environment surrounding the trivalent manganese ion, each glass temperature producing a different color. A method of studying the constitution of glass is thereby indicated.

If glass is solarized at room temperature and then heated for a sufficient period in a closed furnace, the wave-length of maximum absorption again shifts to the equilibrium values. The solid circles in Fig. 1a show the shift produced by such heat treatment; good agreement exists between them and the open circles which represent irradiation changes produced by ultraviolet light on glass at these temperatures.

Electric Quadrupole of the Earth

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THE electromagnetic spectrum of a conducting sphere contains four sets of modes, two each of the electric and the magnetic type.[1] The high frequency modes[2] have finite complex frequencies even when the conductivity of the sphere becomes infinite; their field energy resides primarily in the dielectric outside the sphere. The low frequency modes[3] are aperiodic in the approximation in which the displacement current is neglected. They represent the exponential decay of a current system left to itself; their field energy resides largely inside the sphere for the modes of the magnetic type and almost exclusively so for the modes of the electric type.

In two recent papers[4,5] the vectors giving the field distribution of the aperiodic magnetic modes have been used as an orthogonal system for the development of those more general vector fields which appear when the fluid inside the earth's metallic core is in motion. Further study has shown that the solution of the problem given is as yet incomplete: Through the action of the fluid motion the magnetic modes are coupled to the modes of the electric type, and since the aperiodic electric modes are legitimate solutions of Maxwell's equations, it seems a valid inference that inside the earth's core there exists a magnetic field that can be developed into a vector series of the electric modes. This magnetic field is orthogonal to the ordinary field.[1,4]

The field vectors for the aperiodic electric modes in the interior of the sphere are obtained by merely interchanging the expressions for the electric and magnetic field strength valid for the magnetic modes (given in I), with a suitably adjusted constant factor for each. Outside the sphere there is an electrostatic field; the magnetic field at the outside vanishes. There is a surface charge at the boundary. The boundary conditions lead to the discriminant equation

$$F_{n+\frac{1}{2}}(kR)=0,$$

where R is the radius of the sphere and where k is related to the decay constant exactly as in (30) of I. A derivation, in many respects more satisfactory, of these modes is obtained by starting from a solution which contains the displacement current and letting the latter go to zero.[1] It is not possible, in practice, to detect these modes by measurements outside the core since the magnetic field vanishes and the electrostatic field corresponds to potentials of a few millivolts only.

A survey of the coupling terms caused by fluid motions in the metallic sphere shows that the dipole terms of the magnetic modes are almost exclusively coupled to the quadrupole terms of the electric modes, and *vice versa.* It would therefore appear that the quadrupole field predominates among the modes of the electric type to a degree comparable to the predominance of the dipole field in the magnetic modes. Again, as has been frequently pointed out in I and II, the coupling matrix is not symmetrical, that is, an interaction in one sense between two modes is not, in general, equal to the interaction between the same two modes in the opposite sense. The interaction between the magnetic dipole as the primary and the "electric" quadrupole as the secondary is direct and intense, but this does not apply to the reverse interaction. The latter vanishes, in fact, when everything, the field as well as the fluid motion, has rotational symmetry. There is, however, an interaction from the quadrupole as the primary to the dipole as the secondary when tesseral harmonics are involved. This means, physically, that such a coupling is produced when the pattern of the fluid motion, being inclined relative to the earth's axis, carries out a precession about the latter.

It is a particular feature of the electric quadrupole mode (and of higher modes of even order in n) that it can be produced by an electromotive force acting inside the conducting sphere. To be specific, let us admit, for instance, that the seat of this e.m.f. is at the internal boundary of the core which, from seismic observations, is found at about 0.36–0.40 R and which, in all probability, separates the iron above from the heavier metals below.[6] The active e.m.f. is not simply a potential gradient across the boundary, but is the variation of such a gradient from the polar to the equatorial regions. If such a differential potential gradient exists, it gives rise to an electric current that flows, for instance, from the polar to the equatorial regions in the upper stratum and in the opposite direction in the lower stratum (or *vice versa*). This electric current system produces magnetic lines of force which are closed, and circular, and the magnetic field strength is of opposite sign in the two hemispheres. It is readily seen that this configuration has the symmetry of a quadrupole of the electric modes.

In order to estimate the magnitude of such an e.m.f. in relation to the actual magnetic field of the earth, we may assume that the external dipole field can be extrapolated downwards to the depth of the boundary mentioned. Assuming that the dipole and quadrupole magnetic fields are of the same magnitude there, and using the values of the conductivity from I and II, the corresponding e.m.f. is found to be of the order of 20 millivolts. If one assumed that all the magnetic energy is ultimately supplied from such a source, the primary voltage would probably have to be several times larger than this value. Such voltages seem excessive for the rather quiescent interior of the earth; but speculations of this type are no doubt premature. On the other hand, the introduction of the electric modes raises a number of questions regarding their interaction among themselves and with the magnetic modes in the presence of fluid motions, and these questions are capable of a formal solution without the introduction of further hypothetical elements.

[1] P. Debye, Ann. d. Physik **30**, 57 (1909).
[2] J. A. Stratton, *Electromagnetic Theory* (McGraw-Hill Book Company, Inc., New York, 1941), pp. 559–560.
[3] W. R. Smythe, *Static and Dynamic Electricity* (McGraw-Hill Book Company, Inc., New York, 1939), Chap. 11.
[4] W. M. Elsasser, Phys. Rev. **69**, 106 (1946), quoted as I.
[5] W. M. Elsasser, Phys. Rev. **70**, 202 (1946), quoted as II.

Investigation of Auger Showers by the Proportional Counter Method

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THE main experimental results obtained by us in the fall of 1944 at 3860 m above sea level in the Pamir Mountains, U.S.S.R. (Middle Asia)* are set forth in this Note. Data on Auger showers which are available at present are based on the application of two complementary methods—the coincidence method[1] and ionization chamber method.[2]

This latter method (observation of ionization bursts) permits one to select showers exceeding a given size and this in turn yields (by means of the cascade theory) direct evidence concerning the energy spectrum of the primary shower-producing particles. However two essential limitations must be taken into account in this case.

First of all ionization bursts in thin-walled chambers can be produced not only by Auger showers but by heavily ionizing particles as well.

Secondly, when only a few particles of the observed showers pass through the cross section of the chamber, fluctuations of the number of particles can considerably distort the size distribution curve for bursts. Both of these factors can be overcome if instead of ionization pulses in one chamber we register coincidences caused by these pulses in two chambers arranged in a horizontal plane at a given distance from each other. Under these conditions heavy particles are not counted while fluctuations, as calculations show (D. Skobeltzyn), do not play any appreciable role (even when pulses caused by only two particles in each chamber are recorded).

In the present investigation which was carried out in the open air we employed instead of ionization chambers two trays of proportional counters, the latter being connected in parallel; the tube circuit and experimental method used by us was developed in this laboratory by Professor Veksler.

Each of the trays consisted of 6 proportional counters filled to atmospheric pressure with argon, the total area being $\sigma = 700$ cm^2 (the thickness of the aluminum counter walls was approximately 0.2 g/cm^2). Pulses from each of the trays were fed to a linear amplifier coupled to a multivibrator. The threshold of the multivibrator was regulated by negative bias on the grid of the first tube in each of the channels. The tubes which selected the double coincidences ($\tau = 2.85 \cdot 10^{-5}$ sec.) were placed after the multivibrator and therefore coincidences were recorded only when the linearly amplified pulses in each channel exceeded the multivibrator threshold. By keeping the latter constant and varying the amplification it was possible to vary the minimum amount of ionization in each of the counter trays necessary for registration of the pulses.

During the measurement the gas amplification factor remained constant. In order to determine this latter quantity, and thus to calibrate the apparatus, pulses due to α-particles from Po were used.

The magnitude of the ionization pulse (I) caused by a shower is proportional to the number of particles traversing the given counter tray: $n = I/i_0 l$, where l is the mean path of the particle in the counter (0.8 of the counter diameter) and i_0 is the "probable specific ionization" (75 ion pairs per cm of argon).

A definite particle density of the recorded Auger shower $\rho = n/\sigma$ and a definite average energy** of the primary particles correspond to this n.[4]

The dependence of the number of double coincidences per hour (after subtracting the accidental coincidences) on $n_{\min}$ or $\rho_{\min}$ are given by the curve in Fig. 1 (ν is the integral number of councident bursts of size exceeding $n_{\min}$). Within the investigated interval the dependence of ν on the sensitivity of the recording system (which is proportional to $1/n_{\min}$) turned out to be approximately linear.

The circles on the curve denote the results obtained by Auger[1] at an altitude of 3500 m by using a counter-controlled cloud chamber which is essentially equivalent to an ionization chamber in respect to registration of bursts due to showers (ν is the number of expansions per hour; n the number of tracks).[3]

Auger's cloud chamber data are in satisfactory agreement with our results obtained with proportional counters as concerns the order of magnitude of ν. On the other hand, it should be noted that there is a serious discrepancy between our results and those obtained by using ionization chambers (see the dotted lines, Fig. 1) not only in respect of the absolute number ν but also in respect of the dependence of ν on $n_{\min}$ ($\nu \sim (1/n^2_{\min})$ in the case of ionization chambers).

Calculations based on the cascade theory ($\rho \sim (1/r^{2-S})$)[5]*** show that for a power energy spectrum of the primary particles of the form $dF = (A/E)(dE/E)$ (where dF is the

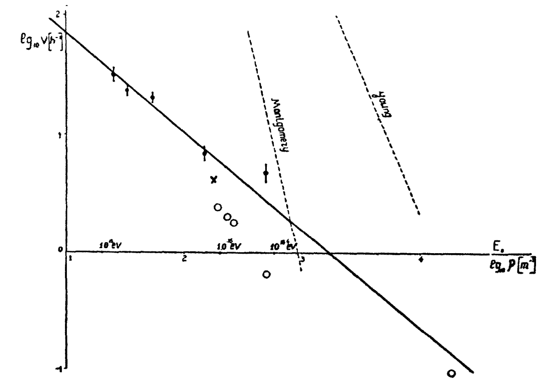

FIG. 1. Continuous curve—logarithm of frequency (ν) of Auger showers *versus* logarithm of density ($\rho_{\min}$) according to data of coincidences in two trays of proportional counters. Broken line—size-frequency curve of bursts in ionization chambers.