Principles of Physics II (PHY112)

Lab

Experiment no: 7

Name of the experiment: Determination of the internal resistance of a cell by using a potentiometer

Theory

Every cell has an intrinsic resistance. When two electrodes of a cell are connected with a resistor, then not only the electrons flow from one electrode to the other through that outside resistor but also, inside the cell, the positive ions rush to the cathode and the negative ions rush to the anode. That means current flow occurs inside the cell between the two electrodes. The resistance faced by this current is the internal resistance of the cell. In this experiment we are going to measure this internal resistance by using a potentiometer.

Potentiometer

Potentiometer is a device to measure potential difference and electromotive force. In this device a wire of 10 m length and uniform cross section is attached with a wooden frame. The wire has significant resistance. Usually it has 10 segments. Each of the segments is of 1 m length. The segments are connected with each other in a series combination. The wire consists of a material, whose thermal coefficient of resistance is low, i.e., its specific resistance does not change much with the change of temperature. Usually, Manganin or Constantan is used.

By using a potentiometer the electric potential difference ("voltage difference") across a component can be determined by applying the principle of a *potential divider*.

Potential Divider

Figure 1 shows a simple potential divider. Two resistors of resistances R_1, R_2 and a voltage source of electromotive force E are connected in series combination. Total I amount of current is passing through the closed loop. Voltage differences across the resistance R_1 and R_2 are V_1 and V_2 respectively. Therefore, according to Kirchhoff's law, $E = V_1 + V_2$

According to Ohm's law, $V_1 = I R_1$ & $V_2 = I R_2$

Therefore, $E = I R_1 + I R_2 = I (R_1 + R_2) \Rightarrow I = \frac{E}{(R_1 + R_2)}$

Finally, we get rule of potential division between two resistors connected in series combination,

$$\boxed{\begin{aligned} V_1 &= \frac{R_1}{(R_1 + R_2)} E \\ V_2 &= \frac{R_2}{(R_1 + R_2)} E \end{aligned}} \qquad (1)$$

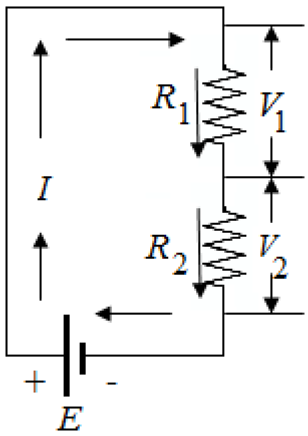

Figure 1: A simple potential divider

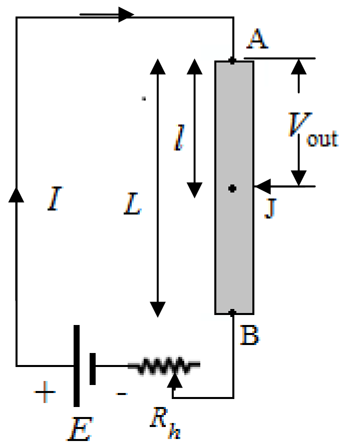

Figure 2: A conductor AB having uniform cross section connected with a cell in series serving as a potential divider.

A conductor of uniform cross section and having significant resistance connected with a cell can serve as a potential divider, as shown in the Figure 2. The rheostat R_h is used to modulate the total current, I. A and B are the two ends of this conductor. A terminal is connected with the circuit at point A. Another terminal comes out from point J. We can slide the second terminal along the conductor. We get an output voltage difference of V_{out} between the A and J terminal. The resistances of the conductor's segments AJ and JB are R_{AJ} and R_{JB} respectively. Total resistance of the conductor, $R= R_{AJ} + R_{JB}$. Suppose, the length of the conductor is L and the length of the AJ segment is l. Since, the conductor has uniform cross section; the resistance of any of its segment is proportional to the length of that segment. If σ is the resistance per unit length of the conductor then $R_{AJ} = l\sigma$ and $R = L\sigma$. According to the potential division rule:

$$V_{out} = \frac{R_{AJ}}{R_{AJ} + (R_{JB} + R_h)} E = \frac{R_{AJ}}{R + R_h} E = \frac{l\sigma}{L\sigma + R_h} E = \frac{E}{L + R_h / \sigma} l$$

$$\Rightarrow \boxed{V_{out} = \frac{E}{L + R_h / \sigma} l} \qquad (2)$$

Let us connect a series combination of a cell of electromotive force E_1 and a galvanometer G with the output terminals A and J (figure 4). **The positive electrodes of E_1 and E are connected with a same node, A.** The resistance R_o is the combined resistance of the galvanometer and the internal resistance of the cell, E_1. After reaching the junction A, the current I gets divided into two flows: I_G and I_C. I_G passes through the E_1, R_o and G. On the other hand, I_C passes through the AJ segment of the conductor. According to Kirchhoff's current rule: $I = I_G + I_C$. Voltages at nodes A, C and J are V_A, V_C and V_J respectively.

I_G amount of current passes through the resistance R_o. According to Ohm's law,

$$V_C - V_J = I_G R_o \qquad (3)$$

Voltage difference across E_1,

$$V_A - V_C = E_1 \qquad (4)$$

By summing equations (3) and (4) we get,

$$V_A - V_J = E_1 + I_G R_o \qquad (5)$$

However, that is the output voltage difference between terminals A and J provided by the potential divider. Hence, according to the equation (2) we can write,

$$\frac{E}{L + R_h / \sigma} l = E_1 + I_G R_o$$

$$\Rightarrow \frac{E}{L + R_h / \sigma} l - E_1 = I_G R_o$$

$$\Rightarrow I_G = \frac{1}{R_o}\left[\frac{E}{L + R_h / \sigma} l - E_1\right] \qquad (6)$$

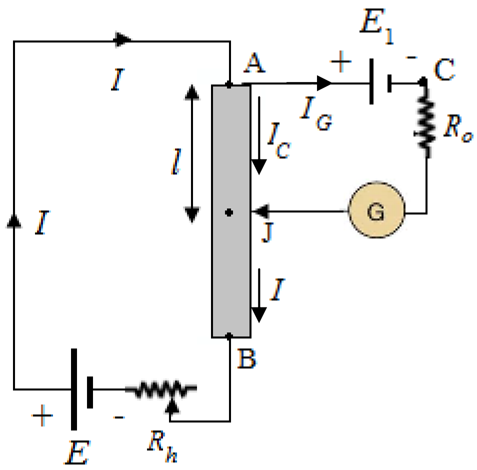

Figure 3: The output terminals A & J of the conductor AB of figure 5 are now connected with a cell of E_1 emf and a galvanometer, G. E_1 and G are in series combination. The resistance R_o is the combined resistance of the galvanometer and the internal resistance of the cell, E_1.

I_G can be positive or negative depending on the parameters which appear inside the square brackets of the right hand side of equation (6).

In Figure 3, both of the positive electrodes of E and E_1 are connected with A. However, instead of that if the negative electrode of E and the positive electrode of E_1 were connected with the junction A, then in equation (6), E would be negative and E_1 would be positive.). Eventually, I_G would be always negative. That means current would always pass through the E_1, R_o & G opposite to our presumed direction as shown in the Figure 3, i.e., it would flow from C to A, instead of from A to C.

Again, if the positive electrode of E and the negative electrode of E_1 were connected with the junction A then in equation (6), E would be positive and E_1 would be negative. Therefore I_G would be always positive. That means current would always pass through the E_1, R_o & G towards our presumed direction as shown in the Figure 3, i.e., it would flow from A to C.

If both of E and E_1 are either positive or negative then depending on l, I_G can be either negative or positive, i.e., the current through G can either flow from C to J or from J to C. Therefore, to make sure that the galvanometer's pointer can deflect towards both sides, the first condition is the polarities of the electrodes of E and E_1, which are connected with the junction A, should be same.

Suppose, both E and E_1 are connected as shown in Figure 3. If we slide the terminal J and keep it near A, then l will be sufficiently small and according to equation (6) the magnitude of the current I_G will be negative. Then the current I_G will actually flow toward the opposite to its presumed direction as shown in Figure 3. If we slide the terminal J and keep it near B, then l will be sufficiently bigger and according to equation (6) the magnitude of the current I_G may be positive. Then the current I_G will flow toward the direction as shown in the Figure 3. Depending on the position of J, direction & amount of the current passing through the galvanometer will be different and the galvanometer's pointer will deflect accordingly.

To observe galvanometer's pointer can deflect towards both directions, depending on the value of l, I_G should be either positive or negative. When l is zero then clearly, I_G (= $-E_1/R_o$) is negative. However, the maximum value of l can be L. So, to get I_G positive,

$$\frac{E}{L+R_h/\sigma}L - E_1 > 0 \Rightarrow \frac{1}{L+R_h/\sigma} > \frac{E_1}{LE} \Rightarrow L + R_h/\sigma < \frac{LE}{E_1} \Rightarrow R_h < \frac{\sigma LE}{E_1} - L\sigma$$

$$\Rightarrow R_h < R\frac{(E-E_1)}{E_1} \text{ [Since, } L\sigma = R\text{]}$$

Therefore, to get the galvanometer's pointer to deflect towards both directions, depending on the position of J, the value of the rheostat should be lower that this cut off value $R\frac{(E-E_1)}{E_1}$.

For a particular position of J on the conductor AB, no current will pass through the galvanometer, i.e., I_G = 0. This is called '*null point*'. The pointer of the galvanometer will not deflect. If I_G = 0 then from equation (6) we get,

$$E_1 = \frac{E}{L+R_h/\sigma}l$$

Here, l is the length of the segment of the conductor between the *null point* and the end A of the conductor where the electrodes of same polarity (in our example, positive electrodes) of E and E_1 are connected. Let's put a subscript 1 under l to denote that this corresponds to E_1.

$$\boxed{E_1 = \frac{E}{L+R_h/\sigma}l_1} \qquad (7)$$

Suppose, now we connect a cell of emf E_2 instead of cell E_1. Now, the length of the segment of AB is found l_2 distance away from A. Therefore,

$$E_2 = \frac{E}{L+R_h/\sigma}l_2 \qquad (8)$$

If we divide equation (7) by equation (8) then we get,

$$\boxed{\frac{E_1}{E_2} = \frac{l_1}{l_2}} \tag{9}$$

By using this equation we can compare two voltages, using a potentiometer.

Principle of Measuring Internal Resistance of a Cell by Using a Potential Divider

Figure 4 shows a real cell which is a series combination of a source of electromotive force E_1 and its internal resistance r.

When a cell is not connected to a circuit, then the potential difference ('*voltage difference*') between its two electrodes is its electromotive force (say, E_1). At first we connect only this cell along with a galvanometer (in series combination) between the A and J terminals of the potential divider, find the null point, and measure the length of the segment between end A and the null point, l_1 (Figure 5).

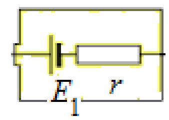

Figure 4: A real cell is a series combination of a source of electromotive force E_1 and its internal resistance r

From equation (7) we get, $E_1 = \dfrac{E}{L + R_h/\sigma} l_1$ (10)

When the cell is connected with a resistor of resistance R then a current, I flows through the complete circuit. It has to encounter the resistance, R of the outside resistor, as well as, the internal resistance, r between the two electrodes inside the cell (Figure 6). The cell's actual electromotive force is the summation of the voltage difference across the outside resistance and that across the internal resistance.

$E_1 = IR + Ir$ (11)

Therefore, $I = E_1/(R+r)$ (12)

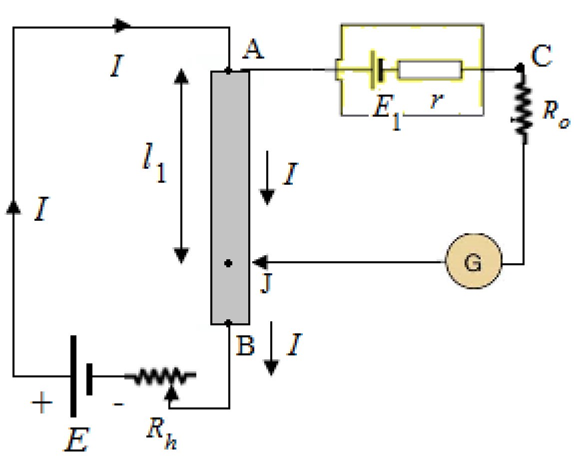

Figure 5: A real cell, along with a galvanometer & the galvanometer's resistance R_o (in series combination) is connected with the output terminals A & J of the potential divider.

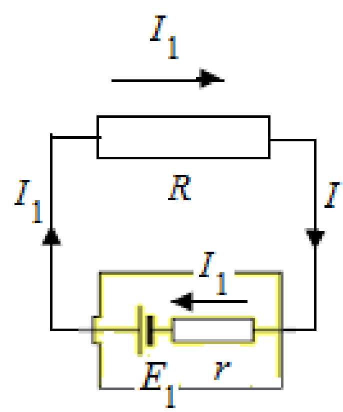

Figure 6: A real cell of electromotive force E_1 and internal resistance r is connected with a resistor of resistance R.

Now, we want to know the potential difference between the two electrodes of this real cell when it is connected with an outside resistor of resistance R. In other words, we want to measure the voltage difference across the resistance R, i.e., IR. To do so we connect this whole circuit with the output terminals (A & J) of the potential divider as shown in the Figure 7. Suppose, now we find the null point l_2 distance away from the end A.

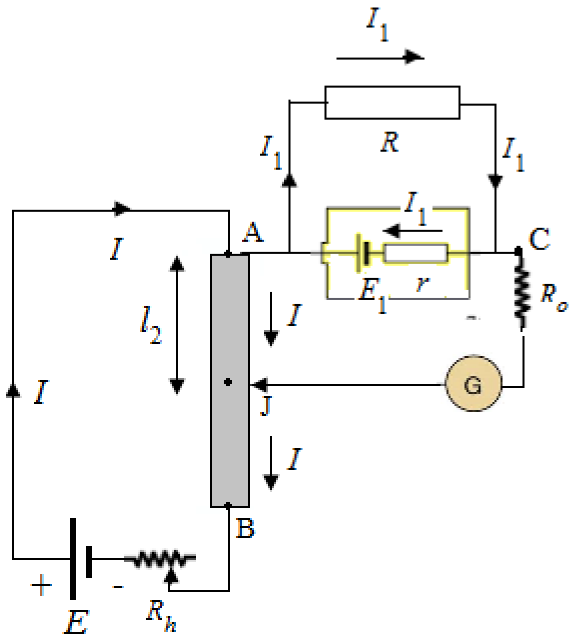

Figure 7: The circuit of Figure 6, along with a galvanometer & the galvanometer's resistance R_o (in series combination) is connected with the output terminals A & J of the potential divider. The positive terminal of the real cell is connected with A. Its negative terminal is connected with C.

Therefore,

$$IR = \frac{E}{L + R_h/\sigma} l_2$$

$$\Rightarrow E_1 - Ir = \frac{E}{L + R_h/\sigma} l_2 \qquad (13)$$

By dividing the equation (13) by the equation (10) we get

$$\frac{E_1 - Ir}{E_1} = \frac{l_2}{l_1}$$

$$\Rightarrow 1 - \frac{r}{\cancel{E_1}} \frac{\cancel{E_1}}{R + r} = \frac{l_2}{l_1}$$ [from equation (12) we know that $I = E_1/(R+r)$]

$$\Rightarrow \frac{R + \cancel{r} - \cancel{r}}{R + r} = \frac{l_2}{l_1}$$

$$\frac{R + r}{R} = \frac{l_1}{l_2}$$

$$\Rightarrow 1 + \frac{r}{R} = \frac{l_1}{l_2}$$

$$\Rightarrow \boxed{r = \left(\frac{l_1}{l_2} - 1\right) R} \qquad (14)$$

This is the equation to find out the internal resistance of a real cell.

Circuit Construction

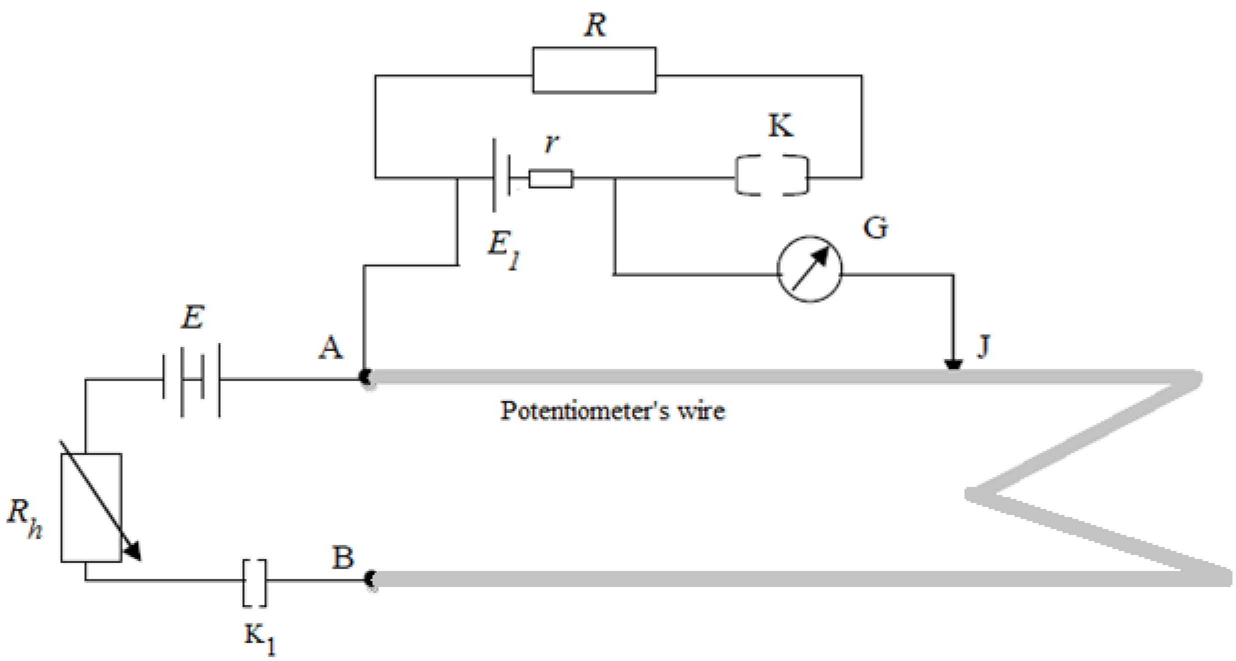

Figure 8: Schematic diagram of the circuit construction to determine the internal resistance of a given cell by using a potentiometer

Compare this circuit construction of Figure 8 with that of Figure 7. The potentiometer's wire, which has a significant resistance, plays the role of the conductor AB. K_1 and K are 'single pole single throw' switches. Positive terminal of the cell E_1 and the DC voltage source E, are connected with end A of the potentiometer's wire. The positive electrode of E_1 is also connected with one end of a resistance box of resistance R. Other end of R is connected with the switch K. K is connected with the negative terminal of the cell (in the Figure 8, with the outside end of the internal resistance of this cell). This outside end of the internal resistance is connected with one end of a galvanometer. The other end of the galvanometer is connected with a jockey. Point of contact between the jockey and the potentiometer's wire is J. End B is connected with the key, K_1. A Rheostat bridges the negative terminal of the DC voltage source E and the key K_1.

When the key K is open then no current passes through R and r. We find out the null point on the potentiometer's wire. The length of the wire between end A and this null point is l_1. Next, we choose a value of R and close the key K. Then we find out the null point in the same way. The length of the wire between end A and this null point is now l_2. We determine the internal resistance r by using equation (14). The key K_1 remains closed while finding out the null point in both cases. It should be kept open while keeping data record, otherwise always a current will pass through the potentiometer's wire which may increase the temperature of the wire and change the resistance of the wire.

Potentiometer as an internal resistance measuring device

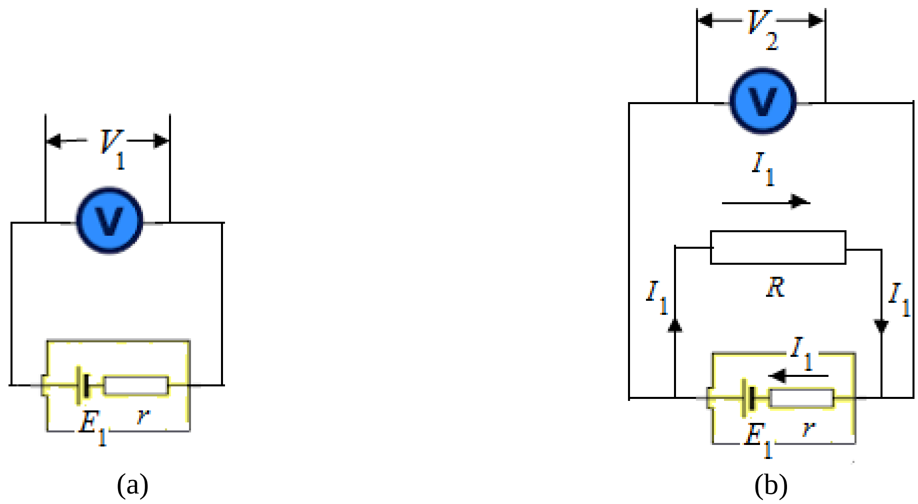

Figure 9: Measuring internal resistance by using a voltmeter

The internal resistance of a cell can be measured by using a voltmeter as well. We can measure the voltage difference between two electrodes of a real cell when it is not connected with any resistor (Figure 9 (a)). It is V_1. Then measure the voltage across the two terminals of the cell again when it is connected with a resistor of resistance R (Figure 9 (b)). It is V_2. Then, the internal resistance of the cell of electromotive force E_1 is $r = \left(\frac{V_1}{V_2} - 1\right)R$ [this is an exercise for you to check it]. However, to cause the deflection of the voltmeter's pointer, a tiny amount of current should be allowed to flow through the voltmeter's coil. This current will also flow through the electrolyte(s), inside the cell between its two electrodes. This current inside the cell has to overcome the cell's internal resistance which results a little potential drop across the cell. Hence, V_1 is slightly lower than the actual electromotive force of the cell. On the other hand, when we use the potentiometer to measure the cell's electromotive force, no current passes through the galvanometer assuring that no current passes through the cell (connected in series combination with the galvanometer), as well. Hence no potential drop occurs across the internal resistance of the cell. This is an advantage of a potentiometer as a measuring device of electromotive force and as well as internal resistance of a real cell.

However, to make the assumption that- 'resistance of a certain portion of the potentiometer's wire is proportional to its length'; the cross sectional area of this wire should be same everywhere. Left and right ends of every segment of the wire should coincides with the 0 and 100cm marks of the meter-scale respectively, otherwise an 'end correction' should be made. Connections of the wires should be tight. Weak connections may cause the fluctuations of the galvanometer's pointer. Voltage of the DC voltage source, E should be same while taking the measurement of l_1 and l_2. When current passes through the wire, it will increase its temperature. Resistance of a body changes with temperature. The potentiometer's wire should consist of a material whose thermal coefficient of resistance is very low, so that the resistance of the wire will not change much due to the change of the temperature.

Apparatus

A potentiometer, a DC voltage source, a cell, a rheostat, two 'single pole single throw' switches, a galvanometer, a resistance box, copper wires (of insignificant resistance).

Procedure

1. Construct the circuit as shown in the Figure 8. Make sure that the galvanometer's pointer deflects towards opposite directions when you make contact between the jockey and the potentiometer's wire near end A and end B. Do it for both cases when K is open and closed. Before you close the key K, make sure that the resistance box has some resistance.
2. Keep the key K open. So, now no current is flowing through the resistance box (of resistance R). Close the key K_1. Find out the null point. Open K_1. Measure the length of the wire-segment between end-A and the null point. This is the value of l_1. Do it for three times. Workout the average value of l_1.
3. Choose R (resistance of the resistance box) = $10\,\Omega$ by plucking the plug of $10\,\Omega$. Close the key K. Now current is flowing through the resistance box. Close the key K_1. Find out the null point. Open K_1 and K. Measure the length of the wire-segment between end-A and the null point. This is the value of l_2 corresponds to the chosen value of R.
4. Repeat step 3 for R = 20, 30, 40, $50\,\Omega$.
5. Work out the internal resistance of the cell, r for every record.
6. Finally, find out the average value of the internal resistance.

Read carefully and follow the following instructions:

- **Please READ the theory carefully, TAKE printout of the 'Questions on Theory' and ANSWER the questions in the specified space BEFORE you go to the lab class.**
- **To get full marks for the 'Questions on Theory' portion, you must answer ALL of these questions CORRECTLY and with PROPER UNDERSTANDING, BEFORE you go to the lab class. However, to ATTEND the lab class you are REQUIRED to answer AT LEAST the questions with asterisk mark.**
- **Write down your NAME, ID, THEORY SECTION, GROUP, DATE, EXPERIMENT NO AND NAME OF THE EXPERIMENT on the top of the first paper.**
- **If you face difficulties to understand the theory, please meet us BEFORE the lab class. However, you must read the theory first.**
- **DO NOT PLAGIARIZE. Plagiarism will bring ZERO marks in this WHOLE EXPERIMENT. Be sure that you have understood the questions and the answers what you have written, and all of these are your own works. You WILL BE asked questions on these tasks in the class. If you plagiarize for more than once, WHOLE lab marks will be ZERO.**
- **After entering the class, please submit this portion before you start the experiment.**

Name: ______________________ ID: _______________ Sec: ___ Group: __ Date: __________

Experiment no: ___

Name of the Experiment: ____

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Questions on theory (all diagrams should be drawn by using a pencil and a scale)

*1) What is internal resistance of a cell? [0.25]

Ans:

*2) See Figure 2. Draw it and work out an expression of V_{out} in terms of E, l, L, R, R_h and σ. σ is the resistance per unit length of the conductor AB. R is the total resistance of the conductor. [1]

Ans:

*3) See Figure 3. Draw it and work out an expression of the current passing through the galvanometer, I_G as shown in equation (6). [2]

Ans:

*4) When I_G is zero, then show that, $E_1 = \frac{E}{L + R_h / \sigma} l$ [0.25]

Ans:

*5) If l_1 and l_2 are the length of the segment of the potentiometer's wire between end A and the null point, correspond to E_1 and E_1, then show that $\frac{E_1}{E_2} = \frac{l_1}{l_2}$ [0.25]

Ans:

*6) Draw the Figure 5 and 7. For Figure 5, show that $E_1 = \frac{E}{L + R_h / \sigma} l_1$ and for Figure 7 show that $E_1 - Ir = \frac{E}{L + R_h / \sigma} l_2$. Finally show that, $r = \left(\frac{l_1}{l_2} - 1 \right) R$. [0.25]

*7) Draw the schematic diagram of the circuit construction to determine the internal resistance of a given cell by using a potentiometer. [0.5]

Ans:

8) In the experiment of the determination of internal resistance (see the figure below) of a cell E_1 the null point of the galvanometer is found at point J_1 when the key K is opened and at the point J_2 when the key K is closed. If the resistance of the resistance box, R= 5 Ohm then what is the internal resistance of E_1? [0.5]

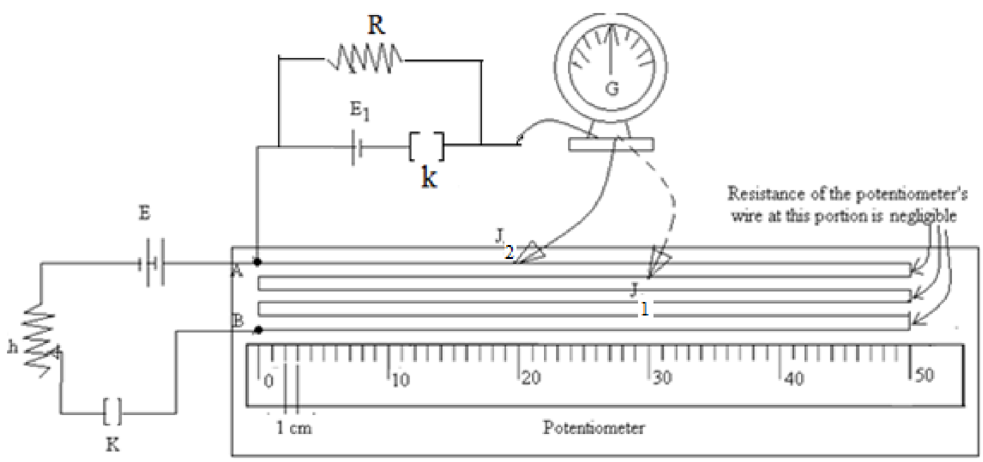

Figure 10: Figure for question (8)

Ans:

- **Draw the data table(s) and write down the variables to be measured shown below (in the 'Data' section), using pencil and ruler BEFORE you go to the lab class.**

- **Write down your NAME and ID on the top of the page.**
- **This part should be separated from your Answers of "Questions on Theory" part.**
- **Keep it with yourself after coming to the lab.**

Data

Table: Data for calculating the electromotive force of a cell.

No of Obs.	Circuit	Resistance R (in ohms)	Value of			Internal Resistance r of cell	Mean r In ohms
			l_1 (cm)	Mean l_1 (cm)	l_2 (cm)		
	open	infinity	……… ……… ………	………			
1.	Closed				….	……	
2	Closed				….	……	
3.	Closed				….	……	
4.	Closed				…..	……	
5.	Closed				…..	…..	

- **READ the PROCEDURE carefully and perform the experiment by YOURSELVES. If you need help to understand any specific point draw attention of the instructors.**
- **DO NOT PLAGIARIZE data from other group and/or DO NOT hand in your data to other group. It will bring ZERO in this experiment. Repetition of such activities will bring zero for the whole lab.**
- **Perform calculations by following the PROCEDURE . Show every step in the Calculations section.**
- **Write down the final result(s)**

Calculations

Results

- **TAKE printout of the ‘Questions for Discussions’ BEFORE you go to the lab class. Keep this printout with you during the experiment. ANSWER the questions in the specified space AFTER you have performed the experiment.**
- **Attach Data, Calculations, Results and the Answers of ‘Questions for Discussions’ parts to your previously submitted Answers of ‘Questions on Theory’ part to make the whole lab report.**
- **Finally, submit the lab report before you leave the lab.**

Name: ___________________________ ID: __________________

Questions for Discussions

1) Explain a way to determine the internal resistance of a cell by using a voltmeter and a resistance box. Show the derivation of the working formula by assuming the current passing through the voltmeter is negligible. [0.5]

   Ans:

2) We can use a voltmeter/multi-meter and a resistance box to measure the internal resistance of a cell. What might be a drawback of using a voltmeter or a multi-meter for this purpose? How can a potentiometer be useful to avoid this drawback? [1]

Ans:

3) Mention the properties of a good potentiometer for performing this experiment. [0.5]

Ans: