Electrical measuring instruments

P5

OBJECTIVES

- uses ammeter to measure an electric current.
- uses voltmeter to measure a voltage difference.
- uses multimeter to measure current, voltage difference and resistance.
- explains the importance of ideal ammeter and ideal voltmeter.
- derives relationship among resistances of a balanced Wheatstone bridge.
- uses Wheatstone bridge relationship to find equivalent resistance of simple networks.
- uses meter bridge accurately to find the temperature coefficient of resistance.

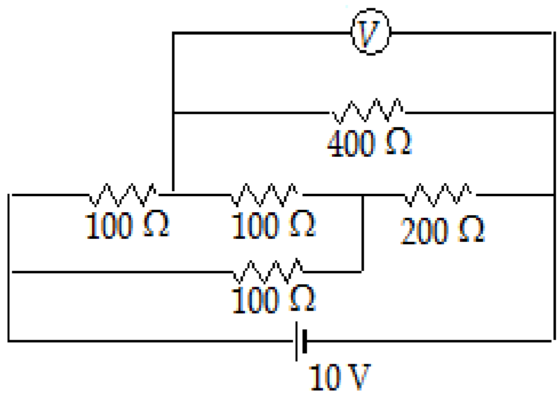
- explains the facts to be considered in using the metre bridge.
- carries out numerical calculations to solve problems using the

Wheatstone bridge

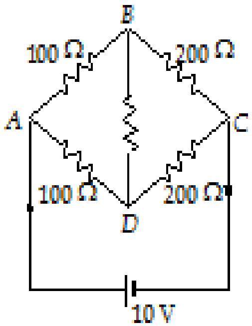
- explains the facts to be considered in using the potentiometer.
- describes the principle of the potentiometer.
- Uses the potentiometer to compare electromotive forces.
- Uses the potentiometer to determine internal resistance of a cell.
- compares advantages and disadvantage of using the potentiometer.
- solves problems related to the potentiometer.

Recap last presentation

An electrical circuit is shown in the figure. Calculate the potential difference across the resistor of 400 ohm, as will be measured by the voltmeter of resistance 400 ohm, either by applying Kirchhoff's rules or otherwise.



Solution:



The equivalent resistance of the voltmeter and the 400Ω resistor in parallel is 200 Ω. The circuit is a balanced Wheatstone bridge.
No current will flow through the 100 Ω resistor connected between *B* and *D*.

Galvanometer

A galvanometer detects the presence of current in the branch where it is connected.
It is the ***basic instrument*** used in making various meters, such

(*i*) *ammeter* (measures current)
(*ii*) *voltmeter* (measures voltage or potential difference)
(*iii*) *ohmeters* (measures resistance)
(*iv*) *powermeter* (measures power)

A galvanometer can detect a current as low as 10^{-9} A.

(i) In DC circuits, usually *moving coil type* galvanometers are used. Its deflection is directly proportional to the current that passes through it, or

$$I \propto \theta \qquad \text{or} \qquad I = K\theta$$

where *K* is called *galvanometer constant*.

(ii) The deflection per unit current is called ***current sensitivity*** of the galvanometer,

$$CS = \frac{\theta}{I} = \frac{1}{K}$$

Shunting a galvanometer decreases its sensitivity. (When a small resistance is connected in parallel with a large resistance, we say that the large resistance is *shunted*).

(iii) The total resistance of the galvanometer between its two terminals is called *galvanometer resistance* and is represented by *G*.

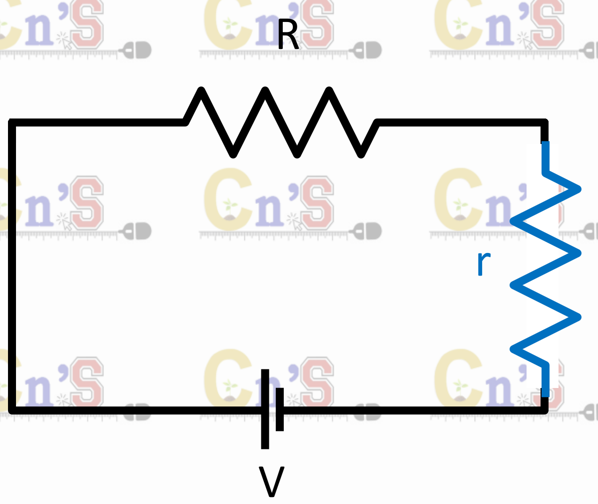
(iv) The current required for full-scale deflection in a galvanometer is called *full-scale deflection current* and is represented by I_g.

Effect of ammeter on circuit

Measuring current in a simple circuit:

- connect ammeter in series

Are we measuring the correct current?



- any ammeter has **some resistance r.**

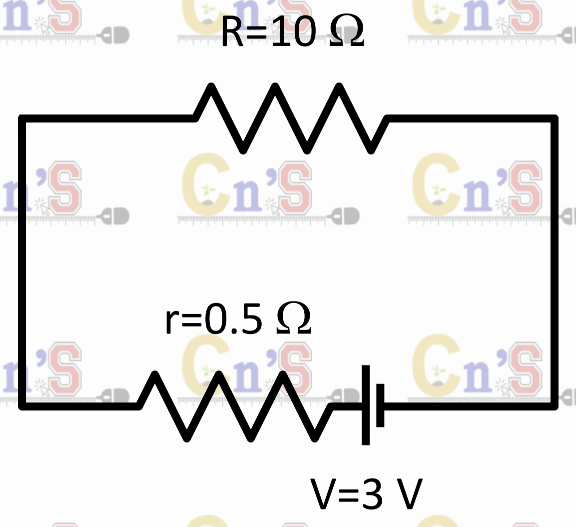
- current in presence of ammeter is $I = \dfrac{V}{R+r}$.

- current without the ammeter would be $I = \dfrac{V}{R}$.

To minimize error, ammeter resistance r must be very small.
(ideal ammeter would have zero resistance)

Example: an ammeter of resistance 10 mΩ is used to measure the current through a 10 Ω resistor in series with a 3 V battery that has an internal resistance of 0.5 Ω. What is the relative (percent) error caused by the ammeter?

Actual current **without** ammeter:



$$I = \frac{V}{R+r}$$

$$I = \frac{3}{10+0.5}\,A$$

$$I = 0.2857\ A = 285.7\ mA$$

You might see the symbol ε used instead of V.

Current with ammeter:

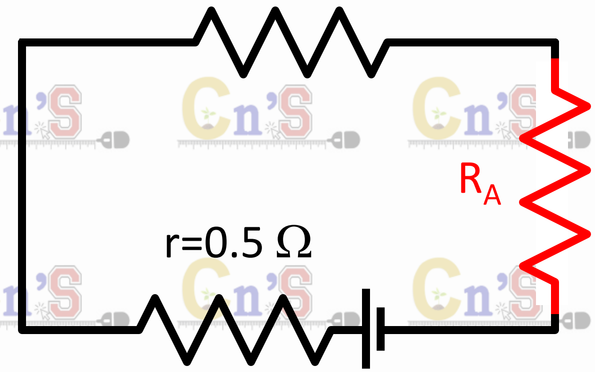
$$I = \frac{V}{R + r + R_A}$$

$$I = \frac{3}{10 + 0.5 + 0.01} A$$

$$I = 0.2854 \text{ A} = 285.4 \text{ mA}$$

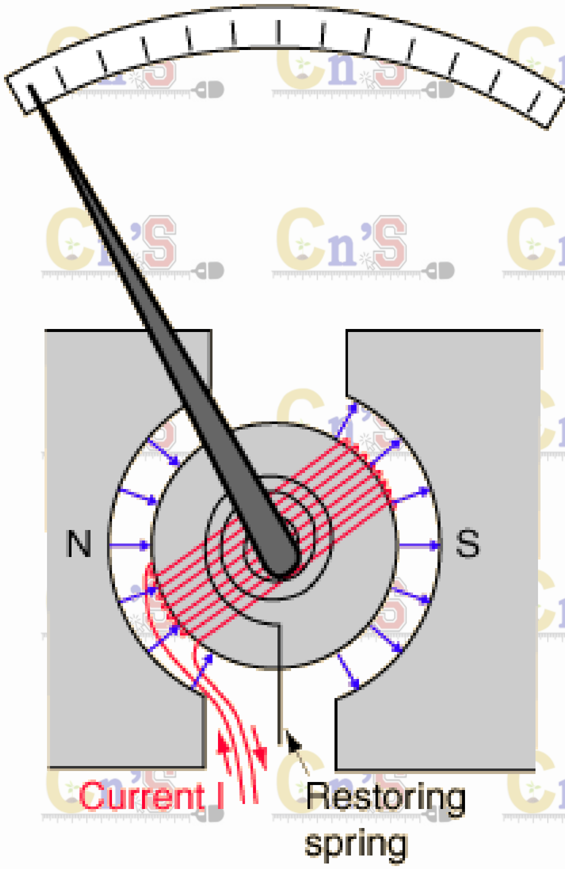
$$\% \text{ Error} = \frac{0.2857 - 0.2854}{0.2857} \times 100$$

$$\% \text{ Error} = 0.1 \%$$



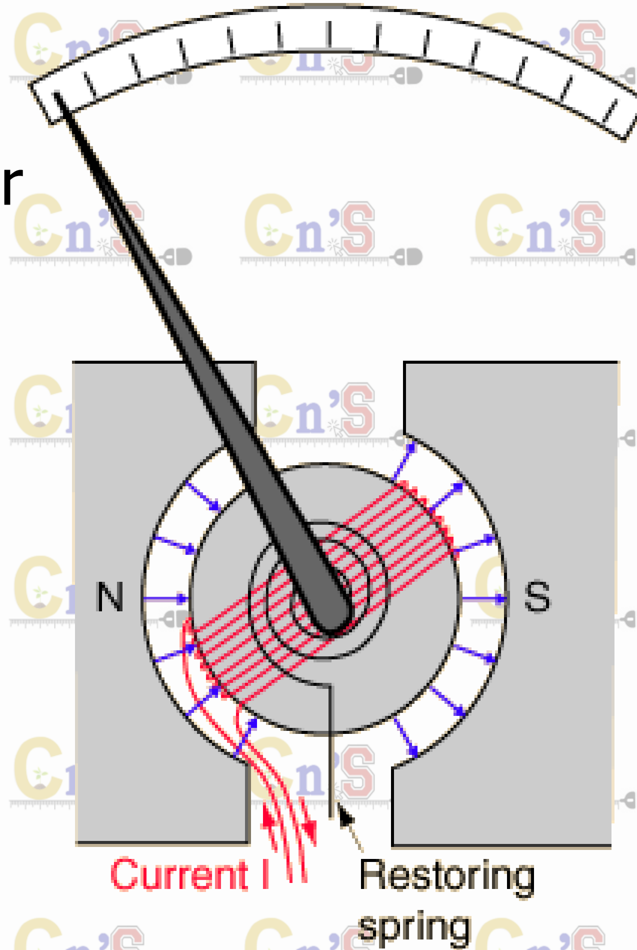
Galvanometer:

- current flows through a coil in a magnetic field
- coil experiences a torque, connected needle deflects



Ammeter can be based on galvanometer

Needle deflection is proportional to current. Each galvanometer has a certain maximum current corresponding to full needle deflection.



An ammeter is an instrument which reads the current passing through it. The ammeter must be inserted into the branch so that the current to be measured passes through it. That is, *an ammeter is connected in series* with the element through which current is to measured.

(i) The reading of an ammeter is always lesser than the actual current in the circuit. If V is the potential difference across a resistance R, the true current is $I = (V/R)$. However, when an ammeter of resistance r is used to measure it, the reading will be

$$I' = \frac{V}{(R+r)}$$

which is less than the true current I.

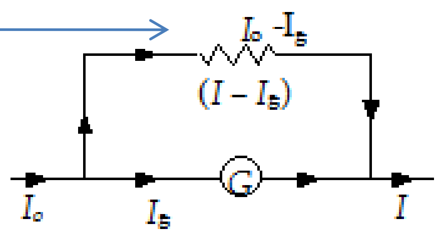
(ii) Smaller the resistance of an ammeter, the more accurate will be its reading. An ammeter is said to be **ideal** if its resistance (r) is zero. However, ideal ammeter cannot be realized in practice.

What if you need to measure a larger current?

Conversion of a Galvanometer into an Ammeter

To convert a galvanometer into an ammeter of a certain ***range***, say I_o, a small resistance S (called ***shunt***) is connected in parallel with the galvanometer. The range means the upper limit of the quantity which can be measured by the instrument. The value of S is chosen such that the current passing through the galvanometer of resistance G becomes equal to its full-scale deflection value I_g. Thus, equating the potential difference across two parallel branches, we have

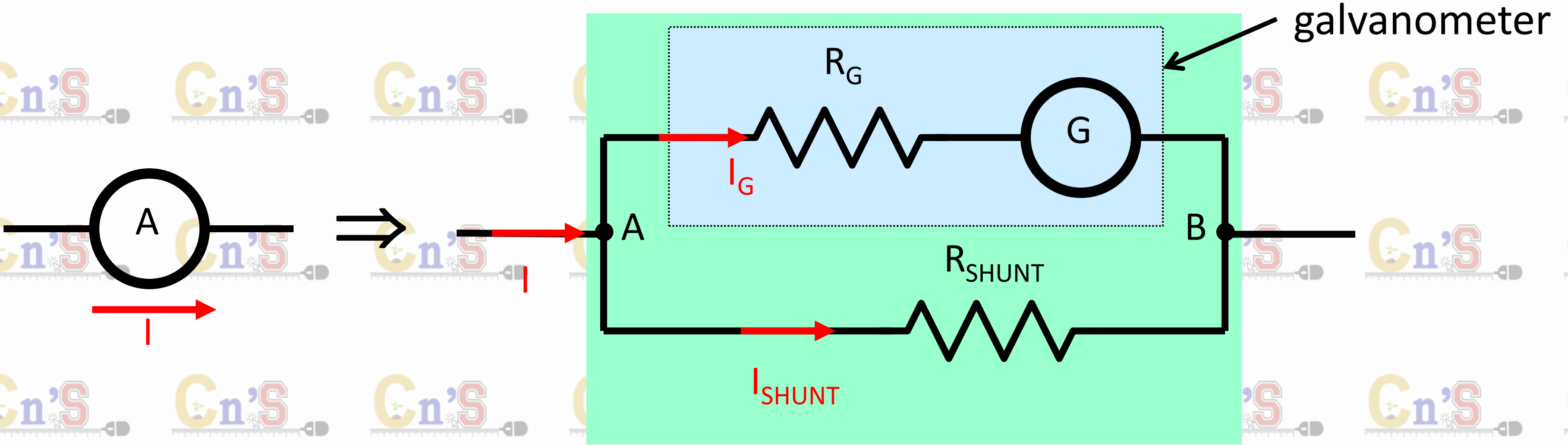
shunt resistor



$$I_g G = (I_o - I_g)\, S$$

or $$S = \frac{I_g}{(I_o - I_g)} G$$

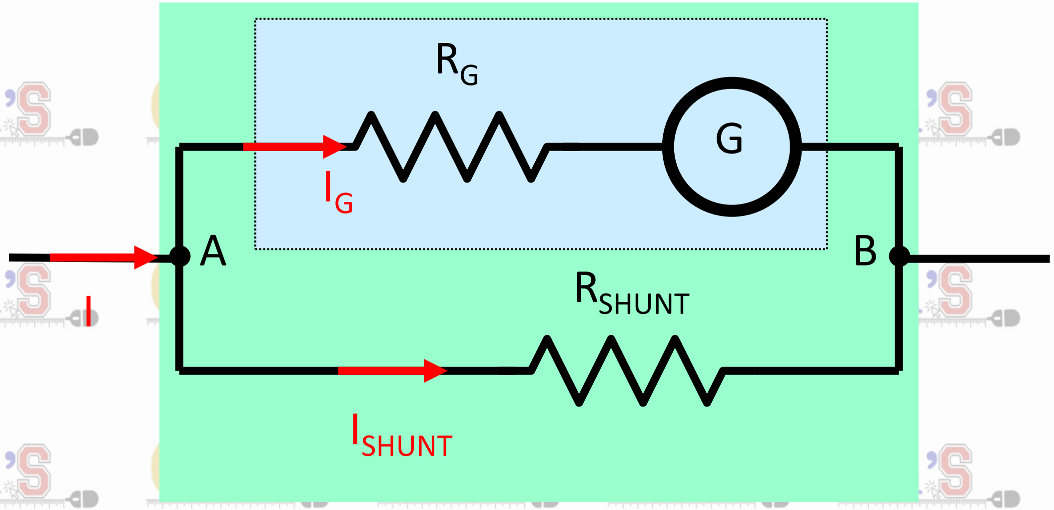
Ammeter uses a galvanometer and a shunt, connected in parallel:



Everything inside the green box is the ammeter.

- Current I gets split into I_{shunt} and I_G

If your galvanometer reads 1A full scale but you want the ammeter to read 5A full scale, then R_{SHUNT} must result in I_G=1A when I=5A. What are I_{SHUNT} and V_{SHUNT}?



Shunt also reduces resistance of the ammeter:

$$\frac{1}{R_A} = \frac{1}{R_G} + \frac{1}{R_{SHUNT}}$$

$$R_A = \frac{R_G R_{SHUNT}}{R_G + R_{SHUNT}}$$

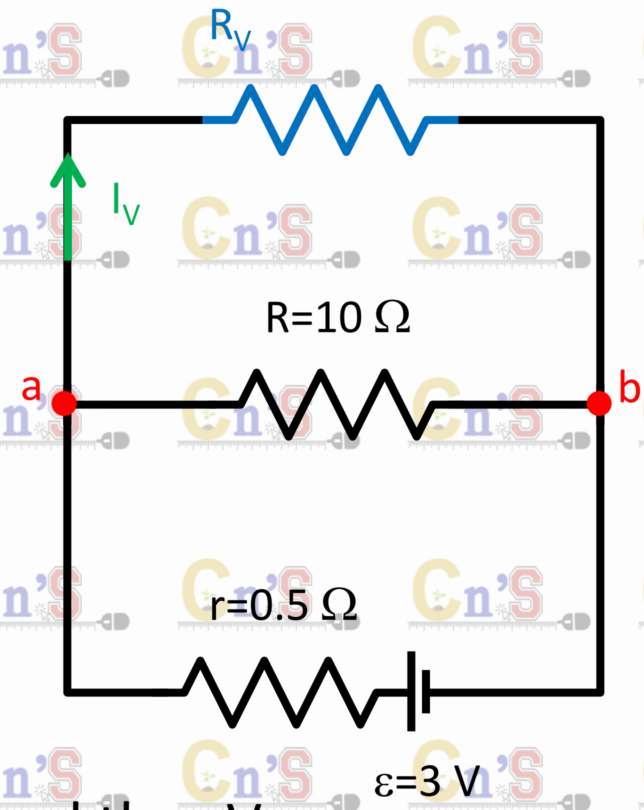
Effect of voltmeter on circuit

Measuring voltage (potential difference) V_{ab} in a simple circuit:

- connect voltmeter in parallel

Are we measuring the correct voltage?

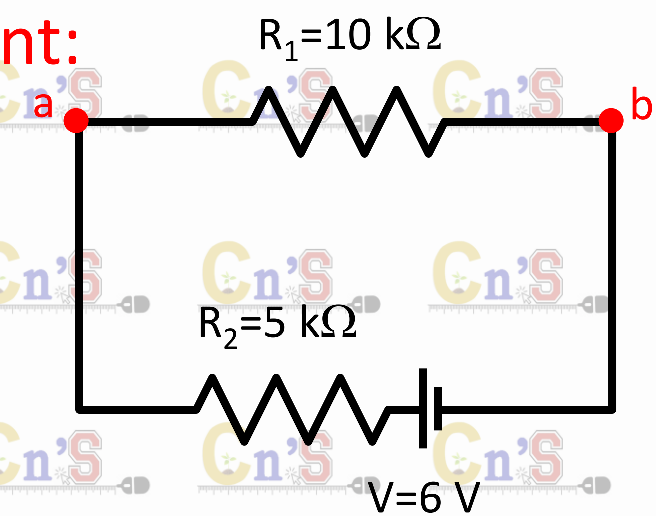
- voltmeter has **some resistance R_V**
- **current** I_V flows through voltmeter
- extra current changes voltage drop across r and thus V_{ab}



To minimize error, voltmeter resistance r must be very large.
(ideal voltmeter would have infinite resistance)

Example: a galvanometer of resistance 60 Ω is used to measure the voltage drop across a 10 kΩ resistor in series with an ideal 6 V battery and a 5 kΩ resistor. What is the relative error caused by the nonzero resistance of the galvanometer?

Actual voltage drop without instrument:



$$R_{eq} = R_1 + R_2 = 15\times10^{3}\ \Omega$$

$$I = \frac{V}{R_{eq}} = \frac{6\ \text{V}}{15\times10^{3}\ \Omega} = 0.4\times10^{-3}\ \text{A}$$

$$V_{ab} = IR = \left(0.4\times10^{-3}\right)\left(10\times10^{3}\ \Omega\right) = 4\ \text{V}$$

The measurement is made with the galvanometer.

60 Ω and 10 kΩ resistors in parallel are equivalent to 59.6 Ω resistor.

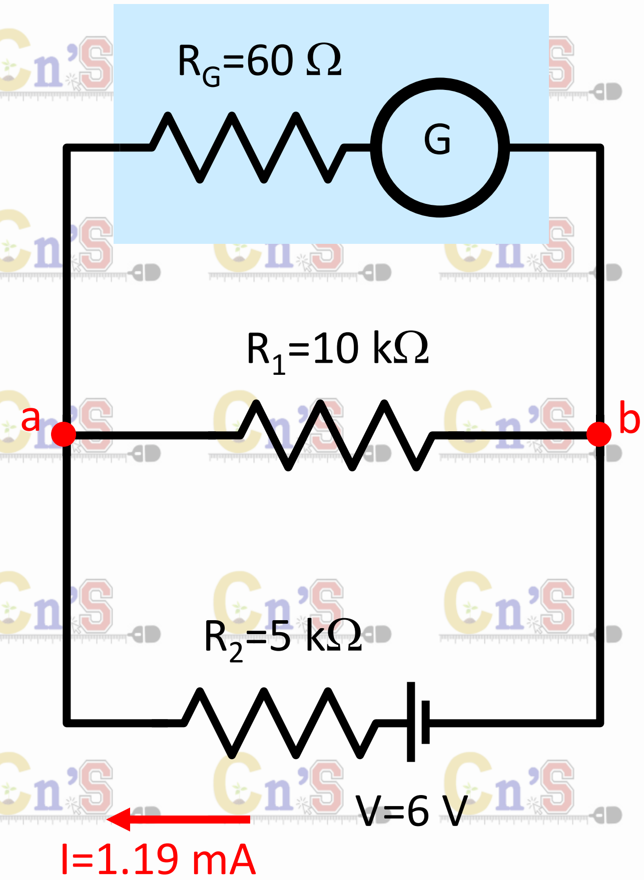
Total equivalent resistance: 5059.6 Ω

Total current: $I=1.186\times10^{-3}$ A

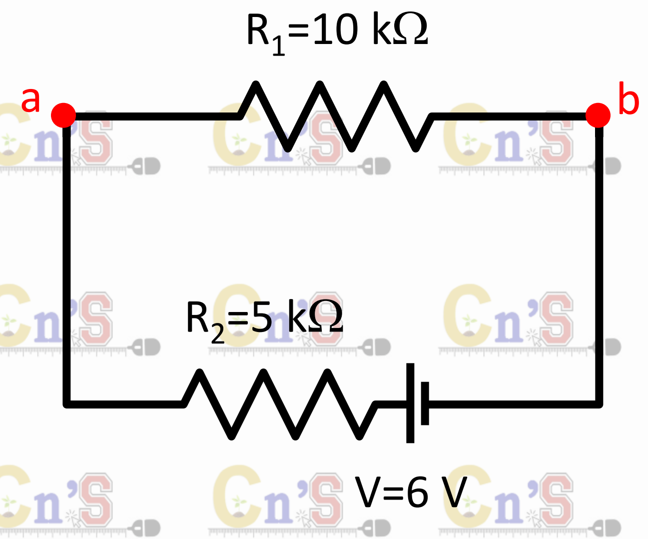
$V_{ab} = 6V - IR_2 = 0.07$ V.

The relative error is:

$$\%\,\text{Error} = \frac{4-.07}{4}\times 100 = 98\%$$



Example: a voltmeter of resistance 100 kΩ is used to measure the voltage drop across a 10 kΩ resistor in series with an ideal 6 V battery and a 5 kΩ resistor. What is the percent error caused by the nonzero resistance of the voltmeter?



We already calculated the actual voltage drop.

$$V_{ab} = IR = \left(0.4\times10^{-3}\right)\left(10\times10^{3}\ \Omega\right) = 4\ \text{V}$$

The measurement is now made with the "better" voltmeter.

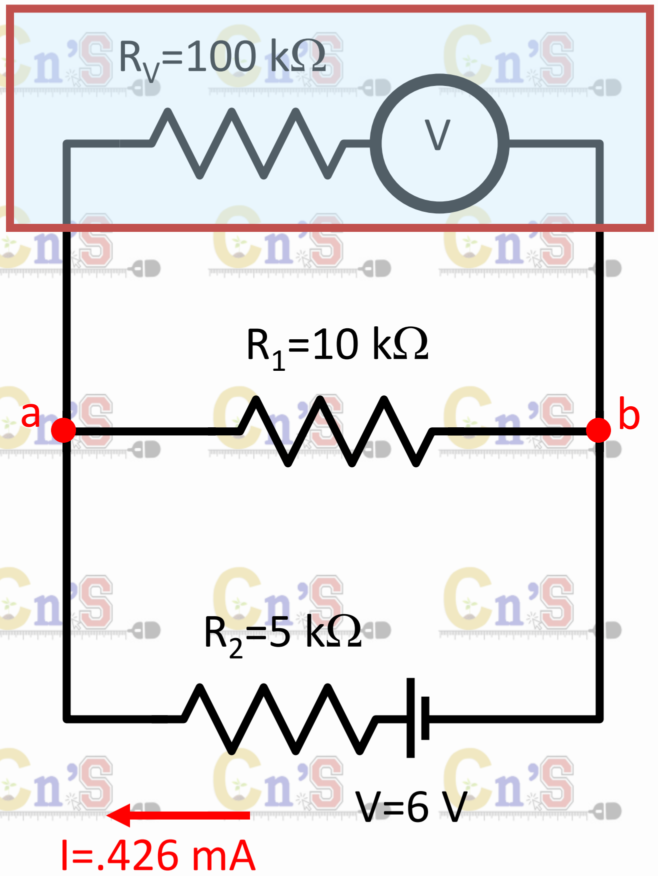
100 kΩ and 10 kΩ resistors in parallel are equivalent to an 9090 Ω resistor.
Total equivalent resistance: 14090 Ω

Total current: $I=4.26\times10^{-4}$ A

The voltage drop from a to b:
$6-(4.26\times10^{-4})(5000)=3.87$ V.

The percent error is.

$$\%\,\text{Error} = \frac{4-3.87}{4}\times 100 = 3.25\%$$

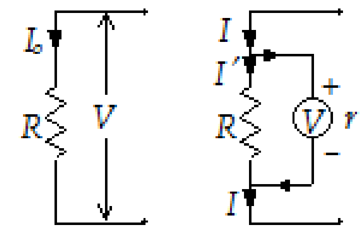


A voltmeter is an instrument which reads the potential difference across its terminals. To measure the potential difference between any two points *A* and *B* in the circuit, the voltmeter terminals are connected to *A* and *B* without breaking the circuit.

(i) The reading of a voltmeter is always lesser than the true value. If a current I_o is passing through a resistance *R*, the true value $V = I_oR$. However, when a voltmeter having resistance *r* is connected across *R*, the current through *R* will become

$$I' = \frac{r}{(R+r)} I_o$$

and so $V' = I'R = \frac{V}{[1+(R/r)]}$



When the voltmeter is connected across *R*, its reading will also be *V*¢ which is less than V.

(ii) Greater the resistance of voltmeter, the more accurate will be its reading. A voltmeter is said to be **ideal** if its resistance *r* is infinite.

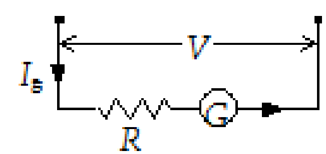
An ideal voltmeter draws no current from the circuit element for its operation.

Conversion of a Galvanometer into a Voltmeter

To convert a galvanometer into a voltmeter of certain range, say *V*, a high resistance *R* is connected in series with the galvanometer. The value of *R* is chosen such that the current passing through the galvanometer of resistance *G* becomes equal to its full-scale deflection value I_g. Thus, we should have

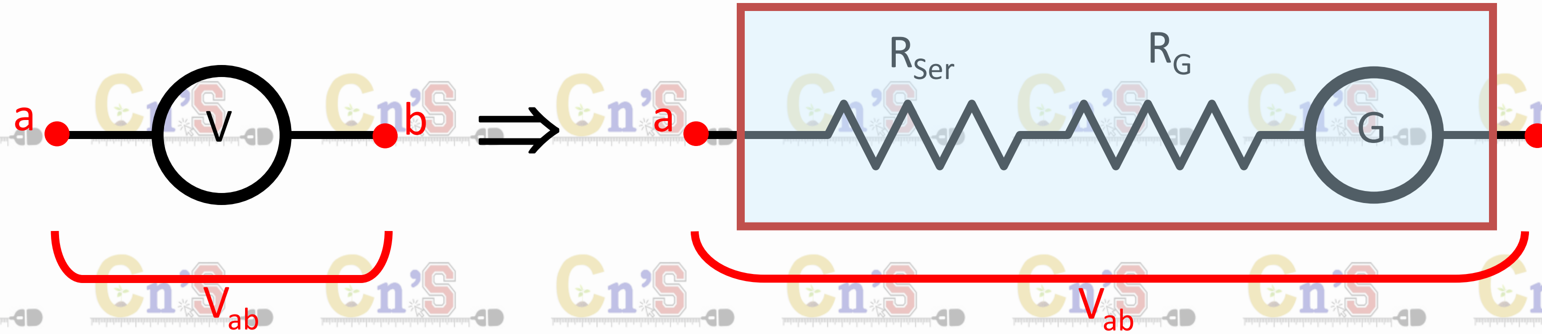
$$V = I_g(G + R)$$

or $R = \frac{V}{I_g} - G$



Designing a voltmeter

- voltmeter must have a very large resistance
- voltmeter can be made from galvanometer in series with a large resistance

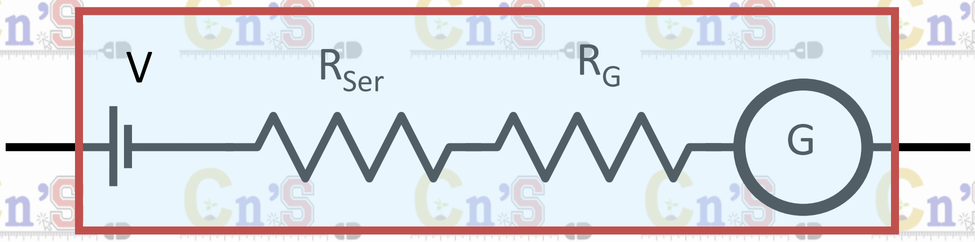


Everything inside the blue box is the voltmeter.

Homework hints: "the galvanometer reads 1A full scale" would mean a current of I_G=1A would produce a full-scale deflection of the galvanometer needle. If you want the voltmeter shown to read 10V full scale, then the selected R_{Ser} must result in I_G=1A when V_{ab}=10V.

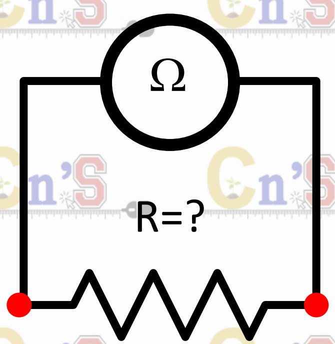
Measuring Instruments: Ohmmeter

- Ohmmeter measures resistance of isolated resistor
- Ohmmeter can be made from a galvanometer, a series resistance, and a battery (active device).



Everything inside the blue box is the ohmmeter.

- Terminals of ohmmeter are connected to unknown resistor
- battery causes current to flow and galvanometer to deflect
- $V = I\,(R_{ser} + R_G + R)$ solve for unknown R



A battery of emf 1.4 V and internal resistance 2 Ω is connected to a resistor of 100 Ω. In order to measure the current through the resistance and the potential difference across its ends, an ammeter is connected in series with it and a voltmeter is connected across its ends. The resistance of the ammeter is 4/3 Ω and that of the voltmeter is 200 Ω. What are the readings of the two instruments ? What would be their reading if they were ideal instruments ?

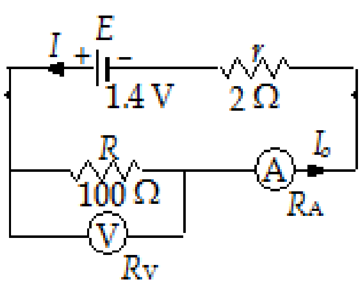
Solution:

Let R_A and R_V be the resistances of the ammeter and voltmeter respectively. Then the total resistance across the emf E is

$$R_{eq} = \frac{RR_V}{R+R_V} + R_A + r = \frac{100\times200}{100+200} + \frac{4}{3} + 2$$
$$= \frac{210}{3}\Omega$$

Therefore, the current

$$I_o = \frac{E}{R_{eq}} = \frac{1.4}{(210/3)} = 0.02A$$



This is the current through ammeter. Hence, the reading of ammeter is **0.02 A.**

Reading of voltmeter = pd across its terminals

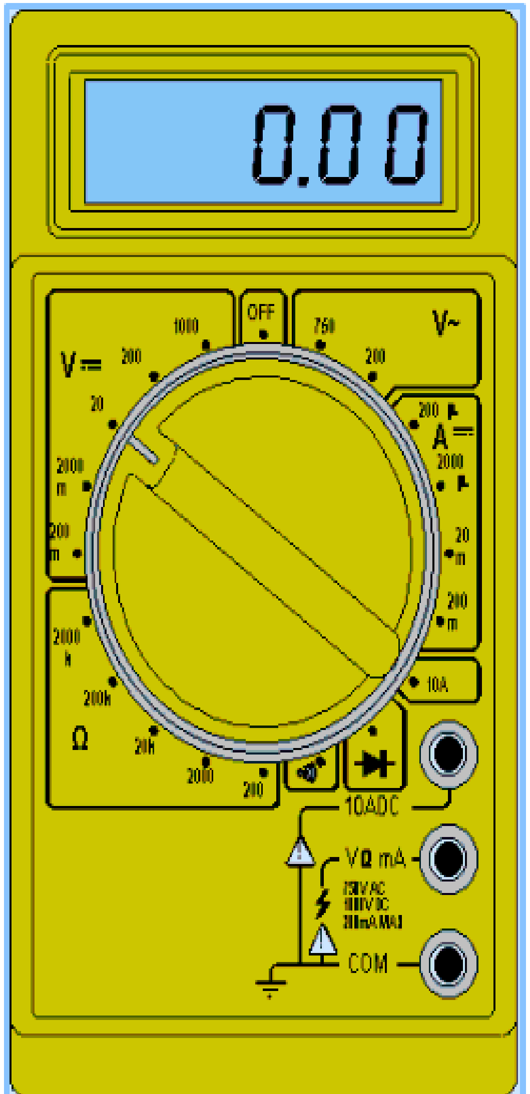
$$= I_o\left(\frac{RR_V}{R+R_V}\right) = 0.02\left(\frac{100\times200}{100+200}\right) = 1.33V$$

If the ammeter and the voltmeter were ***ideal***, $R_A = 0$ and $R_V = \infty$. Then,

The reading of ammeter $= \frac{E}{r+R} = \frac{1.4}{2+100} = 0.0137A$

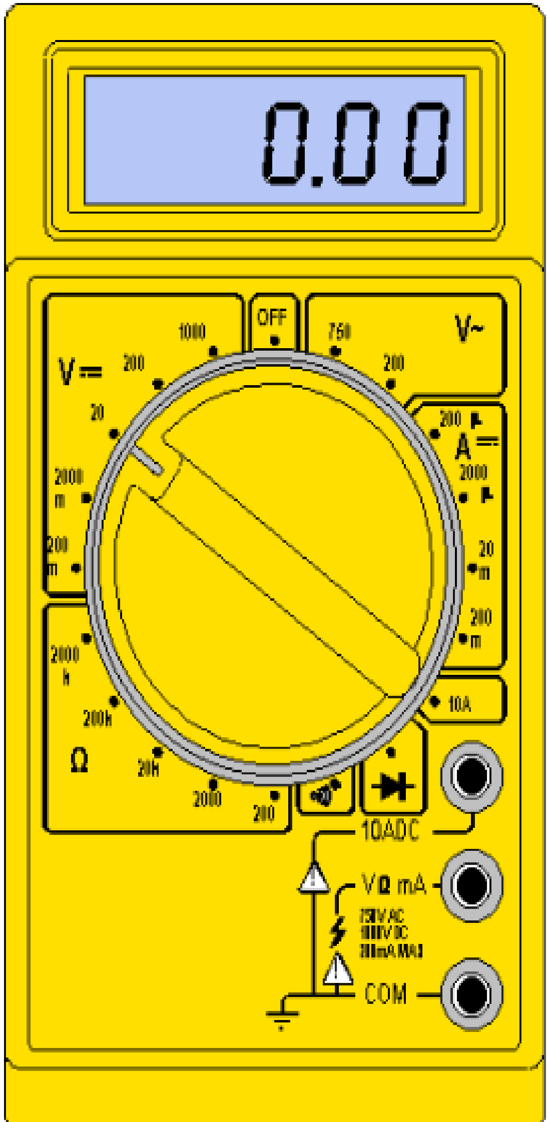
The reading of voltmeter $= I_oR = \frac{1.4}{102} \times 100 = 1.37V$

Digital Multimeter 1



- DMM is a measuring instrument
- An **ammeter** measures current
- A **voltmeter** measures the potential difference (voltage) between two points
- An **ohmmeter** measures resistance
- A **multimeter** combines these functions, and possibly some additional ones as well, into a single instrument

Digital Multimeter 2



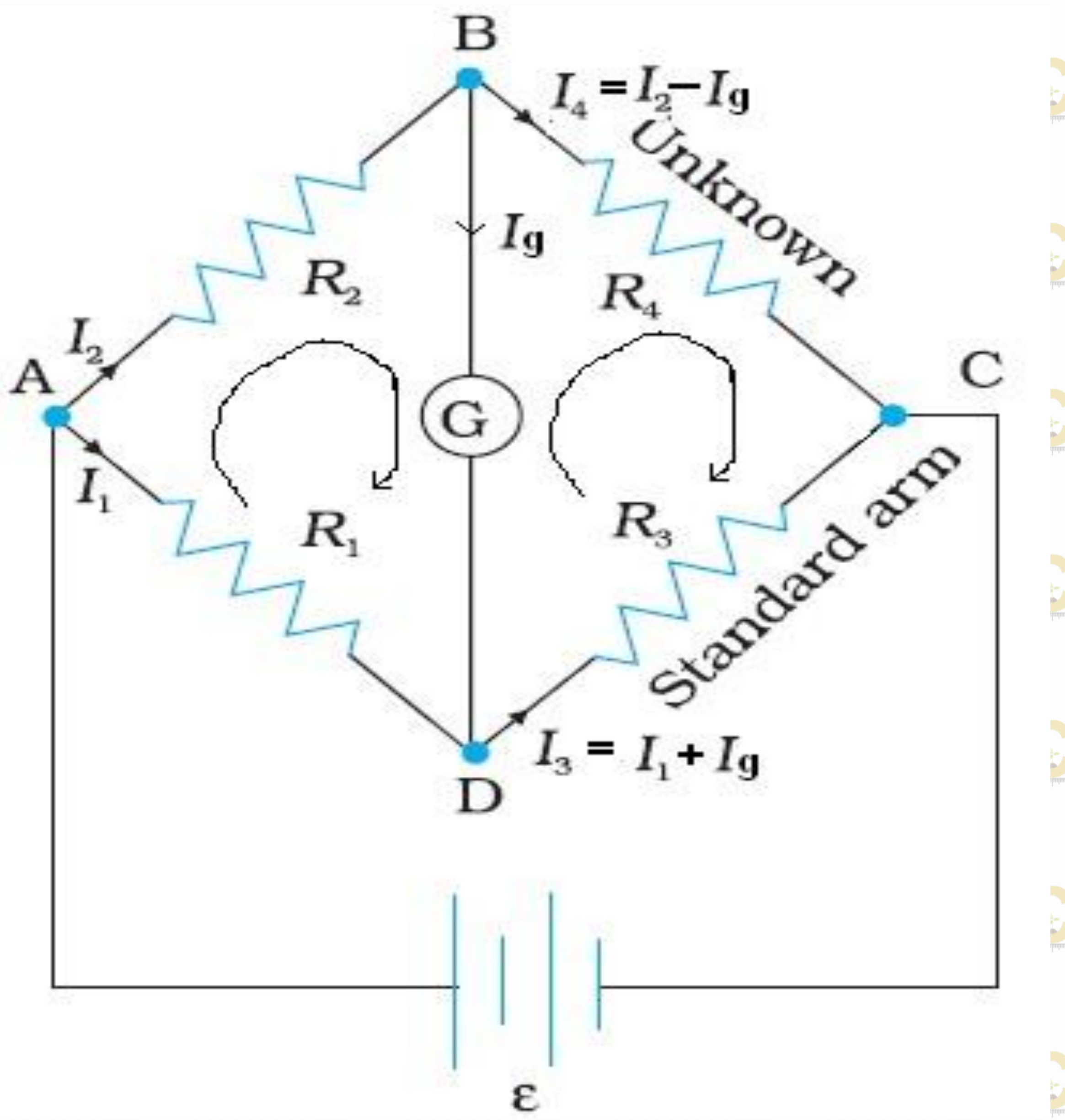
- Voltmeter
  - Parallel connection
- Ammeter
  - Series connection
- Ohmmeter
  - Without any power supplied
- Adjust range (start from highest limit if you don’t know)

Wheatstone Bridge

Wheatstone Bridge is the combination of four resistances, arranged in the form of mesh, used to find out unknown resistance.

- Wheatstone bridge is based on the application of Kirchhoff's rules.
- The bridge has four resistors R1, R2, R3 and R4. Across one pair of diagonally opposite points, 'A' and 'C' a source is connected. (battery arm.)
- Between the other two vertices, 'B' and 'D', a galvanometer of resistance 'G' is connected. (Galvanometer arm.)

Let Ig be the current in the Galvanometer.



Apply Kirchhoff's loop rule to closed loop ADBA

$$I_2R_2 + I_gG - I_1R_1 = 0 \longrightarrow \quad (1)$$

Apply Kirchhoff's loop rule to closed loop CBDC

$$(I_2 - I_g)\,R_4 - (I_1 + I_g)R_3 - I_gG = 0 \longrightarrow \quad (2)$$

The bridge is said to be balanced, when the galvanometer show zero deflection. (i.e. $I_g = 0$, current through the galvanometer is zero.)

∴ the equation (1) and (2) becomes

$$I_2R_2 - 0 \times G - I_1R_1 = 0$$

$$I_2R_2 - I_1R_1 = 0$$

$$I_2R_2 = I_1R_1 \quad (3)$$

$$(I_2 - 0)\,R_4 - (I_1 + 0)R_3 - 0 \times G = 0$$

$$I_2\,R_4 - I_1\,R_3 = 0$$

$$I_2\,R_4 = I_1\,R_3 \quad (4)$$

(3) / (4) gives,

$$\frac{\cancel{I_2}R_2}{\cancel{I_2}R_4} = \frac{\cancel{I_1}R_1}{\cancel{I_1}R_3}$$

$$\frac{R_2}{R_4} = \frac{R_1}{R_3}$$

$$\boxed{\frac{R_2}{R_1} = \frac{R_4}{R_3}}$$

EXTRA Consider four resistances R_1, R_2, R_3, R_4 connected in such a way so as to form a mesh ABCDA. A battery of emf is connected between points A and C. A sensitive galvanometer of resistance R_g is connected between points B and D.

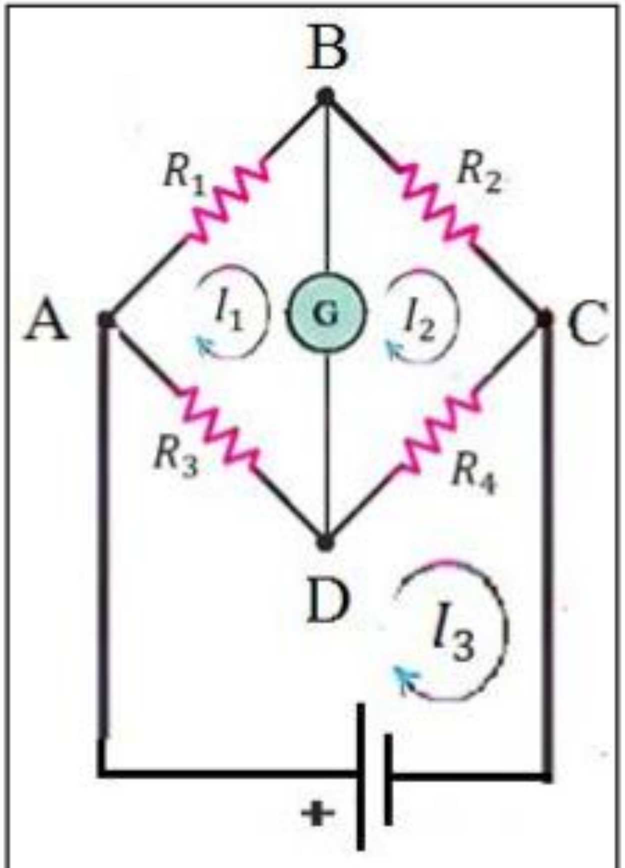
Let the current I_1, I_2, I_3 flows through the loops ABDA, BCDB, ADCA respectively.

The Kirchhoff's 2nd Rule as applied to loop ABDA gives:

$$-I_1R_1 - (I_1 - I_2)R_g - (I_1 - I_3)R_3 = 0 \quad \text{---------} \quad (1)$$

Similarly by applying the Kirchhoff's 2nd Rule to the loop BCDB, we have:

$$-I_2R_2 - (I_2 - I_3)R_4 - (I_2 - I_1)R_g = 0 \quad \text{---------} \quad (2)$$



The current through the galvanometer will be zero if $I_1 - I_2 = 0$ or $I_1 = I_2$. With this condition, the equation (1) and (2) reduces to:

$$-I_1R_1 = (I_1 - I_3)R_3 \quad \text{---------} \quad (3)$$

$$-I_1R_2 = (I_1 - I_3)R_4 \quad \text{---------} \quad (4)$$

Dividing equation (3) and (4), we get:

$$\frac{-I_1R_1}{-I_1R_2} = \frac{(I_1 - I_3)R_3}{(I_1 - I_3)R_4}$$

$$\Rightarrow \frac{R_1}{R_2} = \frac{R_3}{R_4} \quad \text{---------} \quad (5)$$

If we connect three resistance R_1, R_2, R_3 of known adjustable values and unknown resistance R_4 in such a way that no current pass through galvanometer, then the unknown resistance can be find out easily by equation (5).

When is a Wheatstone's bridge most sensitive?

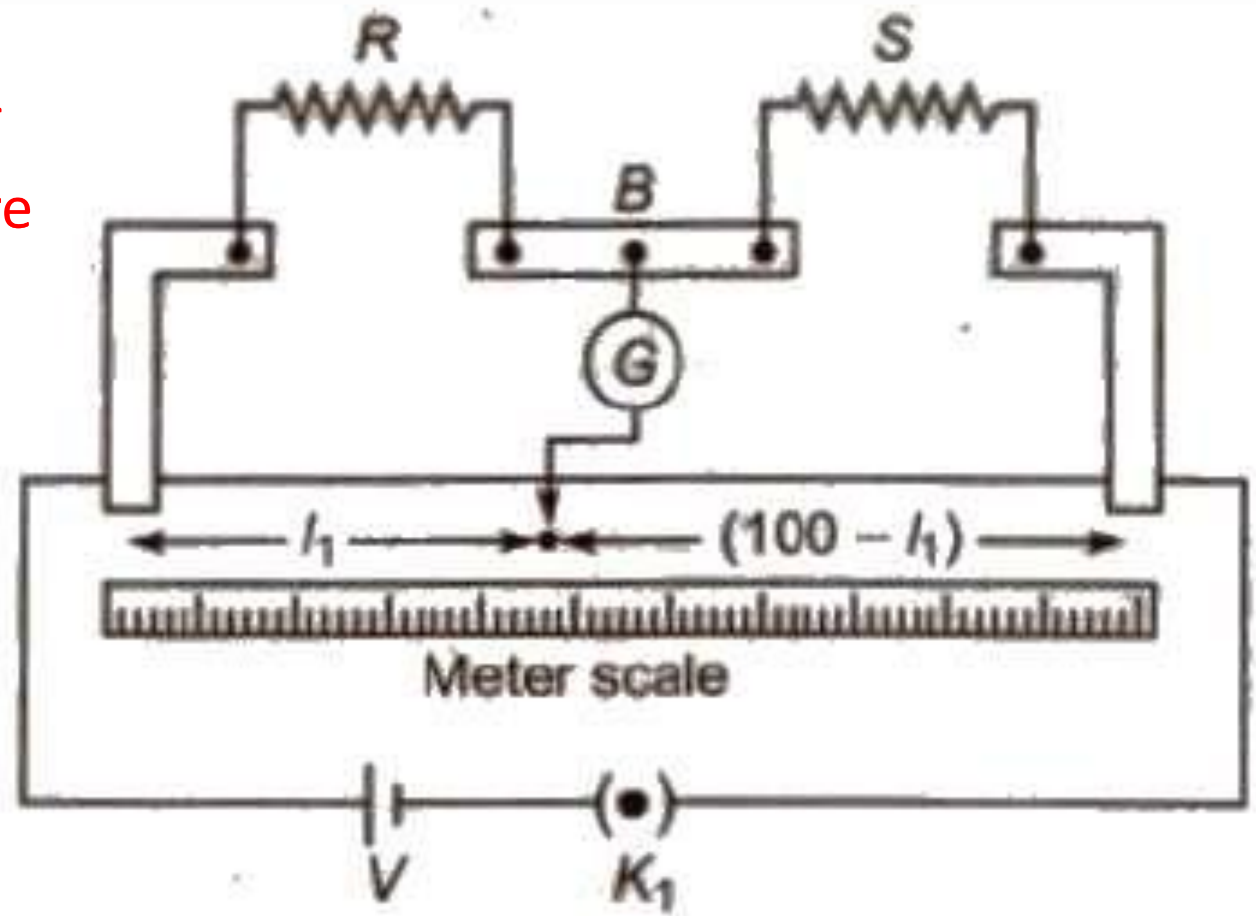
Ans. The bridge is most sensitive when all the four resistances P, Q, R and S are of same order of magnitude.

Meter Bridge

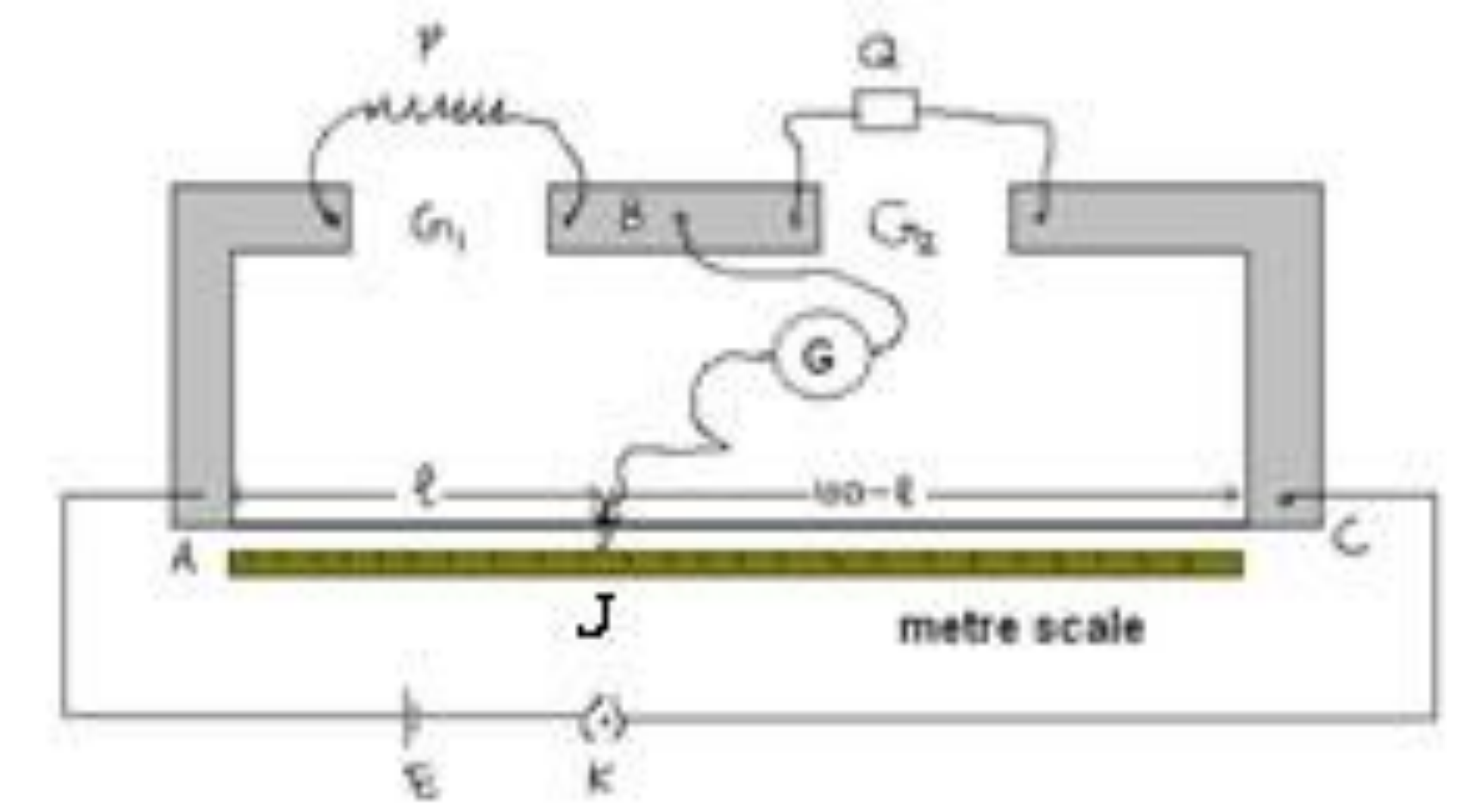
This is the simplest form of Wheatstone bridge and is specially useful for comparing resistance more accurately.

$R / S = l_1 / (100 - l_1)$

where l_1 is the length of wire from one end where null point is obtained.



METER BRIDGE



Slide Wire Bridge or Meter Bridge

It is the practical application of wheatstone brdge. It is used to determine unknown resistance.

Construction: it is consist of 100cm long wire stretched and clamped between two metallic strips bent at right angle as shown in figure.(between two points A and C)

The metallic strip has two gaps G_1 and G_2 where resistance P and Q are connected. A cell E is connected between A and C through a key K. here J is jockey connected to B through galvanometer G. This jockey can be move over wire.

Working: A known resistance is taken out of the resistance box (Q) and jockey is moved till the deflection in the galvanometer is zero.

When galvanometer shows no deflection (say at point J) the bridge is said to be balanced and therefore

$$\frac{P}{Q} = \frac{R}{S} \qquad \text{..........(1)}$$

Here R = resistance of wire segment AJ

& S = resistance of wire segment JC

Let, *r* = resistance of the wire per unit length

If AJ = *l* and JC = *100-l*

Then, R = *r.l* *and S = r (100-l)*

Therefor, $\frac{R}{S} = \frac{r.l}{r(100-l)} = \frac{l}{(100-l)}$ *.................(2)*

From (1) and (2) we have $\frac{P}{Q} = \frac{l}{(100-l)}$

Or $P = \frac{l}{(100-l)}Q$

Hence by knowing Q and *l* we can calculate P

Note: If P is Known and Q is unknown then $Q = \frac{100-l}{l}P$

Q # 21. What do you know about potentiometer? Also describe the advantage of potentiometer over voltmeter.

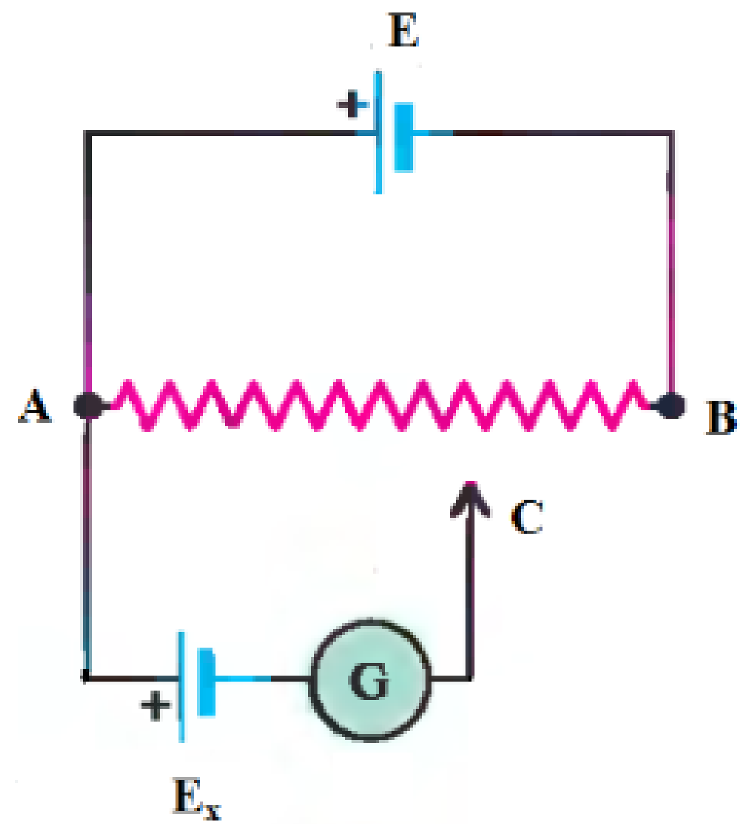
Ans.

Potentiometer

It is a device that is used to measure potential difference between two points without drawing any current from original circuit.

Advantage of Potentiometer over Voltmeter

Potential difference is usually measured by an instrument called voltmeter. The voltmeter is connected across the two points in a circuit between which the potential difference is to be measured. It is necessary that the resistance of the voltmeter be large compared to the circuit resistance across which the voltmeter is connected. Otherwise an appreciable current will flow through the voltmeter which will alter the circuit current and the potential difference measured. Thus the voltmeter can read the correct potential difference only when it does not draw any current from the circuit across which it is connected.



On the other hand, potentiometer is a very simple instrument which can measure and compare potential difference accurately without drawing any circuit current.

Potentiometer

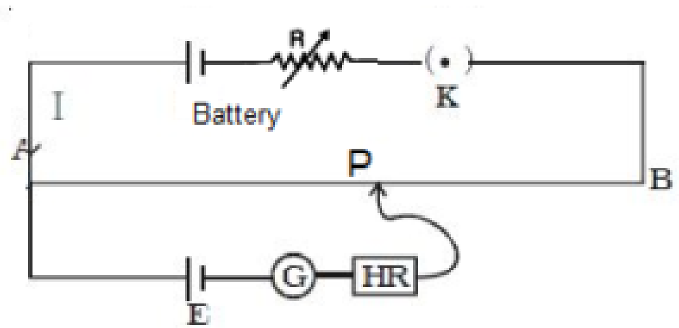
Potentiometer is a device used to measure the internal resistance of a cell, to compare the e.m.f. of two cells and potential difference across a resistor. It consists of a long wire of uniform cross sectional area and of 10 m in length. The material of wire should have a high resistivity and low temperature coefficient. The wires are stretched parallel to each other on a wooden board. The wires are joined in series by using thick copper strips. A metre scale is also attached on the wooden board.

It works on the principle that when a constant current flows through a wire of uniform cross sectional area, potential difference between its two points is directly proportional to the length of the wire between the two points.

- A potentiometer consists of a uniform wire AB several meters long. It is stretched between two points A and B on the wooden board.
- A battery having a sufficiently large e.m.f. E is connected between A and B of the wire. On closing, the key current will flow through the wire.
- The current in the wire can be adjusted by adjusting rheostat connected in series with the battery. The battery maintains a uniform potential gradient along the length of wire.

Principle of Potentiometer:

- When a steady current flows through a wire of uniform cross-section the potential difference per unit length of the wire is constant throughout the length of the wire (or p.d. across any two points of the wire is directly proportional to the length of the wire.
- It can be explained as below.



- Let us consider a uniform wire AB of length l_{AB} and uniform cross-sectional area A. Let R_{AB} be its resistance. Let 'I' be the steady current flowing through the wire. Let V_{AB} be the p.d. across the ends of the wire. Let 'ρ be the specific resistance of the material of wire. Let there be uniform potential drop across the length of wire.

$$\text{We have,} \quad R_{AB} = \frac{\rho \, l_{AB}}{A}$$

By Ohm's law

$$V_{AB} = i \, R_{AB}$$

$$\therefore V_{AB} = i\,\frac{\rho\, l_{AB}}{A} = \left(\frac{\rho i}{A}\right) l_{AB}$$

$$\therefore i = \frac{V_{AB}\, A}{\rho\ l_{AB}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

Let us consider point P on the wire and the length of wire between A and P be ' l_{AP}'

Thus, the resistance of wire of length 'R_{AP}' is given by

$$R_{AP} = \frac{\rho\, l_{AP}}{A}$$

The potential difference across the wire of length ' l_{AP} '

$$V_{AP} = i\,R_{AP} \quad \ldots\ldots\ldots\ldots\ldots\ (2)$$

From equation (1) and (2)

$$V_{AP} = \left(\frac{V_{AB}}{l_{AB}}\right) l_{AP}$$

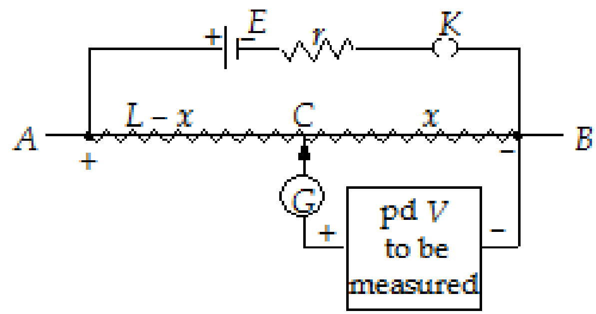
The quantities in bracket are constant.

$$\therefore V_{AP}\ \alpha\ l_{AP}$$

- When a constant current flows through a wire, then the potential difference between any two points of the wire is directly proportional to the length of wire between these two points. In such case, the p.d. per unit length of the wire is constant and called potential gradient of the wire or voltage drop across the wire.

POTENTIOMETER

A potentiometer is an instrument which allows the measurement of potential difference without drawing any current from the circuit being measured. Hence, it acts as an ***infinite-resistance voltmeter.***



The resistance between *A* and *B* is a uniform wire of length *L*, with a sliding contact *C* at a distance *x* and *B*. The potential difference *V* is measured by sliding the contact until the galvanometer *G* reads zero. The no-deflection condition of the galvanometer ensures that there is no current through the branch containing *G* and the potential difference to be measured. *The length x for no-deflection is called as the* ***balancing length.***

If λ is the *resistance per unit length* of the wire *AB*, under balanced condition (i.e., when no current is indicated by galvanometer *G*), the pd to be measured is given as

$$V = V_{CB} = V_{AB}\frac{R_{CB}}{R_{AB}} = V_{AB}\frac{\lambda_x}{\lambda L} = \left(\frac{V_{AB}}{L}\right) \times x$$

The ratio V_{AB}/L is called ***the potential gradient*** in the wire *AB*.

Precautions to be Taken While Using a Potentiometer:

- The e.m.f. of the cell connected across the potentiometer wire should b greater than the e.m.f. to be compared.
- The positive terminal of the cells whose e.m.f. is to be compared must be connected to that end of potentiometer wire where positive terminal of the battery (driving cell) is connected.
- The potentiometer wire must be uniform.
- The resistance of potentiometer wire should be high.

Advantages of a Potentiometer Over a Voltmeter:

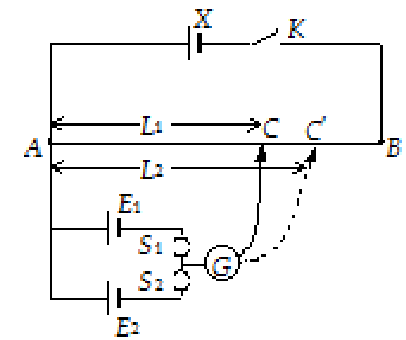
- A potentiometer can be used to measure the internal resistance of cell which can not be measured by the voltmeter.
- A Potentiometer can be to measure e.m.f of a cell which can not be measured by a voltmeter. When a voltmeter is connected in a circuit it draws current through the circuit and thus can measure the potential difference across the cell terminals. When the potentiometer is connected in a circuit it draws no current when the null point is obtained. Thus it measures the e.m.f. of the cell.
- A potentiometer can be used to measure extremely small p.d. accurately which cannot be measured by a voltmeter. It can be done by using very long wire and adjusting very small potential gradient.
- Potentiometer is more sensitive compared to voltmeter.
- The accuracy of potentiometer can be increased by increasing the length of wire. The accuracy of voltmeter cannot be increased beyond the limit.

Disadvantages of a Potentiometer:

- A voltmeter is a direct reading instrument while potentiometer is not so. We have to perform calculations to find the result.
- A voltmeter is portable while potentiometer is non-portable

Comparing Two Cells using Potentiometer

A potentiometer is commonly used for comparison of emfs of cells. A battery X is connected across a long uniform wire AB. The cells E_1 and E_2 (whose emfs are to be compared) are connected as shown along with a galvanometer.

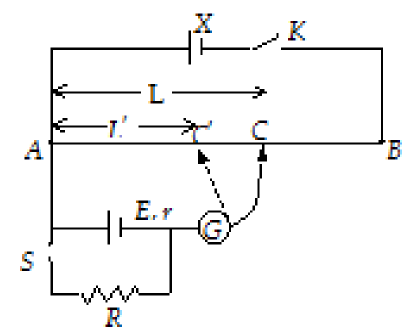


First the key S_1 is pressed which brings E_1 in the circuit. The sliding contact C is moved till the galvanometer shows no deflection. Let the length
$AC = L_1$. Next S_1 is opened and S_2 is closed. This brings E_2 in the circuit. Let C' be the new null point and let $AC' = L_2$. Then, clearly,

$$\frac{E_1}{E_2} = \frac{L_1}{L_2}$$

Measurement of Internal Resistance of a Cell

A potentiometer can be used to find the internal resistance of a cell. First the emf E of the cell is balanced against a length $AC = L$. A known resistance R is then connected across the cell as shown. The terminal voltage V is now balanced against a smaller length $AC' = L'$. Then,



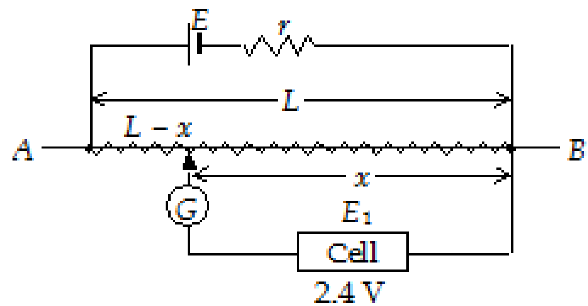
$$\frac{E}{V} = \frac{L}{L'}$$

But we know that $\frac{E}{V} = \frac{R+r}{R}$

$$\therefore \quad \frac{R+r}{R} = \frac{L}{L'}$$

$$\therefore \quad r = \left(\frac{L}{L'} - 1\right) R$$

A battery of emf 4 V is connected across a 10 m long potentiometer wire having a resistance per unit length 1.6 Ω m^{-1}. A cell of emf 2.4 V is connected so that its negative terminal is connected to the low potential end of the potentiometer wire and the other end is connected through a galvanometer to a sliding contact along the wire. It is found that the no-deflection point occurs against the balancing length of 8 m. Calculate the internal resistance of the 4 V battery.



Solution:

emf of cell = (potential gradient) x (balancing length)

$E_1 = \frac{V_{AB}}{L} \times x$

or $\quad 2.4 = \frac{V_{AB}}{10} \times 8 \quad \Rightarrow V_{AB} = 3V$

Consider the loop containing *E*. Applying potential divider concept,

$V_{AB} = E\frac{R_{AB}}{R_{AB}+r}$

$\Rightarrow 3 = 4\frac{1.6\times10}{1.6\times10+r}$

$\Rightarrow r = \mathbf{16/3\Omega}$

Note that as there is no current through the cell and galvanometer, the battery *E*, the internal resistance *r* and the potentiometer wire *AB* are in series.

The potential difference along the wire is proportional to the length of the wire. The sliding contact will move along wire AB until it finds a point along the wire such that the galvanometer shows a zero reading.

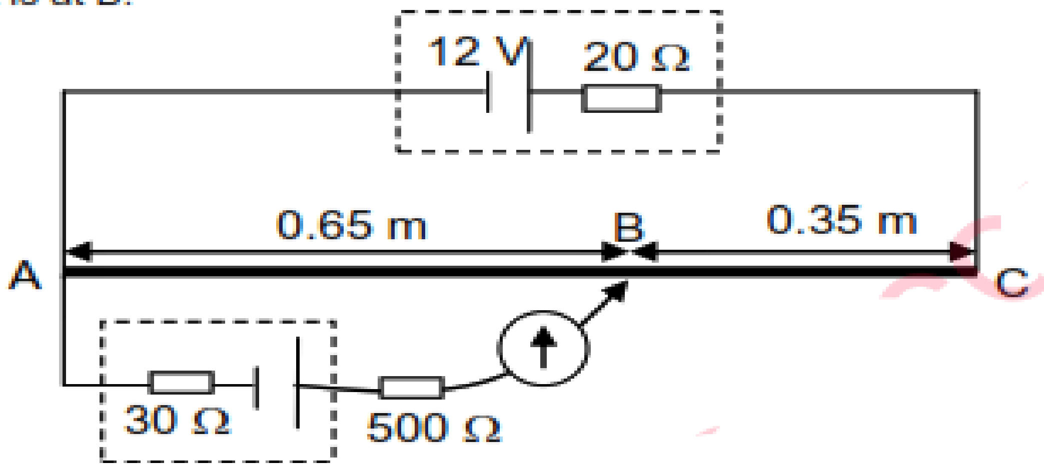
When the galvanometer shows a zero reading, the current through the galvanometer (and the device that being tested) is zero and the potentiometer is said to be "balanced".

If the cell has negligible internal resistance, and if the potentiometer is balanced,

EMF / PD of the unknown source, $V = \frac{L_1}{L_1 + L_2} \times E$

EXAMPLE 14H1

In the circuit shown, the potentiometer wire has a resistance of 60 Ω. Determine the EMF of the unknow cell if the balanced point is at B.



Resistance of wire AB

$= \frac{0.65}{0.65 + 0.35} \times 60 \qquad = 39\ \Omega$

EMF of the test cell

$= \frac{39}{60 + 20} \times 12 \qquad = 5.85\ V$

Questionnaire

Mention one use of meter bridge.

Ans. It is used to determine the unknown resistance of a given coil.

Why are the connecting resistors in a meter bridge made of thick copper strips?

Ans. Thick copper strips offer minimum resistance and hence avoid the error due to end resistance which have not been taken in to account in the meter bridge formula.

70.Write the expression for Unknown resistance R interms of standard resistance S and balancing length l,

Ans. $\mathbf{R} = \frac{Sl}{1-l}$

71. How the error in finding R in a meter bridge can be minimized?

Ans. The error in finding R in a meter bridge can be minimized by adjusting the balancing point near middle of the bridge (close to 50cm) by suitable choice of standard resistance S.

72 .What is a potentiometer?

Ans. It is an instrument consisting of long piece of uniform wire across which a standard cell is connected.

73. Mention the practical use of potentiometer.

Ans. It can be used to determine emf of a one cell knowing emf of the other and also internal resistance of a given cell.

74.Give the equation to compare emf's of two cells in terms of balancing length.

Ans. If l_1 and l_2 are the balancing length's then $\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_1}{l_2}$

75.Give the formula to determine the internal resistance of the cell using potentiometer.

Ans. r = R $\left[\frac{l_1}{l_2} - 1\right]$, l_1 *and* l_2 are the balancing length's without and with the external resistance respectively.

76. What is the advantage of potentiometer?

Ans. The potentiometer has the advantage that it draws no current from the voltage source being measured.

77. Name the device used for measuring emf of a cell.

Ans. potentiometer.

State the principle of working of a potentiometer.

Ans. A potentiometer works on the principle that when a steady current flows through a wire of uniform cross section and composition, the potential drop across any length of the wire is directly proportional to that length.

What is a primary cell ?

Ans. It is a cell which cannot be recharged.

What is a secondary cell ?

Ans. It is a cell which can be recharged.

Why does a secondary cell provide more current than a primary cell of same e.m.f. ?

Ans. A secondary cell has a very low value of internal resistance.

Which of the two cells, the primary or the secondary, is used in automobiles and why ?

Ans. Secondary cell is used because it delivers the desired large starting current due to its low internal resistance.

Can we find the internal resistance of an accumulator or secondary cell?

Ans. No; the internal resistance of an accumulator is so small that It does not cause any appreciable (measurable) potential difference so this method cannot be used.

- What type of cell should be used in the main circuit?
- The cell should have EMF higher than any other cells whose EMFs are to be compared. So we use Accumulator. Its also capable of supplying a steady current for an appreciably long time. But a Primary cell may give a high EMF but it will not give steady current for a long time. Hence it is unable to maintain a constant potential gradient along the potentiometer wire.

Can we draw any amount of current from a primary cell? What limits the value of current drawn?

No, The internal resistance of the cell limits the maximum value

What is potential gradient? The potential drop per unit length.

Ans. It is the fall of potential per unit length of the potentiometer wire. $K = \frac{V}{l}$.

What kind of source of e.m.f. should be used as auxiliary battery?

Ans. The e.m.f. of the source must be steady. A freshly charged accumulator should be used for this purpose.

On what factors does the potential gradient depend?

Ans. Potential gradient depends directly on the strength of the current and resistance per cm of the wire. $K = \frac{I\rho}{A}$.

What is the preferred material used for making potentiometer wires?

Ans. Manganin or Constantan alloy. It is characterised by a low temperature coefficient of resistance and a high resistivity.

How is the sensitivity of a potentiometer affected by the length of its wire ?

Ans. The sensitivity increases with increase in length of the wire.

How does the sensitivity of a potentiometer vary with potential gradient?

The sensitivity of the potentiometer decreases with an increase in potential gradient. Explanation

As the potential gradient increases, greater potential difference is obtained for a small change in length of the wire. Or the length of the potentiometer for a given change in potential will be less. The potentiometer is more sensitive if we get a considerably larger change in length for a given change in potential. Therefore, with an increase in potential gradient, the sensitivity decreases.

What are characteristics of wire of potentiometer?

Uniform cross sectional area, high resistivity, low temperature coefficient.

The electric current should not pass through potentiometer wire for long time ,Why?

It will heat up the potentiometer wire and it will change its resistance, so the potential gradient.

Why is a ten-wire potentiometer more sensitive than a four- wire one?

Ans. The potential gradient, under same conditions, decreases with an increase in the length of the potentiometer wire, Hence, a 10-wire potentiometer (having a smaller potential gradient) is more sensitive than a 4-wire one.

Why the jockey (sliding key) should not be pressed too hard on the wire when sliding over it?

Ans. Sliding the jockey with a hard press, will scratch the wire and make its thickness non uniform. Then the resistance per unit length of the wire will not remain constant because resistance depend upon area of cross-section.

Can we consider the potentiometer as an ideal voltmeter?

Ans. Yes. At null point, the potentiometer does not draw any current. Hence it measure the
emf. The potentiometer is equivalent to an ideal voltmeter.

$V = E - Ir$

Let $I = 0$ then $V = E$

After setting up Potentiometer experiment, you observed that the deflection of the galvanometer is in same direction at both the ends of potentiometer wire. What could be possible reasons?

Ans. The reasons may be

(i) Connections may be loose or incorrect. /the positive terminals of all the cells are not connected at one point.

(ii) The potential difference between the ends of the wire is less than the e.m.f. of the cell which is to be measured.

(iii) The e.m.f. of driving cell is less than the e.m.f. of each cells whose e.m.f. to be compared or measured. (E.M.F. of the primary cell may exceed that of the main circuit cell.)

Important Points

- Potentiometer is an ideal voltmeter.
- Sensitivity of potentiometer is increased by increasing length of potentiometer wire.
- If n identical resistances are first connected in series and then in parallel. the ratio of the equivalent resistance.

$R_s / R_p = n^2 / 1$

- If a skeleton cube is made with 12 equal resistance,each having a resistance R, then the net resistance across

1. The diagonal of cube = 5 / 6 R
2. The diagonal of a face = 3 / 4 R
3. along a side = 7 / 12 R

- If a resistance wire is stretched to a greater length, keeping volume constant, then

$R \propto l^2 \Rightarrow R_1 / R_2 = (l_1 / l_2)^2$

and $R \propto 1 / r^4 \Rightarrow R_1 / R_2 = (r_2 / r_1)^4$

where l is the length of wire and r is the radius of cross-section area of wire.