of the order of 10° for the difference between the two Curie points, supposing that the second Curie point could be qualitatively explained on this sort of basis. The experimental value for the common magnetic materials is about 20°. However, a paper by Forrer[7] seems to show that hysteresis is required to account for the existence of two Curie points.

Conclusion.—The fact that our method, which takes account of one-half the interaction rigorously, gives results comparing closely with those of the simple Heisenberg theory, but differing widely from the result of the use of the Gaussian distribution, seems to indicate that the simple approximation is better than the Gaussian one. The order of validity of the simple approximation is perhaps as good as that of the other assumptions of the Heisenberg theory, except at low temperatures.

In conclusion the author wishes to thank Professor J. H. Van Vleck for suggesting the problem and for many helpful discussions.

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ELECTRICAL CONDUCTANCE OF SHORT GAPS IN AIR

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Communicated August 12, 1935

The transition between an open circuit and electrical contact is generally considered to be abrupt. Yet it seems reasonable that if a gap could be closed gradually enough, there would be a continuous change from open circuit to good contact. Conduction through short gaps usually has been investigated[1] for cases in which the width of the gap is of the order of several wave-lengths of visible light. Very great potential differences are needed to produce measurable currents under such conditions, making it essential to use high vacua for the experiments, as otherwise gaseous discharges occur. It is the purpose of this work to study the dependence of conductance upon gap width under ordinary laboratory conditions (such as obtain for switch contacts in air).[2] To prevent sparking at high field intensities, potential differences are used which are below the ionizing potential of the common gases of air. The use of such small potentials makes it essential to use exceptionally short gaps if the currents obtained are to be capable of measurement, even with modern direct current amplifiers.

In this research the gap considered is effectively that between a sphere and a plane. Assuming that the conductance falls off very rapidly as the gap width increases it can be shown by calculation that the conductances of very short gaps of this type of equal minimum width are proportional to

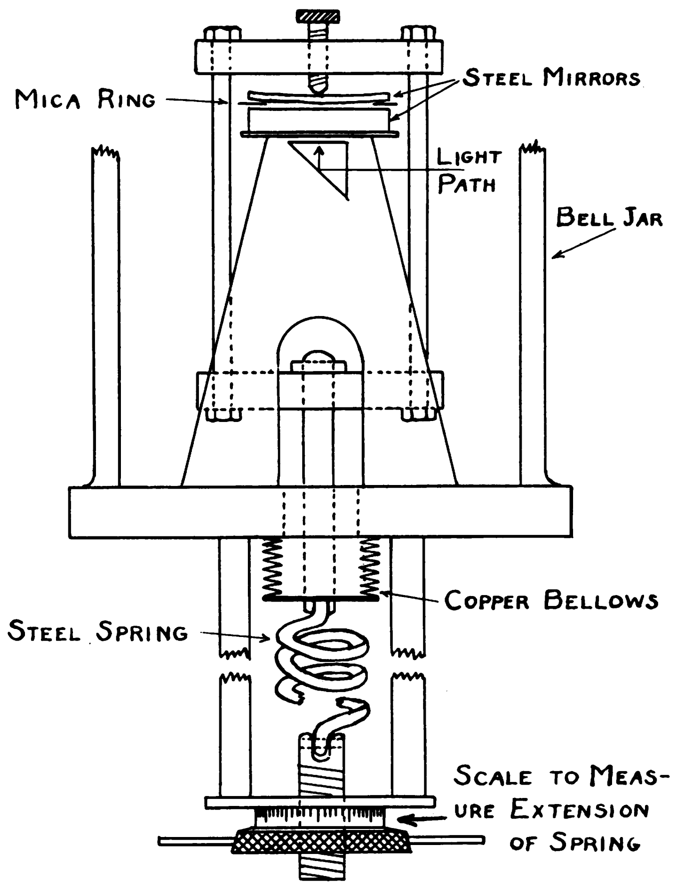

FIGURE 1
Apparatus used to bring two nearly flat surfaces into gradual contact.

the radii of curvature of the spherical surfaces. Three experimental arrangements were used in which the radii of curvature of the spherical electrodes were approximately 14×10^2 cm., 14 cm. and 25×10^{-4} cm. Although the surfaces used in the present work were not rigorously dust-free, all ordinary precautions to remove dust were taken, and it is felt that the results represent what may be expected to occur when ostensibly clean metallic surfaces are brought into contact under everyday laboratory conditions.

One of the experimental arrangements consisted of a gap between a circular stainless steel mirror (plane to within $^1/_{10}$ wave-length of sodium light and 6 mm. thick) and a thin stainless steel mirror (polished plane to within one wave-length and 2 mm. thick); the latter being loaded at the center. The thin disc was supported above the other by a very thin ring of mica as shown in figure 1. The mirrors were 4.0 cm. in diameter and the hole in the mica ring was approximately 3.2 cm. in diameter. The load on the upper disc was applied by means of a stretched spring to avoid the

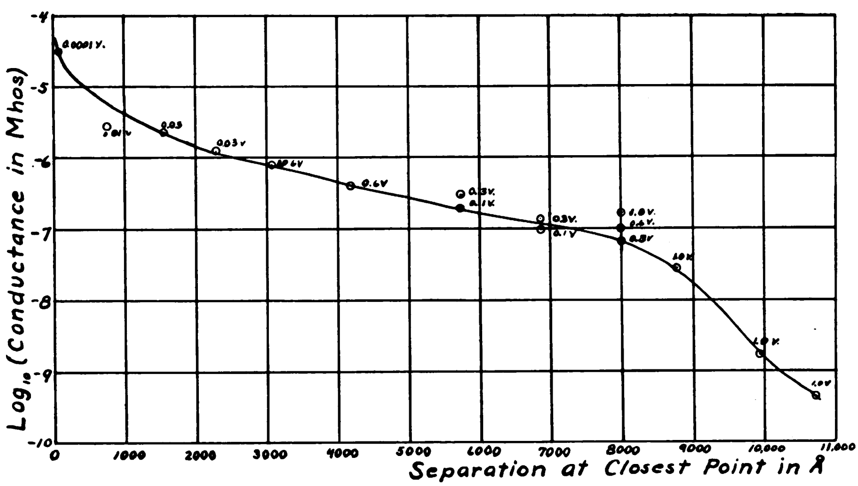

FIGURE 2

Conductance of an air gap between a plane and a sphere of 1430 cm. radius. Since the conductance varies somewhat with the applied potential difference, the latter is indicated at the right of each point. The curve is drawn approximately through the points representing the conductance at the smallest potential difference which would yield accurate measurements.

seismic effects of a direct load. Provision was made for covering the apparatus with a bell jar and for evacuating.

The bending of the upper disc was calibrated by observing interference fringes produced when the lower steel disc was replaced by a heavy piece of optical glass.

It was found that with a separating mica ring thin enough to show interference colors, the two plates acted as though they were in contact. With larger thicknesses of mica, contact occurred only when the upper disc was loaded. As contact was approached by loading, the conductance of the gap gradually increased. A fairly typical graph of the variation of conductance with distance of minimum separation is shown in figure 2.

The separation is considered to be zero when the conductance of the gap no longer changes appreciably with increasing load. Since conductance varies somewhat with applied potential difference, the potential difference for each point is recorded. A curve is drawn through points for which the applied potential difference was just sufficient to allow current measurements to be made. In its essential features, such a curve could be duplicated at will. The exact location of points changed somewhat upon prolonged application of the potential difference or even upon standing. Very much the same conductance values were obtained when a bell jar was placed over the plates and a vacuum of approximately 0.01 mm. of mercury maintained for several days.

Tests for the validity of Ohm's law were made at various separations. For large separations the current is approximately proportional to the square of the voltage. At about 8000 Å where the change of slope of the curve in figure 2 occurs, there is a region in which the current is nearly proportional to the three-halves power of the voltage. Below approximately 2000 Å, Ohm's law holds to within the accuracy of the measurements (about 5%).

An attempt was made after two years to repeat these measurements using the same steel mirrors. In the meantime several small scratches had developed. In general a curve of the same shape was obtained except that the points were very much more irregular. The change in minimum separation from the point at which the current just became perceptible to that of contact was only about one-fourth as large as in the earlier work.

A second set of observations was made using an entirely different type of apparatus in which the radius of curvature of the spherical electrode was about 14 cm. In this apparatus, by means of a compound lever a highly polished steel spherical electrode could be brought very gradually into contact with a stainless steel mirror (plane within a few wave-lengths). One division on the adjusting dial corresponded to a change in separation of 135 Å. The plane steel mirror was supported at three points and could be replaced by a plate of optical glass. The movement of the spherical electrode could therefore be calibrated by means of interference fringes. Electrical measurements were made in the same manner as in the loaded disc experiment and contact was assumed when further turning of the dial produced no further increase in current at a constant very small potential difference. In addition to the conductance measurements, it was possible to make *a direct comparison* of the position of optical contact and the position of electrical contact. These occur within 5000 Å of one another. Leaving the dial of the lever system at the same setting, it was possible to lift the steel mirror from its three-point support and replace it so that a new point on the same plane mirror was used to form the gap. The surfaces were always wiped off very carefully with lens paper before running a conduction experiment. The drawing of a narrow strip of lens paper between the surfaces when they are nearly in contact was tried, but it did not seem to have any effect on the results.

By replacing the steel plate by an optical flat at the close of a conduction

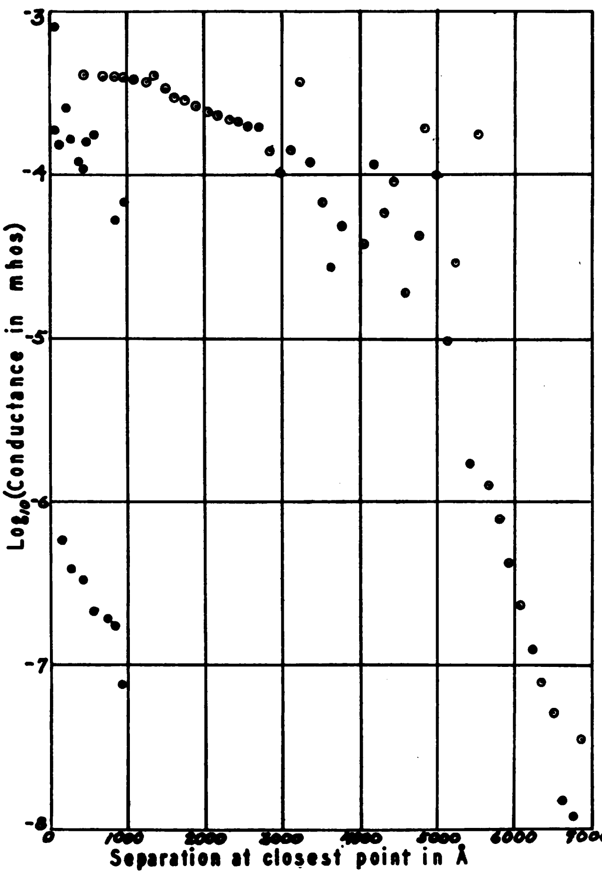

FIGURE 3

Conductance measurements of an air gap between a plane and a sphere of 14 cm. radius. The erratic series of points (circles with dots) was obtained with a newly prepared surface. Subsequent measurements with same surfaces yielded points indicated by circles with crosses in them and by the filled-in circles.

experiment, the region on the spherical electrode where contact occurred could be located by the interference method. Thus a minute inspection is possible of the region where the electric forces were the strongest. Such inspection revealed that the surface was not the same after the experiment as it was at the beginning of the experiment. In each instance there were disturbed places, visible as darker areas in the interference pattern, approximately two microns wide and four or five microns long. When a spot on the spherical electrode was thus used up, a fresh spot could be used in the next experiment by tilting the three-point support and thus changing the point where the spherical surface was tangent to the plane.

Representative points showing the dependence of conductance upon gap width in this experiment are shown in figure 3. The long and extremely erratic series of points illustrates what was usually obtained when a newly prepared surface was used under scrupulously clean conditions. As the mirror was used, the repetition of the experiment gave successively more abruptly rising curves plotted between conductance and gap width. The more abrupt series of points were sometimes fairly reproducible, but the long, erratic ones never were. The change in the nature of the results as the mirrors were used may have been due to the production of sharp prominences on the surfaces by the destructive action of the electrical and mechanical factors which affected them. It is to be remembered in interpreting these points that the gap width was measured from some arbitrarily chosen point where the electrical conduction became very good. Thus, it may be that the gap widths quoted in figure 3 represent, not the separation of the general level of the surfaces, but the distances between conducting projections on either or both surfaces.

In the experiments using the lever, there were many abrupt changes in conductance as the separation was changed. This is to be ascribed to the breaking down of conducting bridges, possibly from mechanical causes and possibly from being burned up by the heating effect of currents that passed through them.

The electrical properties of a gap consisting of two wires of equal diameter crossed at right angles are the same as those of a gap between a plane and a spherical electrode of the same radius as that of the wires Fine tungsten wires were mounted on the opposite sides of the slow motion end of the lever system described in the previous paragraphs. The wires were stretched between supports 0.1 cm. apart. An estimate of the forces exerted transversely to the wires by the largest fields used is 0.1 dyne. This force would be sufficient to cause a displacement of the wire of not more than 25 Ångström units, assuming it is under a tension of 100 gram weights. The diameter of the wires used was 0.002 in.

The small radius of curvature of the electrodes in this experiment reduced very greatly the area over which the surfaces were very close as they approached contact. This change practically eliminated the averaging of the effect of foreign particles scattered over the surface. The result was that the system passed from an open circuit condition to electrical contact in a very abrupt manner. In fact, this change occurred in a distance shorter than the least which could be measured on the lever system used in these experiments. It is therefore impossible to present any conductance-gap width graph for this type of gap. It can be said with certainty, however, as a result of this experiment, that if there was any conductance through the short gaps which was not due to foreign particles or to bridging, such conductance per unit area did not exceed one reciprocal ohm per square centimeter for a gap as narrow as 2×10^{-6} cm. A conduction curve for any gap narrower than this would be subject to serious criticism, as very little is known about the smoothness of any type of polished surfaces within such fine limits.

As a result of these experiments the conclusion may be drawn that appreciable electrical current can pass between surfaces of approximately 4 cm. diameter which are separated as much as 10,000 Å in air. The fact that at such a distance the current is approximately proportional to the square of the applied potential difference leads one to believe that charged dust particles in the air are playing the same part that ions do in solutions. It is thought that the dust particles become charged at one electrode, are drawn over to the other and become discharged or charged oppositely and thus return to the first electrode to repeat the cycle. Such a process seems to take place even if all ordinary precautions are taken to exclude dust from the space between the surfaces or even if the electrodes are placed in a bell jar and the air pressure reduced to 0.01 mm. of mercury for several days. In the present experiments, it seems that when the nearly flat electrodes are brought closer together some of the current is carried by invisible prominences which touch each other. In this way one can account for the fact that gradually the relation between current and voltage changes from an ionic one to an ohmic one. At very small separations the current is definitely ohmic and is probably caused by metallic bridging.

The writers are happy to take this opportunity to express their appreciation for a research grant for this work from the Bache Fund of the National Academy of Sciences.

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