JEE Advanced 2019 - Paper 1 - Physics 12

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Problem *[Multiple Choice Multiple Correct]*

Two identical moving coil galvanometer have $10\,\Omega$ resistance and full scale deflection at $2\,\mu$A current. One of them is converted into a Voltmeter of 100 mV full scale reading and the other into an Ammeter of 1 mA full scale current using appropriate resistors. These are then used to measure the voltage and current in the Ohm's law experiment with $R = 1000\,\Omega$ resistor by using an ideal cell. Which of the following statement(s) is/are correct?

(A) The resistance of the Voltmeter will be $100\,\text{k}\Omega$.
(B) The resistance of the Ammeter will be $0.02\,\Omega$ (round off to 2^{nd} decimal places).
(C) The measured value of R will be $978\,\Omega < R < 982\,\Omega$.
(D) If the ideal cell is replaced by a cell having internal resistance of $5\,\Omega$ then the measured value of R will be more than $1000\,\Omega$.

What to Observe:

- Two identical moving coil galvanometers with resistance $10\,\Omega$ and full scale deflection at $2\,\mu$A.
- One galvanometer is converted into a voltmeter with 100 mV full scale reading.
- The other galvanometer is converted into an ammeter with 1 mA full scale current.
- The voltmeter and ammeter are used to measure voltage and current in an Ohm's law experiment.
- The resistor used in the experiment has resistance $R = 1000\,\Omega$.
- The cell used is ideal.

My Approach:

Voltmeter

Thought

If I take the current through the created voltmeter as I_V, then the voltage across the galvanometer is given by:

$$V = I_V \cdot (R_G + R_S)$$

Since $I_V = I_G$, where I_G is the maximum current allowed by the galvanometer, we can rewrite the equation as:

$$V = I_G \cdot (R_G + R_S)$$

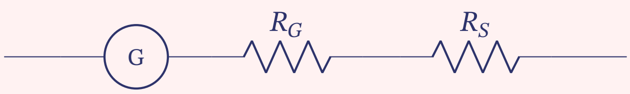

Figure 1. Circuit diagram showing a galvanometer with internal resistance R_G and a series resistance R_S, forming an voltmeter.

Given the voltage $V = 100\,\text{mV} = 0.1\,\text{V}$ and the maximum current $I_G = 2\,\mu\text{A} = 2 \times 10^{-6}$ A, the equivalent resistance R_{eq} is given by:

$$R_{\text{eq}} = \frac{V}{I_G} = \frac{0.1\,\text{V}}{2 \times 10^{-6}\,\text{A}} = 50,000\,\Omega = 50\,\text{k}\Omega$$

Therefore **Option A is incorrect**.

Ammeter

Thought

The ammeter is created by connecting a galvanometer in parallel with a shunt resistance R_P. The current through the galvanometer is given by:
Let the equivalent resistance of the ammeter be R_A. The current through the ammeter, I_A, is related to the current through the galvanometer and the equivalent resistance as follows:

$$I_G R_G = I_A R_A$$

- I_G is the current through the galvanometer.
- R_G is the resistance of the galvanometer.

- I_A is the total current through the ammeter.
- R_A is the equivalent resistance of the ammeter.

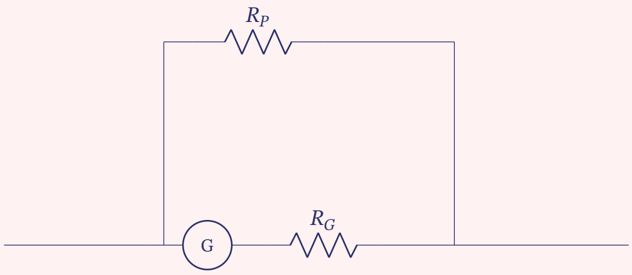

Figure 2. Circuit diagram showing a galvanometer with internal resistance R_G and a parallel shunt resistance R_P, forming an ammeter.

Given that $I_G = 2\,\mu\text{A} = 2 \times 10^{-6}\,\text{A}$, $R_G = 10\,\Omega$, and $I_A = 1\,\text{mA} = 1 \times 10^{-3}\,\text{A}$, we can calculate the equivalent resistance R_A of the ammeter as follows:

$$R_A = \frac{I_G R_G}{I_A} = \frac{(2 \times 10^{-6}\,\text{A}) \cdot 10\,\Omega}{1 \times 10^{-3}\,\text{A}} = 0.02\,\Omega$$

Therefore **Option B is correct**.

Ohm's Law Experiment

Thought

So, since Option C and Option D are referring to the measured value of R, let's solve it generally with an internal resistance r of the cell. For Option C, we can replace r with 0, and for Option D, we can replace r with $5\,\Omega$.

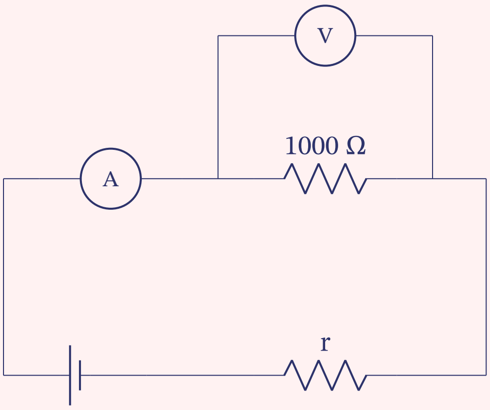

Figure 3. Circuit diagram showing a $1000\ \Omega$ resistor connected with a constructed ammeter and voltmeter, and a cell with internal resistance r.

Using KVL, taking the voltage across the cell as ε and the net current as I, we need to find $\frac{V}{I} = R$, where V is the reading in the voltmeter and I is the reading in the ammeter.
So, applying KVL in the loop, clockwise starting from the cell, we have:

$$\varepsilon - IR_A - V - Ir = 0$$

Now, divide by I:

$$\frac{\varepsilon}{I} - R_A - \frac{V}{I} - r = 0$$

So, since $\frac{\varepsilon}{I} = R_{\text{eq}}$, we can rewrite the equation for $\frac{V}{I}$ as follows:

$$\frac{V}{I} = R_{\text{eq}} - R_A - r$$

We are given:

$$R_{\text{eq}} = R_A + \frac{1000\,\Omega \times 50\,\text{k}\Omega}{50\,\text{k}\Omega + 1000\,\Omega} + r$$

Then, the estimated resistance $R_{\text{estimated}}$ is:

$$R_{\text{estimated}} = R_{\text{eq}} - R_A - r$$

Substitute R_{eq}:

$$R_{\text{estimated}} = \left(R_A + \frac{1000\,\Omega \times 50\,\text{k}\Omega}{50\,\text{k}\Omega + 1000\,\Omega} + r\right) - R_A - r$$

Simplifying:

$$R_{\text{estimated}} = \frac{1000\,\Omega \times 50\,\text{k}\Omega}{50\,\text{k}\Omega + 1000\,\Omega} \approx 980.39\,\Omega$$

Therefore **Option C is correct**.

As the expression is independent of r, we can say that the measured value of R will be the same for any internal resistance of the cell. Therefore **Option D is incorrect**.

Conclusion

Based on the detailed analysis and the computed expression for the estimated resistance $R_{\text{estimated}}$:

$$\boxed{\text{Options B, and C are correct.}}$$

Option A is incorrect because the resistance in the voltmeter calculated does not match the value stated in the option.
Option D is incorrect as the estimated value of $R_{\text{estimated}}$ is independent of the internal resistance.

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