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THE USE OF A BALLISTIC GALVANOMETER AND A PENDULUM FOR MEASURING RAPIDLY FLUCTUATING RESISTANCES.

BY W. H. CLARK.

The degree of accuracy with which physicists have divided the fundamental units of length and mass, the centimeter and the gram, demands a division equally as accurate of the remaining unit, the unit of time. We are all familiar with Michelson's measurement of the standard meter where a half and a quarter wave length of light was a quantity not to be neglected. Our recent literature describes a balance which will weigh to one millionth of a milligram. When we consider these facts and the added fact that time so often enters into our formulæ to the second degree we see the necessity of accurate small divisions of our unit of time. For special purposes such divisions have been made illustrated by the many forms of chronographs. The kind of time measuring instrument is usually determined by the purpose required. There is the gun chronograph, the astronomical, the accoustic and the chronograph for physiological purposes. All of these are more or less complicated in their structure. An instrument exceedingly simple in design and still sufficiently accurate for the purpose has been used in the physical laboratory at the State University of Iowa to measure a rapidly fluctuating resistance. It is a ballistic pendulum which swings over an arc which is graduated with respect to time. The shortest time which could be measured was .00125 second. Keys which opened and closed electrical circuits were placed along the arc at any desired points. These were tripped by the pendulum. A variable resistance was placed in one arm of a Wheatstone bridge circuit. We found that its average value for any interval of time can be expressed in terms of the throw of a ballistic galvanometer where the galvanometer is thrown into the circuit by means of the pendulum for the desired interval of time which must be small compared with the period of the galvanometer. How small this interval should be is also determined by the rapidity with which the resistance changes. If the time is sufficiently short the average resistance practically becomes the actual resistance at the middle of the interval.

THEORY.

The theory of the method is quite elementary. Consider resistances without appreciable capacity or self-induction to be connected in a Wheatstone bridge circuit. Suppose the battery resistance to be small compared with the other resistances. Let the balance be disturbed by changing the resistance in the variable arm by a small amount Δt. Then it can be shown that $\Delta x = \frac{Cd}{\Delta t}$ where Δt is the time that the current flows

through the galvanometer and also the time during which we are considering the change of resistance. The meaning of this equation is that the change of resistance is in the variable arm of the bridge is directly proportional to the deflection of the ballistic galvanometer and to the constant C, and inversely proportional to the interval Δt during which the galvanometer is in the circuit.

APPLICATION TO THE MEASUREMENT OF SMALL CHANGES OF RESISTANCE.

In order to test the linear relation between the deflection and the change of resistance, and between the deflections and the interval Δt known resistances were placed in the Wheatstone bridge circuit. To find the variation of the deflection with the change in resistance, the keys k_1 and k_4 were placed such a distance apart that the interval during which the galvanometer was in the circuit was $\Delta t = .05$ sec. The resistance in the variable arm was varied by different amounts previous to each reading. The readings were taken after the pendulum had operated keys k3 and k4. Observations are recorded in the curve Fig II. It will be noted that there is only a small percentage error in any single observation and further that for a change of resistance as large as 800 ohms there is only a slight variation from the linear relation. For changes as large as $\Delta x = 200$ ohms there is obviously complete agreement between the theory and the experiment. It may be concluded therefor that the deflection is proportional to the resistance.

RELATION BETWEEN DEFLECTION AND THE TIME THAT THE GALVANOMETER IS IN THE CIRCUIT.

In order to test the relation between the deflection and the time that the galvanometer was in the circuit the variable resistance was changed a given amount, 15 ohms, from that required for equilibrium and the distance between the keys k3 and k4 was varied. Between .01 and about .12 sec. the linear relation required by equation $\Delta x=\frac{Cd}{\Delta t}$ holds, but from .12 sec. to .4 sec. there is a slight tendency for the deflection to grow less as the interval is increased. This slightly downward bending of the time-deflection curve for longer intervals of time probably arises from the damping action of the closed coil moving in a magnetic field. It was quite definitely settled that the linear relation between d and Δt was obeyed for values of Δt as small as .0075 sec. but for values less than this there was considerable doubt. It may be stated that the method suggested for determining changes of resistance is applicable through the use of equation $\Delta x=\frac{Cd}{\Delta t}$ for quite large ranges of values for Δx and Δt. The range of applicability will vary to some extent with the apparatus used. There will enter such factors as the theory of the galvanometer, the value of the resistance in the circuit, and self-induction.

In case the change of resistance Δx is large compared with the initial resistance equation $\Delta x=\frac{Cd}{\Delta t}$ can not be applied and the equation involving the resistances in the four arms of the bridge is not easily applied. The change of resistance is a function of the deflection regardless of how large it may be, but it is not easily computed. The easiest way out of the difficulty is to determine the deflections obtained by the unknown variable resistance for different intervals of time and then to substitute various known resistances which will give a range of deflection covering those obtained by the unknown. The deflections with the known resistances can be plotted to give a calibration curve. Then the value of the unknown resistances, or the change of resistance, can be read from the calibration curve. A simple illustration will explain this application of the method.

A Giltay selenium cell was connected at X in figure I. The selenium cell was placed in a dark box in which was also a tungsten lamp. By closing both keys k1 and k2 the storage battery circuit was closed through the tungsten lamp. This illuminated the selenium cell. The method of procedure in the experiment was first to balance the selenium cell in the bridge circuit, after it had recovered, and then set up keys k2 and k4. The key k was closed by hand. When the pendulum was afterward released it closed key k1 and illuminated the cell. When the

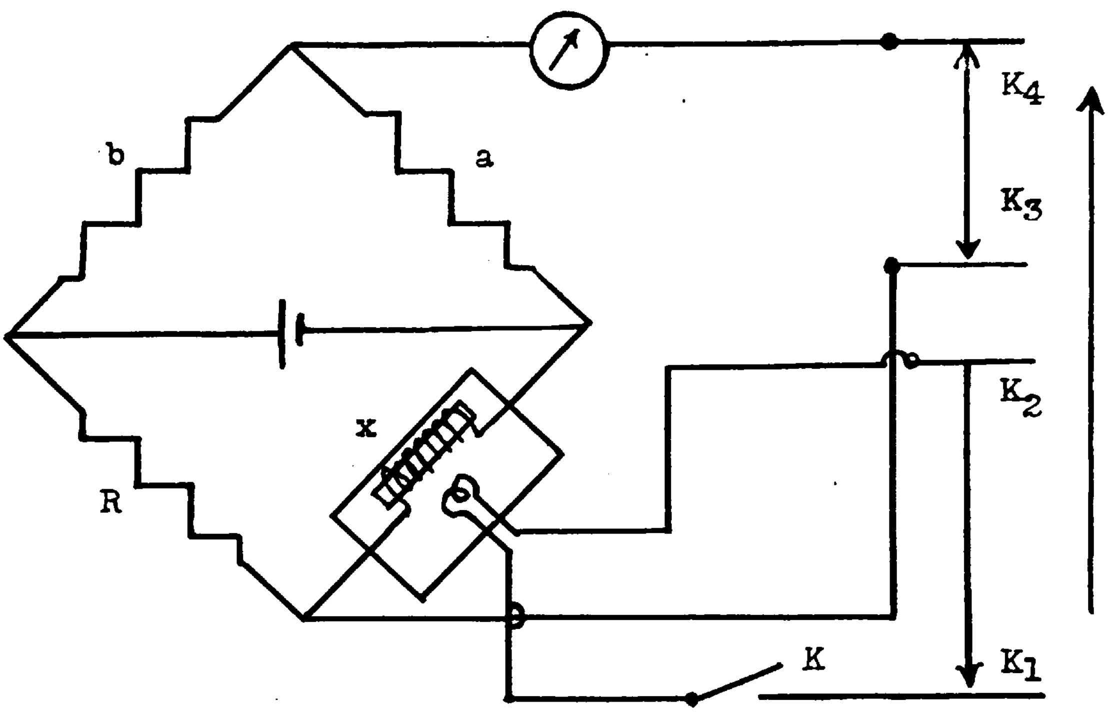

Fig. I.

Use of Ballistic Galvanometer.

pendulum reached key k3 the galvanometer was thrown in circuit, and when key k4 was reached the galvanometer was thrown out of circuit. The distance between keys k1 and k2 gave the interval of time Δt. After the pendulum had thrown k2 k was opened by hand. The following table gives the observations that were made with the selenium cell:

Time cell is exposed to light Sec.	Deflections Mm.	Temperature, Degrees Centigrade
.05	7	24.8°
.10	11	24.4°
.20	35	23.8°
.25	38	23.8°
.30	56	23.8°
.35	52	23.8°
.40	55	23.8°
.45	55	23.8°
.60	58	23.8°
1.00	61	23.8°
2.00	57	23.8°
4.00	56	23.8°
6.00	56	23.8°
8.00	55	23.8°

Then keeping the time constant that the galvanometer was in the circuit and substituting a known variable resistance in place of the unknown data was obtained from which was plotted the calibration curve shown in figure III. It will be observed from the calibration curve that for changes of resistance ranging in value from 500,000 to 564,000 ohms the deflection is almost a linear function of the change in resistance. For greater changes, however, the deflection changes very rapidly and becomes infinite when the change of resistance equals the original resistance in that arm of the bridge. It is interesting to compare the curve with the curve in figure II. Both are deflection-resistance curves, but in figure II the change in resistance begins with zero while in figure III they begin with about 500,000 ohms. The resistances are of entirely different order of magnitude in the two instances. Using the values of the deflections obtained with the selenium cell shown in the accompanying table, we are able to determine the change of resistance from the calibration curve.

Other applications of this method may be found where it is necessary to vary the interval during which the galvanometer is the circuit and also the E. M. F. of the battery. This method would probably adapt itself to determining the change of resistance with application of heat in a bismuth spiral, change of resistance of certain metals, as manganin, and silver-sulphide, under pressure. The method is probably as accurate and as easy to manipulate as any method that has been devised for measuring rapidly fluctuating resistances.

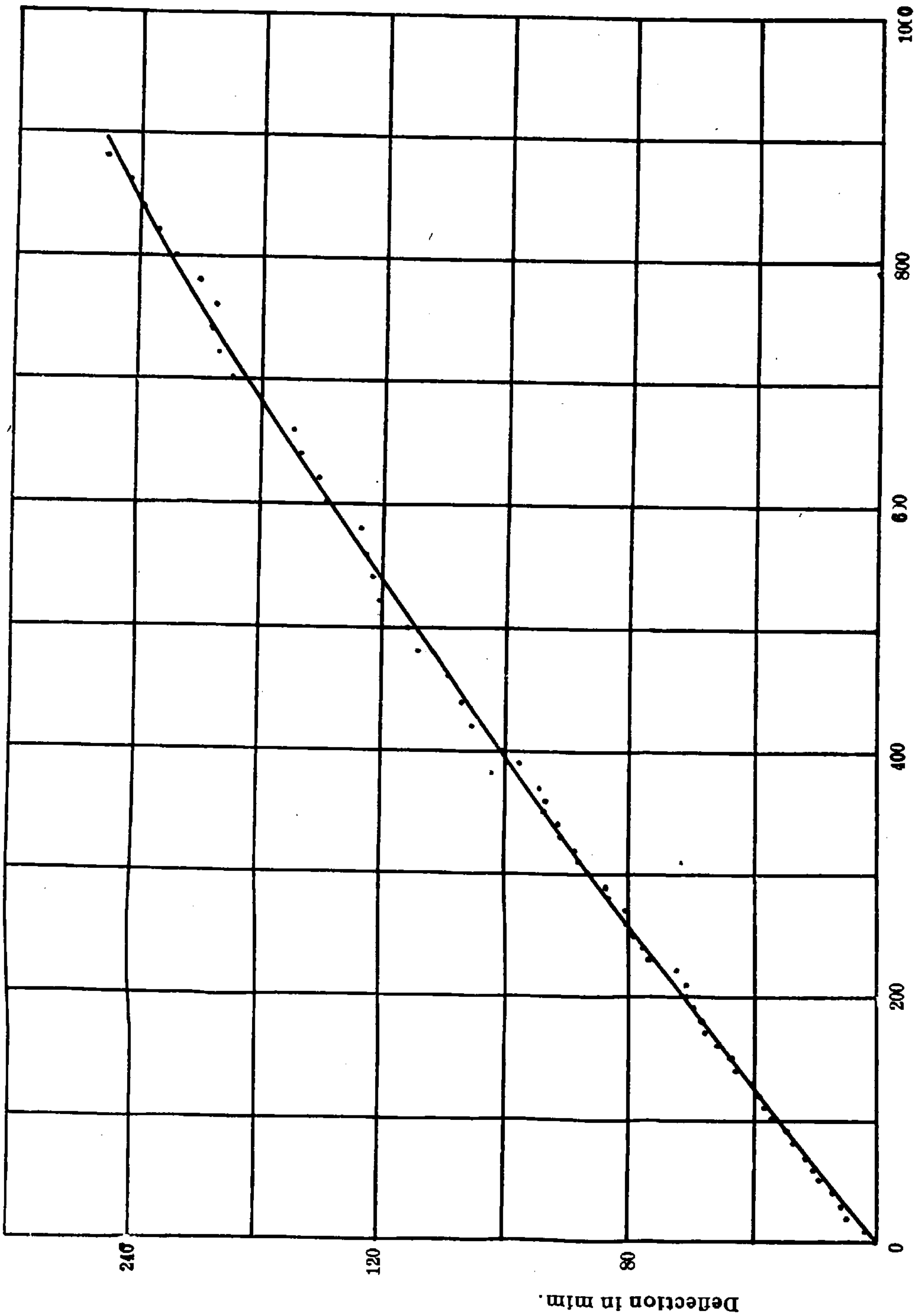

Fig. II. Change of resistance in olms.

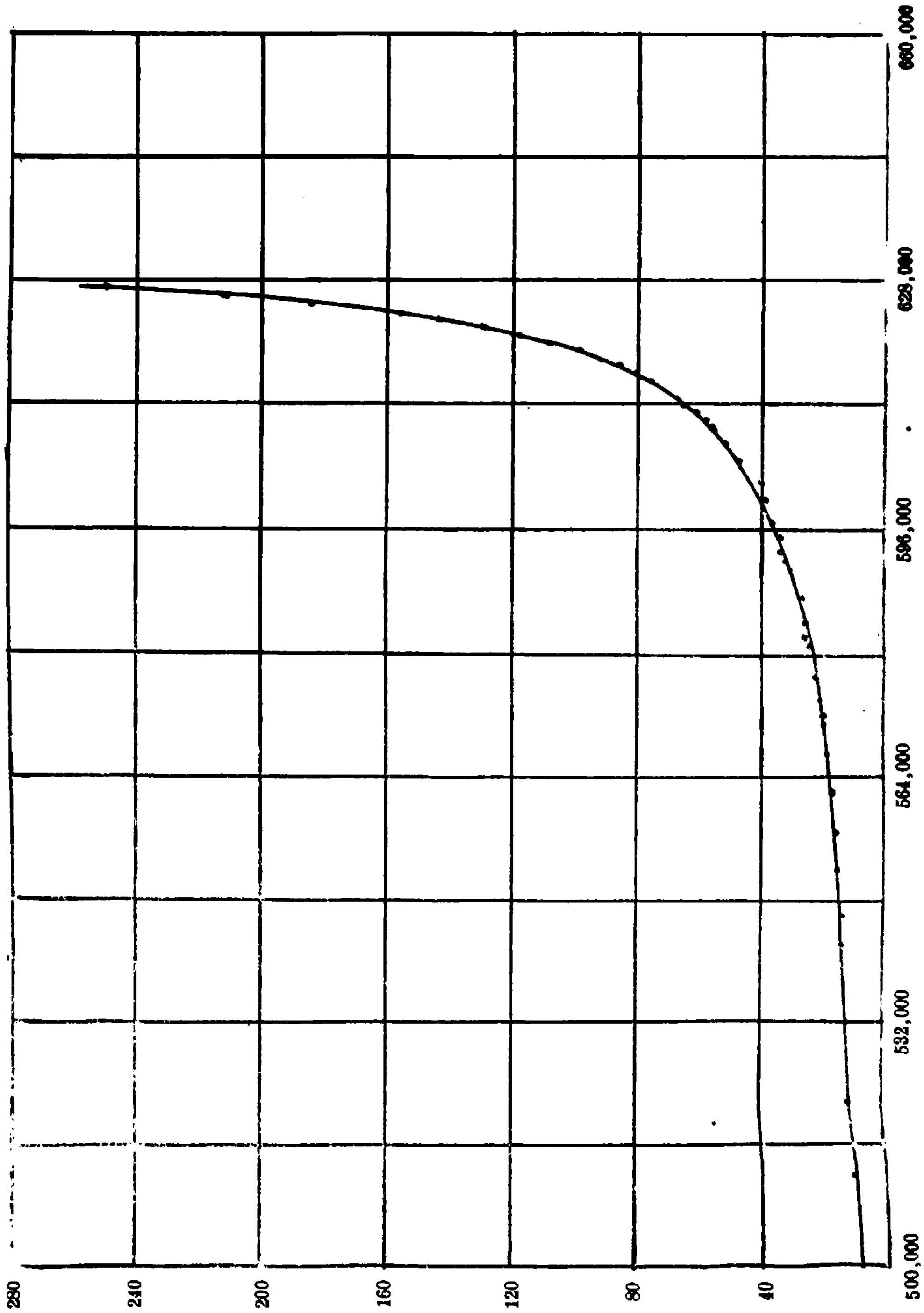

Fig. 111. Change of resistance in olms.