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ELECTROMAGNETISM LABORATORY

EXPERIMENT-4

Title: Measurement of high resistance by leakage of a condenser

Aim:

To determine the measurement of high resistance by leakage of a condenser.

Apparatus and Accessories:

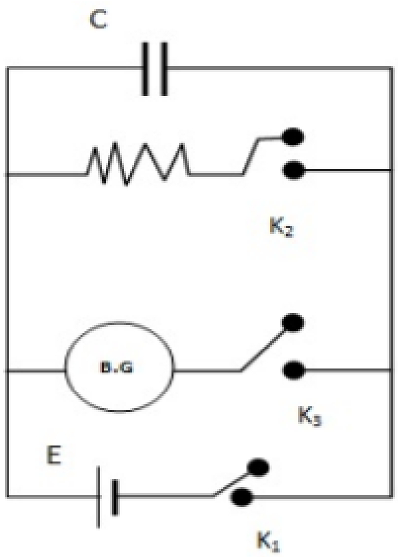
1. Ballistic galvanometer (suspended set up with light and mirror)
2. Condenser
3. High resistor
4. Voltage source
5. Connecting wires
6. Stop Watch

Theory:

When a condenser of capacitance C and initial charge Q is allowed to discharge through a resistance R for a time t, the charge remaining on the condenser is given by the formula below-

$$q(t) = Qe^{\frac{-t}{CR}}$$

$$R = \frac{t}{Cln\frac{Q}{q}}$$



It follows that if the ratio $\frac{Q}{q}$ can be determined experimentally, then R can be found -

1. The condenser C is first changed by joining a and b.
2. a and b are then disconnected and b and d are connected. The condenser discharges

itself through G and the throw σ_0 is proportional to Q.

3. The condenser is then recharged.
4. By connecting the condenser across bc, the charge is allowed to leak through R for a known time t.
5. The charge left on the condenser is then discharged through G. The ballistic through σ is proportional to q. Then,

$$R = \frac{t}{Cln\frac{Q}{q}} = \frac{t}{2.303Clog\frac{\sigma_0}{\sigma}}$$

6. A series of corresponding values of t and σ should be obtained and from the linear graph obtained by plotting t against $log\frac{\sigma_0}{\sigma}$, a value of R may be found.

$$log\frac{\sigma_0}{\sigma} = \frac{t}{2.303CR} = \left(\frac{1}{2.303CR}\right)t$$

where R can be measured by using a ballistic galvanometer

Now we may find a similar expression in terms of voltages-

$$log\frac{Q}{q} = log\frac{V_o}{V_1} = \frac{t}{2.303CR} = \left(\frac{1}{2.303CR}\right)t \quad -- \ (1)$$

where $Q=CV_0$ and $q=CV_1$, with V_0 and V_1 are the voltages of the capacitors corresponding to the charges Q and q.

So, instead of using a ballistic galvanometer, we can measure voltages by a DC mircovoltmeter, and using eq(1), R can be measured.

In practice, it often happens that the condenser C is slightly defective. To test that C is charged and immediately discharged through the air. In this case,

$$V_1(t) = V_0 e^{\frac{-t}{CR_1}}$$

where R_1 is the insulation resistance of capacitor and the capacitor C discharges through the air along with high resistance

$$V_2(t) = V_0 e^{\frac{-t}{CR_{eq}}}$$

$$\frac{V_1}{V_2} = e^{\frac{t}{C}\left(\frac{1}{R_{eq}} - \frac{1}{R_1}\right)} = e^{\frac{t}{CR}}$$

$$ln\left(\frac{V_1}{V_2}\right) = \frac{t}{CR}$$

where $\frac{1}{R} = \frac{1}{R_{eq}} - \frac{1}{R_1} \Rightarrow \frac{1}{R_{eq}} = \frac{1}{R} + \frac{1}{R_1}$ and R is the high resistance.

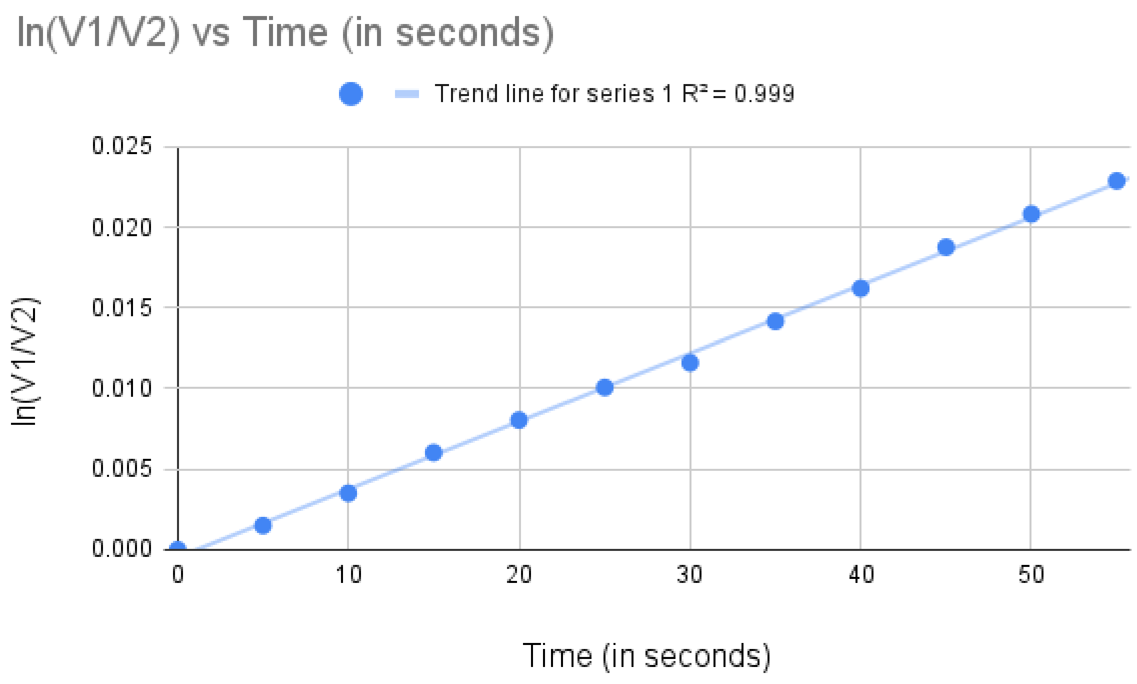
Observations:

Table-1-
C = 200μF, V_0 = 20V
Least count of voltmeter = 0.01V
Least count of stop watch = 0.01 second = Δt

Sl. No.	Time (in seconds)	V_1(Volt)	V_2(Volt)
01	0	28.00	20.00
02	5	19.97	19.94
03	10	19.97	19.90
04	15	19.96	19.84
05	20	19.95	19.79
06	25	19.94	19.74
07	30	19.93	19.70
08	35	19.92	19.64
09	40	19.91	19.59
10	45	19.91	19.54
11	50	19.90	19.49
12	55	19.90	19.45

Graphs:

Graph-1 of Observation Table-1-



Scale of the above graph:

- X-axis- 1 unit = 1 second
- Y-axis - 1 unit = 0.005

Calculations:

Value of slope from the graph, $m = \frac{1}{CR} = 0.0004215826829 s^{-1}$

$\therefore, R = \frac{1}{Cm} = \frac{1}{0.002 \times 0.0004215826829} = 1186006.969\ \Omega = 1.186\ M\Omega$

$\therefore, R \approx 1.186 \times 10^{6}\ \Omega$

$\therefore, R = 1.186\ M\Omega = 1.186 \times 10^{6}\ \Omega$

Finding a line of best fit using the least squared method-

Sl. No.	X (Time in seconds)	Y $(ln(\frac{V_1}{V_2}))$	XY	X^2
01	0	0	0	0
02	5	0.001503382894	0.00751691447	25
03	10	0.003511415697	0.03511415697	100
04	15	0.006030169027	0.09045253541	225
05	20	0.008052383721	0.1610476744	400
06	25	0.01008073053	0.2520182633	625
07	30	0.01160749848	0.3482249544	900
08	35	0.01415594923	0.4954582231	1225
09	40	0.01620288612	0.6481154448	1600
10	45	0.01875847146	0.8441312157	2025
11	50	0.02081821821	1.040910911	2500
12	55	0.02287266167	1.257996392	3025

$\sum X = 330, \sum Y = 0.133596767, \sum XY = 5.180986685, \sum X^2 = 12650$ *and*
$n = 12 = number\ of\ observations$

Substituting these values in the below equations to find the slope and y-intercept of the line of best fit, we get -

$$m = slope\ of\ the\ line\ of\ best\ fit = \frac{n\sum XY - \sum X \sum Y}{n\sum X^2 - (\sum X)^2} = 0.000421559606$$

$$b = y - intercept\ of\ the\ line\ of\ best\ fit = \frac{\sum Y - m\sum X}{n} = -0.000459825$$

Therefore, the equation of the line of best fit is $y = mx + b$, i.e -
$y = 0.0004215596062x - 0.000459825255$
From the equation of the line of best fit -

$$R = \frac{1}{Cm} = \frac{1}{0.002 \times 0.0004215596062} = 1186071.893\ \mathbf{\Omega} = 1.186\ \mathbf{M\Omega}$$

Clearly, the value of R obtained using the equation of the line of best fit is the same as the value of R obtained from the graph.

$\therefore$, R= 1.186 **MΩ** =1.186×10^6 **Ω**

Error:

$$\frac{\Delta R}{R} = \frac{\left(\frac{\Delta V_1}{V_1} + \frac{\Delta V_2}{V_2}\right)}{\ln\left(\frac{V_1}{V_2}\right)} + \frac{\Delta t}{t}$$

$$ln\left(\frac{V_1}{V_2}\right) \times \frac{C}{t} = \frac{1}{R} \quad -- \quad (1)$$

$$-\frac{\Delta R}{R^2} = \frac{V_2}{V_1}\left[\frac{V_2 \Delta V_1 - V_1 \Delta V_2}{V_2^2}\right] \times \frac{C}{t} - \ln\left(\frac{V_1}{V_2}\right) \times \frac{C \times \Delta t}{t^2} \quad -- \quad (2)$$

Dividing equations (2) by (1) and considering all positive terms, we have -

$$\frac{\Delta R}{R} = \frac{\left(\frac{\Delta V_1}{V_1} + \frac{\Delta V_2}{V_2}\right)}{\ln\frac{V_1}{V_2}} + \frac{\Delta t}{t}$$

$\Delta V_1 = \Delta V_2$= 0.01V, Δt= 0.01 second, t = 35 seconds, V_1= 19.92V, V_2= 19.64V and

$ln\left(\frac{V_1}{V_2}\right)$= 0.01415594923

$$\therefore \frac{\Delta R}{R} = \frac{\frac{\Delta V_1}{V_1} + \frac{\Delta V_2}{V_2}}{ln\left(\frac{V_1}{V_2}\right)} + \frac{\Delta t}{t}$$

$$\therefore \frac{\Delta R}{R} = \frac{\frac{0.01}{19.92} + \frac{0.01}{19.64}}{0.01415594923} + \frac{0.01}{35} = 0.071716671$$

$$\therefore \frac{\Delta R}{R} \times 100 = 7.1716671\% \approx 7.172\%$$

$$\Delta R = 0.071716671 \times 1.186 \times 10^6 = 85055.997221\Omega \approx 0.085 \times 10^6\Omega$$

The fractional error in R is $0.085 \times 10^6\Omega$ and its percentage error is 7.172%.

Result:

1. The of the given ballistic galvanometer is (1.186 $\pm$ 0.085)$\times 10^6\Omega$
2. The fractional error in R is $0.085 \times 10^6\Omega$ and its percentage error is 7.172%.

Precautions:

1. The galvanometer coil should be made properly free, i.e, it should be free to rotate.
2. Connection should be proper & tight.
3. A tapping key should be used across the galvanometer.
4. The condenser should be free from dielectric loss.
5. Charging of capacitor is essential before taking the readings of θ_t.
6. After observing θ_0, the galvanometer coil should be at rest for observing the value of θ_t.
7. After the completion of the experiment, the supply should be switched off.

Discussion:

1. The ballistic galvanometer is an instrument, which is used to measure or indicate current in a closed circuit. The galvanometer also is known as the PMMC instrument, works on the principle of permanent magnet moving coil.
2. The deflection in the Ballistic Galvanometer is directly proportional to the charge present in the condenser.
3. Digital Multimeters or LCR meters are used to measure the normal value of resistance (generally 1Ù - 20MÙ) but in the case of a very high value of

resistance, these are unable to measure with high accuracy. The leakage method is a very accurate way to measure the high value of resistance because of the very sensitive ballistic galvanometer with scale & lamp arrangement and very low value of capacitances used in the product.

4. Charge grows exponentially in the condenser.
5. Current sensitivity: The figure of merit or current sensitivity of a moving coil galvanometer is the current required to produce a deflection of 1 mm on a scale kept at a distance of 1 m from the mirror. It is expressed in μA/mm.
6. The wire used for the suspension of the coil is made up of phosphor bronze because phosphor bronze has a low torsional constant. It allows the coil to suspend easily. Also phosphor bronze is nonmagnetic. So it does not comes under the influence of magnetic poles. And phosphor bronze does not oxidize easily. This allows the suspension wire not to get rusted due to atmospheric conditions.
7. Charge sensitivity: The charge sensitivity (the ballistic reduction factor) of a moving coil galvanometer is the charge (transient current) required to produce a deflection (throw or kick) of 1 mm on a scale kept at a distance of 1 m from the mirror.
8. Uses of Ballistic galvanometer:
    a. To compare capacities of capacitors.
    b. To compare e m f of cells.
    c. To find self and mutual inductance of coils.
    d. To find the magnetic flux or to find the intensity of a magnetic field.
    e. To find the angle of dip at a place using an earth inductor.
    f. To find a high resistance, by the method of leakage through a capacitor.