# ELECTRIFICATION BY IMPACT.

BY HAROLD F. RICHARDS.

SYNOPSIS.

*Electrification by Impact; Measurement of the Charge Produced by Collision between a Metal and a Dielectric.*—After briefly discussing the unsuccessful attempts which have been made to formulate a satisfactory theory to explain electrification by friction, the author suggests that impact of dielectric upon metal, without sliding friction, may cause an electrical effect whose laws will shed light upon the frictional phenomenon. An apparatus is described for measuring the electric charge produced when a disc or sphere of dielectric material collides with a metal disc. The charges obtained in this manner ranged from 0.16 to 9.83 e.s.u., and produced potentials of 2.41 to 183.8 volts upon the metallic systems employed. These charges are of the same order of magnitude as those obtained by friction. The experiment was performed with *various metals and dielectrics*, and in every instance the metal received a positive charge. In no case was there any evidence of the erratic variation which others have found to be characteristic of electrification by friction. Curves are given which show the *variation of charge with velocity of impact* and with the *mass of the impinging system*. The charge produced by a single collision increases with each of these factors, but the velocity of impact was found to exert a greater influence than the mass of the moving body, in determining the amount of the charge. In certain cases velocities were attained at which the electrification due to a single impact reached a maximum value.

*Relation of Charge to Capacity.*—The quantity of charge produced by a given collision was shown to be independent of the capacity of the metallic system.

*Effect of Repeated Impacts.*—When many impacts were performed in rapid succession, the amount of charge increased to a maximum. This maximum was shown to be conditioned rather by the quantity of charge present upon the dielectric than by the potential of the metal anvil.

*Discussion of Results.*—The author concludes that there is no direct dependence of the electrical energy upon the mechanical energy lost in impact, and that electrification by impact is similar in nature to the contact effect between metals. The results are considered to support Helmholtz's theory regarding the nature of electrification by friction.

## I. INTRODUCTION.

THE very meager quantitative results and theoretical study of electrification by friction have prevented the formulation of a satisfactory theory to explain the phenomena involved. Perhaps the most important work in this field is that of Owen,[1] who finds many indications that the effect is similar to the contact difference of potential between metals, thus agreeing with Helmholtz.[2] The latter had previously suggested that the function performed by the frictional work is

[1] Phil. Mag., XVII., p. 457 (1909).

[2] Wissenschaftliche Abhandlungen, Erster Band, p. 860.

merely to bring the molecules of the two substances into closer contact. Owen concludes that, with a sufficient amount of frictional work, the charge reaches a constant maximum, and that this maximum is attained with a smaller amount of work the greater the pressure between the rubbing surfaces. He notes further that less work is required to produce a given charge if contact is improved by a series of rubs. Jones,[1] however, definitely rejects these views, as is shown by the following quotation from his paper: "Frictional electricity appears, therefore, to be an effect of a different order from that of contact electricity, and it is worth while considering whether the facts cannot be accounted for on some other hypothesis." He assumes that the rate of production of charge is proportional to the rate at which work is performed, and explains the fact that the charge reaches a maximum value by assuming that back-leakage occurs in an amount proportional to the total charge present. It is difficult to see how this theory can account for the fact that one substance remains positive with respect to another, a phenomenon which is readily explained by the theory of Helmholtz. Thus, in spite of attempts to formulate a consistent theory, no great success has been attained, because the data of electrification by friction remain essentially erratic. This is abundantly shown by the experiments of Owen and Jones, and also by the later work of French[2] and McClelland and Power,[3] who find that not only the amount, but even the sign, of the charge varies with the conditions to which the rubbing surfaces are exposed before an experiment.

The present work was therefore undertaken to find what electrical effect would be produced by intimate contact, *without friction*, between metals and dielectrics. Both Owen and Jones have found that mere contact of such substances does not produce a detectable amount of electrification, but it is probable that the contact in their experiments was not such as would bring the surfaces sufficiently close together to furnish an adequate test. It was my belief that the more intimate contact produced by collision might cause an effect whose laws would shed light upon the nature of electrification by friction. It seems evident that the more definite nature of a single impact at a known velocity will give to the data of such an effect a greater consistency than that which characterizes the results of electrification by friction.

[1] Phil. Mag., XXIX., p. 272 (1915).
[2] Phys. Rev., IX., No. 2, p. 151 (1917).
[3] Roy. Irish Acad. Proc. 34, Sect. A, p. 40 (1918).

## 2. Apparatus.

The apparatus used in the first experiments is indicated in Fig. 1. An ebonite disc *E* fits firmly into a brass socket attached to the lower end of a brass tube *A* sliding in a cylinder *D*. *A* is 2.5 cm. outside diameter, 17.5 cm. long, while *D* is 3.1 cm. inside diameter and 35 cm. long. The sliding tube is provided with studs to form a three-point contact at top and bottom, and these were carefully machined so as to permit free fall with minimum lateral freedom. Uniformity in bore of the stationary cylinder, the low-friction close-fitting contact of the bearing studs, and the relatively large ratio of the length of the falling

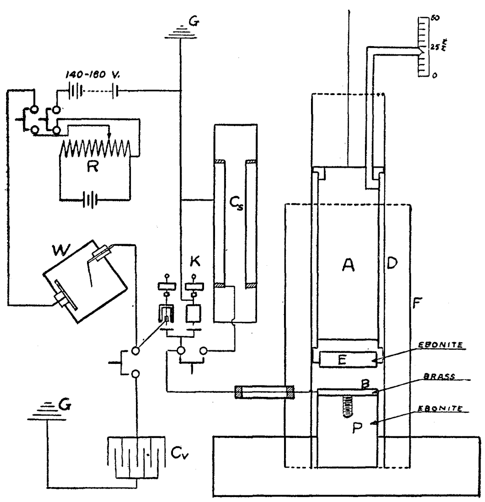


Fig. 1.

tube to its diameter, all combined to ensure uniform orientation of the ebonite surface at the moment of impact with a brass disc *B*. The latter was fastened securely to an ebonite pedestal *P* by means of a threaded projection of its own material. The pedestal was firmly held in a heavy iron base. All the horizontal surfaces were rendered parallel by careful turning in a lathe. An index rigidly attached to the plunging cylinder indicated the height of its fall. The air space between the cylinders provided windage, but windows were also constructed at the base of *D* to prevent compression of air. *F* is an earthed metal cylinder. The ebonite and brass discs were each 2.5 cm. in diameter, and of a thickness of 0.95 and 0.32 cm., respectively.

The charge produced upon the metal disc was measured by means of a Wilson tilted electroscope *W*, which was chosen on account of its low capacity (2.3 cm.), and consequent high sensitivity to quantity of charge. Deflections were observed with a microscope containing a micrometer eyepiece. The plate of the Wilson electroscope was maintained at a constant potential of 140 to 180 volts by a battery of accumulators, and the sign of this potential was always kept the same as that of the charge to be measured, so that the instrument was used in its most stable condition. The scale of the microscope contained 40 divisions, and the position of the goldleaf could readily be estimated to 0.1 division. Calibrations made with multiples of Weston standard cells furnished curves showing the voltages corresponding to given deflections. Various sensitivities were used, ranging from 3 to 10 divisions per volt, and for these values the deflections were nearly, but not quite, proportional to the potential of the goldleaf. Accurate adjustment to the desired sensitivity was obtained by the use of a potentiometer arrangement, indicated at $R$. Under the conditions described, the Wilson electroscope furnished a most convenient and satisfactory means of measuring the charges produced by impact. The metal disc and measuring apparatus could be earthed or insulated either together or separately, by means of a double key $K$ operated by a simple arrangement of two strings. Care to prevent leakage was taken and, in addition, all charged portions of the apparatus were housed in earthed metal boxes for electrostatic protection.

### 3. Measurement of Capacity.

The capacities used in these experiments were so small that they were measured by comparison with a specially-constructed condenser of concentric cylinders possessing a capacity of the same order. The dimensions of the inner tube were 2.70 cm. outside diameter and 43.15 cm. length; the outer cylinder was 4.45 cm. inside diameter and 52.50 cm. long. As the length compared to the space between the cylinders was large, the ordinary formula for capacity can be used. The calculated capacity proved to be 43.23 cm. (electrostatic units). All values of capacity used in the experiments were determined by comparison with this condenser. The capacity of the system was altered whenever necessary by inserting in the circuit an adjustable parallel-plate condenser, whose range of capacity was from 33.9 to 346.1 cm. The sliding plates of this condenser were earthed, and the plates receiving the charge were mounted rigidly on sulphur pedestals.

### 4. Experimental Results.

#### *A. Variation of Charge with Velocity of Impact.*

The surfaces of the brass and ebonite impact discs were made as flat and smooth as possible, and mounted so as to be parallel at the moment of contact. The cylinder, carrying the ebonite disc, was loaded with lead shot to give a total weight to the falling system of 753.8 grams. The ebonite disc was raised to various heights by means of a string passing over a light pulley, and then released by a mechanical trip so as to fall freely upon the brass anvil. The index indicated that there was no rebound, and therefore only a single impact. The ebonite was then raised 20 cm. above the brass disc and the charge on the latter measured. Tests showed that the charged ebonite plunger was sufficiently distant to produce no appreciable inductive effect upon the measuring system. Between successive impacts the ebonite surface was discharged by means of radium. Velocities of impact were calculated from the observed distances of fall.

A single curve was obtained as follows: Three readings were taken at each selected velocity when the height of fall was successively increased, and then the run was repeated with decreasing velocities. The charge

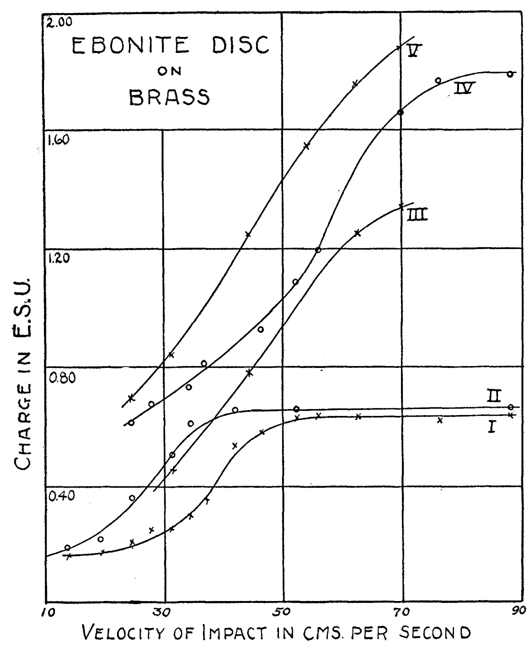


Fig. 2.

produced at a given velocity was then calculated from the six readings of the ascending and descending series, and this average was plotted. The charges obtained at a given velocity usually increased slightly after repeated impacts, probably due to further flattening of the surfaces, and the effect of this small secular variation was eliminated by averaging together the ascending and descending runs. The usual variation from the mean in a series of observations at a single velocity was 3 per cent. No especial care was taken of the surfaces other than an occasional cleansing with alcohol. This treatment made only a small difference, usually increasing the charge by a small amount and rendering consecutive readings slightly more consistent. Upon one occasion cleaning the ebonite with a fine, flat file increased the charge from 0.54 to 0.99 e.s.u., but, in a velocity run immediately following, the charge reverted to its former value.

The curves exhibited in Fig. 2 show the charges obtained with a single impact at various velocities. These representative curves were selected from observations extending over a period of a month or more, during which many hundreds of collisions were produced between the same surfaces. It is seen at once that impact produces charges of the same order as those obtained by friction. These charges were of sufficient magnitude to raise the brass disc to fairly high potentials. Even the relatively low maximum charge shown in Curve II produced a potential of 9.75 volts upon the metallic system, whose capacity was 19.9 cm. ($2.21 \times 10^{-5}$ microfarads). The curves show a steady secular increase in the charge obtained at a given velocity, and also that, in the early work, when the surfaces were fresh, a maximum was attained at the velocities used, whereas no maximum was reached in the later experiments with the same surfaces. It may be supposed that this is due to increase in the contact-area, inasmuch as many collisions would render the ebonite surface more nearly plane.

It is worthy of note that the ebonite disc *always* produced a positive charge upon the brass anvil. There was no tendency towards the reversal of sign observed when charge is produced by friction. Even the slight residual charge obtained when the dielectric was lowered upon the metal with as nearly zero-velocity as possible was always positive, even when in amount it was not more than 0.02 e.s.u.

### *B. Relation of Charge to Capacity.*

An exhaustive series of experiments was performed to find the relation between the capacity of the metallic system and the charge produced upon it by a given impact. The variable condenser was adjusted so that the charge due to a single collision gave a convenient deflection. Three readings were taken when the charge was formed at the capacity of the whole system, then three readings when the capacity of the measuring system was not added until after the impact had taken place. This process was repeated a number of times in close succession, the charge being formed alternately upon the metal anvil and upon the whole system, but always measured at the same capacity. The velocity of impact remained constant throughout. Thus the only variable was the capacity at moment of production of charge. The mean charges found in four such experiments are given in Table I.

TABLE I.

| Experiment No. | Velocity of Impact (cm./sec.). | Capacity at Impact (cm.). | Charge (e.s.u.). |
|---|---|---|---|
| 1 | 67.1 | 19.2<br>152.5 | 1.42<br>1.43 |
| 2 | 62.6 | 19.2<br>134.9 | 1.98<br>1.97 |
| 3 | 70.0 | 123.2<br>168.8 | 2.22<br>2.23 |
| 4 | 62.6 | $\infty$<br>168.8 | 1.04<br>1.02 |

In order to employ infinite capacity the metal disc was earthed at the moment of impact, but insulated before the ebonite disc was raised. It had previously been found that the potential of the system was not altered until the dielectric was lifted.

These results show that the charge is independent of the capacity. On account of the important conclusions which can be drawn from this fact, the observations for one experiment are given (Table II.). Readings were taken alternately at the two capacities.

TABLE II.

| Capacity at Impact. | Volts. | | | | | | Mean Charge. |
|---|---|---|---|---|---|---|---|
| 19.2 | 2.77 | 2.82 | 2.85 | 2.88 | 2.83 | mean 2.83 | 1.42 |
| 152.5 | 2.78 | 2.84 | 2.85 | 2.91 | 2.87 | mean 2.85 | 1.43 |

### C. *Influence of Mass of the Plunging System.*

Fig. 3 shows velocity curves obtained in the same manner as previously described. The ordinates are the potentials produced by a single impact at the capacity of 133.3 cm. The run represented by curve $B$ immediately followed $A$, the mass of the impinging system being decreased as indicated. Runs $C$ and $E$, and $G$ and $F$, were performed similarly. For the smaller mass, the charge is seen to be more nearly proportional to the velocity, and there is not the tendency to approach a maximum shown by the curves for greater mass. The curves show that a mean reduction in weight of 48 per cent. produced a mean decrease in charge of only 16 per cent., for constant velocity of impact.

*D. Effect of Repeated Impacts.*

Experiments were performed with repeated impacts in order to deter-

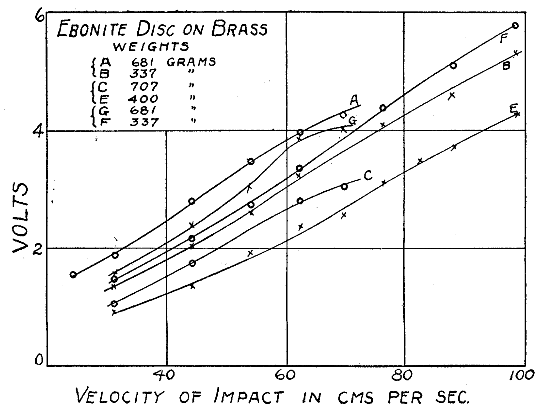


Fig. 3.

mine whether there is a maximum potential or a maximum charge obtainable by collision. Fig. 4, Curve I., shows the results when the

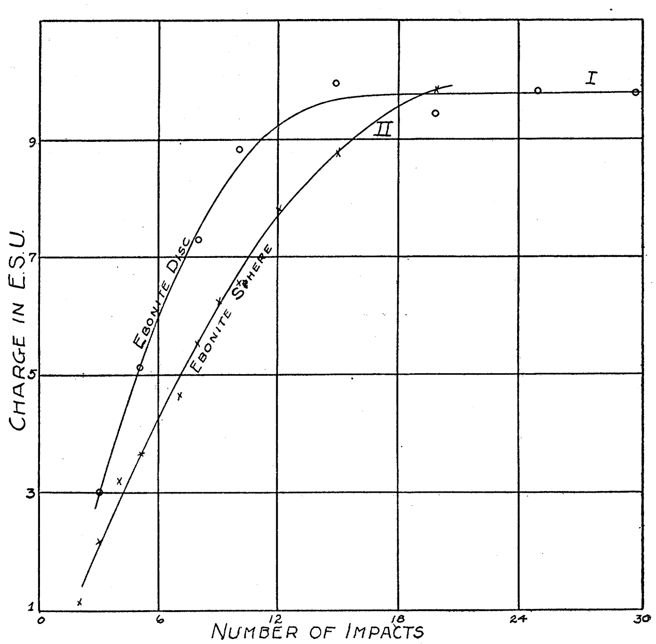


Fig. 4.

ebonite surface was not discharged between successive impacts. Fourteen collisions at a constant velocity of 62.6 cm./sec. could be produced in one minute. Insulation was excellent, so that leakage during the largest number of impacts was nearly negligible and could readily be allowed for by a small correction. The curve shows a maximum charge of 9.78 e.s.u., which produced a potential of 165.1 volts upon the metal disc. The charge was shared with a larger capacity for measurement. Then the ebonite disc, initially uncharged, was allowed to make five impacts upon the brass anvil, which was charged to various potentials by means of accumulators. The results are given in Table III.

TABLE III.

| Velocity of Impact (cm./sec.). | Initial Potential of Brass Disc (Volts). | Charge Added by Five Impacts (e.s.u.). |
|---|---|---|
| 62.6 | 280.2 | 3.31 |
| 62.6 | 350.2 | 3.42 |
| 62.6 | 386.0 | 3.09 |

There is seen to be no indication of a limiting potential, at the voltages used. It is thus evident that the limiting factor is not the potential of the metal anvil, but the amount of charge present upon the dielectric.

### *E. Effect of Static Pressure.*

It has already been mentioned that a charge of approximately 0.02 e.s.u. was always produced when the ebonite disc was lowered upon the brass anvil with as nearly no velocity as possible. To determine whether greater pressure would increase this charge, weights ranging from 4.38 to 12.08 kilograms were placed upon the ebonite disc while it rested upon the brass. No increase in charge was observed.

## 5. THE HURLING EXPERIMENTS.

### *A. Apparatus.*

In order to perform the experiments under widely different conditions, an apparatus was devised for projecting a sphere of dielectric upon an insulated metal disc. The construction is indicated in Fig. 5. A weight $P$ falling upon the short end of a light, rigid oak lever $L$ imparted a high velocity to a small brass tube $H$ sliding in a heavy sleeve. The rise of the sliding tube was small, its motion being suddenly arrested by the abutments shown. The pole of the electromagnet $M$ was provided with a collar $A$ of non-magnetic material, in order to ensure uniform release of the projectile without lateral motion. The ball of dielectric rested in the smoothly beveled edge of the sliding tube. A calibration curve was obtained showing the maximum free rise of the ball for different distances traversed by the falling weight. The action of this hurling device was constant to such a degree that the maximum variation from the mean in a series of flights was only 1.5 per cent. at the highest velocities used. The velocity of the ball at a given height $h$ could readily be calculated fom the formula $v = \sqrt{2g(H - h)}$, where $H$ is the maximum flight for the drop used. The ball could be projected vertically, so as to be pocketed in the hurling cup upon rebound, although in practice the ball was received upon heavy lead foil spread a little to one side of

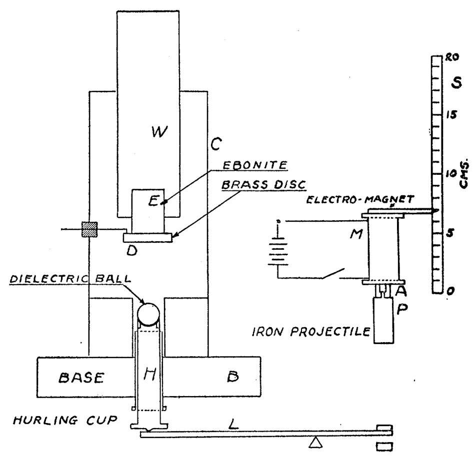


Fig. 5.

the sliding tube, and then rolled into the cup. The metal disc upon which the ball impinged was attached to an ebonite pedestal $E$ inserted in a massive wood cylinder. $C$ is a metal cylinder to afford electrostatic protection. The charge received by the disc was measured in the manner previously described. The capacity of the metal disc and its connecting wire was 16.0 cm.

### *B. Variation of Charge with Velocity.*

Fig. 6 exhibits specimen curves showing the charge produced at various velocities by a single impact of ebonite upon brass. The dielectric sphere was 2.5 cm. in diameter and had a mass of 10.88 grams. The brass disc was 5.0 cm. in diameter by 0.32 cm. thick, and possessed a fairly high polish. The flight of the ball through the air before collision occurred was 11.6 cm. Discharge of the ball was effected before every impact by passing it rapidly through a flame, as it was found that the results were not affected by substitution of this agent for radium. Each point on the curve is the mean of five or six observations at the velocity indicated. The maximum variation of a single reading from the mean was 8 per cent. As in the experiments with the plunging ebonite disc, the initial curves show that the charge reaches a maximum for certain velocities, whereas later work indicated that a much higher velocity would be required to produce a maximum. A possible explanation for this is that after a large number of impacts the ebonite surface was

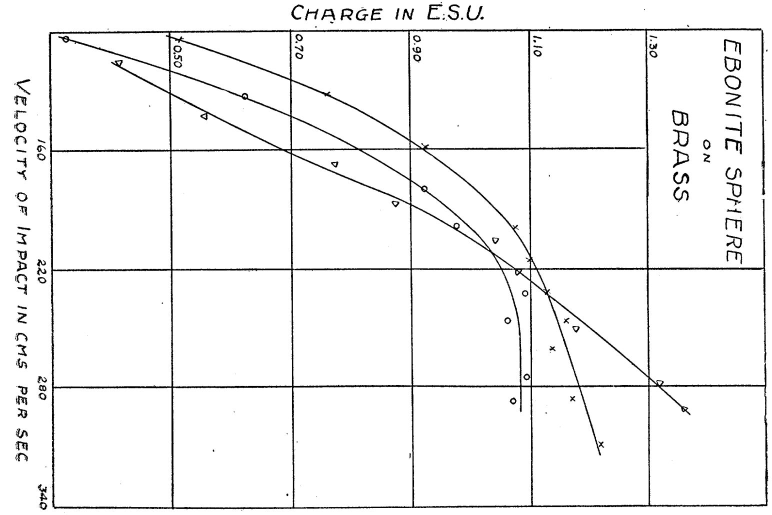


Fig. 6.

slightly bruised and flattened, although the brass showed no signs of wear. The surfaces of the dielectric and metal received no especial care other than an occasional cleansing with alcohol. No reversal of sign of the charge was ever observed; the charge on the brass was positive for all velocities and at every trial.

### C. *Repeated Impacts.*

Fig. 4, Curve II., shows the charge produced by a given number of collisions at a velocity of 179.8 cm./sec. The ebonite ball was discharged between impacts. Seven collisions could be effected in one minute, and leakage during the time required for the largest number of impacts was nearly negligible, so that only a small correction was necessary. Twenty impacts produced a potential of 183.8 volts upon the brass disc. The curve shows that there is a tendency towards a maximum, although the dielectric was discharged between impacts. This result differs from the conclusion based upon the data given in Table III. for a similar experiment with the ebonite disc. The reasons for this will be discussed later.

*D. Various Metals and Dielectrics.*

Tests were made when a zinc disc was substituted for brass, and a glass ball for ebonite, the results of which are shown in Table IV. The charge is due to a single impact. The zinc disc was 5.0 cm. in diameter and 0.5 cm. thick. The glass sphere had a diameter of 1.9 cm. and a mass of 8.23 grams.

Table IV.

| Materials. | Coefficient of Resiliency | Velocity of Impact (cm./sec.). | Charge (e.s.u.). |
|---|---|---|---|
| Ebonite on brass | 0.74 | 292.0 | 1.37 |
| Ebonite on zinc | 0.70 | 166.8 to 252.8 | 0.87 |
| Glass on brass | 0.40 | 200.0 to 285.9 | 0.57 |
| Glass on zinc | 0.30 | 200.0 to 246.5 | 0.81 |

In every instance the metal received a positive charge. An ivory ball also produced a positive charge on brass. In all cases except that of ebonite on brass the metal was permanently indented by the impinging sphere, so that consistent velocity curves could not be obtained. For these cases the mean charge is given for a range of velocities at which the charge was approximately constant.

## 6. Discussion of Results.

The results prove that intimate contact, without friction, between metals and dielectrics produces charges of the same order as those which were obtained by friction in the experiments previously mentioned. It is unlikely that any appreciable portion of the charge is due to friction. In both forms of the experiment, every precaution was taken to eliminate sliding contact of the surfaces. The lateral play of the ebonite disc was exceedingly small, and in the hurling experiments the sphere was projected vertically so as to avoid slipping of the surfaces. The hurling cup fitted the sphere evenly, so that the ball could hardly have possessed any considerable rotation at the instant of collision, and the time of contact was probably only a minute fraction of a second, since the speed of separation due to the large values of the velocity and resiliency was further augmented by gravity. In all published accounts of electrification by friction, repeated mention is made of the erratic character of the effect, which extends even to the sign of the charge. In the present experiments there was never the slightest tendency towards a change of sign, and the value of the charge remained remarkably constant during any one set of runs extending over several days, although it varied between fairly wide limits during the course of several months. In the entire work there were not more than ten instances when the metal received a negative charge, and all of these occurred immediately after the specimen had been cleaned with alcohol, making it clear that, in these cases, the surfaces had not dried completely. The charge was always positive even when it was produced by a contact of almost no velocity. Any residual friction would in all probability have been extremely variable in amount, and this variation, superimposed upon the erratic effect of constant friction, would have seriously affected the consistency of results. Upon several occasions the ebonite disc was rotated by hand upon the brass anvil, which acquired a charge sometimes positive and sometimes negative. Sliding friction may therefore be completely dismissed in considering the results.

Apparently electrification by impact is a surface effect. Since the area of surfaces actually in contact increases with velocity of impact, greater charges can be expected for the higher velocities. This would explain the velocity curves obtained. The secular variation in the amount of charge may be accounted for by the fact that alteration in the shape of the surfaces occurs during lapse of time and repeated collisions.

It does not appear that there is any direct relation between the charge produced and the energy lost by collision. If $Q$ and $C$ represent, respectively, the charge and the capacity of the metallic system, and $E$ the corresponding electrical energy, we may write $Q = \sqrt{2CE}$. If any constant fraction of the mechanical energy lost in impact at a given velocity were transformed into electrical energy, then $E$ would be a constant for impact at that velocity, and the charge would vary directly as the square root of the capacity. Inasmuch as it has been shown that the charge is independent of the capacity, we may conclude that there is no direct dependence of the electrical energy upon the mechanical work performed in collision. As it seems probable that the frictional and impact effects are produced by the same mechanism, it is advisable to discuss the soundness of Jones's[1] conclusions. He states that the charge produced by a given amount of frictional work increases with the capacity of the metallic system. However, he does not mention the values of the capacities used, giving one dimension only for the cylinders employed to vary the capacity. This dimension he terms variously the length or the "thickness." Furthermore, his results are vitiated by a large secular variation, inasmuch as he found it necessary to perform complete runs at each of the different capacities in succession, whereas in the present experiments many readings could be taken alternately at the various capacities in a short time, so that not only would the

[1] Loc. cit.

secular change be small, but it could be eliminated by taking an average value. In this connection it may be noted that the recent work of McClelland and Power[1] contradicts Jones's conclusions that the maximum charge is independent of the temperature and velocity of the rubbing surfaces.

Further evidence in support of the view that there is no direct relation between the mechanical energy and the charge produced is furnished by the curves in Fig. 3. If, for a given velocity of impact, there were a direct proportionality between the electrical and mechanical energies, then in the expression given above, $Q = \sqrt{2CE}$, $E$ would vary directly as the mass of the plunging system. Thus a reduction of 28 per cent. in the charge might be expected when the mass is reduced by 48 per cent. The actual decrease in the charge, however, was only 16 per cent. Additional evidence is afforded by the wide variation in mechanical energy lost per unit charge. For the ebonite ball, using the mean charge (Fig. 6) produced at a velocity of 295 cm./sec., the coefficient of resiliency being 0.74, we find $1.76 \times 10^5$ ergs lost per e.s.u. of charge. A similar calculation for the ebonite disc (Fig. 2) gives $1.50 \times 10^6$ ergs per e.s.u. Owen[2] finds that for ebonite rubbed with copper the same ratio has values ranging between $4.3 \times 10^6$ and $186.0 \times 10^6$.

So far as conservation of energy is concerned, the total electrical energy acquired is compensated by the mechanical work done in separating the charged surfaces. This is apparent at once from the consideration that at the moment the charge is produced the layers of positive and negative electricity almost coincide and therefore the potential of the system is not appreciably raised. No deflection of the goldleaf occurs until the surfaces are separated. However, the failure of the charge to increase when additional pressure is added, unaccompanied by a sudden impact, indicates that a certain amount of work is required to effect the passage of electrons from the metal to the dielectric, although it is possible that static pressures much greater than those used in the present experiments would increase the electrification. In this connection it should be recalled that, in the photoelectric effect, work is done by the electrons in emerging from the surface film. But in the present case so small a portion of the energy lost in impact is utilized in this manner that it cannot be stated how much work is necessary to produce the charge. Probably in the case of two optically flat surfaces the velocity of impact necessary to produce a given charge would be much smaller than in the present experiments.

[1] Loc. cit.

[2] Loc. cit.

The results for repeated impacts with the ebonite disc (Fig. 4) show a limiting charge of 9.78 e.s.u. Some view such as that of Helmholtz, who regarded the frictional effect as similar to the contact difference of potential between metals, must be assumed to account for the direction of the effect. From this point of view a very high maximum potential of the metal might be expected, on account of the vastly greater concentration of free electrons in metals than in dielectrics. This is borne out by the experiments in which an ebonite disc impinged upon metal surfaces at various potentials (Table III.), the charge produced showing no tendency towards a maximum. We may conclude, therefore, that the maximum is conditioned rather by the amount of charge present upon the dielectric than by the potential of the metal anvil.

In the experiment of repeated impacts with the ebonite ball, the latter was discharged between collisions. The curve (Fig. 4) shows that in this case there seems to be a tendency for the positive charge on the metal to leak back to the dielectric. This is at variance with the results mentioned in the preceding paragraph. This tendency towards back-leakage, however, might be greater for the sphere than for the disc, on account of the greater intimacy which higher velocities and curvature of surface would cause. The dissipation of energy per unit area is probably greater in the case of the sphere than of the disc, and the heat developed might also facilitate back-leakage.

It is a pleasure to acknowledge here many valuable suggestions received from Professor L. T. More and Professor R. C. Gowdy during the course of the experiments.

UNIVERSITY OF CINCINNATI,
February 11, 1920.