ELECTRICAL ENGINEERING TESTING

Curve Plotting.

Introduction.—The practice of recording the results of any measurements or tests graphically, as well as in tabular form, in cases where this is possible, cannot be too strongly urged, and is a most important, as well as, in many cases, an indispensable operation. More especially is this the case with a large number of physical measurements, and particularly so with a majority of tests in Electrical Engineering. The practice of curve plotting, as these graphical representations may otherwise be termed, presents the following important features—

(a) It enables the nature of the variation of one quantity with another to be seen at a glance much more clearly than is possible by aid of a table of results.

(b) It enables errors in experimental observations, of which there are sure to be some, to be corrected comparatively easily, which in a majority of cases would be impossible from the table of results.

(c) In the case of the calibration of instruments it enables the law of that under test to be readily observed.

(d) It has the enormous advantage of enabling any intermediate value between those actually observed and tabulated, to, be at once obtained accurately. This, it will readily be conceded, is the most important and valuable feature of all, and the ease, as well as the rapidity with which the operation of obtaining intermediate values can be accomplished, will be dependent on the scales chosen in originally plotting the curve in question.
It may therefore be profitable to indicate the mode of procedure in plotting curves, and with a view to exemplifying it, the results of a particular test are given in Table I, and the corresponding curve or graphical representation in Fig. 1. They relate to the determination of the Brake Horse Power (B.H.P.) of a motor and the corresponding value of its efficiency at each load.

<table>
<thead>
<tr>
<th>B.H.P.</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>30</td>
</tr>
<tr>
<td>1.75</td>
<td>29</td>
</tr>
<tr>
<td>2.5</td>
<td>29</td>
</tr>
<tr>
<td>4.0</td>
<td>29</td>
</tr>
<tr>
<td>6.0</td>
<td>29</td>
</tr>
<tr>
<td>8.0</td>
<td>27</td>
</tr>
<tr>
<td>11.5</td>
<td>26</td>
</tr>
<tr>
<td>16.5</td>
<td>25</td>
</tr>
<tr>
<td>21.0</td>
<td>24</td>
</tr>
<tr>
<td>30.0</td>
<td>21</td>
</tr>
<tr>
<td>50.0</td>
<td>19</td>
</tr>
</tbody>
</table>

In testing work generally at least six or eight different determinations throughout the range should be made, where possible, in order that the curve may be drawn more accurately. In most cases a curve constructed on three or four points only would be practically useless and could not be depended on.

Directions for Plotting—(1) Assuming that all the results are worked out numerically and entered up in tabular form, the first thing to note is what two sets of quantities have to be plotted together, and secondly, the largest value of each set, for beyond this the scale need not extend.

(2) The left-hand vertical and bottom horizontal sides OP and OQ respectively of the squared sheet of curve paper are termed the axes and are rectangular. They intersect in a point O called
the origin. Distances measured vertically are termed ordinates, and those horizontally, abscissae.

3. Carefully note which set of readings have to be plotted on the ordinates and which on the abscissae, and then choose the scales of the axes OP and OQ such that they are as long as possible and include the maximum values to be plotted. Also, if possible, arrange such that one of the smallest divisions represents a simple whole number of one digit. For example, if 33 was the largest number to be plotted and the side of the squared paper contained 100 divisions, let 1 division represent 0.5 only, whereas 66 will give the 33; this is far more convenient a scale for future reference in obtaining intermediate values than 1 division representing 0.33 (i.e. 53 to give the 33 approx.). While it is a great advantage for the numerical length of the axes to be as large as possible, so as to enable the curve to be drawn larger and more accurately, the length should be decided by considerations of future reference to it for intermediate values as just mentioned.

4. The axes must be numbered every 10th division, and under no circumstances with the numbers obtained from experiment.

5. Write along each axis the nature of the quantity plotted on it.

6. Each point must be plotted by finding the point of intersection of the axes representing the two corresponding quantities under consideration at the moment and a distinctive mark there made.

7. When all the points are plotted, a mean curve, as shown by the solid line, Fig. 2, must be drawn through as many points as will allow of a uniform line being drawn.

Some points are always sure to lie on either side of this mean line and denote experimental errors. The object of the curve is to correct for these.

8. In some tests, as for example in "characteristic" determinations with direct current generators, it often happens that curves cross one another and lie close together. In such cases they must be drawn thin and a different notation for the respective sets of points used, such as that represented in Fig. 3.

All confusion will thus be avoided.

Fig. 2.
Calibration and Standardization of Electrical Measuring Instruments.

General Remarks.—This subject is perhaps one of the most important in connection with electrical testing, and we shall therefore devote some considerable attention to it. It will at once be obvious to any one, without any consideration, that a measuring instrument which is reading incorrectly, or one that has been calibrated so long ago that its present readings may not be true, is a useless instrument, or even worse than this, as one is unconsciously liable to take its reading as correct. The importance of correct reading and accurately calibrated measuring instruments cannot be over-estimated, for on their being exchanged the whole crux of further testing, the results of which would otherwise be quite worthless. This the author would emphasize most strongly, for it is unfortunately his experience, and no doubt that of many more like him, that the average experimentalist is only too ready to take the scale reading of any instrument as correct without in the least troubling himself as to whether it actually is or not. This no doubt arises from the little extra trouble required to calibrate such instruments prior to starting some particular test.

Measuring instruments may change their constants and develop errors in their scale readings either from continued use, abuse, or in transit from one place to another, some of course being much more susceptible to alteration than others. Hence in all cases where it is desired to obtain accurate results and do good work, the instruments should be recalibrated and re-standardized frequently, and a calibration curve drawn whenever possible with the date of the test inserted. At the very least six determinations should be made, wherever possible, but preferably ten or twelve, as it is not possible to draw a reliable calibration curve on less than six points. In all cases it is of the utmost importance to see that the connecting wires or cables do not magnetically affect the instruments, for it must be carefully remembered that a wire carrying a current, no matter whether it is straight or otherwise, acts as a magnet.
Such inductive effects will be minimized by running or twisting the "lead" and "return" together, when the two equal and opposite magnetic effects neutralize. An ordinary flexible twin-lead is non-magnetic externally, but it possesses a very small electrostatic capacity.

Instruments are usually calibrated by comparing their readings with those of very accurately calibrated standard instruments. Simultaneous readings must be taken on both to avoid errors due to variation in between. Ammeters are always connected in series and voltmeters are always connected in parallel with their standards.

In the calibration of voltmeters, the employment of keys in any of the branched or parallel circuits containing voltmeters to be calibrated is usually a source of inconvenience and should be avoided, for a key which places, say, a voltmeter of 1500 Ohms resistance in parallel with a similar instrument already reading, will cause the reading to decrease owing to the alteration of the P.D. at the terminals due to inserting such a low resistance meter, and the consequent reduction in the terminal combined resistance.

1) Calibration of an Ammeter by comparison with a Standard D'Arsonval Ammeter.

Introduction.—When a standard current measurer, such as a Kelvin standard balance or a potentiometer set, is not available for comparing the ammeter to be tested with, the following method of calibration may conveniently be employed. It consists in using a good reflecting D'Arsonval galvanometer in conjunction with a low resistance composed of platinum or other suitable material having a small temperature coefficient of resistance, which should preferably be known. The resistance of the D'Arsonval galvanometer may conveniently be something like 2000 to 4000 times that of the low resistance to which it is shunted. The instrument, its scale, and the resistance should be permanently fixed and standardized carefully by means of a copper or silver voltmeter. Then if the current which produces a full scale deflection, with a certain known resistance in series with the galvanometer, is accurately known, the current producing any
other deflection with the same resistance will be very approximately in direct proportion and therefore at once known. Some slight corrections might be necessary for great accuracy when subsequently using these particular constants, due to alteration of resistance through change of temperature and to the deviation of the D'Arsenal readings from the direct proportional law, for which correction see Appendix, p. 420.

Apparatus.—Secondary battery $R$ capable of giving the maximum current required; reflecting D'Arsenal galvanometer $G$ (p. 569); switch $S$; key $K$; carbon rheostat $R$ (p. 597); resistances box (r); ammeter $A$ to be calibrated; low resistance $PP$, either of the form shown (p. 603), or simply a sheet of the metal.

N.B.—It is assumed that the galvanometer and low resistance in combination has been carefully standardized previously and now constitutes the standard D'Arsenal ammeter.

Observations.—(1) Connect up as in Fig. 3, and adjust the pointer of $A$ to zero and the spot of light from $G$ to the left-hand end of the scale used as a temporary or false zero in this test.

(2) Insert the proper resistance in (r) as given from the constants of standardization for the maximum current to be measured and corrected for the temperature of the room at the time of the test.

(3) With $K$ large, close $S$ and adjust the current through the ammeter to be calibrated to about $\frac{1}{10}$th of the maximum scale reading by means of $R$. Then note simultaneously its reading $A$ and the deflection $J$ on $G$ when $K$ is passed.

(4) Repeat 3 for about ten different readings on $A$ rising by about equal increments to the maximum with no decreasing of current.

(5) Repeat 3 and 4 for a similar descending set of the same readings on $G$, noting the corresponding ones on $A$, avoiding all increasing of current, and tabulate your results as follows—
(6) Plot curves having values of true current \( (a) \) as abscissa and \( A \) as ordinates.

**Inferences.**—Enumerate any sources of error in ammeters generally. What can you infer from your experimental results? Why should the current be so carefully increased only in 4 above and decreased only in 5 above?

(2) Calibration of an Ammeter by comparison with a Kelvin Composite Balance used as a Centi-ampere Meter.

**Introduction.**—The following is a convenient and ready means of calibrating any ammeter reading up to 1 ampere, employing a Kelvin composite balance used in the manner mentioned, as a standard for comparison. A complete description of the construction and manipulation of the instrument will be found on p. 554, to which a reference should be made and the constants obtained therefrom.

**Apparatus.**—Kelvin composite balance \( K.B. \) (p. 554); ammeter \( A \) to be tested; switch \( S \); adjustable resistance \( R \) (p. 600, at \( A \)); source of current \( C \) at a P.D. of from 40 to 60 volts.

**Observations.**—(1) Connect up as in Fig. 4, adjusting both instruments carefully to zero. Make quite certain that the connections are as indicated.

(2) Turn the switch in front of the balance to "volts" so as to place the fixed and movable fine wire coils in series with each
other and with the circuit. Now adjust the balance and its sensibility by employing the proper weights as given in the table of constants (p. 556), so that the maximum current to be measured on A would give a reading on K.B. as nearly right across the scale as possible.

(3) With R as large as possible close S and obtain about \(\frac{1}{10}\) of the maximum scale reading on A by varying R. Note this and simultaneously the corresponding position (d) of the slider of K.B.

(4) Repeat 3 for about ten different values of current on A (by altering R) rising by about equal increments to the maximum.

(5) Repeat obs. 4 for a similar set of descending values of current, and tabulate your results as follows:

<table>
<thead>
<tr>
<th>Name</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite Balance used: No.</td>
<td>Constante...</td>
</tr>
<tr>
<td>Ammeter tested...</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Upper Reading...</th>
<th>True Amper...</th>
<th>Reading on A...</th>
<th>% Error of...</th>
<th>Mean % Kew...</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ascending</td>
<td>Descending</td>
<td></td>
</tr>
</tbody>
</table>

(6) Plot a calibration curve for the ammeter tested having readings on A as ordinates and “True Currents” as abscissa.

Inferences.—What sources of error are ammeters in general liable to? Can anything in particular be inferred from your experimental results?

(3) Calibration of an Ammeter by comparison with a Kelvin Composite Balance used as a Hekto-ampere Meter.

Introduction.—The Kelvin composite balance can be used as a standard ammeter for the measurement of direct currents up to about 500 amperes, and hence any other ammeter can be readily calibrated by comparison with it. A description of the construction of the balance will be found on p. 551, together with the method of using it to measure heavy currents. In this connection it will be seen that the current to be measured passes through the thick fixed wire coils only, which not on the movable...
coils of fine wire carrying a small auxiliary current from preferably an independent source of e.m.f. The accuracy therefore of the calibration will depend on the accuracy with which the current through the moving coils is measured, and this is a disadvantage in the use of the composite balance for current measurement.

**Apparatus.**—Kelvin composite balance K.B.; ammeter $A$ to be tested; low reading accurately calibrated ammeter $(a)$; rheostats $R$ (p. 597) and $r$ (p. 600); switches $S_1$ and $S_2$; battery $C$ capable of giving the current corresponding to the highest scale reading on $A$.

**Note.**—If a second battery, such as six small cells, is available the auxiliary current circuit may preferably be fed from it, for then this current will remain unaltered when the main current through $A$ is altered.

**Observations.**—
1. Connect up as in Fig. 5 if only one battery is used, and adjust the pointers of $A$ and $a$ to zero, and also that of $K.B.$ in the manner mentioned on p. 596. Make quite certain that the connections are as indicated in the diagram.

2. Turn the switch on the balance (in front) to "Niddle" so as to put the fine wire movable coil only in connection with the small terminals, and therefore in series with the auxiliary circuit.

3. Adjust the balance and its sensibility by employing the proper weights as given in the table of constants (p. 597) so that the maximum current to be measured on $A$ would produce as nearly as possible a full scale reading on $K.B.$

4. With $r$ at its maximum close $S_1$ and adjust the current through the fine wire movable coil to its proper value, as given with the constant, by varying $r$. Always make quite sure that it has this value before taking each reading on $K.B.$

5. With $R$ large, close $S_1$ and obtain about $\frac{1}{4}$th of the maximum scale reading on $A$ by varying $r$. Note simultaneously the reading on $A$ and the position $(d)$ of the slider of $K.B.$
(6) Repeat 5 for some ten different values of current on \( A \) (by altering \( B \)) rising by about equal increments to the maximum.  
(7) Repeat obs. 6 for a similar set of decreasing currents and tabulate as follows—

<table>
<thead>
<tr>
<th>Name</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite Balance</td>
<td>No.</td>
</tr>
<tr>
<td>Constants used</td>
<td>Current in Young Cell</td>
</tr>
<tr>
<td>Ammeter tested</td>
<td>Type</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Meter Reading</th>
<th>True Amp.</th>
<th>Reading on A.</th>
<th>% Err of A.</th>
<th>Meter x Err.</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(8) Plot "calibration" curves for the ammeter tested having readings on \( A \) as ordinates and true currents as abscissas.

Inferences.—What source of error are ammeters in general liable to? Can you infer anything in particular from your experimental results?

(4) Calibration of an Ammeter by comparison with a Kelvin Centi-ampere Balance.

Introduction.—Any ammeter reading up to 1 ampere can be readily calibrated by comparison with a Kelvin standard centi-ampere balance. A full description of this instrument, together with the table of constants, will be found on p. 516, and the method of using it is precisely the same as that of the composite balance used as a centi-ampere meter, except that there is no switch at all on the balance in question. The operator should refer to the Appendix (p. 516) for details in connection with the balance.

Apparatus.—This, with the exception of the balance, is precisely the same as is required for the corresponding calibration by the composite balance.

Observations.—These, together with the diagram of connection and the inferences, are precisely the same as for the test on p. 7 and will not therefore be repeated here. The operator must refer to the similar test using the composite balance.
(5) Calibration of a Direct Current Ammeter.

(Crompton Potentiometer Method.)

Introduction.—This method is a very convenient and accurate one for calibrating ammeters, and in it the measurements are referred to and obtained in terms of a standard Clark cell and standard resistance. The principle of the method is a direct application of Ohm's Law, and consists in measuring the fall of potential down an accurately known standard low resistance connected up in series with the circuit through which the current to be measured is passing. This fall of potential is measured in terms of the E.M.F. of the Clark's cell through the medium of the potentiometer, employing the principle of the Clark-Poggendorff method for comparing two or more E.M.F.'s. A detailed description of this will be found in a separate work by the author on Practical Electrical Testing for 1st and 2nd year students and others. The Crompton potentiometer is a specially arranged form of comparing instrument by means of which the calibration can be easily and quickly carried out. Before proceeding further the operator should refer to a detailed description of this piece of apparatus which will be found in the Appendix (p. 510) together with the method of using it. The present method possesses the all-important advantage that the measurements are all in terms of the Official Board of Trade standard—the Clark cell—that their accuracy is great, and without any very special means this can be obtained to at least 1 in 1000, and that the range is almost limitless from 0 continuously up to maximum commonly met with in practice. The accuracy of the results in the present method is more particularly dependent on that with which the standard low resistance is known. The value of this must be such that the fall of potential down is due to the maximum current to be measured is not greater than 1.5 volts, while at the same time the carrying capacity must be such as to allow it to pass this current without sensible heating, which would thereby alter its resistance.

Apparatus.—Crompton potentiometer $P$ (p. 510); secondary Battery $B$ capable of easily giving the maximum current required for a full scale reading on the ammeter $A$ to be calibrated.
switch S; one secondary cell (a) for the "working cell" of the potentiometer; accurately known standard low resistance R (p. 399); sensitive D'Arsonval or moving coil galvanometer (g) (p. 589); standard Voltmeter E; carbon rheostat (r) (p. 597).

![Diagram of electrical components](image)

**Observations.**—(1) First place the lower of G and E (Fig. 208) on studs 14, and that of H on studs 1 or 2 for protection. Now connect up as in Fig. 6, in which only the row of terminals on the potentiometer P is shown symbolically for brevity.

(2) Adjust the galvanometer g approximately, and A carefully, to zero, levelling them if necessary. See that a suitable low resistance standard R is employed, and one that will give a full fall of potential at its ends not exceeding 1-5 volts (= A x R) for the maximum current to be used (vide p. 13).

(3) "Set the potentiometer" by the standard cell in the way described on p. 614, the contact lever H above referred to being on studs IV, thus inserting A (Fig. G) in the circuit of g, which must be done so that its B.M.R. opposes that of b. Now close S and adjust rA so as to obtain about 1/20th of the full scale reading on A.

(4) With the positions of the resistances G and C (Figs. 207 and 208) as found in 3, unscrew, turn the lever of H towards III so as to throw into circuit g the fall of potential down R which as seen across terminals III. Now adjust the lever of the resistance H (Fig. 207) and the sliding key C so that no deflection occurs on g on pressing this latter.

N.B.—If it is impossible to get a balance owing to the deflection of g being always to one side, the E.D. across III is assisting, instead of opposing (as it should be) the fall due to b in the
stretched wire; the wires from \( R \) to \( III \) must then be interchanged.

1. If the lever at \( E \) is on stand 1 (literally 1000) and the slider \( C \) at 315 on the scale, the P.D. across \( R = 1315 \) volts and the true current \( A \) through \( A \) if \( R = 0.1 \) Ohm is \( \frac{1315}{0.1} = 13150 \) amperes.

Note simultaneously the readings on \( P \) and \( A \) when balance is obtained. Turn \( II \) to \( IV \) again and see whether the balance in ohms still holds. If it does not, reset \( P \).

2. Take about ten different scale deflections on \( A \) rising by about equal increments to the maximum by varying \( P \) and repeat 4, noting the new values of \( P \) and \( A \).

3. Repeat 4 and 5 for a similar descending set of readings on \( A \) and tabulate your results as follows:

<table>
<thead>
<tr>
<th>Meters</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clark Cell: Fo...</td>
<td>Temperature =... ( \times ) C:</td>
</tr>
<tr>
<td>Potentiometer setting: X th...</td>
<td>E...</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Meters</th>
<th>Data</th>
<th>E.M.F. Measured (C)</th>
<th>True E.M.F. ( E_1 ) volts</th>
<th>True Current ( A_1 ) amperes</th>
<th>Error of reading ( E_1 - A_1 )</th>
<th>( % ) Error</th>
</tr>
</thead>
</table>

It should be carefully noted whether a "Clark" cell or "Carhart-Clark" cell is being used before setting the potentiometer in 3, and that the assumed E.M.F. for this purpose at the particular temperature is correct, the temperature coefficient of E.M.F. being very different in these two cells (see p. 645).

Standard Weston (cadmium) cells have an international value of E.M.F. of 1.0183 volts at 0 C, with a temperature coefficient of \(- 0.0003396\) volt per rise of 1 C, between 0 and 100 C. In 1905, for a range of 0 C to 100 C, Wolff obtained the relation giving the E.M.F. at \( \times \) C, namely:

\[
E_1 = x_0 - 0.000446(e - 20) - (9.5 \times 10^{-7})(e - 20)^3
\]

(7) Plot calibration curves for the ammeter tested having values of \( A \) as ordinates and true amperes \( A_1 \) as abscissae.

Inferences.—What can you infer from your experimental results, and can you suggest any source of error which might affect the results?
(6) Determination of the "Constant" of a Galvanometer or Ammeter by Means of a Copper Voltameter.

Introduction. — From the results of a large number of tests it has been found that, using the necessary precautions, the constant of an electric current instrument can be obtained with certainty to within 1½% of absolute accuracy by the electrolysis of copper. The voltameter (V) should consist of three or more pure copper plates dipping into a saturated solution of copper sulphate contained in a suitable glass or earthenware vessel, there being one, more "anode" than "cathode," and the two sets arranged alternately with an anode at each end. The plates should be as square as possible, and placed from ½" to 3" apart; if too close, polarization will take place when strong currents are used, and the current density ( reckoned in amps. per sq. cm.) is too great. There should not be less than 30 sq. cm. per amp.; if there is, the plate surface will be too small and the deposit on the cathode irregular, some of it falling to the bottom of the vessel. The resistance of V will also become high and variable, due to the formation of copper oxide, and will give trouble in keeping the current constant. The solution should be a saturated one (sp. gr. 1.211) of pure copper sulphate crystals and distilled water, with 1% by vol. of strong sulphuric acid added, which is necessary to insure success. The vol. of solution should be about 1400 cc. per amp. The anodes may be made of about No. 18 S.W.G., and the cathodes or gain plates of No. 30 S.W.G. pure copper, all edges and corners being smooth and rounded. The electrolytic equivalent (Z) of any substance, in this case copper — No. gms. deposited by 1 coulomb.

\[
\begin{array}{c|c|c|c}
\text{Cathode area} & \text{Values of (Z) for Copper.} \\
\hline
\text{(sq. in.)} & \text{10°C} & \text{20°C} & \text{30°C} \\
\hline
90 & 0.0083259 & 0.0083259 & 0.0083259 \\
90 & 0.0083259 & 0.0083259 & 0.0083259 \\
110 & 0.0083259 & 0.0083259 & 0.0083259 \\
130 & 0.0083259 & 0.0083259 & 0.0083259 \\
150 & 0.0083259 & 0.0083259 & 0.0083259 \\
170 & 0.0083259 & 0.0083259 & 0.0083259 \\
190 & 0.0083259 & 0.0083259 & 0.0083259 \\
210 & 0.0083259 & 0.0083259 & 0.0083259 \\
230 & 0.0083259 & 0.0083259 & 0.0083259 \\
250 & 0.0083259 & 0.0083259 & 0.0083259 \\
270 & 0.0083259 & 0.0083259 & 0.0083259 \\
290 & 0.0083259 & 0.0083259 & 0.0083259 \\
310 & 0.0083259 & 0.0083259 & 0.0083259 \\
330 & 0.0083259 & 0.0083259 & 0.0083259 \\
350 & 0.0083259 & 0.0083259 & 0.0083259 \\
370 & 0.0083259 & 0.0083259 & 0.0083259 \\
390 & 0.0083259 & 0.0083259 & 0.0083259 \\
410 & 0.0083259 & 0.0083259 & 0.0083259 \\
430 & 0.0083259 & 0.0083259 & 0.0083259 \\
450 & 0.0083259 & 0.0083259 & 0.0083259 \\
470 & 0.0083259 & 0.0083259 & 0.0083259 \\
490 & 0.0083259 & 0.0083259 & 0.0083259 \\
510 & 0.0083259 & 0.0083259 & 0.0083259 \\
530 & 0.0083259 & 0.0083259 & 0.0083259 \\
550 & 0.0083259 & 0.0083259 & 0.0083259 \\
570 & 0.0083259 & 0.0083259 & 0.0083259 \\
590 & 0.0083259 & 0.0083259 & 0.0083259 \\
610 & 0.0083259 & 0.0083259 & 0.0083259 \\
630 & 0.0083259 & 0.0083259 & 0.0083259 \\
650 & 0.0083259 & 0.0083259 & 0.0083259 \\
670 & 0.0083259 & 0.0083259 & 0.0083259 \\
690 & 0.0083259 & 0.0083259 & 0.0083259 \\
710 & 0.0083259 & 0.0083259 & 0.0083259 \\
730 & 0.0083259 & 0.0083259 & 0.0083259 \\
750 & 0.0083259 & 0.0083259 & 0.0083259 \\
770 & 0.0083259 & 0.0083259 & 0.0083259 \\
790 & 0.0083259 & 0.0083259 & 0.0083259 \\
810 & 0.0083259 & 0.0083259 & 0.0083259 \\
830 & 0.0083259 & 0.0083259 & 0.0083259 \\
850 & 0.0083259 & 0.0083259 & 0.0083259 \\
870 & 0.0083259 & 0.0083259 & 0.0083259 \\
890 & 0.0083259 & 0.0083259 & 0.0083259 \\
910 & 0.0083259 & 0.0083259 & 0.0083259 \\
930 & 0.0083259 & 0.0083259 & 0.0083259 \\
950 & 0.0083259 & 0.0083259 & 0.0083259 \\
970 & 0.0083259 & 0.0083259 & 0.0083259 \\
990 & 0.0083259 & 0.0083259 & 0.0083259 \\
\end{array}
\]
**ELECTRICAL ENGINEERING TESTING**

Apparatus.—Voltaimeter (V); rheostat R (p. 207); switch S; ammeter A to be standardized; secondary battery; drying cup- 
gard D, not shown; acid bath.

Observations.—(1) Connect up as indicated in Fig. 7, and 
adjus t A to zero. Light the gas jet under the steam boiler of D, 
after ascertaining that the latter contains enough water.

(2) Determine the necessary area of cathode, and hence the 
number of gain plates required for the current to be used, 
reckoning both sides in contact with liquid as the effective area 
of cathode.

(3) Carefully clean the cathodes all over with fine emery cloth 
until quite bright, then dust with a dry clean cloth, and do not 
touch the part to be immersed with the fingers. Clean the anodes 
if they look dirty.

(4) Carefully weigh the gain plates on a chemical balance to 
1 m. g., and note their weights (W.) grams.

(5) Insert the same area of trial plate to act as cathode, so as 
to adjust the current to the value required, then remove them, 
making sure that the + of battery is joined to anode.

(6) Insert the weighted gain plates and at a convenient and 
note the instant of time switch on, quickly adjusting the current to 
its proper value.

(7) Keep it flowing for at least thirty minutes, and maintain it 
constant all the time by altering R, if necessary. (Note.—1.177 
grams of copper (copper) are deposited per amp.-hour approx.)

(8) Note the exact instant of switching off. Very carefully 
remove the gain plates so as not to scratch them, rinse in acid- 
ulated water to prevent the tarnish copper oxidizing, then in clean 
water, and place in D to dry.

(9) When dry and cool re-weigh the gain plates and note the 
weights W. grams.

(10) Repeat 2-9 for one or two other current strengths and 
labelate as follows—

<table>
<thead>
<tr>
<th>Weight of plate in</th>
<th>Deposit W</th>
<th>Time in Bats</th>
<th>Reading of</th>
<th>Time (in sec.)</th>
<th>Z or E</th>
<th>2 E direct</th>
</tr>
</thead>
<tbody>
<tr>
<td>grams</td>
<td>(in 2R - 2F)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below 2 F</td>
<td>Above 2 F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
(7) Calibration of Direct Current Voltmeters.  
(Poggendorff's Method.)

Introduction.—The following method is a convenient one for enabling low-reading voltmeters up to about 3 or 4 volts to be easily and rapidly calibrated by comparison with one or two Clark's standard cells. Some convenient form of meter bridge, either circular or ordinary, is required. The principle of the method will be seen to be practically the same as the "Clark-Poggendorff" method of comparing two E.M.F.'s.

Apparatus.—Metro bridge of some convenient type, either the ordinary straight or circular form; secondary battery B giving an E.M.F. a little in excess of the maximum voltage to be recorded on the voltmeter V to be calibrated; key k; carbon sheet cell A (p. 597); sensitive galvanometer G (p. 572); high resistance (r) of about 10,000 ohms; standard cell (S) of known E.M.F. It will be observed that the metro bridge, of whatever form is used, is represented symbolically by PQ in Fig. 8, and if the general scheme of the connections is understood, there will be no difficulty with them when using any form of bridge.

![Diagram](image)

Fig. 8.

Observations.—(1) Connect up as in Fig. 8, adjusting V carefully to zero and S to about zero. See that like poles of B and S
are connected to the same end $P$, when the respective E.M.F.'s will oppose one another.

(2) Adjust $R$ to a high value and likewise ($p$), which might preferably be about 10,000 ohms, and is merely for the purpose of preventing the standard cell $S$ from sending but a very minute current when its circuit is closed at the tapping key or sliding contact $C$, which at first might be far from the correct position of balance. When $C$ is moved to such a position that the deflection on $G$ is small, ($p$) may temporarily be cut out of circuit so as to make the sensitivity of the test a maximum.

(3) Now close $K$ and alter $R$ so as to obtain about 1/10th of the maximum scale reading on $P$.

(4) Find a position for $C$ such that on making contact with the bridge wire by means of it, no deflection occurs on $G$, $r$ being manipulated as in obs. 2. Note the reading on the voltmeter $V$ calibrated and the position of $C$ where $PC = r_1$ and $QC = r_2$.

(5) Re-insert $r$ and repeat obs. 3 and 4 for about ten readings on $V$ rising by about equal increments to the maximum.

(6) Calculate the true volts $V_x$ from the relation:

$$ V_x = \frac{r_1 + r_2}{r_1} \times \text{E.M.F. of standard cell,} $$

and tabulate your results as follows:

<table>
<thead>
<tr>
<th>Name</th>
<th>E.M.F. of Standard Cell</th>
<th>Volts at $t^\circ$C.</th>
<th>$r$</th>
<th>$r_1 + r_2$</th>
<th>Standing on $V$</th>
<th>True Volts</th>
<th>$V_x$</th>
<th>X Error of Voltmeter</th>
<th>Testing</th>
</tr>
</thead>
</table>

Note.—The E.M.F. of a Clark's standard cell = 1.4340 legal volts at 16$^\circ$C, and its E.M.F. at other temperatures may be found from the relation:

$$ \text{E.M.F.} = 1.4340 [1 - 0.0007 (t - 16)] \text{ legal volts,} $$

where 0.0007 is the temperature coefficient of the cell and $t$ = its temperature in degrees Centigrade. For a Carhart-Clark cell the coefficient is 0.000338. For table of E.M.F.'s see p. 643.

(7) Plot a calibration curve of the voltmeter under test having values of $V$ as ordinates and $V_x$ as abscissae.

Inferences.—Does the accuracy of the above test depend on
anything in particular? Show how the relation given in 6 can be obtained and state any assumptions made in deducing it.

(8) Calibration of a Voltmeter by Comparison with a Standard D'Arsonval Voltmeter.

Introduction.—The method may conveniently be employed for calibrating a voltmeter when neither a Kelvin standard balance nor a "potentiometer set" is available for use as a standard with which to compare the instrument under test. In the present case a fairly sensitive and good form of D'Arsonval galvanometer combined with a high resistance placed in series constitutes the standard voltmeter which together with its scale is permanently fixed up. The arrangement is very carefully standardised and its constants found with the aid of a Clark’s standard cell and Clark’s potentiometer method (p. 10), and thus a reliable standard voltmeter is obtained.

If the voltage which produces a full scale deflection with a certain resistance in series with the instrument at a given temperature is known, then that causing any other deflection under the same conditions will be in direct proportion and therefore to once known. For considerable accuracy some small corrections would be necessary in using these constants at some other time owing to the difference in temperature altering the resistance of the galvanometer coil and those in series with it, and to the D'Arsonval not exactly fulfilling the direct proportional Law, for which correction see p. 190.

The D'Arsonval and its resistance can be arranged in one of two ways—(a) as represented in Fig. 8, assuming that a sufficiently high adjustable known resistance for placing in series with it is available. If then the "figure of merit" of G, i.e. the sur-passing (a) per scale division, is accurately known, the extra high resistance (r) necessary to be placed in series with it so that the
required maximum voltage applied to \( AD \) (Fig. 6) may produce a
full scale deflection on \( G \), can be found by Ohm's Law as follows—

If \((a)\) is the maximum scale reading to be obtained by a
maximum voltage \( V \), then if \((e)\) is the resistance of the galvan-
ometer \( G \), we have \((e + g) = \frac{V}{c} = \frac{V}{V + \omega d}\).

\[ \therefore r = \left( \frac{V}{\omega d} - g \right) \text{ ohms.} \]

(b) If \( G \) is very sensitive and sufficient resistance is not avail-
able the arrangement in

Fig. 10 may be used, \( r \)

dow taking the form of

two resistance boxes \( r_1 \)
and \( r_2 \).

In this case \( r_1 \) will be
small, compared with the
resistance of \( G \) and with
\((r_1 + r_2)\), and this sum
large compared with the
resistance of \( V \), the voltmeter to be calibrated.

If \( V \) and \( v \) are the voltages across \( AD \) and \( r_1 \), respectively and
\((e)\) the resistance of \( G \), whose "figure of merit" is \((e)\),

then \( V : v = r_1 + \frac{r_2}{r_1 + r} = \frac{s}{r_1 + r} \)

and if \((e)\) has the same meaning as before \( v = \omega d \),

whence \( \frac{r_1}{r_1 + r} = \frac{\omega d}{r_1 + r} \cdot \frac{r_1}{r_1 + r} \)

assuming \( r_2 \) to be negligibly small compared with \( g \) and \( r_2 \) we
have \( \frac{r_2}{r_2} = \frac{\omega d}{V} \) approximately, which is obvious from a con-

sideration of Ohm's Law.

Referring to Fig. 8 it will be seen that discarding the
cell \( S \), the standard D'Arsenval \( G \) with its extra resistance \( r \)
may be employed to actually measure the P.D. between \( F \) and \( G \),
whence knowing the ratio of \( PQ \) to \( PQ \) the true volts corre-

sponding to any reading on \( V \) (Fig. 8) can at once be obtained.

Thus the arrangement just referred to practically brings us to

Fig. 10.

Apparatus.—Secondary battery \( B \) of a sufficient number of cells

to give the highest reading on the voltmeter \( V \) to be calibrated; a fairly high resistance D'Arsenval galvanometer \( G \) (p. 565) preferring tapping key \( k \); one or two high resistance boxes \( r_1 \) and \( r_2 \); variable unknown high resistance rheostat \( R \); this latter, however, will be of no use if the resistance of the rest of circuit is very high, and in this case the voltage drop to \( B \) will have to be varied by altering the number of cells in the battery.

Observations.—(1) Connect up as shown in Fig. 10, which latter arrangement will be found to be the one most common in practice. Adjust the spot of light of \( G \) to the left-hand end of the scale as a temporary or false zero so as to obtain a full scale deflection up to the other end for the maximum voltage to be measured.

(2) Insert the proper resistances in \( r_1 \) and \( r_2 \) as given from the constants of standardization for the maximum voltage to be measured and corrected for the temperature of the room at the time of the test.

(3) Close \( k \) and adjust \( R \), or alter the number of cells in \( B \) so as to obtain about \( \frac{1}{5} \) of the maximum scale reading on \( V \) and note simultaneously the readings on \( V \) and \( G \).

(4) Repeat 3 for about ten different readings on \( V \) rising by about equal increments to the maximum.

(5) Repeat 3 and 4 for a similar descending set of the same readings on \( G \), noting the corresponding ones on \( V \) and tabulate your results as follows—

<table>
<thead>
<tr>
<th>Bank</th>
<th>Type</th>
<th>Date</th>
<th>Temperature C</th>
<th>Resistance R</th>
<th>Current</th>
<th>( V ) in Volts</th>
<th>( V ) in ( h ) ( V/V ) of Voltaimeter</th>
<th>( A ) in Volts</th>
</tr>
</thead>
</table>

\( \text{V} \) Instead of the variable high resistance rheostat \( R \) shown in beach 8-31 which may not be available, the following arrangement for varying the voltage across the parallel combination of voltmeter tested and standard, will be found convenient, namely—connect two variable lamp resistances \( R_0, R_2 \) in series across the supply and short one of them \( R_1 \) with the voltmeter and standard in parallel, the lamps of each rheostat being operated in parallel and using for a voltage \( v \) that of the supply. Then by keeping 1 lamp in \( R_1 \) and varying \( R_2 \), the voltage across \( R_2 \) can be varied from \( 1 \) that of the supply to its full value; while by keeping 1 lamp in \( R_0 \) and varying \( R_1 \), the voltage across \( R_1 \) can be varied from \( 1 \) that of the supply to 0; thus covering the full range of supply volts on \( R_2 \).
(6) Plot "calibration curves" having values of true voltage
(c) as ordinates and \( V \) as abscissae.

\[ \text{Inferences.} \quad \text{Enumerate any sources of error in voltmeters generally. State clearly what you can infer from the results of your tests.} \]

(9) Calibration of a Voltmeter by Comparison
with a Kelvin Composite Balance used as
a Voltmeter.

\[ \text{Introduction.} \quad \text{The composite balance when used in conjunction with separate anti-inductive resistances may be conveniently employed as a standard direct or alternating current voltmeter capable of measuring pressures up to about 600 volts.} \]

The following method assumes the use of such an instrument, and the reader should refer to p. 654, et seq., for the construction and mode of using this form of balance and for the table of constants and sensitivities.

\[ \text{Apparatus.} \quad \text{Adjustable, fairly high resistance} \; R \; (p. \; 603); \]

switch \( S \); voltmeter \( V \) to be calibrated; Kelvin Composite Balance \( K.N. \), with its non-inductive resistance \( r \) (p. 653); battery of secondary cells capable of giving the maximum voltage to be used, which we therefore assume to be direct.

\[ \text{Observations.} \quad (1) \; \text{Connect up as in Fig. 11, adjusting both instruments carefully to save, and make quite certain that the connections are as indicated.} \]

(2) Turn the switch in front of the balancer to "Volts" so as to place the fixed and movable fine wire coils in series with one another across the terminals. Observe that the anti-inductive resistance \( r \) is numbered the same as, and therefore belongs to the balance in use, and make quite sure of having the correct resistance in it in use (p. 666).

(3) Adjust the balance and its sensibility by employing the proper weights as given in the table of constants (p. 656), so that
the maximum voltage to be measured on $V$ would produce as nearly as possible a full scale reading on $R$.

(4) With $R$ as large as it can be, close $S$, and obtain about $1/4$th of the maximum scale reading on $V$ by altering $R$. Note simultaneously the reading on $F$ and position ($d$) of the slider of $R.B.$

(5) Repeat 4 for some ten different values of voltage on $V$ (by altering $N$ or the number of cells in the battery) rising by about equal increments to the maximum.

(6) Repeat obs. 6 for a similar set of decreasing voltages, and tabulate your results as follows—

<table>
<thead>
<tr>
<th>Name</th>
<th>Date</th>
<th>Compares Between: No...</th>
<th>Conducts...</th>
<th>Voltmeter tested...</th>
<th>Temperature...</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Initial reading $d$</th>
<th>Voltage $A.D.$</th>
<th>Cells Volt $F_r.$</th>
<th>Reading on $F_r.$</th>
<th>First Reading</th>
<th>Second Reading</th>
</tr>
</thead>
</table>

H.N.—The values $F_r.$ taken from the readings on the standard corrected for temperature.

(7) Plot a calibration curve for the voltmeter tested having readings on $F_r.$ as ordinates and true volts $F_r.$ as abscissae.

Inferences.—What sources of error are voltmeters in general liable to? Can anything in particular be inferred from the above results?

(10) Calibration of a Voltmeter by Comparison with a Kelvin Centi-ampere Balance used as a Voltmeter.

Introduction.—The Kelvin Standard Centi-ampere balance when used in conjunction with extra anti-inductive resistances constitutes a most convenient standard voltmeter with which to calibrate any other voltmeter to be calibrated, up to about 800 volts.

For larger voltages, up to 2500 volts, special non-inductive high resistances are provided for inserting in series with the cells of the instrument. The combination then constitutes a standard voltmeter by means of which any other voltmeter, either for direct or alternating currents, reading up to 2500 volts, can be calibrated, by comparison, in the ordinary way.

A complete description of this balance, together with the
method of using it, will be found on p. 516 et seq., where the table of constants is given.

In the present test the apparatus, observations and inferences are precisely similar to that of the corresponding calibration by means of the composite balance used as a voltmeter, the centi-amperes balance being substituted for this latter. They will consequently not be repeated here, but may be seen on p. 31.

(11) Calibration of a Direct Current Voltmeter.
(Crompton Potentiometer Method.)

Introduction.—The method is a very convenient and accurate one for the purpose, and consists in calibrating the voltmeter to be tested in terms of the E.M.F. of a Clark’s standard cell, a known fraction only of the voltage applied to the instrument being actually compared with the standard E.M.F. The principle of the method is identical with that of the “Clark-Poggendorff” method for comparing two or more E.M.F.’s, a full description of which will be found in a separate work, by the author, on Practical Electrical Testing, for 1st and 2nd year students and others. The Crompton Potentiometer is a specially arranged form of comparing instrument by means of which the calibration can be easily and quickly carried out. A detailed description of it will be found on p. 516, to which the reader should in the first instance refer. There are three extremely important features in connection with the present method, using the potentiometer; firstly, the enormous range of applicability, for the instrument can be used equally well in the measurement of current and resistance as well as voltages from 0 to almost any practical amount; secondly, the measurements are in terms of the official Board of Trade Standard—the Clark cell—though any other standard can be used; thirdly, the accuracy is great and under ordinary conditions the measurements are accurate to at least 0.5%, and with care, using a very accurately adjusted instrument, accuracy to something like 0.1% can be obtained. In this form a potentiometer the highest voltage which can be compared directly in 1.5 volts, and hence the fractions employed of all higher pressures to be measured must fall within this limit.

Apparatus.—Crompton potentiometer P (Fig. 200); secondary cellery B capable of giving the maximum voltage required for a
full scale reading on the voltmeter \( V \) to be calibrated; key or switch \( S \); one secondary cell (\( \delta \)) for the "working cell" of the potentiometer; "volt box," i.e., divided resistance cell for obtaining a fraction (less than 1/5 volt) of the total P.D. to be measured (p. 512); sensitive D'Arsenval or moving coil galvanometer (\( \gamma \)) (p. 569); standard Clark cell \( E \); fairly high resistance rheostat \( R \) (p. 503). See footnote, p. 20.

Observations.—(1) After placing the levers of \( G \) and \( R \) on studs 14 and that of \( H \) on studs 1 or 2 for practice, connect up as in Fig. 12, in which only the row of terminals on the potentiometer \( V \) is shown, symbolically, for the sake of brevity.

(2) Adjust the spot of light of the galvanometer to somewhere about zero on the scale, and the resistance \( ad \) and \( cd \) in the "volt box" so that \( ad = \pi \) of \( cd \), supposing, of course, that not more than 150 volts is across \( cd \). Carefully level and adjust \( V \) to zero if it requires it.

(3) "Set the potentiometer" by the standard cell in the way described on p. 514, the contact lever \( H \), Fig. 208, p. 512, being on studs \( H \), thus inserting \( R \) in the circuit of \( g \) in such a way as to oppose that of \( b \), close \( S \), and adjust \( R \) so as to obtain the full scale deflection on \( V \).

Note.—This last operation will only be possible when \( R \) is comparable with the parallel resistances of \( ad \) and \( V \). If both these are very high then altering \( R \) will have very little effect on the reading of \( V \) unless \( R \) is high also in comparison.

(4) With the positions of the resistances \( G \) and \( G \) (Fig. 208, p. 512), as found in 3, unaltered, turn the lever of \( H \) in stud
ELECTRICAL ENGINEERING TESTING

III so as to throw into circuit with $g$ the $\frac{1}{4}$th part of the voltmeter P.D., which was across terminals III. Now adjust the

**N.B.**—If no balance can be obtained owing to there being no

reversal of deflection on $g$, the fractional P.D. across III is

assisting instead of opposing (as it should be) the fall of potential
due to (b) in the stretched wire. The wires from $ad$ to III must

then be interchanged. If the lever at $K$ is on stud 12

(basically 12,000) and the slider $C$ at 325 on the scale, the voltage

across $ad$, i.e. at the terminals of $V = 128.25$ volts. Note these

positions on $PP$, and simultaneously the reading $V$ on the instru-

ment to be calibrated.

(6) Reduce $Y$ by about $\frac{1}{4}$, either by cutting out cells in $B$ or

by altering $R$ or both, and repeat 4, noting the new values of

$Y$ and $PP$. Turn $II$ to $IV$ for a moment and see whether the

balance in obs. 3 still holds, if not repeat as in obs. 3 above.

(6) Repeat 4 and 5 for some ten or twelve different readings on $Y$ decreasing by about equal amounts to the lowest,

(7) Repeat 4 to 6 for a similar ascending set of observations,

and tabulate your results as follows—

<table>
<thead>
<tr>
<th>Voltmeter Reading $V$</th>
<th>Voltmeter Reading $V'$</th>
<th>True Volt Across $V_t$</th>
<th>Error of Voltmeter $V_t - V'$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As it may sometimes be the case that a Carhart-Clark and not

a Clark's standard cell has to be used, care should be taken that

the E.M.F. assumed at the particular temperature is correct, the

temperature coefficient of E.M.F. being very different in the two

cases (vide pp. 17 and 643).

(8) Plot a calibration curve for the voltmeter tested having

values of $V$ as ordinates and true volts $V_t$ as abscissae.

**Inferences.**—What can you infer from the results of your test?

Are there any sources of error which might vitiate the results?
(12) Calibration of a High Tension Alternating Current Voltmeter.

Introduction.—In the ordinary high tension systems of distribution of electrical energy by alternating currents, the average working pressures are about 2000 or 2500 volts. The "electro-magnets" and "hot wire" types of voltmeters are unsuitable for measuring such high pressures, which can best be dealt with by means of a third class of instrument known as the electrostatic voltmeter; a description of two forms of which will be found in the Appendix (p. 562).

These instruments are almost universally employed for measuring alternating current pressures, and they have the all-important advantage of being unaffected by variation of frequency. Owing usually to the difficulty experienced in obtaining direct current pressures of the above magnitude for testing purposes, alternating currents have nearly always to be employed for calibrating high tension voltmeters. Thus it will be seen that none of the preceding methods are available in the present case, but the calibration can be effected by what may be termed the "fractional potential difference" method, using an accurately calibrated low tension electrostatic voltmeter for comparison in the manner to be described later.

This low tension voltmeter, which may conveniently be one of Lord Kelvin's multi-cellular electrostatic instruments reading to, say, 150 volts, should be very carefully calibrated by one of the preceding methods—preferably the potentiometer, one using a Clark's cell as a standard of E.M.F. and direct current pressures of course. For accurate work, however, the following remarks should be observed. In these voltmeters the movable needle system is usually aluminium and the fixed system brass, whereas owing to aluminium being electro-positive to brass, the instrument will read from 0·7 volt to 0·9 volt too low when the + pole of the direct current source is connected to needle, and the same amount too high if the — pole is joined to the needle system instead. In calibrating this low reading voltmeter by the potentiometer, it should be connected up through a reversing key to the rest of the apparatus and the mean of the readings, before
and after reversing the polarity on its terminals, taken as the Corrections for alternating currents, since when used with such
the above-named error does not occur. Again with direct currents
an electrosstatic voltmeter passes no current, but owing to it
possessing a perfectly definite though very small capacity, it will
behave like a condenser with alternating currents, i.e. a pulsating
or "charge and discharge" current will be set up in its
circuit. Thus it will be seen that if, as in the present method,
such an instrument is shunted across part of a circuit carrying
an alternating current, the current in the voltmeter branch may
be quite comparable with that in the main circuit, in other words
the P.D. between the points to which it is shunted would be
lowered somewhat by the voltmeter, and $\phi$ would not bear
to the whole P.D. the ratio of the resistance of the two portions of
the circuit. To avoid such an error the resistance of the main
circuit should be such that the maximum pressure to be used
sends a sensible current such as from $\frac{1}{2}$ to $\frac{1}{4}$ an ampere through
it, which will consequently be very large compared with the
current in the voltmeter branch. Thus the presence of this latter
will not affect the value of the P.D. between the two points to
which it is applied, and consequently the ratio of the whole P.D.
to the fraction thus tapped will equal the ratio of the whole
resistance to the fraction across which the electrosstatic voltmeter
is placed.

Apparatus.—Alternator $A$, capable of supplying a low pressure,
and of being driven at any required speed by
a direct current, electromotor ( preferably), or
other prime mover, its
existing circuit $B$ consist of the field coils
of $A$ (shown), together
with switch, rheostat,
ammeter and source of
excitation (not shown), but which can be varied so as to vary the
E.M.F. of $A$; step-up transformer $F$ capable of increasing the
pressure from that of $A$ to the maximum required for a full
scale reading on the high tension voltmeter $V$ to be calibrated;
low tension electrostatic voltmeter \((v)\) (p. 502), reading to say 150 volts, and which has been previously carefully calibrated by reference to a standard Clark cell on the potentiometer; switch \(s\). A divided non-inductive high resistance \((eh)\) capable of standing the highest pressure to be used on \(P\), and of carrying an appreciable current, say of the order of \(\frac{1}{2}\) to \(\frac{1}{4}\) an ampere continuously without excessive heating.

**Caution.**—Under no circumstances whatever is any part of the high tension circuit to be touched while "alive," and the indiarubber gloves are to be worn throughout the test by the operator reading the electrostatic voltmeters.

**Observations.**—(1) Connect up as in Fig. 13, and carefully level and adjust the pointers of \(F\) and \(v\) to zero. For the high tension side use well insulated wires for the connections, and keep them in mid-air as much as possible.

(2) If the voltmeter \(v\) to be calibrated reads up to, say, 2500 volts, and \(v\) to only 150 volts, place this latter across a convenient fraction \((a, e)\), say \(\frac{1}{4}\)th of the whole non-inductive resistance \((a, b)\), which in this case may conveniently be something like 5000 Ohms.

(3) Start the alternator \(A\), close \(s\), and then adjust the speed and excitation so as to obtain the lowest scale reading on \(v\). Note simultaneously that on \((v)\) also.

(4) Repeat 3 for ten or twelve different voltages on \(v\), shunt by about equal increments to the maximum, and tabulate as follows—

<table>
<thead>
<tr>
<th>Event . . .</th>
<th>Data . . .</th>
</tr>
</thead>
<tbody>
<tr>
<td>H.T. voltmeter tested . No . . .</td>
<td>Type . . .</td>
</tr>
<tr>
<td>Whole resistance . (R_{ex}) . Ohms .</td>
<td>Range . . .</td>
</tr>
<tr>
<td>Load resistance . (R_{ex}) . Ohms .</td>
<td>Made by . . .</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(V)</th>
<th>(R_{ex})</th>
<th>(f)</th>
<th>(\frac{f}{100})</th>
<th>(\frac{f}{100})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(M_{true})</td>
<td>(V_{true})</td>
<td>Error of (\frac{V_{true}}{100}(F-P))</td>
<td>Mean Error</td>
<td></td>
</tr>
</tbody>
</table>

* (5) Plot a calibration curve for the high tension voltmeter having values of \(V\) as ordinates and true volts \(F\) as abscissae.

**Inferences.**—Enumerate what you consider to be the advantages and disadvantages of electrostatic voltmeters.
(13) Complete Test of both Direct and Alternating Current Ammeters and Voltmeters for the various sources of Errors.

Introduction.—The principle involved in the action of any type of ammeter or voltmeter will come under one of the following heads—

1. Heating effect of the current or P.D. to be measured.
2. Electrostatic effect of attraction or repulsion between fixed and movable conducting surfaces, close to, but insulated from one another, when electrified to opposite potentials.
3. (c) Electro-magnetic effect of the current in a coil of wire on iron or wire core.
4. Electro-Dynamic action of the current in one part of circuit on the same current in another part of that circuit, causing electro-dynamic attraction or repulsion between the two.

There are briefly eight principal sources of error to which ammeters and voltmeters in general are liable, namely—

(a) Error in the calibration owing to the standards employed in the two cases being different.
(b) Error through a partial demagnetization of the permanent field, causing an alteration in the sensibility, in the case of permanent steel magnet instruments.
(c) Error caused by the sensibility of the instrument being temporarily altered by external magnetic influences.
(d) Error due to a current producing a different deflection depending on the magnitude of the current previously measured compared with the one in use at the time.
(e) Error due to the instrument giving a different scale reading for different directions of the same current.
(f) Error in the case of voltmeters due to alteration of the resistance of the instrument caused by change of temperature, whether from the room or passage of the current.
(g) Error in alternating current instrument due to alteration of frequency.

4. Error due to friction at the pivots in all classes.

Error (a) applies to all four classes of instruments, and cannot very well be remedied except by re-calibration.

It is clear that classes 1 and 2, being entirely non-magnetic,
may be dismissed as not being liable to magnetic errors. Class 3, however, and 4, which latter type may or may not contain iron, are liable to large errors arising in the case of direct currents from the remanence of the iron used (error $d$), or magnetic hysteresis, and from the proximity of, and the external magnetic effect of currents in neighbouring wires and of magnets (error $e$). In the case of alternating currents from hysteresis, addy currents in the metal work about the instrument ro-riding on the coil, and change of frequency (error $g$) in the alternating currents.

![Diagram](image)

Fig. 11.

In this latter class of work the instruments should contain no iron at all, and very few metal fittings. In good direct current instruments where iron is a necessity, it should be very soft, and well laminated, and there should not be much of it.

**Apparatus**—Ammeter or voltmeter $M_1$ to be tested; suitable variable rheostat $R$, which in the case of the ammeter test must be capable of carrying the maximum current required by $M_1$; and in the case of the voltmeter test must have a large resistance so as to be quite compatible with that of $M_1$; switch, or key $S$; source of electrical supply $E$, whether direct, or alternating current; standard accurately calibrated ammeter or voltmeter $M_2$, which must not contain any iron, and preferably no metal fixings.

N.B.—The standard $M_2$ may be either a Kelvin standard balance (p. 646); Siemens electro-dynamometer (p. 577); Cardew, or electrostatic voltmeter (p. 662), preferably the latter, which not only is non-magnetic, but also has no temperature error. See footnote, p. 20.

**Observations.**—(1) If an ammeter is being tested, connect up as in Fig. 14 (I), but if it is a voltmeter, then as in Fig. 14 (II). Care-
fully adjust the pointers of \( M \) and \( M' \) to zero if they require it, leveling them also when necessary so that all moving parts can move quite freely. Place \( M \) and \( M' \) at some distance apart so that there can be no possibility of one affecting the other. Also run the connecting leads close together so that their magnetic effect due to the current in them may not affect the instruments.

(2) Error due to External Magnetic Effect. \((A)\)

With \( R \) at its maximum, close \( S \), and obtain about \( 1 \) full scale reading on \( M \). Note the corresponding reading of \( M' \), which must be kept quite constant and steady when no magnet is near. Now move a powerful permanent magnet in a plane perpendicular to the axis about which the moving system of \( M \) oscillates and passing through its center, the axis of the magnet pointing to \( M \) always, and its pole nearest to \( M \) being moved so as to be always at about 15° away from \( M \). Note the alteration (if any) of the reading of \( M \).

(3) Repeat 2 for a full scale deflection on \( M \).

(4) Repeat the last part of 2, pertaining to the motion of the magnet, with no current flowing, i.e. \( S \) open, and tabulate your results as shown in the table below.

N.B.—The magnet must not be allowed to affect \( M' \) in any way, and the latter must be far enough away to ensure that this is the case.

If \( M \) is an alternating current instrument, and an alternating supply is being used, the frequency must be maintained constant in 2 and 3 above, as well as the reading of \( M' \) in the particular test.

(5) Error due to Remanence or Residual Magnetism. \((B)\)

With \( R \) at maximum, close \( S \), and carefully take a gradually increasing set of about ten simultaneous readings on \( M \) and \( M' \) from the lowest to full scale, by gradually diminishing \( R \), gently tapping the instruments to eliminate any pivot friction.

(6) Repeat for a similarly obtained decreasing set, the same scale reading of the standard \( M' \) being obtained when descending as was obtained on ascending. Tabulate your results as indicated in the following table.

N.B.—This test of course only applies to direct current instruments, and the error in question may amount to over 20\%.
(7) **Error due to Variation of "Frequency" with Alternating Current Instruments.** (C.)

Close $S_1$ and adjust $R$ to give some convenient scale deflection on $M$ and $M_0$, which latter must be kept constant by means of $R$. Now vary the frequency, by altering the speed of the alternator if this is under control, from the smallest to the greatest possible so as to obtain about ten different values, and note the simultaneous readings on $M$ and $M_0$ at each.

(8) **Error due to Body Currents in Metal Filar with Alternating Currents.** (D.)

If either $M$ or $M_0$ possesses a moving coil, the terminals of which can be got at to send a current through this coil only of the instrument, as in either a Kelvin balance, Siemens dynamometer, or Farr direct reading dynamometer instruments. Proceed as follows—Adjust the pointer of this instrument carefully to zero, and send the maximum alternating current through this moving coil alone, noting whether it deflects. If it does, oddy currents are being set up in the metal windings and react on the moving coil causing it to deflect.

(9) Repeat 8 for the same current at different frequencies, and tabulate your results as in the following table—

---

**Standard Instrument used:** Type ... No. ... Meter ... Constant ...  
**Instrument tested:** Type ... No. ... Maker ...

---

<table>
<thead>
<tr>
<th>A. Internal Magneto.</th>
<th>B. Retractor or External Magneto.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position of Fielding Engine</td>
<td>Reading on</td>
</tr>
<tr>
<td>M.</td>
<td>M.</td>
</tr>
<tr>
<td>M. reading</td>
<td>M. reading</td>
</tr>
<tr>
<td>M. deflection</td>
<td>M. deflection</td>
</tr>
<tr>
<td>N. error</td>
<td>N. error</td>
</tr>
</tbody>
</table>

---

C. Effect of Frequency.  
D. Effect of Deflection.
(10) ERROR DUE TO REVERSAL OF CURRENT THROUGH THE INSTRUMENT. (E.)

Connect up as shown in Fig. 14, but instead of connecting M directly in series as shown, join it up now to the circuit through a reversing switch or key, so that the current through it may be reversed in direction though that in the rest of the circuit and therefore through M is still unidirectional.

With H large, close S and obtain any ¼ full scale deflection on H, noting that on H, which must be constant, now reverse current in M and again note H's value for the same one as before on M. Next reverse and note it again.

(11) Repeat this operation for about 5 scale readings on M up to the maximum at roughly equal intervals.

N.B. — This test of course only applies to direct current instruments. Tabulate as follows —

<table>
<thead>
<tr>
<th>Standard instruments used</th>
<th>Type</th>
<th>No.</th>
<th>Maker</th>
<th>Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument tested</td>
<td>Type</td>
<td>No.</td>
<td>Maker</td>
<td>H steer</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>R, Effect of Direct Current</th>
<th>E, Barre Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>M, (measured)</td>
<td>M, (measured)</td>
</tr>
</tbody>
</table>

(12) ERROR IN VOLTMETERS (ONLY) DUE TO HEATING OF COILS BY PASSAGE OF CURRENT. (F.)

Close S and adjust R to obtain about ¼ scale reading on M, note the corresponding reading on H, which must be an electrostatic voltmeter. Maintain H constant for, say, quarter of an hour and again read M.

(13) Repeat 12 for a full scale reading on M, and tabulate as before.

N.B. — The error in voltmeters due to change in the temperature of the room is readily calculable when the latter is obtained by a thermometer.
(14) Plot the following curves for tests—
A. Having readings on \( M \) as ordinates, and \( M \) as abscissae
   for both ascending and descending curves.
B. Having readings on \( M \) as ordinates and frequency in \( \frac{\text{sec}}{\text{sec}} \) as abscissae.
C. Having readings on \( M \) as ordinates and frequency in \( \frac{\text{sec}}{\text{sec}} \) as abscissae.
D. Having readings on \( M \) as ordinates and frequency in \( \frac{\text{sec}}{\text{sec}} \) as abscissae.

Inferences.—State very clearly and concisely what you can infer from the results of your observations.

(14) Calibration of a Wattmeter by Comparison with a Kelvin Composite Balance used as a Wattmeter.

Introduction.—The following is a convenient method of calibrating a Wattmeter by means of direct currents, using a Kelvin composite balance as the standard Wattmeter with which to compare the one to be tested. The construction of the balance is detailed on p. 354, where the mode of using it as a Wattmeter is also given, and it will merely suffice to say here that it is used very similarly to the Helmholtz coil, the only difference being that as a Wattmeter, the fine wire movable coils (only) are placed in series with an extra anti-inductive resistance across the mains supplying the power measured by both Wattmeters. It may here be noted that it is not necessary for the current through the thick winding and the pressure across the thin coil to be developed by one and the same source. For since the Wattmeter deflection is as to the products of the currents flowing through the two coils, clearly these may come from two totally different sources. In fact it is distinctly preferable to have them separate when possible, for then the variations of the main current will not affect the constancy of the pressure on the fine coil.

This same test serves to determine the "constant" \((k_y \text{ as})\) of the Wattmeter, or in other words the number by which the scale reading must be multiplied so as to obtain the power in Watts.

The following reasoning will no doubt render this clearer.
Assuming the general principle and construction of, suppose, a Siemens Wattmeter to be understood. Let $C$ and $v$ = the currents flowing through the fixed thick- and movable thin-wire coils respectively when a deflection of the torsion head and its pointer on the scale is $D'$ or divisions. Then the force acting between the coils is $\propto C \times v$, but (a) $\propto$ to the pressure $V$ at the terminals. Hence the deflecting couple acting between the coils $\propto C \times V = \text{Watts}$. Now when the index is brought back to 0 again by turning the torsion head, thereby twisting up the spring and introducing the control, we have—tension of spring $\propto \text{Watts} \propto CV$; but the force of tension is $\propto$ to angle of torsion of such a spring.

\[ \therefore D = CV \]

or $KD = CV$ = Watts measured and causing a deflection $D$, where $K$ is the "constant" of the Wattmeter tested. It may be found that $K$ is not perfectly constant throughout the whole scale. In this case the Watts should be obtained from a calibration curve rather than by the product $KD$.

**Apparatus.**—Kelvin composite balance ($K$,$R$) (p. 501), with its anti-inductive resistance $r$ (p. 503); switch $S$; variable power-absorbing resistance $R$ (p. 646); ammeter voltmeter $V$ (preferably electromagnetic); main current battery $B$; Wattmeter ($W$) to be calibrated; [pressure battery $b$ and adjustable resistance $K$, if available (Fig. 10)]; adjusting rheostat $L_2$ (p. 597).

**Observations.**—(1) Connect up either as in Fig. 15 or 16, and in the present test assume the latter for actual experiment, and make quite certain that the connections are as indicated in Fig. 15.

(2) Carefully level the instruments that require it, adjusting their pointers to zero, and if $W$ has a suspended coil see that this is quite free to move.
Notes.—Care should be taken to run the "in" and "out" wires carrying the main current to \( W \) and in the rest of the circuit close together or twisted in order that the currents flowing in them shall exert no magnetic influence on the instruments.

(3) Turn the switch on the balance to "Watts" so as to place the movable fine wire coils across the small terminals. Observe whether \( e \) is numbered the same as, and therefore belongs to the balance in use, and make quite certain that the correct resistance is being used in \( e \) (p. 5.3).

![Diagram of electrical equipment]

Fig. 10.

(4) Adjust the balance and its灵敏度 by using the proper weights as given in the table of constants (p. 288), so that the maximum Watts to be measured on \( W \) would give, as nearly as possible, a full scale reading on \( K.B. \).

(5) With \( R \) fairly large, close \( S \), and adjust the voltage as read off on \( V \) to the desired amount by altering \( R_0 \), and then maintain this voltage constant, observing that it is so before taking every reading.

(6) \( R \) being fairly large, close \( S \), and alter \( R \) so as to obtain about \( \frac{3}{4} \)th of the maximum scale reading on \( W \). Note simultaneously the reading on \( W \) and position \( (d) \) of the slider of \( K.B. \).

(7) Repeat 6 for some ten different deflections on \( W \) (by varying \( K \)) rising by about equal increments to the maximum, the pressure remaining constant all the time.

(8) Repeat ols. 7 for a similar set of decreasing readings on \( W \), and tabulate your results as follows—
45) Calibration of a Wattmeter by Comparison with a Standard Ammeter and Voltmeter.

Introduction.—The following method of calibration by direct currents entails the use of an accurately calibrated standard ammeter and standard voltmeter. These may be either Kelvin balance or ordinary instruments which have recently been carefully compared with accurate standards, and a record of the calibration curves of which are obtainable.

It should be remembered that the constant of a Wattmeter obtained with direct currents will only be true for alternating currents providing the self-induction of the line wire moving coil or its circuit is practically zero or very nearly so. In other words, the instrument must contain no iron and also be very nearly "non-inductive." This is a matter of great importance, for Wattmeters are in most cases only required to measure power in alternating current circuits.

Apparatus.—Standard ammeter (A) and voltmeter (V); Wattmeter (W') to be calibrated with its anti-inductive resistance, [r] if there is one; battery of secondary cells B; switch B'; suitable resistance R for absorbing power (p. 468), which must be non-inductive if alternating currents are employed; carbon rheostat (R) (p. 397).

Observations.—(1) Connect as shown. Carefully level all the instruments, adjusting their pointers to zero, and see that
the swing coil of the Wattmeter is quite free to move. Care
should be taken to run the "leading in" and "out" wires
carrying the main current to the Wattmeter, close together or
twisted. Also the main wires of the rest of the circuit close
together in order that the current flowing in them shall exert
magnetic influence on any of the instruments.

(2) $R$ being at its maximum value, close $\delta$ and adjust $R$ so
as to obtain about $\frac{1}{4}$th of the full load current through $W$, the
pressure being maintained at standard voltage by varying the
carbon resistance ($A$). Note the readings of all the instruments.

(3) Repeat 2 for about ten different readings on $W$ rising by
about equal increments to the maximum current allowable, and
calculate for each the percentage error of the Wattmeter and the
mean. Tabulate as follows—

<table>
<thead>
<tr>
<th>Name</th>
<th>Make</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wattmeter No.</td>
<td>Wattmeter</td>
<td>°C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type Volt.</th>
<th>True Volt.</th>
<th>Wattmeter Reading</th>
<th>Wattmeter Constant</th>
<th>Per cent. Error of Wattmeter</th>
<th>Max. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V$</td>
<td>$W = AV$</td>
<td>$R$</td>
<td>$N + R$</td>
<td>$P$</td>
<td>$\epsilon$</td>
</tr>
</tbody>
</table>

(4) Plot a curve having values of $(P)$ as abscissa and the
corresponding Wattmeter readings $(P)$ as ordinates.

(16) Calibration of a Wattmeter with Alternating Currents. (Three-Voltmeter Method.)

Introduction.—Wattmeters form a class of measuring instru-
ments the chief application of which consists in measuring
accurately the power taken up in alternating current circuits. The great value of a Wattmeter in such measurements practically disappears with direct currents as the individual factors of power, namely "volts" and "amperes," are usually here required, and in addition the product of the two can easily be obtained and at once gives the "true power." With alternating currents, however, this last remark is not true, and herein lies the great value of the properly constructed Wattmeter, in that it measures the true power in such a circuit. For it to be capable of doing this, however, it must be carefully constructed, and there must be no iron and preferably no other metal work near the coils. Wattmeters when used on alternating current circuits are liable to the following sources of error: (a) owing to the fine wire coil possessing some self-induction and consequently impedance, the current in it is not able to rise to the same maximum strength which it would do for a direct P.D. of similar magnitude; (b) this impedance causes a lag in phase of the current in the fine wire coil behind the P.D. across which it is placed. 

(c) A third source of error common also to all voltometers, and occurring both with direct and alternating currents, is that due to the alternation of the resistance of the fine wire coil due to change of temperature, and which can be minimized in the manner described later on. From the preceding remarks it will therefore be evident that when a so-called "Non-inductive Watmmeter" is calibrated with direct currents (which is usually the case) its "constant" so obtained will not be correct for alternating currents. The instrument will also read differently for variation of the "frequency" of the current even though the actual power being measured remains the same. Thus a Wattmeter may with advantage be calibrated with alternating currents on a circuit having the same "constants," namely voltage, frequency and "wave form," etc., as that in which it is eventually desired to measure the power. The calibration can be performed by what is commonly known as the 3-voltmeter method of measuring power in alternating current inductive circuits, and by it the "true power" may be obtained with almost any degree of accuracy desired by using an accurately calibrated voltmeter and by repeating the observation two or three times, noting the mean. It has the advantage that only
one alternating current voltmeter is required, though three similar ones may be used if available.

**Apparatus.**—Alternator \( D \) and its exciting circuit (not shown) under rheostatic control or other convenient source of alternating current supply; inductive portion \( PQ \) of the circuit in series with a strictly non-inductive portion \( QR \); two 2-way keys \( k_1 \), \( k_2 \) (p. 587); Chronm. or low-resistance electrostatic voltmeter \( V \) accurately calibrated; main switch \( K \); Wattmeter \( W \) to be calibrated; alternating current ammeter to indicate the current merely for reference only.

**Note.**—The resistances of \( IQ \) and \( QK \) should both be fairly small compared with that of the voltmeter \( V \).

**Observations.**—(1) Connect up as in Fig. 18, and adjust the pointers of all the instruments to zero, leveling such as need it. See that all instruments are in use thoroughly, and then start \( D \).

(2) Adjust the speed of \( D \) so as to obtain the desired "frequency," say 100 per sec., at the same time varying the excitation to get the proper voltage, suppose 100 volts across \( PR \). Adjust the resistance of \( PR \) so as to pass about \( \frac{1}{2} \) of the full load current (necessary to give a full scale reading on \( V \)) through \( W \). Then the speed and voltage being constant, note the reading on \( a, \) \( \psi \), and in quick succession the voltages \( V_1, \) \( V_2 \) and \( V \) across \( PQ, \) \( PR, \) and \( QA \) respectively by moving \( k_1 \) and \( k_2 \) simultaneously.

(3) Repeat 2 for about ten different currents rising by about equal increments to the maximum allowable.

(4) Calculate the power absorbed in \( PR \) from the relation

\[
W = \frac{V^2}{2r} \cdot (V_2^2 - V_1^2 + V_3^2) \text{ Watts,}
\]

where \( r \) is the ohmic resistance of \( QA. \)

If \( r \) is unknown or liable to be altered by the heating effect
of the current, its value \( V_2 / A \) may be substituted in the above
relation. If the current and voltage are sine functions,
\[
\cos \theta = \frac{V_A^2 - V_1^2 - V_2^2}{2V_1V_2}
\]

(5) Repeat 2-4 for a different frequency, say 60 cycles per sec., to see whether the Wattmeter "constant" \((K)\) alters, and tabulate your results as follows—

<table>
<thead>
<tr>
<th>Bank</th>
<th>Wattmeter tested</th>
<th>Maker</th>
<th>Range</th>
<th>Date</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>Power Factor</td>
<td>Angle</td>
<td>Line Current</td>
<td>Approx. Power</td>
<td>Wattmeter Power</td>
</tr>
<tr>
<td>RPM</td>
<td>%</td>
<td>°</td>
<td>A</td>
<td>kW</td>
<td>kW</td>
</tr>
</tbody>
</table>

**Note.**—Errors made in measuring the voltages \( V_1, V_2 \), and \( V_2 \)
or in the graduation of the voltmeter scale will have least effect
on the results when \( V_2 = V_1 \). If the formula in 4 is used with
the substituted value of \( V_2 \), this latter may consist of glow
bumps, so the resistance may vary with the different mean current
strengths.

(6) Plot a calibration curve for the Wattmeter tested, having
values of deflection \( d \) as ordinates and true power \( W_2 \) as
abscissae.

**Inference.**—Prove the formula given in 4 and state any
assumption made in obtaining it. What inferences can you
draw from the results of your test and explain why the resist-
ance of the voltmeter \( V \) should be large compared with either
\( PQ \) or \( QR \).

(7) Calibration of a High Tension Watt-
meter. (By Ohm's Law, using an auxiliary
transformer.)

**Introduction.**—It is not always possible in actual practice and
testing work to avoid the use of a Wattmeter on a high tension
circuit, as for instance would be the case in measuring the
efficiency of a high tension transformer run off the terminals
of a high tension alternator. The Wattmeter in such a case
should be a specially arranged one for the following reasons—
(1) Owing to the high pressure in the fine wire moving coil circuit, an extremely high non-inductive resistance, capable of standing the full pressure across its terminals, would otherwise have to be put in series with the fine wire swing coil if an ordinary Wattmeter was employed.

(2) Owing to the difficulty in obtaining the above resistance.

(3) The risk entailed in handling such an instrument, and of the breakdown of the insulation of the whole arrangement under the high pressure.

The best arrangement of a high tension Wattmeter, and which gets over these difficulties, is that shown symbolically in Fig. 19, together with the connections for its calibration.

The Wattmeter \( W \) consists of an ordinary Siemens electrode-dynamometer; the mercury cups, forming the terminals of the swing coil, are connected to a separate pair of terminals by the side of the other pair forming those of the fixed coil. There is thus no electrical connection between the fixed and moving coils. These latter are connected to the low pressure coil of a small auxiliary transformer \( T \). The high tension side of \( T \) is placed across the high pressure mains (m.a.), hence the moving coil of \( W \) passes a current which depends on the R.M.F. of m.a., and at the same time there is no fear of a breakdown of insulation since both coils of \( W \) are passing ordinary currents. The actual current which \( T \) sends through the swing coil of \( W \) may be as small as convenient.

Apparatus.—High tension Wattmeter \( W \) to be calibrated arranged as mentioned above, with its fixed and movable coils separate. Small auxiliary (H.T.) transformer \( T \); high and low tension electrostatic voltmeters \( V \) and \( r \) respectively; strictly non-inductive resistance \( A, B, C, E \) capable of being placed
across the (H.T.) mains etc., and of carrying enough current at that pressure to enable a considerable scale deflection to be obtained on W. A part AC of the whole resistance AB should have such a value (r) and be of such a carrying capacity as not to be heated and changed by the current through ACD and as will have a P.D. across its terminals capable of being read on p.

Note.—As a precaution, india-rubber gloves must be worn, and an india-rubber mat provided to stand on.

Observation.—(1) Connect up as in Fig. 19, and adjust the instruments carefully to zero.

(2) Close switch (S) and adjust p to read the desired amount which W has to deal with on future occasions. Note the readings of V, r, and W, and tabulate as follows—

<table>
<thead>
<tr>
<th>Name</th>
<th>Wattmeter tested: N</th>
<th>Meter</th>
<th>Range</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Non-inductive Resistance</th>
<th>Volts on</th>
<th>Current through A</th>
<th>Watts in ACD</th>
<th>Reading on Constant of Wattmeter</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>V</td>
<td>V</td>
<td>V</td>
<td>V</td>
</tr>
</tbody>
</table>

Inferences.—To the method liable to any sources of error, and if so, state them.

(18) Calibration of an Electricity Meter (on Constant Supply).

Introduction.—An electricity meter, which performs the same kind of office to a consumer of electrical energy as a gas-meter does to one using ordinary gas, is an electrical instrument that requires carefully calibrating or standardising at some time or another. There are a great number of different forms of electricity meters, but they all come under one or other of four main classes, namely—Electromagnetic, Thermal, Motor, Clocks affected. It is not, however, our intention to dilate on these further as their theory and description comes under the scope of the ordinary textbook, but there are some points in general which may be remarked. Practically all meters measure one or other of two things, namely,