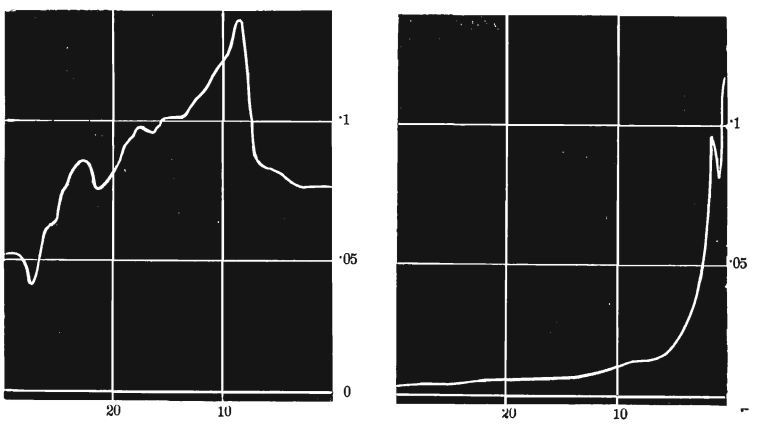
ART. XLVII.—*Application of Photography to Electrical Measurements;* by JOHN TROWBRIDGE and HAMMOND VINTON HAYES.

IN the study of electromotive force and of voltaic cells it is often desirable to have long continued observations. The complete history of the action, for instance, of the Daniell cell with different strengths of solution extending over hours or days, if it could be presented to the eye as a curve, would be valuable to those who desire to know the behavior of such a cell while it is doing work under definite conditions. Such curve could be obtained by patient observation, but it would be unprofitable labor for one to spend his time in watching the excursions of a galvanometer needle, if the needle can be made to record its movements by any device.

The method we have used enables one to study the action of a cell at one's leisure, the apparatus running at night or during the day when one is occupied with other work. A beam of light from a gas flame passes through a vertical slit placed in front of the flame and is reflected from the concave mirror of a tangent galvanometer, of few turns of wire, through a horizontal slit in a dark box in which a sheet of sensitive paper is placed. By means of this arrangement of a vertical and a horizontal slit a small point of light is obtained. A stationary concave mirror is placed near the needle of the tangent galvanometer, so that the same beam of light may be reflected by both this mirror and the one attached to the galvanometer needle. The spot of light given by the stationary mirror serves to mark the zero point of the needle when no current is passing through the galvanometer. The photographic paper is placed in a slide which is lowered uniformly by the unwinding of a string from a little cylinder placed either upon the hour hand or the minute hand of a cheap eight-day clock. When the electrical current from the voltaic combination, which is being used, passes through the galvanometer its changes in strength for different times are indicated by the relations of the two lines drawn upon the sensitive paper. The line drawn by the light from the stationary mirror is a straight one, and serves for the abscissa

1. 2.



of times, while the perpendicular distances from the curve drawn by the mirror attached to the needle of the galvanometer to this axis of times give the ordinates of the curve drawn by the latter. Rapid printing paper was used and an ordinary gas flame gave a sufficiently strong spot of light to produce an actinic effect.

Fig. 1 represents the action of a modification of Trouvé's battery. During this experiment, which lasted for thirty minutes there were five ohms in the external circuit. The right hand portion of the diagram shows the strength of current when the circuit was made, and it will be observed that the battery was not at its best until ten or twelve minutes after making the circuit; from this maximum point the strength of the current gradually diminishes. Fig. 2 shows the action of the same battery with ten ohms external resistance. Under these conditions we find at the instant of making circuit a strong current which rapidly diminishes within the first five minutes to one-sixth of its first strength.

Knowing the distance of the galvanometer from the sensitive paper the strength of the current may be calculated by measuring the distance between the two lines at any instant and proceeding as with an ordinary galvanometer and scale.

From a comparison of the two figures the electromotive force may be determined by Ohm's law, if the distance between the lines is measured at the instant the current is made. Then knowing the electromotive force, current, and external resistance, we can readily find the internal resistance. This resistance will be the liquid resistance of the cell only for the moment that the circuit is made, for afterward the variation in electromotive force due to polarization, and the change in resistance of the liquid due to electrolytic action will combine to cause changes. Since, however, the changes in electromotive force due to polarization are much more rapid in their action than the changes in battery resistance a very small error will be introduced if we compare points near each other on those parts of the curve in which the variation in current is greatest: during the small fraction of a minute that is taken the change in battery resistance will be infinitesimal and may be neglected.

We have selected these photographs as an example of the large variations that some batteries present and the consequent usefulness of some such way of studying their action. From measurements upon these photographic charts the variations in electromotive force and internal resistance can be studied by obtaining such charts under different conditions of external resistance. It is evident that the same photographic method can be employed to study the swing of the needle of a short coil galvanometer which indicates the gradual heating of a thermopile. In this way the conduction of heat along a bar could be studied.

Jefferson Physical Laboratory.