



## XV. A potentiometer for alternating currents

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His method for measuring polarization was somewhat similar to that used in this work. As bearing upon "the change of polarization with time" I would refer especially to the investigation of Dr. E. Root upon this subject, discussed by Prof. von Helmholtz, *Wisch. Abh.* vol. i. p. 835. These experiments by Dr. Root seem to prove clearly that the liberated ions penetrate deeply into the electrode, even when liberated upon but one side of it, as in this case. I take great pleasure in expressing here my thanks and deep obligation to Professor A. Kundt and Dr. L. Arons for their kind sympathy and direction in this work.

Physical Laboratory, Univ. of Berlin,  
August 1892.

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## XV. *A Potentiometer for Alternating Currents.*

By JAMES SWINBURNE\*.

### ARGUMENT.

A direct pressure is balanced against an alternating pressure by means of a differential electrometer with single-fibre suspension, a null method being employed. An alternating and a direct current are similarly compared by means of a differential dynamometer with the controlling spring removed.

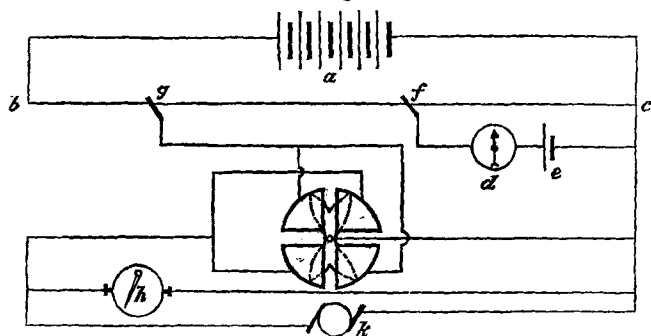
ONE of the chief difficulties in the way of the accurate measurement of alternating pressures and currents arises in the calibration of the instruments. Some of the alternating-current instruments, such as those on the electro-dynamometer principle, give the same reading whether a direct or alternating current is used; and electrometers and some forms of electromagnetic instruments with soft iron cores are also adapted equally well for direct and alternating-current work. This is not the case, however, with a large class of instruments, and the only method at present available for calibrating such instruments is comparing them with another instrument which has been calibrated by means of a direct current. Such a practice allows errors to creep in. No careful electrician would trust to direct-current instruments calibrated second-hand, and accuracy is just as important in alternating-current work. In addition to this, the collection of cells and resistances which are now included under the name "potentiometer" is exceedingly useful in any laboratory where it can be permanently set up, as it measures currents and pressures throughout an enormous

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range with an accuracy that is quite unattainable by means of any other forms of voltmeter or ampere-meter. It is therefore of the highest scientific importance to be able to extend the potentiometer method into alternating-current work, so that comparisons can be made directly with a standard cell.

In October 1891\* I described two forms of alternating-current so-called ohmmeter. These instruments measured either a quantity  $R$  such that  $E^2/R$  was the power when  $E$  was the effective or virtual pressure, or a quantity  $r$  such that  $Cr^2$  was the power when  $C$  was the virtual or effective current. Of course in a circuit with capacity or self-induction,  $R$  and  $r$  are not equal. One form of alternating ohmmeter was electrostatic, the other electromagnetic. The electrostatic ohmmeter can be coupled up in such a way as to compare two pressures, and one of these may be alternating and the other direct. The electrostatic instrument has the advantage over the electromagnetic in requiring only one connexion to the moving system, or needle, and that connexion has not to carry any appreciable current. The needle may therefore be suspended by means of a single silk fibre, connexion being made through a hanger dipping into water, and this hanger may end in a vane to make the instrument dead-beat. As the ohmmeter does not need any torsional control, but should be, on the contrary, as free as possible, this form of instrument can be made exceedingly sensitive. For potentiometer work it is best not to use the instrument for giving the ratio of two electromotive forces, but to design it as a differential galvanometer which shows whether the pressures are equal or not.

Fig. 1.



The disposition of the whole apparatus is shown diagrammatically in fig. 1. In this scheme  $a$  is a battery maintaining

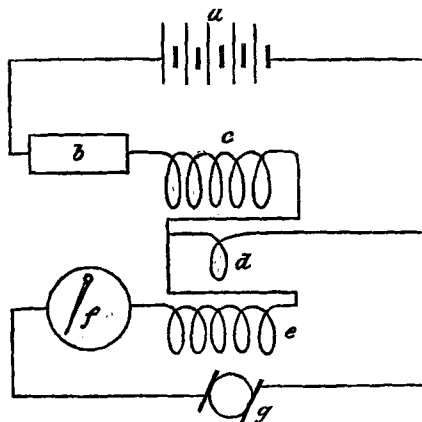
\* 'Industries,' October 30, 1891.

a current in the resistance  $bc$ , which is regulated by an adjustable resistance so that the standard cell  $e$  is balanced when its contact  $f$  is touched down at the mark corresponding to its electromotive force at the temperature at which it stands;  $k$  is an alternating dynamo, and  $h$  is the alternating voltmeter to be calibrated. The differential electrometer is connected up as shown. The double fishtail-shaped needle is pulled one way by a force varying as the square of the direct electromotive force, and the other way by a force varying as the square of the alternating pressure. The fishtail shape is necessary to ensure that the needle is in stable equilibrium when the forces are equal. Fig. 1 is, of course, a mere diagram. Resistance-coils for adjustment are left out, and  $bc$  is shown as a stretched wire, whereas it is made up of resistance-coils. As to sensitiveness, it depends on the construction of the electrometer; but, as already explained, there is no controlling force except that due to the suspending fibre. Take as an example an instrument that will indicate one volt when there is no pressure on the other side: it will admit of the comparison of two pressures of approximately 100 volts within one in ten thousand; and it will serve for comparing 2000 volts within one in four million. To find the true zero of the instrument the four quadrants are connected together. The key for making this connexion is not shown.

One of the great advantages of the potentiometer method in direct-current work is the ease with which large currents can be measured by the fall of potential over very small resistances. As the electrometer must be used idiostatically in alternating work it is not sensitive to very small pressures; and the method given is, unfortunately, useful only for pressure measurements. Accurate current measurements can be taken by the use of a differential dynamometer. This instrument has two fixed and one moving coil. The direct circuit is through one fixed and the alternating through the other fixed coil, and both circuits are led through the moving coil. The controlling spring is removed. This method is somewhat more complicated than in the case of pressure, and mercury contacts are necessary. The arrangement is shown in fig. 2. The battery,  $a$ , supplies a direct current, which is measured by the fall of potential over the low resistance,  $b$ , and which passes in one of the fixed coils,  $c$ , and the moving coil,  $d$ . The alternating-current circuit is led through the circuit,  $f$ , whose current is to be measured, and through the other fixed coil,  $e$ , and the moving coil,  $d$ . There is a slight error due to the whole of the alternating circuit being in shunt to the moving coil considered as part of the direct-current circuit, and *vice versa*; but this is very minute. If

$c$  and  $e$  are wound close together so that there is no appreciable time-lag in any current induced in  $c$  by  $e$ , the small error due to the mutual induction of these coils cancels out.

Fig. 2.



Of course a double dynamometer might be used, but then four mercury connexions are needed. It is not unlikely that a method with no mercury contacts can be made available, and greater accuracy could then be attained.

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XVI. *Calculation of the Magnetic Field of a Current running in a Cylindrical Coil.* By Professor G. M. MINCHIN, M.A.\*

LET there be a series of very close circular currents running in the same sense and lying on a right cylinder of radius  $a$  whose axis is  $OO'$  (fig. 1), and let it be required to find the magnetic potential of this system at any point,  $P$ , in space.

Replace each of these circular currents by its equivalent magnetic shell, which we shall take as a uniform circular plate coinciding with the aperture of the circle. Supposing the currents to circulate in the sense  $ACB$ , the upper surface of each plate (as seen in the figure) will be positive and the lower negative. Each circle being touched all round by the one below it, the negative surface of any plate will coincide with the positive of the one next below it; so that we shall be left with a terminal positive plate,  $ACB$ , and a terminal

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