A LABORATORY MANUAL OF PHYSICS

FOR ADVANCED LEVEL CERTIFICATE,
SCHOLARSHIP AND INTERMEDIATE SCIENCE STUDENTS

BY

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Electricity
Part 2

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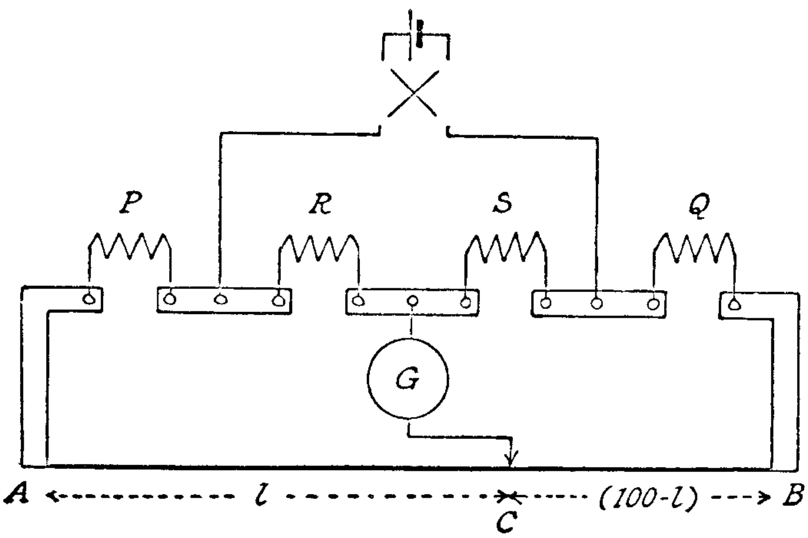
CONTENTS

LIST OF ADDITIONAL EXPERIMENTS DESCRIBED IN THE TEXT

Electricity

COMPARISON OF TWO NEARLY EQUAL RESISTANCES BY THE CAREY-FOSTER BRIDGE



Apparatus

Metre bridge with four openings, copper shorting strip, dry cell, commutator, sensitive centre-reading galvanometer, two nearly equal resistances, e.g. an approximate one-ohm coil P, and a standard one-ohm resistance Q, two approximately equal resistances R and S of about 5 ohms (the values of these resistances need not be known).

Method

Connect up the circuit as shown, where P and Q are the resistances to be compared. Obtain a balance position C at a point l_1 cm. from the end A. Now reverse the current and find the new point of balance. Take the mean of the two readings for l_1. By this means any slight error due to thermo-electric e.m.f.s at the junctions is eliminated, and this procedure is followed for each arrangement of the resistances. P and Q are now interchanged, and a balance is obtained at l_2.

Now make $P = 0$ by shorting with the copper strip, and repeat the above experiment interchanging Q and the copper strip. Let the corresponding balance position be l_3 and l_4.

Note.—The connecting leads are not changed over with the resistances when an interchange is made.

Theory

Let σ be resistance per cm. length of the wire.

Let α and β be the "end resistances" (contact resistances, and resistances of adjacent copper lathes) at A and B respectively.

Then for 1st balance position (l_1 cm. from A),

$$\frac{R}{S} = \frac{P + l_1\sigma + \alpha}{Q + (100 - l_1)\sigma + \beta}$$

for 2nd balance position with P and Q interchanged (l_2 cm. from A),

$$\frac{R}{S} = \frac{Q + l_2\sigma + \alpha}{P + (100 - l_2)\sigma + \beta}$$

whence

$$\frac{R}{R + S} = \frac{Q + l_2\sigma + \alpha}{P + Q + 100\sigma + \alpha + \beta} = \frac{P + l_1\sigma + \alpha}{P + Q + 100\sigma + \alpha + \beta}$$

giving (since denominators are equal),

$$P + l_1\sigma + \alpha = Q + l_2\sigma + \alpha$$

i.e.

$$P - Q = (l_2 - l_1)\sigma \quad . \quad . \quad . \quad . \quad . \quad (1)$$

From 3rd balance position with $P = 0$ (l_3 cm. from A) and 4th balance position with the strip and Q interchanged (l_4 cm. from A) we obtain as above;

$$0 - Q = (l_4 - l_3)\sigma$$

or

$$\sigma = \frac{Q}{l_3 - l_4} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Thus from (1) and (2)

$$P = Q + (l_2 - l_1) \cdot \frac{Q}{(l_3 - l_4)}$$

i.e.

$$\frac{P}{Q} = 1 + \frac{l_2 - l_1}{l_3 - l_4}.$$

Results

$l_1 =$	,	,	mean =	cm.	$l_2 =$	,	,	mean =	cm.
$l_3 =$	,	,	mean =	cm.	$l_4 =$	,	,	mean =	cm.

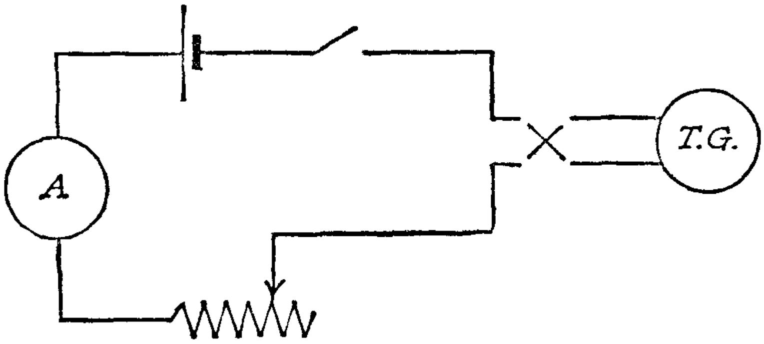
$$\therefore \frac{P}{Q} = \underline{\hspace{4cm}}$$

Note

From equations (1) and (2) above it will be seen that in order to get positions of balance, the value of Q, and also the difference between P and Q, must be less than the total resistance of the bridge wire.

EXPERIMENT 88

DETERMINATION OF THE HORIZONTAL COMPONENT OF THE EARTH'S MAGNETIC FIELD FROM THE REDUCTION FACTOR OF A TANGENT GALVANOMETER



Apparatus

Accumulator, switch, ammeter, rheostat, commutator, tangent galvanometer.

Method

The tangent galvanometer is set with the plane of its coil in the meridian, and with the aluminium pointer over the zero marks. The switch is now inserted, and by means of the variable resistance the current is regulated to a given value which is read off on the ammeter. In taking the reading of the deflection on the galvanometer, both ends of the needle are read; the current through the galvanometer is now reversed by the commutator, and both ends again read. (Precautions in reading θ are similar to those in reading angles with the deflection magnetometer—see p. 145.)

The above is repeated for a series of values of the current.

In arranging the circuit it is important to see that the ammeter and galvanometer are as widely separated from each other as possible to avoid any effect of the permanent magnets in the ammeter on the deflection of the galvanometer.

Theory

The magnetic intensity H at the centre of a current bearing coil of n turns of mean radius r is

$$H = \frac{2\pi nI}{10r},$$

I being the current in amps.

For a tangent galvanometer with the plane of its coil in the meridian, this force will be at right angles to the magnetic meridian and hence the needle will be deflected through an angle θ such that

$$H = H_0 \tan\theta \text{ (see p. 145)}$$

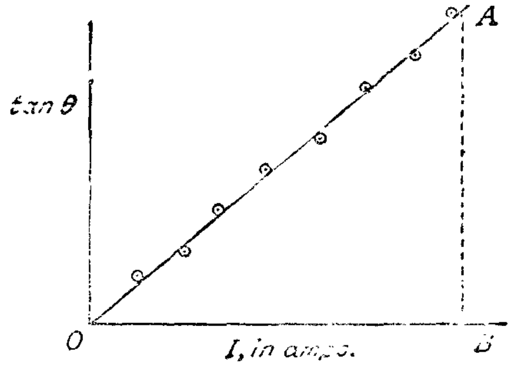
i.e.
$$\frac{2\pi nI}{10r} = H_0 \tan\theta$$

or
$$I = \left(\frac{10H_0 r}{2\pi n}\right)\tan\theta$$

The quantity $\frac{10H_0 r}{2\pi n}$ is known as the *reduction factor* (k) of the galvanometer,

i.e.
$$k = \frac{10H_0 r}{2\pi n}$$

from which
$$H_0 = \frac{2\pi nk}{10r}.$$



Results

I in amp.	Galvanometer readings				Mean θ	$\tan\theta$

$$n = \qquad \text{turns}$$

$$r = \qquad \text{cm.}$$

$$k = \frac{I}{\tan\theta} = \frac{OB}{AB} \text{ from graph.}$$

$$\therefore H_0 = \frac{2\pi n OB}{10 r AB}$$

$$= \underline{\qquad\qquad\qquad} \text{ oersteds.}$$

Note

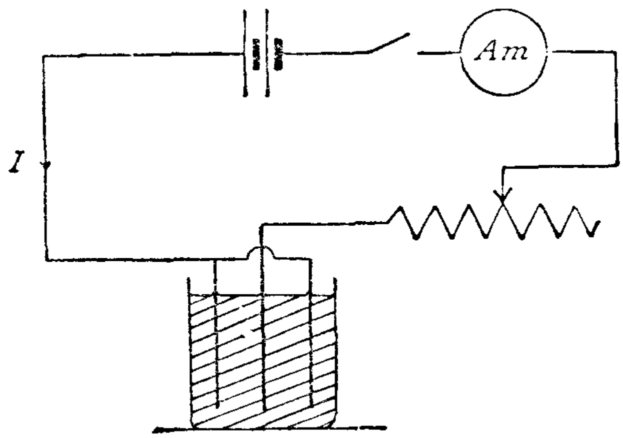
The value of k can be obtained using a copper voltameter (see Expt. 89) instead of the ammeter as described above. If the weight of copper deposited on the cathode in t secs. is W, the steady deflection of the galvanometer being θ, we have

$$I = \frac{W}{zt} = k \tan\theta \quad \text{(where } z \text{ is the E.C.E. of copper).}$$

Thus
$$k = \frac{W}{zt \tan\theta}$$

from which
$$H_0 = \frac{2\pi n}{10r} \cdot \frac{W}{zt \tan\theta}.$$

DETERMINATION OF THE ELECTRO-CHEMICAL EQUIVALENT OF COPPER



Apparatus

Copper voltameter (with two anodes and central cathode), two accumulators, key, ammeter reading up to 2 amp., rheostat, stop-clock, methylated spirit, emery paper.

Method

Thoroughly clean the copper plates with emery paper and wash them in water. Place the plates in a jar containing copper sulphate solution (sp. gr. 1·15 to which 1 per cent. of sulphuric acid has been added) with the two outer plates connected together and to the positive of the accumulator battery, and the central plate (cathode) through to the negative of the battery. Put in the key and adjust the rheostat so that a current not exceeding $\frac{1}{50}$ amp. per sq. cm. of cathode surface flows. After 4 or 5 min. take out the central plate, wash it thoroughly in water, immerse it in methylated spirit or ether and allow to dry. The drying process can be accelerated by holding the plate well above a bunsen flame, but care must be taken not to oxidize the fine copper deposit. Weigh the plate and replace it in circuit. Allow the current (controlled by the rheostat) to flow for 20 or 30 min.; then withdraw the cathode, clean and dry as before and reweigh.

Theory

The electro-chemical equivalent (z) of an element is the weight of it in gm. liberated from solution by the passage of unit quantity of electricity.

Thus the wt. liberated by q coulombs is

$$W = zq = zIt \qquad \text{(where } I = \text{current in amps. and } t = \text{time in sec.).}$$

$$\therefore z = \frac{W}{It}.$$

Results

	First weight of cathode	=	gm.
	Final ,, ,, ,,	=	gm.
∴	weight of copper deposited	=	gm.
	Current	=	amp.
	Time	=	sec.

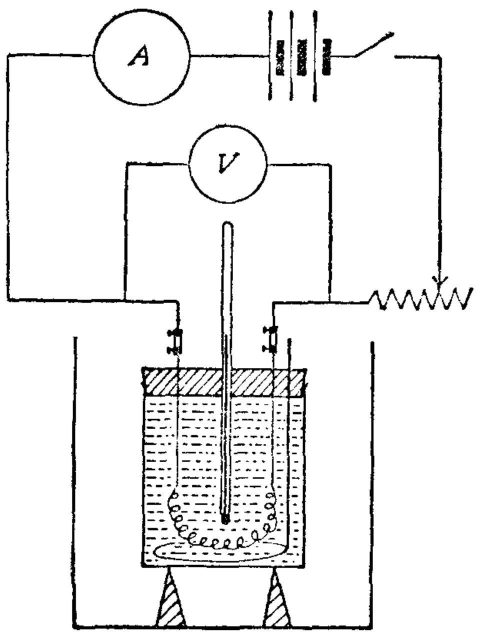
$\therefore z =$ ____________ gm./coulomb.

Notes

(1) Faraday's 1st law of electrolysis may be verified using the above circuit. Keep I constant and find the weights of copper deposited in 15, 30, 45, etc., min. Thus show that $W \propto t$. Then pass $\frac{1}{2}$, 1, $1\frac{1}{2}$, etc., amp. for the same time and find respective weights of copper deposited and show $W \propto I$. Thus $W \propto I \times t$, i.e. weight deposited is proportional to the quantity of electricity passing.

(2) If the value of z is known, the value of the current flowing in the circuit can be accurately found in this way, thus giving a check on the accuracy of the ammeter reading. The error at the $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, etc., amp. ammeter readings having been determined in this manner, a calibration chart of error against ammeter reading can be drawn up for use with the ammeter.

DETERMINATION OF THE MECHANICAL EQUIVALENT OF HEAT BY AN ELECTRICAL METHOD



Apparatus

Three accumulators, key, rheostat, voltmeter reading up to 5 volts, and of fairly high resistance, ammeter reading up to 2 amp., copper calorimeter with outer protecting calorimeter, stirrer of stout copper wire, tenth-degree thermometer, small heating coil made by coiling one metre of 24-gauge manganin wire and soldering to the ends of stout copper leads passing through a cork fitted into the top of the calorimeter. The windings of the coil should be insulated by immersing in a solution of shellac varnish and drying off in a hot-air oven. Stop-clock.

Method

Arrange the circuit as shown. Weigh the calorimeter (and stirrer) (w gm.), fill it with sufficient distilled water to cover the heating coil and reweigh and thus obtain the weight of water (W gm.) in the calorimeter. Immerse the coil in the calorimeter with the thermometer and stirrer, and place the calorimeter on heat-insulating supports inside the larger calorimeter. Insert the key and adjust the rheostat to give a suitably large current through the coil. Stir the water well, and at a given instant the thermometer is read and the stop-clock simultaneously started. Keep the ammeter reading constant by adjusting the rheostat when necessary, and read the thermometer at the end of 10 min. when the circuit is broken. Now allow the calorimeter to cool by radiation for 5 min., when the thermometer is again read. The water should be stirred continuously throughout.

Theory

When a current of I amp. passes between two points of a conductor between which there is a P.D. of E volts, the energy dissipated in t sec. is

$$EIt \text{ joules.}$$

This energy appears as heat in the conductor, and is given by—

$$H = \frac{EIt}{J} \quad . \quad . \quad . \quad (1)$$ (J being the mechanical equivalent of heat in joules per calorie).

Let θ_1° C. be the initial temperature,
θ_2° C. be the final temperature after t sec.,
θ_3° C. be the temperature after a further $\frac{t}{2}$ sec.

Then, since by Newton's law of cooling the rate of cooling is proportional to the excess temperature, it follows that the cooling correction for t sec. is equal to the average rate of cooling × time (t), which is equal to $\frac{1}{2}$ final rate of cooling × time, or final rate of cooling × $\frac{1}{2}$ time.

Thus the required correction is equal to the fall in temperature at the final temperature θ_2 which takes place in half the time of the experiment and thus is $(\theta_2 - \theta_3)$.

∴ Final temperature corrected for radiation losses is

$$[\theta_2 + (\theta_2 - \theta_3)]° \text{ C.}$$

Then if the weight of water is W gm. and the weight of stirrer and calorimeter w gm., and specific heat of copper is taken as 0·1,

$$H = (W + 0{\cdot}1w)\,[\theta_2 + (\theta_2 - \theta_3) - \theta_1] \text{ cal.} \quad . \quad . \quad . \quad . \quad (2)$$

∴ From (1) and (2)

$$J = \frac{EIt}{(W + 0{\cdot}1w)[\theta_2 + (\theta_2 - \theta_3) - \theta_1]} \text{ joules/calorie.}$$

Results

$W =$	gm.,	$w =$	gm.
$I =$	amp., $E =$	volts, $t =$	sec.
$\theta_1 =$	° C., $\theta_2 =$	° C., $\theta_3 =$	° C.

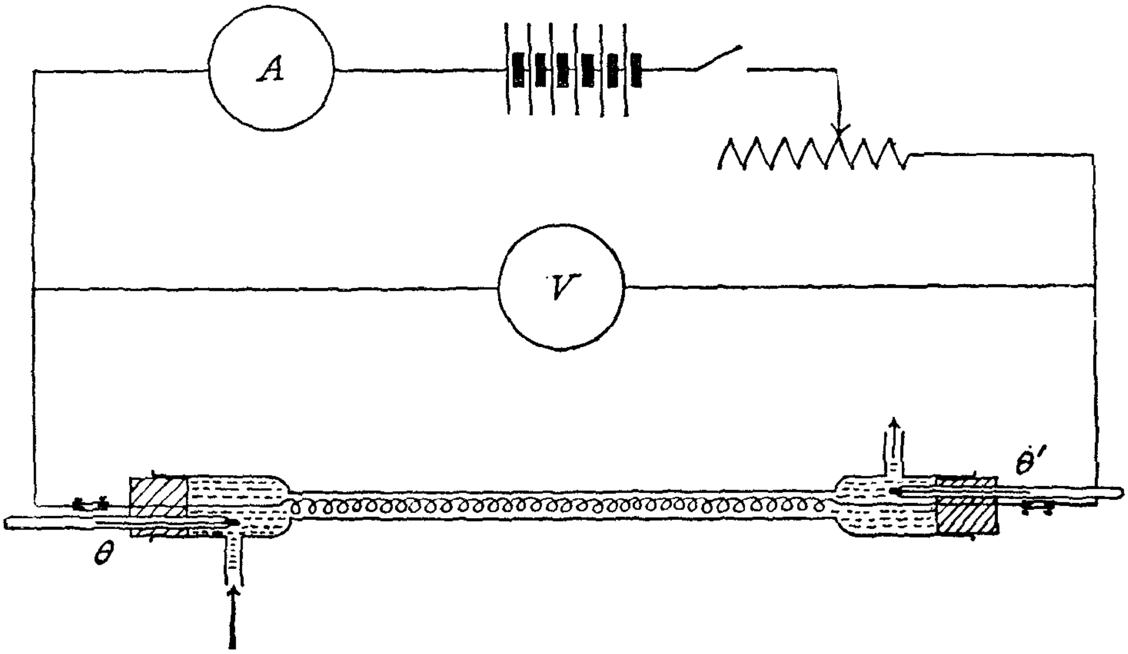
∴ $J =$ ______________ joules/cal.

Notes

(1) If a high-resistance voltmeter is not available it cannot be assumed that the main circuit current I, as indicated by the ammeter, is also that through the heating coil. It will be necessary to allow for the current taken by the voltmeter which will be $\frac{E}{R'}$, E being the voltmeter reading and R' its resistance. The current in the heating coil is thus $\left(I - \frac{E}{R'}\right)$ and this must be substituted for I in the expression for J given above.

(2) Alternatively the resistance R of the heating coil can be determined by previous measurement, using a Wheatstone bridge, and the electrical energy dissipated calculated from I^2Rt, thus dispensing with the voltmeter. It should be remembered, however, that the resistance obtained in this way is the "cold" resistance of the coil and will thus be less than its actual resistance under the conditions of the experiment (see Expt. 85).

DETERMINATION OF THE MECHANICAL EQUIVALENT OF HEAT USING A CALLENDAR AND BARNES CONTINUOUS-FLOW CALORIMETER



Apparatus

Five 2-volt accumulators, ammeter up to 2 amp., key, rheostat, voltmeter of fairly high resistance reading up to 10 volts, two $\frac{1}{10}$° C. thermometers, constant-head device, e.g. an overflowing tank fitted with siphon delivery tube or arrangement as used in Expt. 26, stop-clock, beaker (to collect outflow water), laboratory form of Callendar and Barnes continuous-flow calorimeter. This may be made in the following manner. Two boiling-tubes have holes blown in them at the sides and the ends. Short tubes are fitted to the sides, and a piece of glass tubing about 25 cm. × 1 cm. is fused to the ends of the boiling-tubes in the manner shown. A 2-metre length of 24-gauge manganin wire (shellacked and heat treated as in Expt. 90) is now coiled to fit inside the glass tubing and its ends soldered to two stout copper wires which pass through corks fitted into the open ends of the boiling-tubes. The corks are also bored to take the thermometers, and after fitting they are coated with wax to prevent leakage of water.

Method

The circuit is fitted up as shown. The flow of water through the apparatus from the constant-head device is adjusted to a suitable steady rate by means of a screw clip on the connecting rubber tubing. Care must be taken to release and expel all entrapped air from the apparatus. Now insert the key and adjust the rheostat to a given current, and when the steady state has been attained, take the thermometer readings. The rate of flow of water is now determined by collecting the outflow water in a beaker and weighing the amount obtained in a given time. The experiment is repeated with another current, adjusting the rate of flow so that the mean temperature of the outflowing and inflowing water is the same as in the first experiment.

Theory

Let m_1 and m_2 be the rates of flow of water in gm. per second,
θ_1 and θ_2 be the temperatures of the inflowing water in ° C.,
θ_1' and θ_2' be the temperatures of the outflowing water in ° C.,
I_1 and I_2 be the respective currents in amp.,
E_1 and E_2 be the respective P.D.s across the heating coil.

When the steady state has been attained:
Heat generated in heating coil = Heat absorbed by water + Heat radiated to surroundings.

Since the mean excess temperature of the apparatus over the surrounding temperature is the same in both experiments, the heat lost to the surroundings will be the same in each case. Let this amount of heat be H cal./sec.

Then:

1st *experiment* $$\frac{E_1 I_1}{J} = m_1(\theta_1' - \theta_1) + H \qquad (1)$$

2nd *experiment* $$\frac{E_2 I_2}{J} = m_2(\theta_2' - \theta_2) + H \qquad (2)$$

subtracting (2) from (1)

$$\frac{E_1 I_1}{J} - \frac{E_2 I_2}{J} = m_1(\theta_1' - \theta_1) - m_2(\theta_2' - \theta_2)$$

$$\therefore J = \frac{E_1 I_1 - E_2 I_2}{m_1(\theta_1' - \theta_1) - m_2(\theta_2' - \theta_2)} \text{ joules/calorie.}$$

Results

$m_1 =$	gm./sec.,	$m_2 =$	gm./sec.
$\theta_1 =$	° C.,	$\theta_2 =$	° C.
$\theta_1' =$	° C.,	$\theta_2' =$	° C.
$I_1 =$	amp.,	$I_2 =$	amp.
$E_1 =$	volts,	$E_2 =$	volts

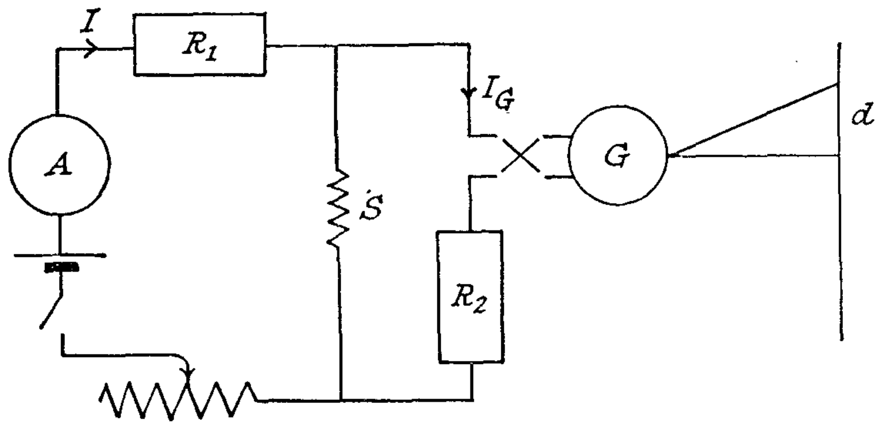
$\therefore J =$ ____________ joules/calorie.

Notes

(1) It is important that two identically reading thermometers be used in this experiment as otherwise appreciable errors may be present in the values of $(\theta' - \theta)$. If it is not possible to procure two such identical thermometers, the difference between the readings of the thermometers used when placed in a bath at the mean temperature of the experiment should be taken and allowed for in obtaining the temperature rise of the water as it emerges from the calorimeter. Alternatively each stage of the experiment can be repeated with the thermometers interchanged and average values of $(\theta' - \theta)$ used.

(2) If a high-resistance voltmeter is not available the current taken by the voltmeter must be allowed for as in Expt. 90.

DETERMINATION OF THE SENSITIVITY OF A GALVANOMETER

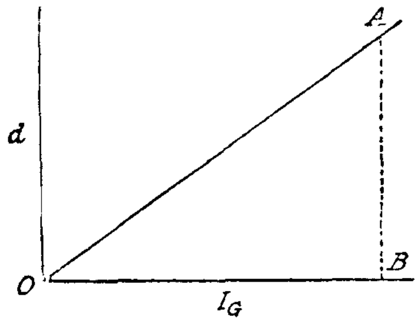


Apparatus

Accumulator, key, milliammeter reading up to 10 milliamp., rheostat, standard 2-ohm resistance S, two resistance boxes R_1 reading up to 2000 ohms, and R_2 reading up to 1000 ohms, commutator, sensitive moving-coil galvanometer (reflecting type) with lamp and scale.

Method

Arrange the circuit as shown in the diagram. Take out a fairly large resistance from R_2 in order to protect the galvanometer. Take also a high resistance from R_1 and insert the key. By means of R_1 (coarse adjustment) and the rheostat (fine adjustment), obtain a suitable current (I) through the ammeter and note the deflection of the galvanometer. Reverse the current through the galvanometer by the commutator, take the deflection on the other side of the scale zero, and thus obtain a mean of the deflections. The deflections are read in millimetres on a scale placed 1 metre distant from the galvanometer mirror. Now adjust R_1 and the rheostat to obtain other values of I, in each case obtaining the corresponding mean deflection of the galvanometer—keeping R_2 constant throughout the experiment. Then plot a graph of galvanometer deflection d against current through the galvanometer I_G (see p. 195) from which to obtain the required sensitivity.



Theory

The current sensitivity of this type of galvanometer is defined as the deflection (in mm. at 1 metre) produced by 1 milliamp.

If I is the current through the milliammeter and G is the known resistance of the galvanometer, the current (I_G) through the galvanometer is

$$I_G = \frac{S}{R_2 + G + S}.I \text{ milliamp.}$$

If the deflection is d mm., the sensitivity is $\frac{d}{I_G}$ mm. at 1 metre per milliamp.

Results

I	I_G	d

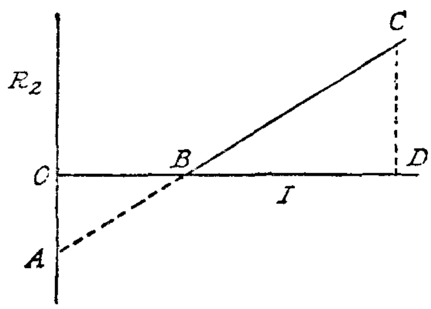
From the graph:

$$\text{sensitivity } \left(\frac{d}{I_G}\right) = \frac{AB}{OB}$$

= ________ mm. at 1 metre per milliamp.

Note

If the galvanometer resistance is not known, both the sensitivity and the galvanometer resistance can be obtained by the following variant of the above experiment.



Adjust both R_1 and R_2 to obtain a suitable galvanometer deflection (d). Now alter R_2 and adjust R_1 so as to obtain the same galvanometer current. Repeat several times, tabulating corresponding values of I (ammeter reading) and R_2 such that d is always const. (I_G const.).

Then I_G (const.) $= \frac{S}{R_2 + G + S}.I$;

re-arranging we get $R_2 = \frac{S}{I_G}.I - (G + S)$.

Plot R_2 against I, and from the graph:

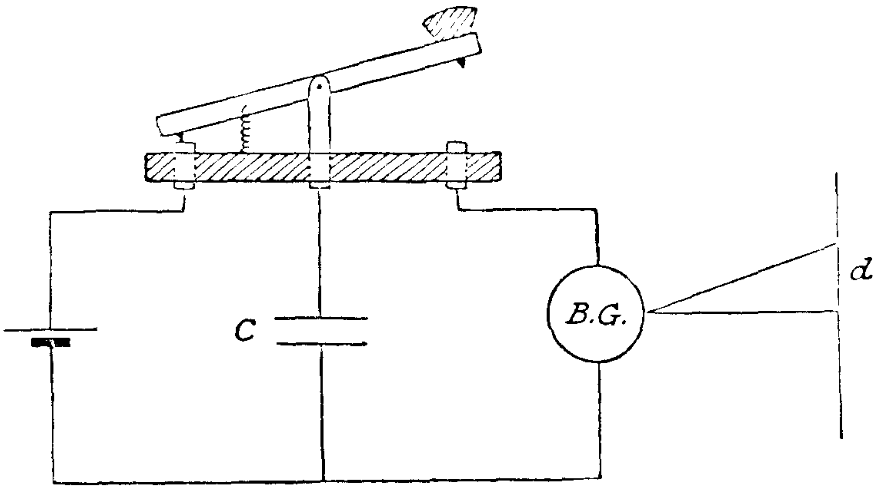
when $I = 0,\ R_2 = -(G + S) = OA$,

i.e. $G = |\,OA\,| - S$.

Also slope of graph $= \frac{S}{I_G} = \frac{CD}{BD}$,

i.e. $I_G = S \times \frac{BD}{CD}$ and thus find sensitivity $= \frac{d}{I_G}$.

COMPARISON OF CAPACITIES USING A BALLISTIC GALVANOMETER



Apparatus

Two condensers, accumulator, charge and discharge key, ballistic galvanometer (reflecting type).

Method

Each condenser is connected in turn as shown in the circuit above. In the normal position the condenser is connected directly across the cell, and draws an amount of charge from it to acquire a potential equal to the potential difference between the terminals of the cell. The battery is now put out of circuit by depressing the key, and the condenser is discharged through the ballistic galvanometer. The deflection is noted. The experiment is repeated several times to obtain an average deflection. This procedure is followed for each condenser.

Note

In order to reduce damping to a minimum, the coil of a ballistic galvanometer is wound on a non-metallic frame (this eliminates electro-magnetic damping in the frame). In consequence of this the coil continues to oscillate for some considerable time after each throw. To expedite the taking of repeated readings a shorting switch may be connected across the galvanometer terminals and used to steady the movement of the spot and bring it to its equilibrium position after each deflection has been read.

Theory

The ballistic galvanometer is an ordinary sensitive galvanometer in which the moving system has a sufficiently large moment of inertia as not to be appreciably displaced when a transient current (as from the discharge of a condenser) passes through it. The coil is then subject to an impulsive couple, and it can be shown that the subsequent throw is a measure of the quantity Q of electricity discharged through the coil. Thus if d is the throw as measured on a scale with a reflecting type galvanometer

$$Q \propto d.$$

Let the capacities of the condensers be respectively C_1 and C_2. They will take charges Q_1, Q_2 on being connected across the cell to acquire the P.D. of V volts.

Then $\quad Q_1 = C_1V \quad$ where $Q_1 \propto d_1$

and $\quad Q_2 = C_2V \quad$ where $Q_2 \propto d_2$,

hence
$$\frac{C_1}{C_2} = \frac{Q_1}{Q_2} = \frac{d_1}{d_2}.$$

Results

1st condenser. Deflections : , , , , , ,

—mean deflection $d_1 =$

2nd condenser. Deflections : , , , , , ,

—mean deflection $d_2 =$

$$\therefore \frac{C_1}{C_2} =$$

Notes

(1) If a standard condenser is available, the capacities of other condensers may be evaluated by this method.

(2) By comparing the capacities of a parallel plate condenser, firstly with a slab of an insulating medium between the plates, and then with the slab removed, the specific Inductive capacity of the dieletric can be found—

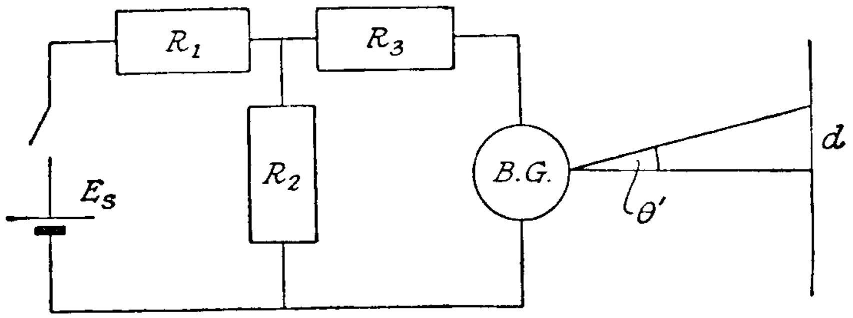
$$C_1 = \frac{Ak}{4\pi t} \qquad C_2 = \frac{A}{4\pi t} \text{ (}k\text{ for air} = 1\text{)}$$

where t is the thickness of the dielectric.

$$\therefore \frac{C_1}{C_2} = \frac{d_1}{d_2} = k$$ (d_1 and d_2 being the corresponding deflections in the two cases.)

(3) The laws of condensers in series and parallel can be verified by this experiment.

CALIBRATION OF A BALLISTIC GALVANOMETER



Apparatus

Ballistic moving-coil galvanometer (reflecting type) of known resistance, circuit-key, three resistance boxes—R_1 up to 10,000 ohms, R_2 up to 1000 ohms, R_3 up to 10,000 ohms—stop-watch.

Method

The purpose of this experiment is to obtain the charge q passing through a ballistic galvanometer in terms of the resulting angular throw θ (radians) by calibrating the galvanometer in terms of the steady deflection θ' produced by a measured current.

The circuit is arranged as shown in the diagram. Resistances of 10,000, 100, and 10,000 ohms are taken out of R_1, R_2, and R_3 respectively. The key is now inserted and the value of R_2 adjusted to obtain a suitable deflection (d mm.) on the screen placed 1 metre from the galvanometer. If a commutator is included in the circuit, the deflection on the other side of the scale zero can be taken and so a mean value for d obtained. The steady deflection θ' is then calculated from the linear deflection d $\left(\theta' = \dfrac{d}{1000}\right)$, and the current through the galvanometer (i) calculated from the circuit values.

Now find the period of vibration of the moving system with the galvanometer on open circuit.

Note.—The above experiment provides an alternative method to that indicated in Expt. 92 of obtaining the sensitivity of a galvanometer, when a standard cell is available.

Results

$R_1 =$ ohms, $R_2 =$ ohms, $R_3 =$ ohms, $G =$ ohms.

$T =$ sec., $d =$ mm. at 1 metre, i.e. $\theta' =$

$\therefore\ q = \qquad \theta$

Theory

Let c be the couple per unit angle of twist, T be the periodic time, A be the effective coil area, and H be the field due to the permanent magnets.

Then for ballistic use

$$q = \frac{cT}{2\pi AH}.\theta \quad . \quad . \quad . \quad (1)$$

where θ is the ballistic throw,

and for steady current

$$i = \frac{c}{AH}.\theta' \quad . \quad . \quad . \quad (2)$$

where θ' is the deflection for a steady current of i units, hence from (1) and (2)

$$q = \frac{T}{2\pi}.\frac{i}{\theta'}.\theta.$$

Now i (current through the galvanometer) $= \frac{R_2}{R_1 + R_2}.E_s \div (R_3 + G)$,

where E_s is the E.M.F. of the standard cell, and G is the resistance of the galvanometer.

$$\therefore\ q = \frac{T}{2\pi\theta'}.\frac{E_s R_2}{(R_1 + R_2)(R_3 + G)}.\theta.$$

Notes

(1) The damping effects of air resistance, etc., on the moving system of a ballistic galvanometer produce a gradual shrinkage in the amplitudes of the successive deflections when subject to a ballistic throw. The successive left and right deflections are in a constant ratio known as the decrement (d).

Thus
$$\frac{\theta_1}{\theta_2} = \frac{\theta_2}{\theta_3} = \frac{\theta_3}{\theta_4} = \quad . \quad . \quad . \quad = d = e^{\lambda} \text{ (say)},$$

where $\lambda = \log_e d$ and is called the *logarithmic decrement.*

Thus for a complete vibration $\frac{\theta_1}{\theta_3} = e^{2\lambda}$, and for a quarter vibration, if θ is the undamped deflection, and θ_1 the first observed deflection, $\frac{\theta}{\theta_1} = e^{\frac{\lambda}{2}}$, i.e. $\theta = \theta_1 e^{\frac{\lambda}{2}}$ or

$$\theta = \theta_1\left(1 + \frac{\lambda}{2} + \frac{\lambda^2}{4.2!} + \quad . \quad . \quad .\right).$$

$\therefore$ since λ is small,
$$\theta = \theta_1\left(1 + \frac{\lambda}{2}\right).$$

To find λ. Use the circuit shown on p. 196 to obtain a ballistic throw and let θ_1 be the first deflection, and θ_{21} the 21st (i.e. 20 half-vibrations in between), then—

$$\frac{\theta_1}{\theta_{21}} = e^{20\lambda} \qquad \text{i.e. } \lambda = \tfrac{1}{20}\log_e \frac{\theta_1}{\theta_{21}}.$$

(2) Having calibrated the ballistic galvanometer, and using the circuit as in Expt. 93 but with a standard cell across the condenser, an absolute value for the capacity of the condenser can be obtained as follows:

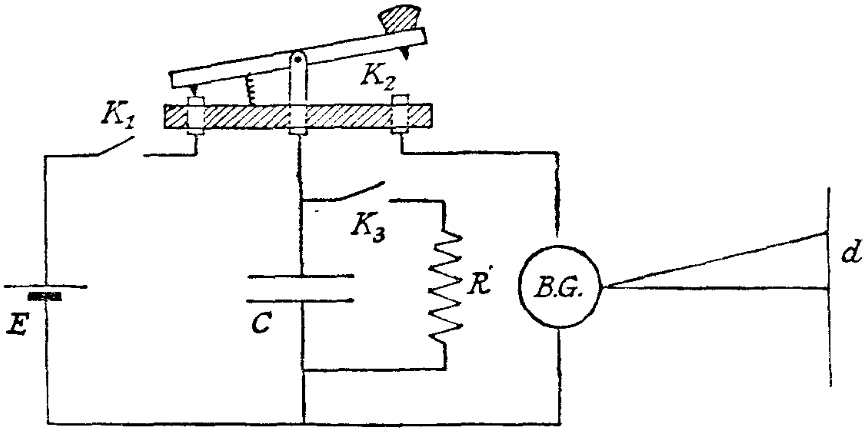
$$q = k\theta_1\left(1 + \frac{\lambda}{2}\right)$$

where θ_1 is the observed throw (expressed in radians), λ the log dec, and k the constant of calibration,

but $q = CE_s$.

$$\therefore\ C = \frac{k\theta_1\left(1 + \frac{\lambda}{2}\right)}{E_s}.$$

DETERMINATION OF HIGH RESISTANCE BY LEAKAGE



Apparatus

Accumulator, condenser of capacity 1 or 2 mfd., ballistic galvanometer (reflecting type), plug key K_1, charge and discharge key K_2, tapping key K_3, accurate stop-watch, a high resistance of the order of 100 megohms. This latter may be obtained by filling approximately 10 cm. length of ordinary glass tubing with a mixture of xylol and alcohol, and fusing platinum wires through the ends to serve as electrodes.

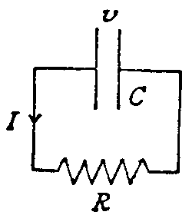
Method

Connect up the circuit as shown. Close K_1 and allow C to charge up across E. Now depress K_2 and observe the deflection d_0 of the ballistic galvanometer. Repeat several times to obtain a mean value for d_0. Release K_2 and again allow the condenser to charge up. Open K_1 and depress K_3 and at the same time start the stop-watch. After the interval of few seconds depress K_2 and observe the deflection d. Repeat with K_3 down for different intervals of time, in each case obtaining d as the mean of several observations. Plot the graph shown on p. 201 from which to obtain the value of R.

Finally, the insulation resistance of the condenser must be obtained. This is done by removing the high resistance R', and after the condenser has charged up, K_1 is opened and the condenser allowed to stand for a specified time t'. At the end of this interval K_2 is depressed and the deflection d' noted.

Note.—All connecting wires should be kept clear of each other and be prevented from touching the bench, instrument cases, etc.

Theory



Consider the circuit shown.

$$I = \frac{v}{R} = \frac{q}{CR},$$

q being the charge on the condenser plate when its potential is v,

since I is reducing q, $I = -\frac{dq}{dt}$.

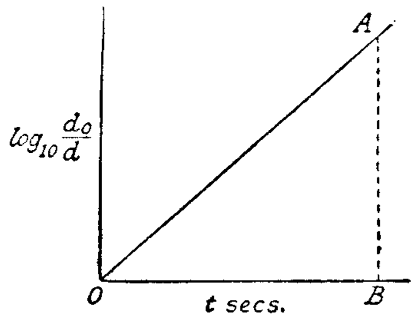
$$\therefore \frac{dq}{dt} = -\frac{q}{CR} \quad \text{or} \quad \frac{dq}{q} = -\frac{dt}{CR}.$$

Integrating we get

$$\log_e q = -\frac{t}{CR} + \text{const.}$$

$q = q_0$ (the initial charge) when $t = 0$. $\therefore$ const. $= \log_e q_0$,

i.e. $\log_e q - \log_e q_0 = -\frac{t}{CR}$ or $q = q_0 e^{-\frac{t}{CR}}$.



Hence $$R = \frac{t}{C \log_e \frac{q_0}{q}}.$$

Now $q_0 \propto d_0$ and $q \propto d$

$$\therefore R = \frac{t}{C \log_e \frac{d_0}{d}} = \frac{t}{2{\cdot}3026\, C \log_{10} \frac{d_0}{d}}.$$

Results

$C =$ mfd.

t	d_0	d	$\log_{10} \frac{d_0}{d}$

The straight-line graph shown above is

$$\log_{10} \frac{d_0}{d} = \frac{t}{2{\cdot}3026\, CR}$$

i.e. $$\text{gradient} = \frac{1}{2{\cdot}3026\, CR} = \frac{AB}{OB}.$$

$$\therefore R = \frac{OB}{2{\cdot}3026\, C \times AB}$$

$=$ megohms (since C is in mfd.).

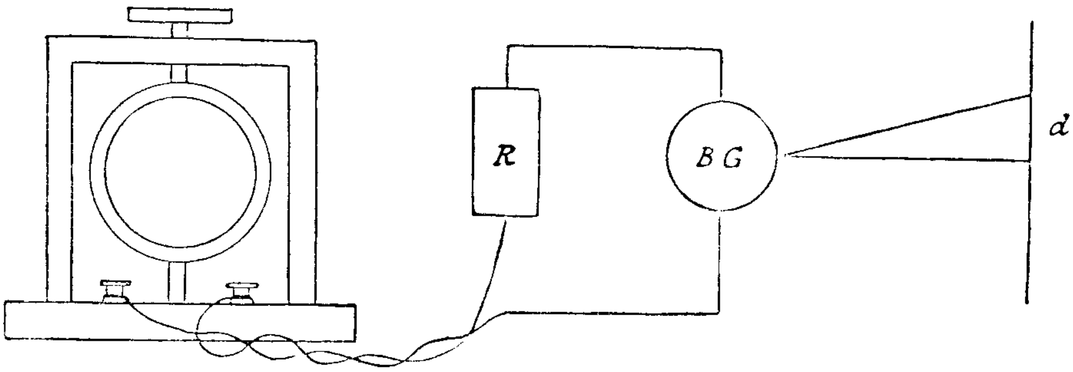
Insulation resistance S of condenser:

$d_0 =$ $d' =$ $t' =$ sec. $\therefore S = \frac{t'}{2{\cdot}3026\, C \log_{10} \frac{d_0}{d'}} =$ megohms

$\therefore$ Corrected value R' of high resistance will be given by:

$\frac{1}{R'} = \frac{1}{R} - \frac{1}{S} =$ $\therefore R' =$ __________ megohms.

DETERMINATION OF THE ANGLE OF DIP USING AN EARTH INDUCTOR



Apparatus

Earth inductor (with about 1000 turns of area 500 sq. cm.), resistance box, ballistic galvanometer (reflecting type).

Method

The earth inductor is connected by a length of flex in circuit with the resistance box and the ballistic galvanometer. The coil is first placed with its plane vertical and with its axis along the meridian. Turn the coil sharply through 180° and note the deflection of the galvanometer. The coil is now rotated through 180° in a contrary direction and the deflection on the other side of the scale zero noted, and so the mean deflection (d_1) is obtained. (The resistance box is adjusted to obtain a suitable deflection before the readings are taken.)

The coil is now placed with its plane horizontal and the mean deflection (d_2) of the galvanometer for a half revolution of the coil is again obtained.

Note.—The value of R must be kept the same in both parts of the experiment.

Notes (continued from p. 203)

(2) Using a calibrated ballistic galvanometer (see Expt. 94) a value of the Earth's horizontal component H_0 can be obtained using the earth inductor. Thus on rotating the coil through 180° when placed with its plane vertical and its axis along the meridian, the quantity of charge q set in motion through the coil is

$$q = \frac{2nAH_0}{(R' + G)10^8} \text{ coulombs } (R' \text{ and } G \text{ being in ohms})$$

$$= k\theta\left(1 + \frac{\lambda}{2}\right)$$

where k is the constant of calibration, θ the observed throw in radians, and λ the log dec. (see p. 199).

Hence $$H_0 = \frac{(R' + G)k\theta\left(1 + \frac{\lambda}{2}\right)10^8}{2nA} \text{ oersteds.}$$

Theory

Let e, i be the instantaneous values of the induced e.m.f. and current in a coil (included in a circuit of total resistance R) moving in a magnetic field H. Let N_1 and N_2 be the initial and final flux through the coil, and N the instantaneous flux, then—

$$e = -\frac{dN}{dt} \quad \text{and} \quad i = \frac{e}{R} = -\frac{1}{R}\frac{dN}{dt},$$

but $i = \frac{dq}{dt}$. $\therefore\ dq = -\frac{dN}{R}$ from which by integration, the quantity of charge (q) set in motion in the coil $= -\frac{(N_2 - N_1)}{R} = \frac{N_1 - N_2}{R}$,

i.e. $$q = \frac{\text{change of flux through coil}}{R}.$$

1st position of coil:

$N_1 = nAH_0, \quad N_2 = -nAH_0.$

$$\therefore\ q_1 = \frac{2nAH_0}{R' + G} \propto d_1 \quad . \quad . \quad . \quad (1)$$

2nd position of coil:

$N_1 = nAV, \quad N_2 = -nAV.$

$$\therefore\ q_2 = \frac{2nAV}{R' + G} \propto d_2 \quad . \quad . \quad . \quad (2)$$

Where n = no. of turns on coil.
A = area of coil (πr^2).
R' = box resistance (+ resistance of coil).
G = galvanometer resistance.
H_0 = Horizontal component of Earth's field.
V = Vertical component of Earth's field.
δ = angle of dip.

From (1) and (2):

$$\frac{V}{H_0} = \tan\delta = \frac{d_2}{d_1}.$$

Results

Readings for $d_1 =$, , , , , , $\therefore$ mean $d_1 =$ mm.

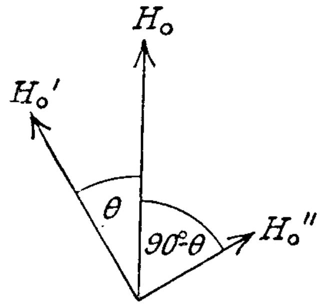
" " $d_2 =$, , , , , , $\therefore$ mean $d_2 =$ mm.

$$\therefore\ \delta = \tan^{-1}\frac{d_2}{d_1} = \qquad ^\circ.$$

Notes

(1) The direction of the magnetic meridian can be found by using the Earth inductor in the following manner:

Place the coil with its plane vertical in any position (with its axis making some unknown angle θ with the meridian) and find the deflection d' of the galvanometer on rotating the coil through 180°. Now place the coil with its plane still vertical in a position at right angles to its former position and obtain the deflection d'' of the galvanometer as before.



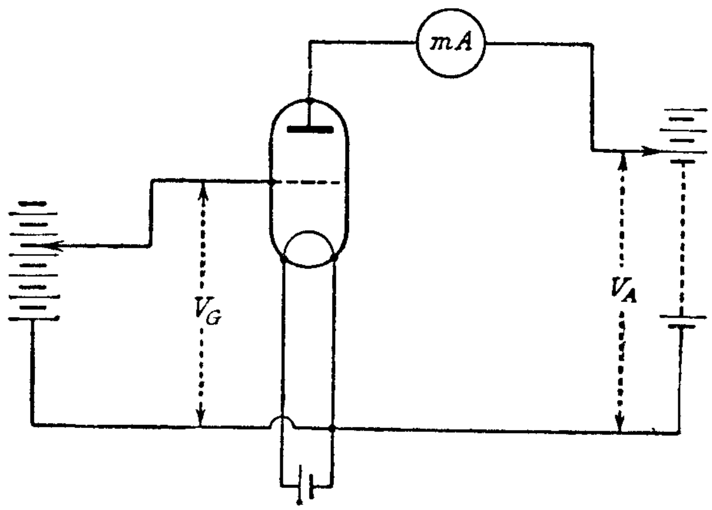
Then $$q_1 = \frac{2nAH_0'}{R' + G} = \frac{2nAH_0\cos\theta}{R' + G} \propto d'$$

and $$q_2 = \frac{2nAH_0''}{R' + G} = \frac{2nAH_0\sin\theta}{R' + G} \propto d'',$$

(H_0' and H_0'' being the resolved parts of H_0 in directions parallel to the axis of the coil in the two positions —see figure.)

i.e. $\theta = \cot^{-1}\frac{d'}{d''}$ and hence the direction of the meridian can be found.

DETERMINATION OF THE CHARACTERISTICS OF A TRIODE VALVE



Apparatus

Any general-purpose triode battery valve, valve-holder, high-tension battery with 20-volt tappings, grid-bias battery, 2-volt accumulator, milliammeter reading up to 15 or 20 milliamp. (e.g. " all-test " milliammeter).

Method

Connect up the circuit as shown and apply 100 volts to the plate (anode). Apply negative grid bias until the plate current just ceases to flow. Now reduce the negative bias in steps of $1\frac{1}{2}$ volts to zero, taking corresponding readings of the plate current. Reverse the grid-bias battery and apply positive bias until the plate current approaches saturation. Repeat the experiment with a plate voltage of 80 volts, and plot the curves of plate current against grid volts for the two plate voltages.

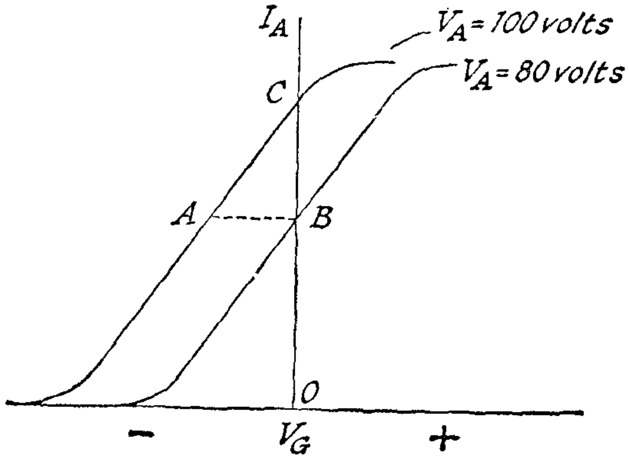
Note.—Before deriving the results, the 80- and 100-volt markings on the H.T. battery must be checked by a voltmeter.

Notes

(1) The value of μ obtained is known as the " static " amplification factor. Under conditions of actual performance with a load resistance R in the plate circuit it can be shown that an alternating voltage V_G applied between filament and grid produces an alternating voltage across R of $\frac{\mu R}{R + R_0} . V_G$. The expression $\frac{\mu R}{R + R_0}$ is called the " dynamic " amplification factor or stage gain which approaches the value μ as R is progressively increased. This would cause an increasing drop of potential across R, however, and necessitate increased values of H.T. voltage if the valve is to operate. It can be shown that for minimum distortion consistent with maximum power input the value of R should be about twice the impedance of the valve.

(2) By removing the grid-bias battery and connecting the grid to the plate the valve may be made to function as a diode. The student should investigate how the plate current varies with the applied plate volts, repeating the experiment for different values of the filament current (an ammeter and control rheostat should be included in the filament circuit). Comment on the shape of the curves obtained, and by plotting values of log i_A against log V_A obtain an empirical law connecting the plate current with applied voltage at a constant filament temperature.

Theory and Results



V_G	i_A for $V_A = 80$ volts	i_A for $V_A = 100$ volts

(1) *Amplification factor* (μ)

$$= \frac{\text{change in plate volts to produce a given change in plate current}}{\text{change in grid volts to produce the same change in plate current}}$$

$$= \frac{20}{AB} = \underline{\qquad\qquad\qquad} \qquad = \frac{\delta V_A}{\delta V_G}.$$

(2) *Mutual conductance* (g)

= change in plate current for unit change in grid volts.

$$= \frac{BC}{AB} = \underline{\qquad\qquad\qquad} \text{ milliamp. per volt} \qquad = \frac{\delta I_A}{\delta V_G}.$$

(3) *Impedance* (R_0)

= change in plate volts to produce unit change in plate current

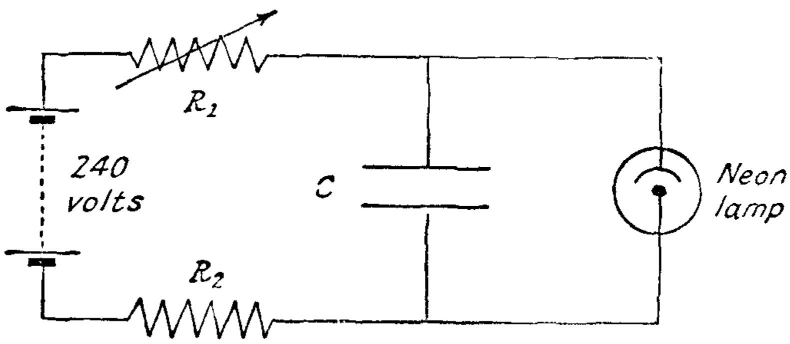
$$= \frac{20}{BC} \times 1000 = \underline{\qquad\qquad\qquad} \text{ ohms.} \qquad = \frac{\delta V_A}{\delta I_A}.$$

or alternatively;

since $$R_0 = \frac{\delta V_A}{\delta I_A} = \frac{\delta V_A}{\delta V_G} \times \frac{\delta V_G}{\delta I_A} = \frac{\mu}{g}.$$

$$\therefore \text{ impedance} = \frac{\text{amplification factor}}{\text{mutual conductance}} \times 1000 \text{ ohms.}$$

DETERMINATION OF THE CAPACITY OF A CONDENSER USING A FLASHING NEON LAMP CIRCUIT



Apparatus

Two 120-volt H.T. batteries, neon lamp, condenser of unknown capacity, set of condensers of known capacities from 0·1 to 2 mfd., fixed ½-megohm resistance, variable megohm resistance, stop-watch.

Method

Connect up the circuit as shown with the two H.T. batteries connected in series to supply a P.D. of 240 volts. Insert the condenser of least capacity and adjust R_1 so as to obtain a measurable rate of flashing in the neon lamp. Find the period of flashing (T) by timing 20 flashes with the stop-watch. Find the flashing period for each of the known condensers keeping R_1 constant. The neon lamp can then be calibrated by drawing a graph of flashing period against capacity for a constant value of the circuit resistance.

The flashing period for the unknown condenser is now found, and its capacity read from the graph.

Notes

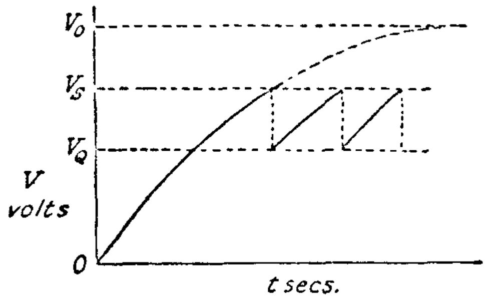
(1) To avoid the possibility of photo-electric interference with the functioning of the neon lamp, the experiment should be conducted in a dark room, or alternatively the lamp may be supplied with a hood, the flashes being observed through a small sighting hole at the side. If the slower flashing periods tend to be irregular a slight degree of general illumination may be required to stabilise the flashing sequence.

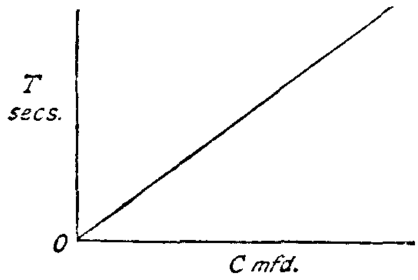
(2) In addition to the visual observation of the flashing period, counts may be taken aurally by taking leads from the ends of R_2 to the input of a simple resistance-capacity coupled amplifier unit, the amplified output being fed to a pair of high-resistance headphones.

(3) No high degree of accuracy is claimed for this method, the circuit having been assumed entirely non-inductive. The exercise is, however, an interesting illustration of a simple repeated stroke ("saw tooth") time base circuit and demonstrates in a visual manner the effect of capacitance (and resistance) on the frequency of sweep.

Theory

The condenser C charges through the high resistance until the P.D. between the condenser plates attains the "striking voltage" (V_S) of the neon lamp (*c.* 170 volts). The neon gas





then ionizes and the condenser is discharged until its P.D. is reduced to a value (V_Q) known as the "quenching voltage". At this voltage ionization ceases, and the cycle of operations is repeated.

Let t_1 be the time for the condenser to charge up to V_S volts, and t_2 be the time for it to charge up to V_Q volts. Then since the relationship between V (the condenser P.D. after t sec.) and V_0, the applied voltage, is

$$V = V_0\left(1 - e^{-\frac{t}{CR}}\right),$$

we have $t_1 = CR \log_e \dfrac{V_0}{V_0 - V_S}$ and $t_2 = CR \log_e \dfrac{V_0}{V_0 - V_Q}$, where $R = R_1 + R_2$ (see diagram)

$\therefore$ the flashing period $T = t_1 - t_2 = CR \log_e \dfrac{V_0 - V_Q}{V_0 - V_S}$ (ignoring the very much smaller discharge period).

Results

C mfd.	T sec.

For unknown condenser $T =$ sec.

$\therefore$ from graph $C =$ __________ mfd.