through lead is entirely due to ionization, although this is probably not always the case as will later be mentioned. In this respect the new particle behaves more like protons than electrons, and especially for energies higher than 10^9 ev we cannot discriminate between the two by specific ionization, because it becomes nearly the same for both. The range in lead, however, as a function either of $H\rho$ or of energy is sensitive to the difference of mass of the particles. We can thus draw a series of mass $H\rho$ curves for various values of ranges. By means of these curves, we can determine the mass of a particle, if we know its range and $H\rho$ from Wilson tracks. As the range we chose 3.5 cm of lead mounted in the middle of our Wilson chamber. In order to filter the electronic component of cosmic rays, a lead block 20 cm thick was inserted between the two controlling counter tubes, placed above the Wilson chamber as described before.

Until now we have obtained only one track which can probably be used for the determination of the mass. The initial value of $H\rho$ of the particle was 7.4×10^5 gauss-cm and after passing through lead it became 4.9×10^5 gauss-cm, showing the loss of about a half of the energy. The loss of energy by ionization and the range in lead calculated from the thickness of the lead bar and the final $H\rho$ are consistent, if we assume the mass in question of the particle to be 1/7 to 1/10 that of the proton. The above values of $H\rho$ and the specific ionization shown by the corresponding tracks are in accordance with the assumed mass. This value must necessarily be provisional and subject to a possible alteration. For accurate determination we need more tracks of appropriate energies.

From our present experimental results we cannot conclude whether the penetrating component of cosmic rays at sea level consists exclusively of these new particles or in part of protons. There are observed some particles which are stopped by 3.5 cm of lead and can be interpreted as protons on the mass $H\rho$ curve. On the other hand we observe some particles of high $H\rho$ which seem to be stopped by the lead plate. The ionization alone cannot account for such a large loss of energy, even if they are protons. We do not know as yet whether we have here to do with the presence of particles heavier than protons or with a certain type of loss of energy other than ionization for the new particles or for protons. The disintegration of lead nuclei caused by these particles must be taken into account in the problem, as can be seen from one of our photographs. Although the exact determination of the composition of the penetrating component of cosmic-ray particles has thus not yet been possible, its large part no doubt consists of the above new particles, through the existence of which various difficulties in connection with cosmic-ray phenomena e.g., ionization, radiative effect,[7] penetrating power, etc. now find a natural explanation.

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[4] J. C. Street and E. C. Stevenson, Bull. Am. Phys. Soc. **12**, No. 2, 13 (1937).

[5] S. H. Neddermeyer and C. D. Anderson, Phys. Rev. **51**, 884 (1937).

[6] J. Crussard and L. Leprince-Ringuet, J. de phys. **8**, 215 (1937).

[7] E. J. Williams, Phys. Rev. **45**, 729 (1934); *Kernphysik*, (Berlin, 1936), p. 123.