cool one-twelfth of a degree, or if a mass of air be heated to any excess above the surrounding mass it will fall to one-half of that excess in about one-twelfth of a second.

For reasons stated in the preceding paper it is evident that this value must err rather in being too large than in being too small.

Preliminary Results by a New Method for the Study of Impact.*

By A. W. Duff and J. B. Meyer.

The purpose of this paper is to briefly describe an apparatus for the study of impact of masses of wood on one another, and to state a few results obtained by means of it. It was intended to include in the investigation not only the change in the relative velocity of the impinging bodies produced by impact, but also the length of time the bodies are in contact, the closeness of approach produced by their mutual compression, and the internal vibrations to which impact gives rise. The apparatus was constructed by Mr. Meyer, and the present results obtained by him early in this year, but only a small part of the contemplated work was completed when it had to be discontinued. Calling, as usual, the ratio of the velocity of separation after impact to the velocity of approach before impact the coefficient of restitution, it may be stated that the results to be given here are only a few isolated determinations of the coefficient of restitution and of the time of contact.

In principle the apparatus consists of a block dropped vertically on a much larger mass of the same material, the circumstances of the impact being recorded in a curve traced by a pencil attached to the block on a vertical revolving drum covered with a sheet of paper. To describe the apparatus more fully, it consists of two vertical beams mortised in a massive cross-shaped base, the beams adjustable so that the space between can be regulated. The height of the beams is 8 feet. Between these beams as guides the block can descend with comparatively little friction. On the base, the larger of the two impinging masses, or the plate as we shall call it, is rigidly clamped. Immediately in front of the beams is fixed on cone bearings a vertical rotating cylinder around which a sheet of paper is wrapped. The cylinder is 2 feet in diameter and $2\frac{1}{2}$ feet in height. Fastened to the top of the descending block is a small removable board, to which is attached a brass tube carrying a pencil. The tube is secured in position by a catch attached

* This paper is an abstract of a thesis presented by Mr. J. B. Meyer for the degree of B. Sc., and placed in the library of Purdue University.

to a lever arm. By a crossbar placed at any desired height, this lever is tripped up as the block descends, the pencil is released and shot forward by the tension of rubber bands so as to press against the paper-covered cylinder. Were the cylinder at rest, the pencil would merely describe a vertical line, turning back on the same line at the moment of impact. When the cylinder is in rotation the pencil describes a curve which is abruptly reversed at the moment of impact. As the block usually bounces several times before coming to rest, this curve consists of successive loops meeting at sharp angles which correspond to the successive impacts. This will be fully understood by a glance at the record sheet shown on the wall. If now we draw tangents to these curves at a point of impact, and denote by Vi the velocity of the block immediately before impact, by Vr its velocity immediately after impact and by Vc the velocity of the surface of the cylinder at the moment of impact, then—

$$\frac{\frac{Vr}{Vc}}{\frac{Vi}{Vc}} = \frac{\tan a'}{\tan a} = \frac{\frac{y'}{x'}}{\frac{y}{x}},$$

or, if x' be taken equal to x, we have $e = \frac{Vr}{Vi} = \frac{y'}{y}$, the coefficient being considered negative, since Vr is a negative quantity. Thus the actual velocity need not be known so far as the determination of e is concerned, and the process is reduced to the drawing of two tangent lines and the measuring of the ordinates corresponding to equal abcissae measured from the point of impact.

To enable us to find the time of contact during impact, or, briefly, the duration of impact, it is necessary to know the speed of the cylinder. Now once in each rotation of the cylinder it thrusts up a vertical wire attached to the short arm of a lever, causing the longer arm to descend and complete an electric circuit and give a record on the drum of an electro-chronograph. The speed of the drum is determined by a parallel record of the time of vibration of a second's pendulum which completes another electric circuit whenever it passes through the vertical. The electro-chronograph thus used is one made by the Geneva Society, of Switzerland; its drum can be made to rotate once in a second under the control of a Foucault regulator. From the curve exhibited it is plain that the impinging bodies compress each other during the first period of contact, and upon separation they more or less regain their original forms; so that at each rebound a portion of the line traced by the pencil when at rest is intercepted between the curves traced by the pencil. Dividing the length of the portion so intercepted by the product of the circumference of the cylinder and the number of revolutions per second we have the duration of contact. It is not necessary always to determine the speed of the cylinder by means of the chronograph, for, having once found a good average value for the velocity of impact for a certain height of drop, the velocity of the cylinder at any other impact from the same height of drop can be found from the inclination of the impact curve.

$$\text{Thus } \frac{V_i}{V_c} = \tan \alpha$$
$$\text{and } V_c = \frac{V_i}{\tan \alpha}$$

It may also be noted that the amount of mutual compression at impact is at least approximately given by the extent to which the curve sinks below the zero line.

By making the moment of inertia of the cylinder large, its speed during the time of contact may be considered as constant. It should be noted that the results do not depend upon the friction between the block and the guides, for we are concerned only with the actual velocities just before and just after impact, no matter how they are attained.

PRELIMINARY TESTS WITH THE APPARATUS.

The method here employed for the determination of the coefficient of restitution, consists in principle, in the dropping of a mass on a plate so large that the motion communicated to it may be neglected, so that the relative motion is merely that of the block. As a matter of fact in the arrangement adopted, the stationary plate is only about ten times as large as the block, but it is so solidly clamped to the base of the massive structure that it is assumed to be practically immovable. It might however be suspected that the result would depend upon the stationary block, *i. e.*, its mass, or its vertical thickness, for evidently if it were too thin it would in reality be on the elasticity of the base beneath it that the force of rebound would depend.

To test this point, a short beam of well-seasoned cherry was taken whose cross-section was a rectangle, one side of which was three times as long as the other, so that the beam was three times as thick in one direction as that in the other. The actual dimensions of the beam were $2' - 1\frac{1}{2}'' - 4\frac{3}{4}''$.

If these thicknesses for the stationary mass be too small, it should be shown by the coefficient of restitution being different for impacts in the direction of the greater thickness and in the direction of the smaller thickness. The impinging block used was also cherry, the grain being vertical and the impinging surface turned into a hemisphere of 7 centimeters radius. The value of e found with the greater thickness of the beam vertical was .35 and with the smaller thickness vertical was *.36*. Another beam of the same material was then taken whose cross-section was a square, the side being equal to the greater side of the rectangle in the preceding. The mean value obtained by large number of impacts was *.355*. It will be understood that the mass in this case was three times as great as that in the preceding cases, and that all three values agreed very closely. Hence it is assumed that the thickness in these cases was sufficient and that practically the base acted like a very great mass.

In the preceding, the drops were from the same height. The next point tested was whether or not the height was so great that the limit of elasticity of the wood was passed. A series of determinations was made with all other circumstances similar, but with different heights of drop each time, varying from 1 to 6 feet, and the values of e while varying from *.34* to *.38* showed no regular dependence on the height of drop. It may be stated that such differences as here obtained occurred frequently, although usually smaller in amount. They are mostly attributable to the lack of homogenity in parts which seem superficially quite similar in structure. The mean value of e in this series was *.363*.

It may be stated that the same impinging block was used over and over again. Had there been any effect produced by the crushing of the impinging surface of the block, it seems evident that it would have shown itself in a change of the value of e. As no such appeared, it seems evident that no such effect existed. To settle the question, however, a series of determinations was made with a newly turned impinging surface each time. The radius of curvature was much larger in this case. The result was that the values for e obtained in these tests were practically constant and unchanged by the successive impacts of the impinging surface, but were notably large with this larger radius of impinging surface, the mean value being *.42*, while with the smaller radius of curvature it was *.36*. The effect of curvature will be spoken of later.

In all the preceding tests the impacts were on new and undinted surfaces of the base plate. This was necessary because an effect due to the dinting of the plate had been observed though not accurately examined. We now more carefully tested this point and found that under successive impacts on the same spot of the base plate the value of e rose steadily from the earlier value of *.36* to *.49*, showing a permanent effect due to a crushing of the material of the base plate. The radius of curvature as formerly was 7 cm.

Again, to find the effect of curvature of the impinging block, a series of tests were made, first with a curvature of 3 cm., then of 7 cm., and then of 10 cm., and it was found that the corresponding values of e were—for 3 cm., *.32;* for 7 cm., *.37;* for 10 cm., *.42*, thus showing that the value of e increased with increasing values of the radius of curvature.

The last point tested was the effect of the *mass* of the impinging block, those so far used weighing about one kilogramme, or two and a fifth pounds. The mass was now doubled and the radius of curvature being 7 cm., as in the earlier tests, a value of *.36* was obtained. It was now found that with the height of drop *120 cm.*, or *4 ft.*, the value of *e* remained the same as before, namely, *.36*, but that for a drop of *6 ft.*, the value decreased to *.33*, and with a much heavier mass the value sank to *.25*. Attention might be here called to the fact that there might seem to be some contradiction between the statements that while greater height and therefore greater force of impact with the light block on fresh parts of the base plate did not affect the value of *e*, an increase of the impinging mass showed a decrease in the value of *e* with increasing force of impact, while successive impacts on the same spot showed an increasing value of *e*. The explanation would seem to be that whereas beyond a certain limit, increasing force of impact produced an initial crushing of the surface from which there is only imperfect recovery, when successive impacts take place on the same spot, at each impact there is a greater area of resisting surface encountered, and also less unrestored crushing, and hence a greater velocity of rebound with a consequent increase of *e*. The point seems to merit a more careful investigation than it received in these purely preliminary experiments.

These tests point out the limits as regard mass of impinging block and height of fall within which it is safe to work in comparing the coefficients of restitution of different materials. It also shows that for a comparison of different materials it is necessary to adopt the same curvature of impinging surface and to use a fresh part of the base plate for each impact. Hence in the following comparison the masses of the impinging blocks are uniformly one kilogramme, radius of curvature of the impinging surface *10 cm.* and the height of fall 120 cm.

TABLE OF COMPARISON.

Material.	*Value of e.*	*Duration of Contact.*
White pine	.38	.0017 seconds.
White poplar	.42	.0016 "
Cherry	.42	.0016 "
Hard maple	.45	.0012 "

In the above it will be understood that in all cases the grain of the impinging block was vertical and that of the base plate horizontal. The first remark that may be made about these results is the surprising closeness of the values of *e* for the different materials, varying between *.38* and *.45*, while the duration of contact varied between *.0012 sec.* and *.0017 sec.* It may also be noted that the values of *e* varied in the inverse order to the duration of contact.

A few determinations were also made with the grain of both block and plate horizontal, the other circumstances, curvature and height, being the same as in the above table.

These results are given as they be of interest but very little reliance can be placed upon them as they were somewhat hastily made and time did not permit of repetition.

Material.	*Value of e.*	*Duration of Contact.*
White poplar	.42	.0024 seconds.
Cherry	.49	.0014 "
Hard maple............	.56	.0012 "

These seem to show in a more pronounced manner the connection between duration of contact and the coefficient of restitution, but for reasons above stated we hesitate to regard the law as established.

It may be added, by way of a postscript of less serious content, that the length of time of contact of a base ball with a bat and the corresponding value of the coefficient of restitution, were determined by this method. These values are for the duration of contact $\frac{1}{160}$ seconds, and for the coefficient of restitution $\frac{3}{5}$.

Variations in the Spectrum of the Open and Closed Electric Arc.

By Arthur L. Foley.

[Abstract.]

The image of a normal electric arc appears to consist of three regions—a central violet portion, an outer yellow sheath or flame and an intermediate sheath of blue. By means of a Rowland grating and a Brashear mounting, and a concave mirror to focus the image of the arc upon the slit, a photographic study was made of the spectra of these regions under four conditions: (1) A vertical arc and a vertical slit, (2) a vertical arc blown out by a horseshoe magnet, (3) a horizontal arc and a vertical slit, (4) a horizontal arc and a horizontal slit.

The accompanying table gives the results of a study of the three regions of the arc with the slit vertical and through the center of each region. Two exposures were made in each position, three seconds and thirty seconds in the violet and blue regions, ten seconds and thirty seconds in the outer or yellow sheath. An exposure of three seconds in the latter brought out only ten lines.