exhausted and sealed. During operation it was kept at a temperature of 130°.

The continuous spectrum was at first attributed to the arc and much time was wasted in an attempt to improve the black background. That it was fluorescent light was proved by inserting a strip of dense cobalt glass between the arc and the tube: this absorbs the region between 4358 and 4915, and since no reduction of the continuous background was found, it was clear that fluorescence was present. Having heard reports that traces of nitric acid had been found in heavy water, a small amount was made alkaline with NaOH and distilled *in vacuo* in an inverted U tube at room temperature with the condenser end in ice. The fluorescence was still strong and as it was suspected that it was excited by 3650 a strip of noviol glass was substituted for the cobalt. This greatly reduced the continuum and the pair of Raman lines came out with sufficient contrast to permit of measurement. As the spectrograms were made with a short focus Steinheil portrait objective (F 2.5) no claim of great accuracy is made.

The $\Delta\nu$ values for liquid and vapor are as follows:

	Vapor	*Liquid*
H^2OH^1	2674	2623
H^2OH^2	2601	2517

Cross and Van Vleck calculated 2720 for H^2OH^1.

No trace of the line of longer wave-length for H^2OH^1 appeared on the plate. The water was supplied through the kindness of Professor Taylor of Princeton.

R. W. Wood

The Johns Hopkins University,
April 23, 1934.

Magneto-Resistance of Bismuth Films at Low Temperature

In measuring the temperature dependence of magneto-resistance in bismuth I have recently used films from 0.1μ to 4μ thick. These were produced by evaporation in a vacuum (*ca.* 10^{-5} mm Hg) onto thin mica strips under as nearly identical conditions as possible. All were of the same surface dimensions, 5 mm wide and 15 mm long. The resistance was measured by a Wheatstone bridge arrangement, current parallel to the long side of the film, field (*ca.* 16 kilogauss) parallel to its surface. Measurements were carried out at two temperatures, +20°C and −180°C, the upper temperature being kept down to avoid possible recrystallization and oxidation. Since the interest lay in the temperature variation, the usual procedure was departed from by plotting the ratio $[\Delta R_{-180}/\Delta R_{+20}]$ where ΔR_t refers to the change of resistance in the magnetic field at temperature t. If, as is usually supposed, the ratio $\Delta R/R$ for polycrystalline bulk material, at a given temperature and field, is a characteristic of the metal then it is readily seen that the above ratio is likewise characteristic thereof. The film thickness was determined in the usual manner by weighing.

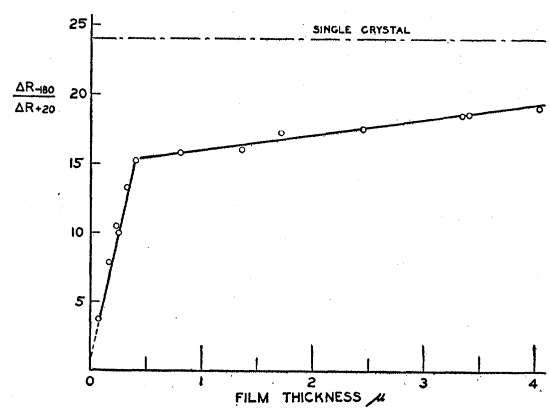

Fig. 1.

The results are shown in Fig. 1. It is seen that a definite discontinuity occurs in $[\Delta R_{-180}/\Delta R_{+20}]$ as a function of thickness somewhere below 1μ. If the inverse ratio $[\Delta R_{+20}/\Delta R_{-180}]$ had been chosen for plotting, the curve would resemble the familiar resistivity-thickness relation for thin films. That is to say, when the resistivity is large the magneto-resistance ratio here plotted is small, and *vice versa*. The dotted line represents the value deduced from Stierstadt's results[1] for a large single crystal of the $P_1{}^{\perp}$ type (H in (111) $\perp i$). This particular crystal type is chosen for comparison because other observers report that evaporated bismuth films have a fiber structure with the principal axis perpendicular to the plane of the film.

The following possible explanation of these results is offered. Ehrenfest and Raman[2] have suggested that the large diamagnetism of massive bismuth is due to electrons moving with long free paths in definite crystallographic planes, the paths being limited in length by a secondary structure in the crystal. The liquid metal has a much feebler, temperature independent, diamagnetism because such long free paths have disappeared. Experiments on colloidal powders by a group of Indian physicists and on single crystals by Goetz and his collaborators have tended to support these hypotheses. Now there is every indication that the electrons responsible for this diamagnetism are intimately associated with the phenomena of change of resistance in a magnetic field.[3] For very small particle sizes the free paths should be shorter than in metal with normal secondary structure, the metal should behave more nearly as the liquid does, i.e., should show temperature independence of the susceptibility and temperature independence of the magneto-resistance.[4] Now it is generally supposed that a thin film is "colloidal" in character—the average particle size being smaller, the thinner the film.

[1] Stierstadt, Zeits. f. Physik **80**, 636 (1933).
[2] Raman, Nature **124**, 412 (1929).
[3] de Haas, Nature **127**, 335 (1931).
[4] Berndt, Ann. d. Physik **23**, 932 (1907).

On this basis we explain the form of the resistivity-film thickness function. Hence from what has been said above we should expect the magneto-resistance to approach temperature independence ($[\Delta R_{-180}/\Delta R_{+20}]\rightarrow 1$) as the film thickness approaches zero. Further a discontinuity in the temperature dependence should occur as soon as the average particle size falls below that of the unit of the secondary structure. Both these effects are seen to occur.

The widely suggested view in the literature that thin films are "amorphous" is not supported by these experiments. All the films examined were found to have directional properties in the magnetic field and these properties were consistent with the expected fiber structure mentioned previously.

If the above explanation be correct, then we should find that the magnetic susceptibility of colloidal powders should approach temperature independence as the particle size is reduced below the critical size. To my knowledge no observations on this point have been published.[5]

Finally, I should like to record my thanks to Professor L. W. McKeehan for his interest and advice in this work.

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April 23, 1934.

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[5] There is, however, an old observation by Owen (Ann. d. Physik **37**, 657 (1912)) wherein he has measured the temperature variation of the susceptibility of supposedly colloidal bismuth. The temperature variation does appear to be less pronounced than for the massive material.

Collision Problems and the Conservation Laws

In a recent letter to the *Physical Review*, Synge[1] has suggested a graphic method of determining the implications of the relativistic conservation laws in collision problems.

Other than to distinguish between when it is zero and different from zero, Synge's scheme makes no reference to rest-mass; it also omits consideration of the effect of an electromagnetic field; the results given by his method are therefore by no means final.

It is not difficult to include the rest-mass within Synge's scheme; but a transition to a different space seems theoretically desirable. Instead of Synge's Minkowski space of coordinates x, y, z, ct, it seems more logical to represent the momentum-energy, p_x, p_y, p_z, E, of a particle as a radial vector[2] in a space whose coordinates are values of momenta and energy. Such a space is really the dual of a tangent space of the general relativity theory and has interesting properties that I hope to discuss more fully elsewhere. Since its metric can be taken as the same as that of the Minkowski space, Synge's diagrams and deductions will be unaltered when transplanted to this new space.

The rest-mass, m, is given by the well-known equation

$$E^2/c^2-p_x{}^2-p_y{}^2-p_z{}^2=m^2c^2,$$

and from this it is evident that if the rest-mass of a particle is conserved, its representative vector must always terminate on a certain hyperboloid, depending on m. In an elastic collision of elementary particles, therefore, in which matter is neither created nor destroyed, each representative vector always terminates on its own hyperboloid; but in a collision of the second kind, since the excitation energy adds to the rest-mass of the particle excited, the above restriction is somewhat relaxed. And when creation or annihilation occurs, it is completely relaxed; yet the hyperboloids retain a real significance. For example, let us consider the collision of two photons to produce two particles of matter, and, for simplicity, let us use only the two dimensions p_x, E in the diagram. Since a suitable Lorentz transformation can always give the two photons the same relative energy, we may represent them by the vectors OL_1, $OL_2(OK=h\nu)$, lying symmetrically on the "light-cone" of the $p-E$-space. Let us assume that only particles of electronic rest-mass may be materialized and let the hyperbola shown correspond to this rest-mass. Then, if L_1L_2 meet the hyperbola in P_1 and P_2, OP_1 and OP_2 must represent the precise momenta and energies (and thus also the rest-masses) of the products of the collision. That this is so is evident from the conservation laws which, as in Synge's case, require the resultant vector of

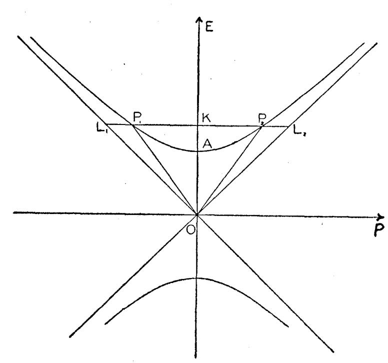

FIG. 1.

the system to remain constant. But since L_1L_2 will not always intersect the hyperbola, it follows that there is a minimum frequency, depending on OA, below which materialization of particles of electronic mass cannot occur in a collision of this type.

Synge's deductions, and the above, are valid in the absence of an electromagnetic field, but when such a field is present it would seem that almost any result of a collision is possible! For example, a *single* photon "striking" a potential hill can produce two material particles, despite the impossibility of combining two vectors lying within the light-cone of the figure to produce a resultant vector

[1] J. L. Synge, Phys. Rev. **45**, 500 (1934).

[2] A point would be preferable, but less graphic.