

EXPERIMENT 2-2

THE POTENTIOMETER

Object: To construct a slide-wire potentiometer and use it to measure voltages without drawing current from the source of emf, e.g., a dry cell and a thermocouple.

Introduction

The potentiometer is an instrument which can be used to measure the emf of a source (or the potential difference between two points in a circuit), *without drawing any current*. It is a null device, which essentially balances the unknown potential difference against an adjustable potential difference, which in turn can be calibrated in terms of a standard voltage cell.

[The "standard cell" is a saturated Weston cell, containing an electrode of mercury in contact with a paste of mercurous sulfate and an electrode of cadmium amalgam in contact with a saturated solution of cadmium sulfate. When little or no current is drawn from the cell, it produces a terminal voltage of long-term stability. The precise value for each cell is given on its label.]

The potentiometer is commonly used to measure voltages in situations where the circuit condition would be altered by the flow of current to a meter. One example is the measurement of the emf of a flashlight dry cell; such a cell has an appreciable **internal resistance**, and its terminal voltage will be lowered when current is drawn from it. Another example is the measurement of the small voltage across a **thermocouple**, used to determine temperature differences by means of the *thermal emf* produced at the junctions of dissimilar metals. In this case, the thermal emfs cannot supply sufficient current to be measurable on an ordinary meter.

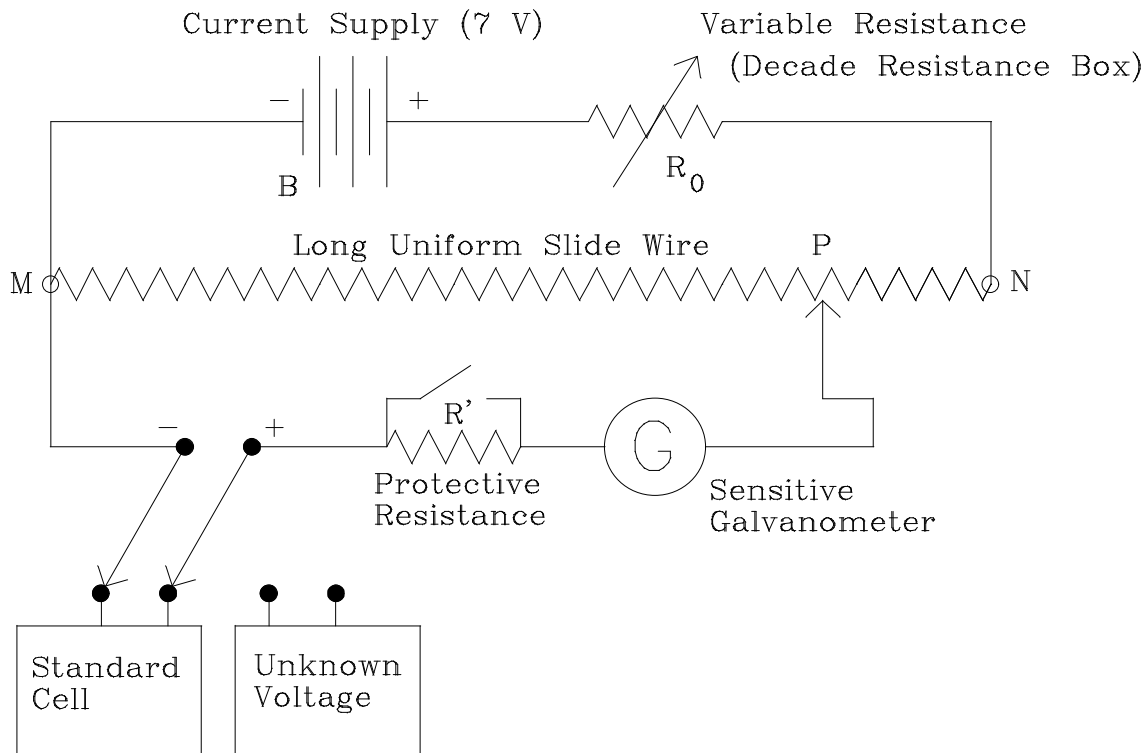


Figure 1.

A schematic diagram of the potentiometer is shown in Figure 1, where:

B is a stable current source with a constant voltage greater than any voltage to be measured.

MN is a long wire of uniform cross-section.

P is a sliding contact which varies the resistance between M and P such that it is proportional to the distance MP .

R_0 is a variable resistance, which can be adjusted to reduce the total voltage across MN .

G is a sensitive galvanometer which indicates zero current when the needle deflects neither to the left nor to the right.

R' is a protective resistance to limit the current through the galvanometer when the potentiometer is not balanced. The shorting button bypasses R' , to increase the sensitivity in determining a null current only *after* an approximate balance is obtained.

Standard Cell

The normal method of using a potentiometer is first to calibrate it with the standard cell voltage V_S . The movable contact P is adjusted to a position P_S at which the galvanometer reads zero, (first with the shorting button open, and then, more precisely, with the shorting button depressed). At this setting, the difference in potential between M and P is equal to the known value of V_S .

Unknown Voltage

Next, the standard cell is replaced by the source of unknown voltage V_X , and the procedure is repeated to find a point P_X where the galvanometer reads zero. The value of V_X can then be determined from the ratio of the two distances along the slide wire (MP_X and MP_S) along with the known value of V_S .

Internal Resistance of a Dry Cell

A dry cell can be considered as the equivalent of a source of chemical emf \mathcal{E} in series with an **internal resistance** r . When a current I is drawn from the cell, the voltage across the terminals of the cell will be $\mathcal{E} - Ir$. The maximum current that can be drawn from such a cell is thus \mathcal{E} / r . (As a dry cell is used up, the value of \mathcal{E} remains relatively constant, but the value of r rises appreciably.)

The Thermocouple

If two dissimilar metals, such as copper and iron, are joined together, as in Figure 2, and if the two junctions are at different temperatures, a **thermal emf** will be generated. This effect is utilized in making a **thermocouple**, an instrument for the accurate and rapid measurement of temperatures.

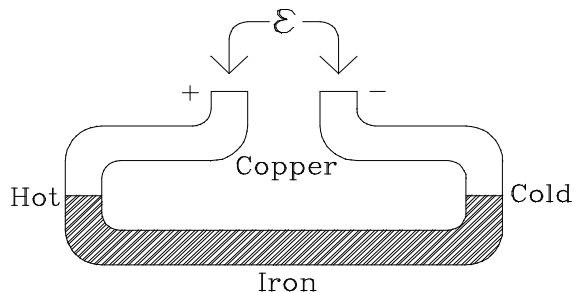


Figure 2.

Figure 3 shows a convenient laboratory thermocouple made of two twisted junctions of copper and constantin (a copper-nickel alloy) wires. If one junction is kept in a mixture of ice and water, (i.e., at 0°C), the temperature of the other junction can be determined by measuring V_X . The junctions have very little heat capacity and will reach thermal equilibrium very quickly. Note that the thermal emf is very much smaller than the emf of a dry cell (in millivolts, as opposed to volts.)

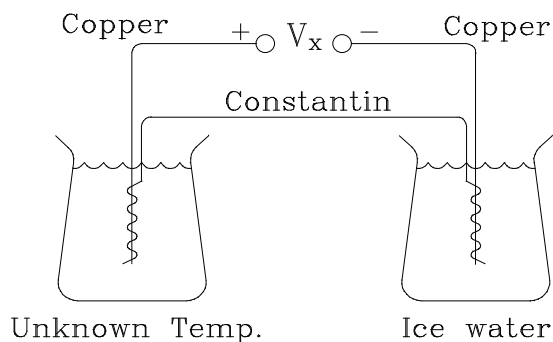


Figure 3.

Procedure

1) *Measure the emfs (\mathbf{e}) of two dry cells, first singly and then for the two cells in series:* Before each measurement, first adjust R_0 , (a decade resistance box), so that the voltage across MN is larger than the value of V_x to be measured, and then use the standard cell to calibrate the potentiometer for this setting.

CAUTION: Never use a standard cell to supply *current* to a circuit; it is to be used only as a reference *voltage* when negligible current is drawn. Since drawing a large current would damage the cell, a large protective resistor has been built into the cell holder.

2) *Measure r , the Internal Resistance of a dry cell:*

One way to determine r would be to connect the cell to an external load, such as a light bulb, and measure both the voltage V across the terminals of the cell and the current I which it is delivering to the load. Then the difference between \mathbf{e} , (measured in part 1), and V would be Ir .

However, you can alternatively determine r without measuring I . To do this, connect a calibrated variable resistance R (another decade box), as the load across the terminals to the dry cell, as shown in Figure 4. When R is adjusted so that V equals exactly half of the emf of the cell, i.e., $\mathbf{e} / 2$, then the value of R is just equal to r . This is so because, with the potentiometer balanced, the only current which flows in the external circuit is the current I around the loop $abcd$. Thus we have:

$$\left. \begin{array}{l} \mathbf{e} = IR + Ir \\ V = IR = \mathbf{e}/2 \end{array} \right\} \quad \begin{array}{l} 2IR = IR + Ir \\ \therefore R = r \end{array}$$

To utilize this method, the best procedure is first to set MP to half of the value it had for the measurement of \mathbf{e} before R was connected, that is, set the potentiometer to measure $\mathbf{e} / 2$. Then adjust R until the potentiometer is balanced at this setting.

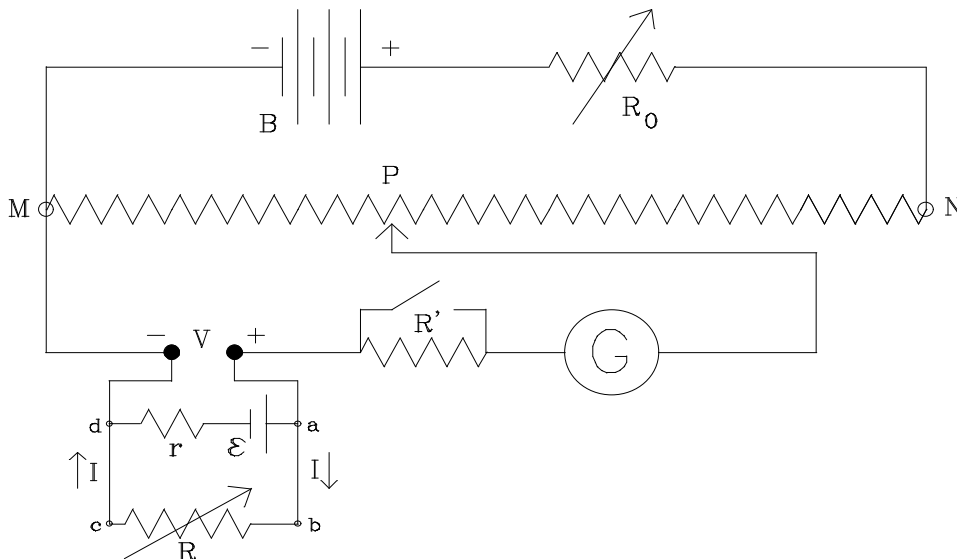


Figure 4.

3) *Use the thermocouple with the potentiometer to make a calibrated thermometer:*

Since the thermocouple output is in millivolts rather than in volts, a much larger value of R_0 is necessary to reduce the current and thus the voltage across MN . Therefore, replace the decade resistance box with a (variable) 100 kohm resistor. You can then set up a direct-reading thermometer by:

- a) placing one junction in ice water (0°C) and the other junction in boiling water (100°C),
- b) placing the contact P at the extreme (100) position on the slide wire,
- c) adjusting the variable resistor R_0 until the potentiometer is balanced. Note that the unbalanced potentiometer will now produce much less deflection of the meter, so more care will have to be taken to find a balance.

(Be sure *NOT* to connect the standard cell into the circuit while the large value of R_0 is being used.)

Check the linearity of the direct-reading thermometer that you have set up by removing the hot junction from the boiling water and using it to measure some intermediate temperatures such as room temperature and body temperature, which you can monitor with an ordinary centigrade thermometer.