On the Primary Cosmic-Ray Spectrum*

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ON the basis of a series of high altitude rocket experiments during the past several years, we are now able to report absolute directional intensities of charged particles *above the atmosphere* at geomagnetic latitudes 0°, 41°N, 50°N, and 58°N. Table I summarizes *vertical* intensities obtained with G-M tube coincidence telescopes containing about 3 g/cm² of copper.

In addition there may be noted other results obtained by balloon investigators *near* the top of the atmosphere as shown in Table II.

TABLE I. Vertical intensities obtained in rocket flights.

Geomagnetic latitude λ	Experimental vertical intensity $j(0°)$	Geomagnetic cut-off[a] momentum/charge ratio pc/Ze	Reference
0°	0.028 ±0.004/sec. cm² steradian	15.0 Bev	b
41°N	0.073 ±0.006	4.8	c,d
50°N	0.18 ±0.02	2.6	e
58°N	0.29 ±0.03	1.2	e

[a] Derived from the simple Störmer cone. At intermediate latitudes, the effect of the penumbra has been judged to be small from the work of M. S. Vallarta, Phys. Rev. **74**, 1837 (1948). At high latitudes there appears to be no such assurance.
[b] J. A. Van Allen and A. V. Gangnes, Phys. Rev. **78**, 50 (1950).
[c] J. A. Van Allen, Paper No. 53a, p. 195, of Proceedings of the Echo Lake Cosmic Ray Symposium June 23–28, 1949 (ONR, November, 1949).
[d] S. F. Singer, Paper No. 54, p. 206, of Proceedings of the Echo Lake Cosmic Ray Symposium, June 23–28, 1949 (ONR, November 1949); Phys. Rev. **77**, 729 (1950).
[e] Preliminary results of January, 1950 Aerobee flights from the USS Norton Sound, to be reported in full later.

A composite plot of the data of Tables I and II is given in Fig. 1. The plot has been made with momentum-charge ratio (magnetic rigidity) as abscissa because of its generality in relating the intensities of *any* charged component of geomagnetic latitude.

If the atmospheric albedo has a negligible contribution to the experimental vertical intensities, then Fig. 1 exhibits the integral number spectrum (that is, the directional intensity of particles of momentum/charge ratio greater than pc/Ze as a function of pc/Ze) of the primary radiation in absolute units. If the intensity contribution of albedo is in the same proportion to the primary intensity at all latitudes, then Fig. 1 exhibits the *form* but not the absolute value of the integral number primary spectrum.

At any rate, Fig. 1 represents the current status of this type of direct attack, on the determination of the primary spectrum:

(a) Comparing the directly measured intensities with primary intensities deduced from the atmospheric ionization integrals,[1] it is seen that the former are markedly higher at all latitudes.

(b) In the range 2.6 to 15 Bev, our integral number spectrum (see Fig. 1) can best be fitted by $N(>pc/Ze)=0.48(pc/Ze)^{-1.1}$ (sec. cm² steradian)$^{-1}$, corresponding to a differential number spectrum $dN=0.53(pc/Ze)^{-2.1}d(pc/Ze)$. This spectrum is considerably flatter than that hitherto deduced from ionization measurements and other considerations.[2]

TABLE II. Vertical intensities obtained in balloon flights.

Geomagnetic latitude λ	Experimental vertical intensity $j(0°)$	Geomagnetic cut-off momentum/charge ratio pc/Ze	Reference
52°N	0.168 ±0.003/sec. cm² steradian	2.2 Bev	a
52°N	0.20	2.2	b
56°N	0.22	1.5	c
69°N	0.29	0.27	b

[a] M. A. Pomerantz, Phys. Rev. **75**, 1721 (1949).
[b] Deduced from, but not explicitly stated by M. A. Pomerantz, Phys. Rev. **77**, 830 (1950), using geometric factors from reference a.
[c] Deduced from, but not explicitly stated by Winckler, Stroud, and Shanley, Phys. Rev. **76**, 1012 (1949).

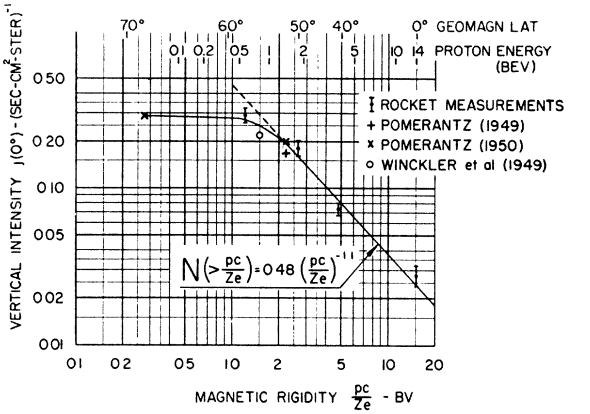

FIG. 1. Vertical intensity of charged particles above and near the "top of the atmosphere" as determined by G-M counter telescopes at various latitudes *vs.* magnetic rigidity for cut-off in the vertical direction as deduced from geomagnetic theory.

(c) A marked flattening of the form of the spectrum appears to occur for rigidities below about 1.5 Bev ($\lambda=56°$). Previously, the Pasadena group[1,3] has been able to show that the latitude effect continues beyond 51°. We feel fairly certain about the change in slope in the vicinity of 56°, but cannot preclude a small rise between 58° and 69°, since atmospheric absorption may have produced an appreciable effect in the balloon measurements at 69°. Clarification of this point can be achieved by a rocket measurement above the atmosphere at high latitude.

Note added in proof.—Dr. Pomerantz informs us in private communication that he interprets his two series of measurements, references a and b of Table II, as in close agreement at 52°, slightly contrary to our deductions from the published curves. His absolute intensity at 69° is thus presumably lowered to about 0.25, a value somewhat less than our intensity 0.29±0.03 above the atmosphere at 58°. Our conclusions remain unchanged.

* Supported by Navy Bureau of Ordnance under Contract NOrd 7386.
[1] H. V. Neher, Paper No. 60, p. 235, of Proceedings of the Echo Lake Cosmic Ray Symposium June 23–28, 1949 (ONR, November, 1949).
[2] L. Janossy, *Cosmic Rays* (Oxford University Press, New York, 1948), pp. 297 ff. D. J. X. Montgomery, *Cosmic Ray Physics* (Princeton University Press, Princeton, 1949), pp. 150 ff.
[3] Biehl, Neher, and Roesch, Phys. Rev. **76**, 914 (1949).

Magnetic Susceptibility of αFe_2O_3 and αFe_2O_3 with Added Titanium

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THE magnetic susceptibility of αFe_2O_3 and αFe_2O_3 with added titanium has been measured at low temperatures and a transition found not previously reported in the literature.

The oxides used were pigment grade αFe_2O_3 analyzing 99.1 percent Fe_2O_3, and rutile T_iO_2. The mixed powders were pressed into bars and sintered in oxygen at atmospheric pressure at 1100°C for 16 hours. The bars were ground to a fine powder in a mullite mortar. Structure and lattice constants were determined both above and below the transition point by x-ray diffraction and found to be those given for αFe_2O_3 by Wyckoff.[1] The magnetic susceptibility was measured by the Gouy method. The field strength of the magnet was measured by a rotating coil and voltmeter calibrated against a permanent magnet whose field strength had been measured by the Bureau of Standards. The powdered sample was held in a glass tube (0.181 cm² cross section) extending out of the field above and below and having a thin glass

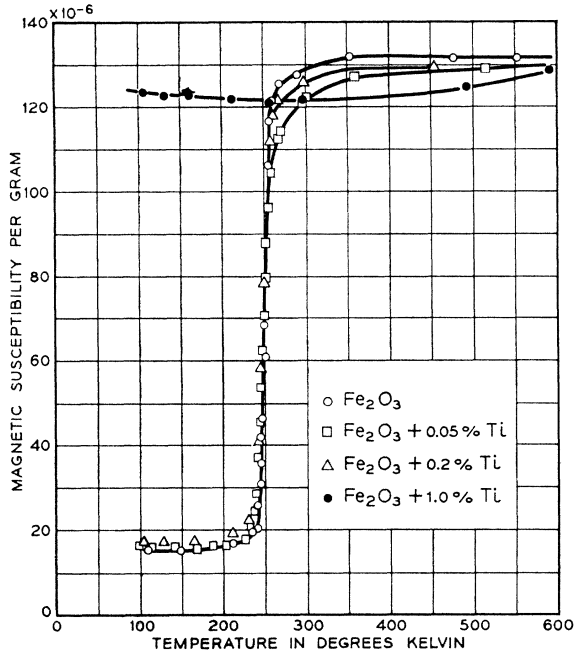

FIG. 1. Magnetic susceptibility per gram as a function of absolute temperature for αFe_2O_3 and αFe_2O_3 with added titanium. The amounts of titanium added are shown as number percent of total metal atoms.

partition at the center. The temperature was measured in the vicinity of the sample with a chromel *P*-alumel thermocouple. The procedure of measurement was to cool the sample to the lowest temperature in zero field and make measurements with increasing temperature, at each temperature point weighing the sample and tube in zero field and in a field of 2000 gauss. A check measurement was also made on αFe_2O_3 while cooling without removing the field. Results were the same as those obtained by the above procedure.

The results are shown in Fig. 1. The presence of ferromagnetism is indicated by the high value and behavior of the susceptibility in the high temperature range. Ferromagnetism was also indicated by permanent magnetization and particle size dependence of susceptibility in the high temperature range. A rough determination of the Curie point of αFe_2O_3 and αFe_2O_3+Ti showed it to be between 660°C and 690°C. Susceptibility above the Curie point was 19×10^{-6}. Reheated the powdered αFe_2O_3 in oxygen at atmospheric pressure for 16 hours at 1100°C and again for 16 hours at 980°C did not significantly decrease the susceptibility. The low temperature susceptibility of samples showing the transition was only slightly field dependent, decreasing from 16.7×10^{-6} to 14.8×10^{-6} for a field increase of from 2000 to 5000 gauss.

No data have been found in the literature for the susceptibility of αFe_2O_3 below 0°C. Above this temperature, a considerable amount of contradictory information is available, which has been reviewed by Selwood.[2] Extensive measurements have been made by Endo,[3] Hayes[4] and Chavalier.[5] Snoek,[6] Hayes[4] and Néel[7,8] have speculated on the cause of ferromagnetism in αFe_2O_3. The Curie point of αFe_2O_3 is about 680°C. Above this point the susceptibility is 19×10^{-6}. The limit of room temperature susceptibility as particle size is decreased is 20×10^{-6}. Acording to Néel, αFe_2O_3 is essentially antiferromagnetic with a weak ferromagnetism superimposed upon the antiferromagnetism. Néel[8] shows that, from the point of view of structure, a narrow region having magnetite structure could exist in a plane perpendicular to the trigonal axis of αFe_2O_3 and introduce a small amount of ferromagnetism. It has been observed by Smith[9] that a single crystal of αFe_2O_3 was ferromagnetic in a direction perpendicular to its trigonal axis but not in the direction of the trigonal axis.

From the data reported here, it appears that αFe_2O_3 is essentially antiferromagnetic, as suggested by Néel, with weak ferromagnetism superimposed upon antiferromagnetism above 250°K. It seems to be energetically preferable for the spins in the ferromagnetic regions to become antiparallel below 250°K except in the presence of a considerable amount of titanium impurity.

[1] Wyckoff, *The Structure of Crystals* (A.C.S. Monograph 19 and 19A), pp. 254, 36.
[2] P. W. Selwood, *Magnetochemistry* (Interscience Publishers, Inc., New York), pp. 220–226.
[3] K. Endo, Tohoku Imp. Univ. Sci. Rep. **25**, 879 (1937).
[4] E. T. Hayes, Bureau of Mines Report No. 3570.
[5] R. Chavalier and S. Mathiev, Ann. de physique **18**, 258 (1943).
[6] J. L. Snoek, Physica **3**, 463 (1936).
[7] L. Néel, Ann. de physique **3**, 137 (1948).
[8] L. Néel, Ann. de physique **4**, 249 (1949).
[9] Smith, Phys. Rev. **8**, 721 (1916).

Superconductivity of Columbium

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IN view of the fact that measurements on the zero field transition of columbium[1–3] have shown widely different values and since $H-T$ data have been obtained only in the liquid helium region,[4] we have investigated the zero field transition, and have measured the $H-T$ curve between 5° and 9°K, of cylindrical specimens of columbium. The material was obtained from Fansteel Metallurgical Corporation with an analysis indicating maximum amounts of titanium, iron, silicon dioxide, and tantalum as respectively 0.002, 0.01, 0.03, and 0.2 percent. The latter maximum figure was dictated by the extreme difficulty of determining the presence of tantalum in columbium when present in amounts less than 0.2 percent. A spectrographic survey of the material by Professor T. I. Taylor of the Chemistry Department of Columbia University indicated traces of iron and molybdenum as the only observable impurities.

In addition, comparison measurements were made on an older sample of columbium which in slow neutron scattering experiments at Columbia[5] had shown evidence of containing 0.4 percent of tantalum. A spectrographic survey in this case indicated tantalum to be present in an amount not greater than 1.0 percent.

The necessary temperatures were obtained by the use of a charcoal desorption cryostat to be described in a forthcoming paper in this journal. Temperatures were measured by means of a helium gas thermometer which was filled to 1 atmos. at 20.4°K. The accuracy of the calculations was checked against observations at the tiple point of hydrogen and at the transition temperature of lead.[6]

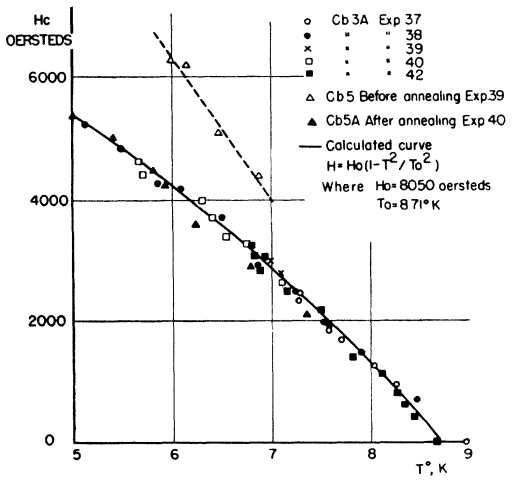

FIG. 1. Magnetic fields at completion of S-N transitions in Cb.