clusions and hypotheses of this investigation is found: (1) in the experiments on photoelectric emission and electrical conductance of Bi films[6] reported by one of the present authors (A.H.W.) which in turn are confirmed by Armi's experiments with thin Pb films,[7] (2) in Kirchner's[8] electron diffraction study of Bi films less than 100A thick which led him to conclude that the films were of a fibrous nature;[9] (3) in electron microscope pictures of various thin films which show that patches some 500A long separated by gaps of about half this length are present.

The results of the present investigation are considered very definite evidence that true photo-conductance is not a property of thin metallic films. This is the majority opinion of other investigators.[1] The experiments of Fukuroi[1] and Bartlett[1] most nearly resemble the present ones. Fukuroi's experiments with thin films of mercury, cadmium, and zinc condensed on glass or quartz are in agreement with this investigation. Bartlett measured the photo-resistance of bismuth films deposited by cathode sputtering and found a small photo-conductance effect but comparison with the present results is difficult because he reports no film thicknesses.

[6] A. H. Weber and D. F. O'Brien, Phys. Rev. **60**, 574 (1941).
[7] E. L. Armi, Phys. Rev. **63**, 451 (1943).
[8] F. Kirchner, Zeits. f. Physik **76**, 576 (1932).
[9] A "cracked" crystalline film is as useful to "explain" the present results as is a fibrous film which necessarily contains cracks. An electron diffraction study of thin Bi films is in progress at Saint Louis University.

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Atom-Annihilation Cosmic Rays at Mexico City

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The directional intensity studies at Mexico City made by Schremp and Baños indicate the value of this method of studying the bright lines predicted by the atom-annihilation hypothesis of Millikan, Neher, and Pickering. The observed peak seems clearly to be such a bright line, as shown by the shape and slope of the curves at the zenith, and the effect of atmospheric absorption at large zenith angles. However, the agreement with the observations of Millikan, Neher, and Pickering is much more doubtful, as shown by the following discrepancies: The peak comes at too small a zenith angle, and would be observed over too wide a range of latitude. These difficulties are of such a sort as to be readily cleared up by further directional studies.

IN two papers,[1] Millikan, Neher, and Pickering present the atom-annihilation hypothesis of the origin of cosmic rays, which supposes the primaries to arise from the change of the mass of atoms into energy of two particles in interstellar space. This results in what in optics is called a "bright line" spectrum with all the particles occurring at definite energy values. Besides the balloon measurements, they present a few data on vertical intensity variations at ground level in Mexico. The possible error assumed is 2 percent while the changes measured are some 4.8 percent. They interpret their values in terms of a two-step increase in intensity which is possible. But it is equally true that a straight line can be drawn through all their values hitting within the 2 percent error every point except Junction, Texas (magnetic latitude $\lambda = 39.5°$, incorrectly given in II as 38.5°), and this point falls even farther off the broken curve assumed in II.

Particular interest therefore attaches to the ground level measurements of Schremp and Baños[2] on the directional intensities at Mexico City. Despite certain inconsistencies,[3] some of which are pointed out below, some important facts can be deduced from a direct consideration of the curves they give. They themselves point

[1] R. A. Millikan, H. V. Neher, and W. H. Pickering, Phys. Rev. **61**, 397 (1942) (hereafter called I); Phys. Rev. **63**, 234 (1943) (called II).

[2] E. J. Schremp and A. Baños, Phys. Rev. **58**, 662 (1940) (called III); Phys. Rev. **59**, 614 (1941) (called IV).
[3] The N–S and E–W asymmetries near the zenith are in very poor agreement with those found by T. H. Johnson [Phys. Rev. **47**, 91 (1935); **48**, 287 (1935)] at Mexico City.

out the existence of a prominent maximum of positive primaries in the exact direction (20° S of west) in which the theory of Lemaitre and Vallarta[4] predicts the maximum admission. Though the uncorrected theory assigns to these primaries an energy 10 or 11 Bev, the correction for the weakness of the earth's field on this side of the world will bring the value of the energy much closer to that of the oxygen-annihilation band found in II at a latitude not very different from this. Such a peak might represent either a banded or continuous spectrum; this appears to be the former. Since the observations give directly the total intensity from all primaries of energy greater than the critical energy[5] corresponding to the given latitude and direction, the energy distribution $I(E)$ of the primaries must be obtained as the negative derivative of the observed intensity distribution. Now the peak represents an increase of some 2.5 percent per degree from the zenith, or more if an allowance is made for the absorption at the peak. It is clear from the curves that if the same rate of increase continues during the next 12° interval, the absorption of the atmosphere must reduce the intensity by a factor about 100/160 which seems impossibly large. A calculation based on the usual formula [Eq. (85) of reference 5] with the exponent 2.5 gives a weakening of about 15 percent, which is much more easily compatible with a decrease from 130 percent to 100 percent of the zenith intensity, as would be required if the increase ceased with the passage of the peak. A drop of some 30 percent is indeed observed in the NE azimuth.

Such difficulties due to atmospheric absorption are a minimum at the zenith, where the absorption is least and varies most slowly. Hence the clearest indication that the peak does indeed correspond to a bright line of a discrete spectrum are found here. The first of these is the immediate observation that the curves are concave upward at the zenith. Now, of the three factors that determine the intensity variation at the zenith, the absorption of the atmosphere and the directional dependence of the critical energy[4] can only give a curve convex upward. Hence the curve of total intensity must be concave upward at this point, which is just past the high energy edge of the peak. In other words, the peak must represent a sharp step in the total intensity, or a bright line in $I(E)$.

A similar conclusion may be reached by the comparison of the east–west and north–south asymmetries at the zenith. Since the E–W asymmetry is due to the difference of the positive and negative primaries, while the N–S is due to their sum, it is first necessary to consider whether there exist negative primaries, and in what amount. Reference III shows an actual peak at 18° in the east,[6] but this disappears in IV. However, the authors conclude, from a comparison with the NE azimuth, that such a hump, due to negative particles, exists. On the basis of a continuous spectrum, the NE and E curves should fall off most steeply, the N and SE curves next.* The E curve lies above the NE, but the SE does not lie above the N. Hence the indication cannot be considered clear unless there is some influence that would invalidate the north curve. Such an influence might be the presence of the penumbra[7] of the positive particles in the N and NW azimuths. If this invalidates the N curve as a basis for comparison, then the negative peak is present to the extent of about 39 percent of the positive. This will reduce the expected E–W asymmetry by a factor 0.61, and increase the N–S by a factor 1.39, so that the ratio of asymmetries, E–W/N–S, will be decreased to 0.44 of what it would be with positives alone.

The theoretical value for positives alone may best be scaled off from Fig. 7 of reference 4, which gives a value of 2.08 for the ratio E–W/N–S. If there is a penumbra in the north, and hence a negative peak, the ratio would be 0.91. The experimental value of this ratio is somewhat uncertain.[8] As measured from III, it comes out

[4] G. Lemaitre and M. S. Vallarta, Phys. Rev. **50**, 493 (1936).

[5] Cf. T. H. Johnson, Rev. Mod. Phys. **10**, 193 (1938).

[6] The position is precisely symmetrical to the 12° west, with respect to the magnetic meridian, here tilted some 3° east.

* Cf. reference 4, Fig. 7.

[7] The effect of the penumbra may be roughly inferred from the work of R. A. Hutner, Phys. Rev. **55**, 15 (1939); *ibid.* **55**, 614 (1939).

[8] A similar determination of the asymmetries at high latitudes [D. Cooper, Phys. Rev. **58**, 288 (1940), H. S. Ribner, Phys. Rev. **56**, 1069 (1939)] gives, as might be expected, a null result. The agreement between the two high latitude papers is very poor. I am indebted to Dr. L. N. Garlough for the calculation of the correlation coefficient as −0.82, a value which has a probability of 1/30 of being accidental in the small sample available.

2.28; from IV it is 3.57. This difference is largely due to a marked decrease in the slope of the N–S curve, which, however, leaves its shape unchanged. If we consider the later curves more reliable, the discrepancy between 3.57 and 2.08 would make the continuous spectrum theory untenable. If the difference is to be attributed to the penumbra, which would raise the northward intensity and lower the asymmetry ratio, then the negative primaries must be included, and the comparison becomes 3.57 to 0.91. It seems very doubtful that the presence of the penumbra could lower the experimental value of the N–S asymmetry by a factor of four. Hence in either case it is difficult to accept the continuous spectrum as determining the conditions at the zenith.

Having thus determined the existence of a bright line in the primary energy spectrum at Mexico City, the next step is the attempt to identify it with one of those found by Millikan, Neher, and Pickering in II. The nearest line found by them is what they call the oxygen-annihilation band, which sets in sharply at Victoria, $4\frac{1}{4}°$ north of Mexico City, but is not observed at all at Valles, only $2\frac{1}{2}°$ north. The intensities seem to depend greatly on method of measurement and depth (considerably greater in II), and afford little basis for comparison. But the theory[4, 9] gives clear indications of the relation between the latitude and zenith angle effects in these latitudes. The vertical direction would correspond to a rigidity difference of 0.040 stoermer between Victoria and Mexico City, and this would correspond to a zenith angle of some 40° at Mexico City. This is not very close to the observed value of 12°.

Another difficulty is with the sharpness of the edge observed. If the solid angle covered by the balloon telescopes is $25° \times 45°$ ($\frac{1}{2}$ effective), as in I, then at Valles, well north of Mexico City, and where the present peaks must occur at smaller zenith angle, considerable intensity should be observed. This is not found. It will be noted that these discrepancies are of the sort that can largely be straightened out by further studies of the directional effects at different latitudes and atmospheric depths. Such studies clearly would reveal a great deal about the details of the different atom-annihilation bands.

[9] G. Lemaitre and M. S. Vallarta, Phys. Rev. **49**, 719 (1936).

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Cascade Showers in Lead

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Cascade showers of energies up to 500–1000 Mev have been photographed in a cloud chamber that contained eight lead plates. A comparison with theory is made in terms of the size of a shower at its maximum as a function of the total number of particles in the shower. The conclusion reached is that the theoretical cross sections for radiation and pair production are essentially correct for energies up to 500–1000 Mev.

Very few experiments have been performed that allow an experimental verification of shower theory for monoenergetic electrons. Anderson[1] and others have measured the energy loss of electrons in solid plates as a function of incident energy. Recent developments[2] indicate that an interpretation of atmospheric absorption curves in terms of shower theory is considerably obscured by the additional difficulties of separating shower phenomena from mesotron production, etc. Other experiments[3] have involved the average effects of electrons (and mesotrons) of all energies. On the other hand, detailed theo-

[1] S. H. Neddermeyer and C. D. Anderson, Phys. Rev. **51**, 884 (1937); P. M. S. Blackett, Proc. Roy. Soc. **A164**, 257 (1938); C. D. Anderson, Phys. Rev. **57**, 357 (1940).
[2] M. Schein, W. P. Jesse, and E. O. Wollan, Phys. Rev. **57**, 847 (1940).
[3] M. A. Starr, Phys. Rev. **53**, 960 (1938); see, e.g., D. K. Froman and J. C. Stearns, Rev. Mod. Phys. **10**, 133 (1938).