Electro Motive Force

P3

- Explain how electromotive force is built in a simple cell using electrode potential.
- Show that there is a potential difference between the terminals of any electric source.
- Explain that the potential difference which is needed to apply across any electric circuit to flow current is supplied by an electric source.
- Name several electric sources and conduct a discussion to understand their energy transformations.
- Define electro motive force.
- Explain that the rate of energy supplied from a source is given by the product EI.
- Introduce internal resistance of a source.
- Apply the law of conservation of energy for a circuit having one source and one external resistor to obtain $EI = I^2R + I^2r$.
- Obtain $V = E - Ir$ from the above equation.

- Explain that the potential difference between the terminals of a source is obtained when current flows from the above expression.
- Explain the followings using $V = E - Ir$.
  - The potential difference between the terminals of a source is equal to the electro motive force when there is no current flow.
  - If the internal resistance of the source is zero, the potential difference between the terminals of the source is always equal to the electro motive force; for any value of current.
- Assign students to design an experiment to find the electro motive force and the internal resistance of a dry cell.
- Give expressions for equivalent *emf* and internal resistance of a series combination of sources.
- Give an expression for a parallel combination of identical sources
- Give the graph for the variation of power dissipation with external resistance
- State the condition needed for maximum power dissipation
- Guide students to solve problems related to electromotive force

Potential difference

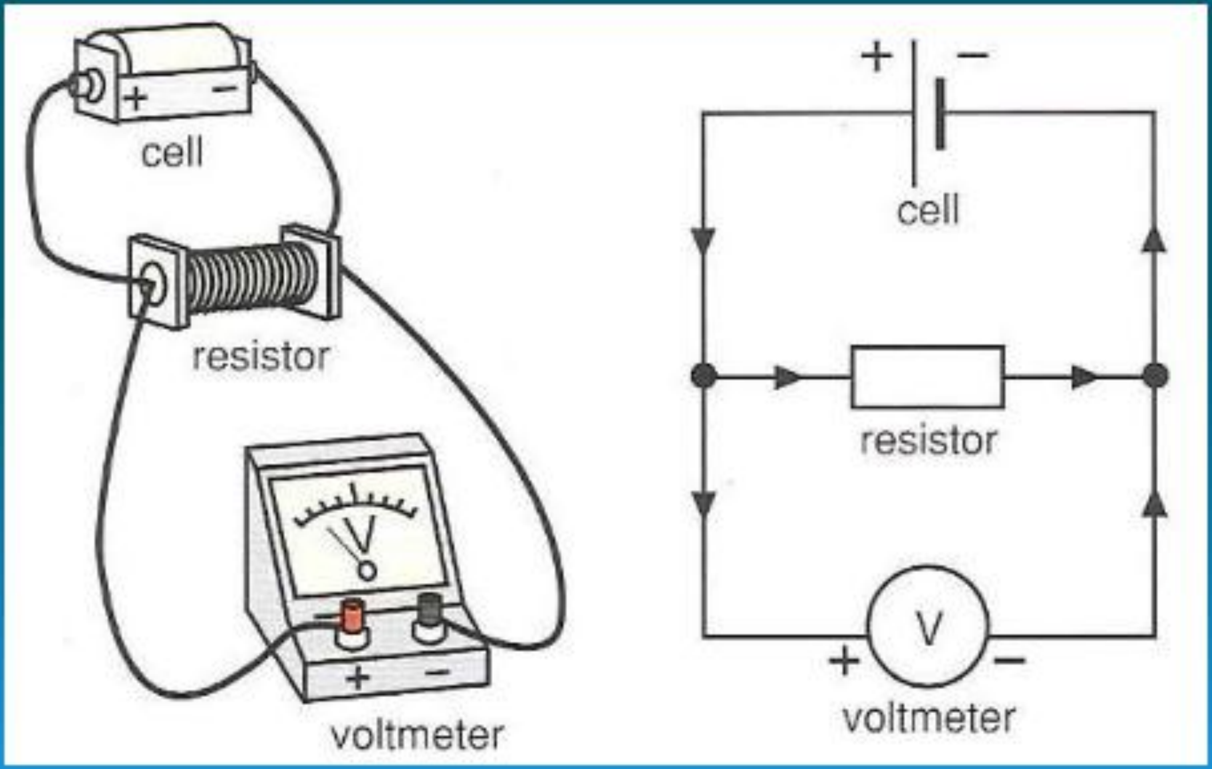
- The **potential difference** across a component is defined as the work done to drive a unit charge through the component.

$$\text{Potential difference} = \frac{\text{Work done}}{\text{Charge}} \qquad V = \frac{W}{Q}$$

- The SI unit for potential difference is **joule per coulomb (J/C)** or the **volt (V)**.

Measuring Potential Difference

- The potential difference across two points in a circuit can be measured by a voltmeter.



Voltmeter – measures voltage

Does NOT require the current to pass through it.
It must be placed in parallel to the circuit element.

Ideally voltmeters have INFINITE resistance so that they do not draw current away from circuit.

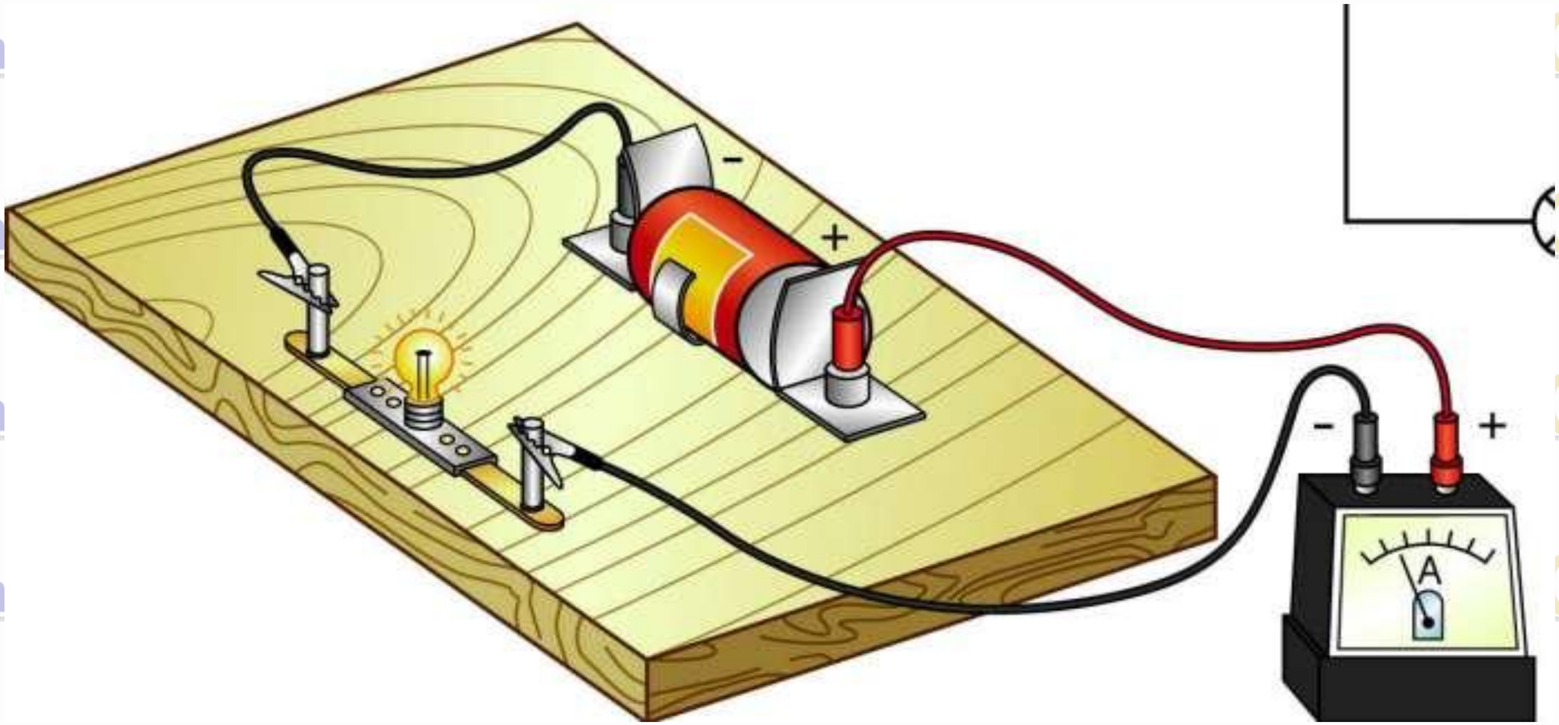
Instrument to Measure Current

An **ammeter** is an instrument used for measuring electric current.

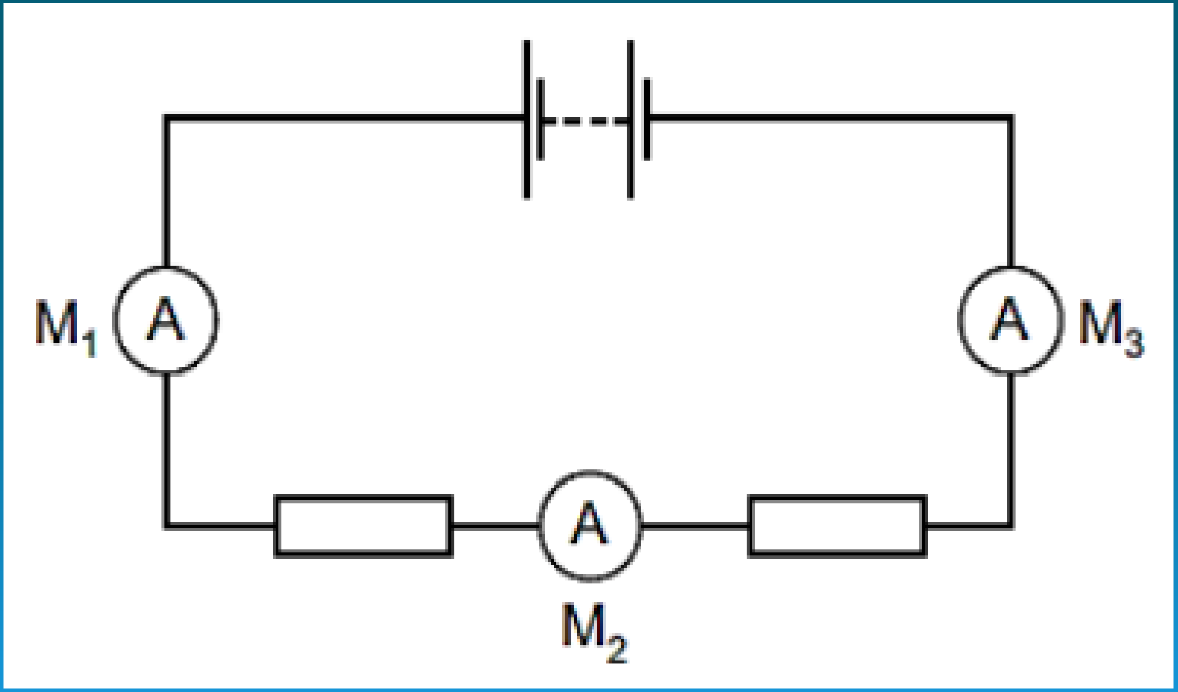
Ideally ammeters have ZERO resistance so that they do not affect the energy of the circuit

AMMETER

It must be connected in series in the circuit.



The diagram shows a battery connected to two identical resistors. Three ammeters M_1, M_2 and M_3 are connected in the circuit.



Meter M_1 reads 1.0 A.
What are the readings on M_2 and on M_3?

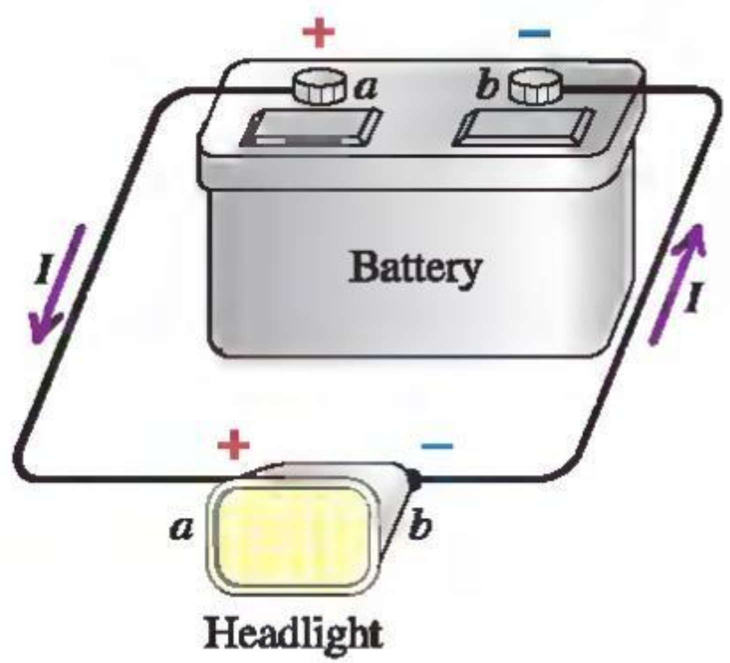
	reading on M_2 / A	reading on M_3 / A
A	0.5	0.0
B	0.5	0.5
C	0.5	1.0
D	1.0	1.0

Cn'S

Sources of Electromotive Force

The devices that provide emf in electrical circuits, to sustain steady current flow in the circuit, are called sources of emf. These sources provide energy to charge carries to make the steady flow of current possible. Source of current converts some non-electrical energy (chemical, mechanical, heat or solar energy) to electrical energy.

Consider a source of electromotive force is connected to a resistor as shown in the figure.



Other Examples

1) Cells which convert chemical energy into electrical energy.

ii) Electric generators convert mechanical energy into electrical energy.

iii) Thermo couples convert heat energy into electrical energy.

iv) Solar cells convert light energy into electrical energy.

Effects of Current.

The presence of current due to EMF produces various effects through which it can be detected. Its some effects are given below

i) Heating effect.

ii) Magnetic effect.

iii) Chemical effect.

Electromotive force

- In a cell or battery, the chemical changes take place which provide the energy required to push the electric charge (electrons) round the circuit.
- The electromotive force (e.m.f.) of any electrical source is the work done by the source in driving a unit charge around a complete circuit.
- The SI unit for e.m.f. is joule per coulomb (J/C) or the volt (V).

Electromotive Force

The amount of energy supplied per unit charge in order to move it in a circuit is called electromotive force. The electromotive force is not actually a force.

The unit of emf is joule/coulomb

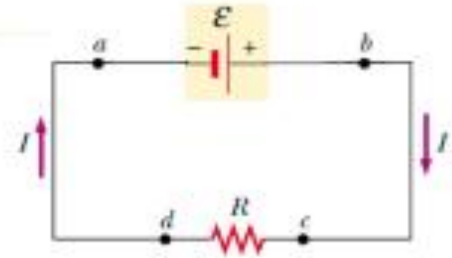
1 volt = 1 joule/coulomb

The source of emf maintains its one terminal at a high potential and its other terminal at low potential, as indicated by the + and – signs. Therefore, the emf of the battery would cause positive charge carriers to move in the external circuit as shown by the arrows marked .

In its interior, the source of emf acts to move positive charges from the point of low potential to the point of high potential. The charges then move through the external circuit, dissipating energy in the process, and return to the negative terminal, from which the emf raises them to the positive terminal again, and the cycle continues again and again to make the steady flow of current possible.

Determination of Current in a Single Loop Using Energy Conservation Principle

Consider a single loop circuit consists of one source of emf $\mathcal{E}$ and one resistor R as shown in the figure. In time dt a charge $dq(= Idt)$ moves through the source of emf. The energy supplied by the source of emf to the charge carries can be find out by expression:



$$Electromotive\ Force = \frac{Energy\ Supplied}{Charge}$$

$$\Rightarrow Energy\ Supplied = (Electromotive\ Force)(Charge)$$

$$\Rightarrow Energy\ Supplied = (\mathcal{E})(dq) = \mathcal{E}\, I\, dt$$

The energy supplied by the battery is dissipated in the resistor R. The total energy dissipated is determined as:

$$Power\ Dissipated = \frac{Energy\ Dissipated}{Time}$$

$$\Rightarrow Energy\ Dissipated = (Power\ Dissipated)(Time)$$

$$\Rightarrow Energy\ Dissipated = (I^2R)(dt) = I^2R\, dt$$

From the conservation of energy principle, the work done by the source must equal to the internal energy dissipated in the resistor, i.e.,

$$\mathcal{E}\, I\, dt = I^2R\, dt$$

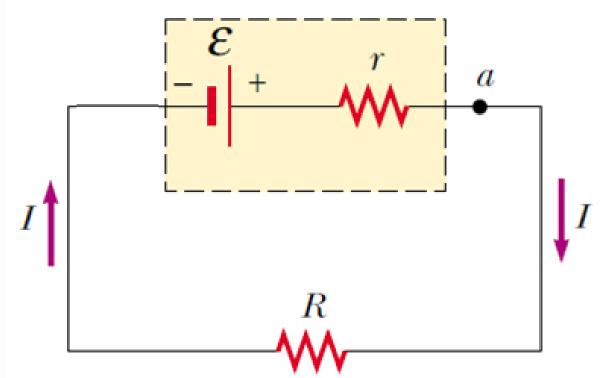
Solving for I, we obtain

$$I = \frac{\mathcal{E}}{R}$$

This is the expression of electric current moving through a single loop circuit.

Determination of Current in a Single Loop Circuit by Considering the Internal Resistance of a Source of EMF

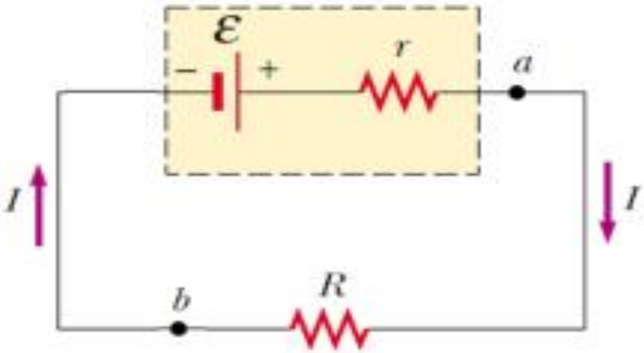
- All the sources of emf have an intrinsic internal resistance, which can't be removed because it is the inherent part of device.
- Consider a single loop circuit consists of one source of emf E having internal resistance r and one resistor R as shown in the figure. Let a steady current I flow through the loop. Applying Kirchhoff's voltage rule, we have:

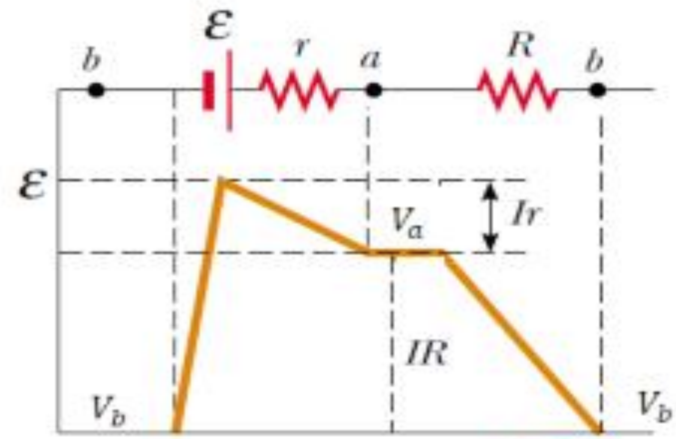


- E- Ir – IR = 0
- Thus the expression of the current from this single loop of current becomes: I= E / r+ R
- Note that the internal resistance reduces the current that the emf can supply to the external circuit.

33.7 DETERMINATION OF POTENTIAL DIFFERENCES BETWEEN THE POINTS OF CIRCUIT

Consider a circuit which consists of a resistor R and a source of emf $\mathcal{E}$ with internal resistance r as shown in the figure below:





We want to find out the expression of potential difference V_{ab} between the two points a and b of an electrical circuit. If V_a and V_b are the potential at points a and b, respectively

$$V_b + IR = V_a$$

$$\Rightarrow V_{ab} = V_a - V_b = IR$$

$$\Rightarrow V_{ab} = IR$$

As for the single loop, given above, we have

$$I = \frac{\mathcal{E}}{R+r}$$

Thus eq. (1) will become:

$$V_{ab} = \left(\frac{\mathcal{E}}{R+r}\right) R$$

$$\Rightarrow V_{ab} = \mathcal{E}\frac{R}{R+r}$$

This is the expression of electric potential of electric potential difference between the two points of an electrical circuit.

. **Describe the relationship between the emf of a battery and terminal potential difference. Explain this relationship on the basis of energy consideration.**

Ans. Consider a battery of emf E having internal resistance r. The current I flowing through the circuit is given by:

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

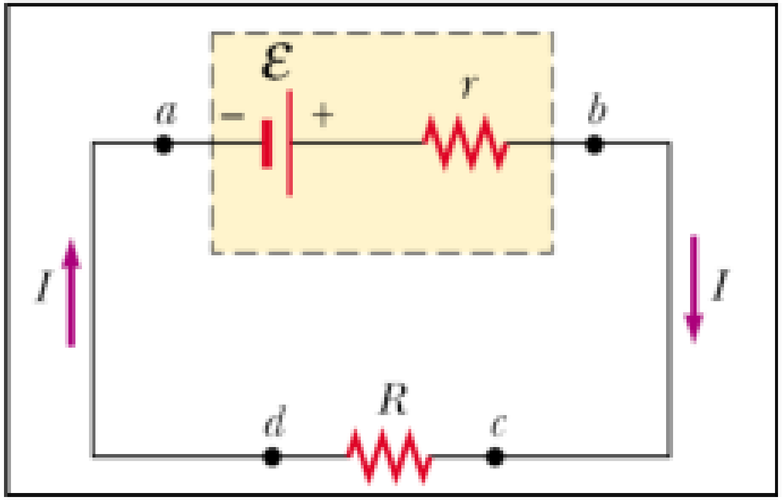
Or

$$E = IR + Ir \quad \text{----------------} \quad (1)$$

Here $IR = V$ is the terminal potential difference of the battery in the presence of current I and Ir is the voltage drop on internal resistance of the battery.

Explanation

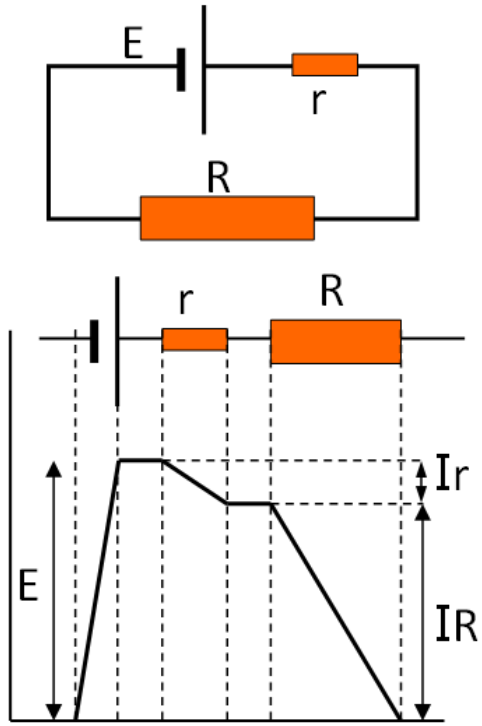
The left side of equation (1) is the emf of the battery, which is equal to the energy gained by unit charge (electron) to move from its negative to positive terminal. The right side of the equation gives an account of the utilization of this energy. It states that, as a unit charge passes through a circuit, a part of its energy equal to Ir is dissipated into the cell and the rest of the energy is dissipated into the external resistance R. it is given by the potential drop IR.



E.M.F and internal resistance

All cells have a resistance of their own and we call this the **internal resistance** of the cell. The voltage produced by the cell is called the **electromotive force** (e.m.f) and this produces a p.d (V = IR) across the cell and across the external resistor (Ir).

The e.m.f (E) of the cell can be defined as the maximum p.d that the cell can produce across its terminals, or the open circuit p.d since when no current flows from the cell no electrical energy can be lost within it.



$$E = V + Ir = IR + Ir$$

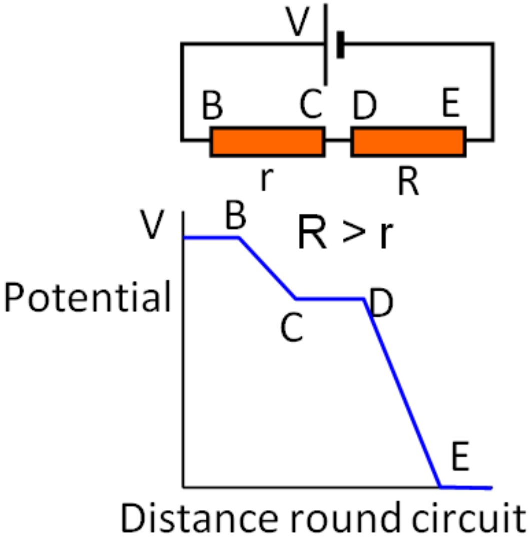
Potential round a circuit

The electrical potential energy of a unit charge at a point in a circuit is called the potential at that point.

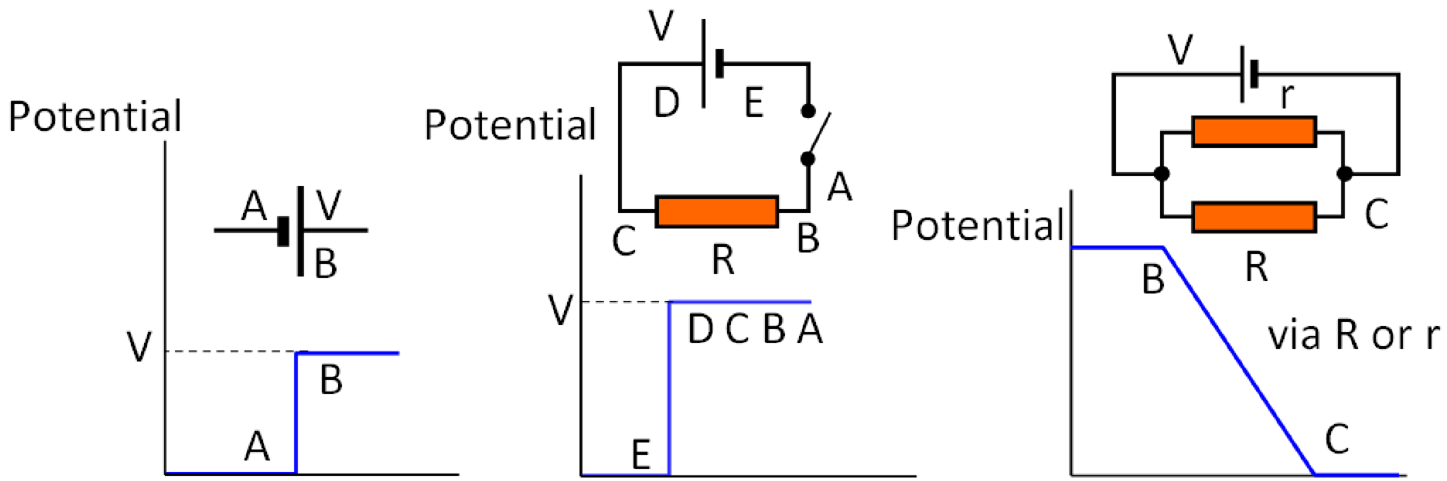
Potential difference between two points in a circuit is the work done in moving unit charge (i.e. one coulomb) from one point to the other

The units for potential difference are therefore Joules per coulomb, or volts. (1 volt = 1 Joule/coulomb).

From the cell to B there is no resistance and so no loss of electrical energy or drop in potential. In the resistors r and R energy is converted to heat and so the potential drops from B through to E. From E to the cell there is no loss of electrical energy and so the potential at E is the same as that at the negative terminal of the cell – zero.



Potential and energy



Electrical energy = Charge x Potential difference (Voltage)

Joules = Coulombs x Volts = Amps x Time x Volts

Electrical energy = ItV

Sources of emf:

The electro motive force is the maximum potential difference between the two electrodes of the cell when no current is drawn from the cell.

Comparison of EMF and P.D:

	EMF	Potential Difference
1	EMF is the maximum potential difference between the two electrodes of the cell when no current is drawn from the cell i.e. when the circuit is open.	P.D is the difference of potentials between any two points in a closed circuit.
2	It is independent of the resistance of the circuit.	It is proportional to the resistance between the given points.
3	The term 'emf' is used only for the source of emf.	It is measured between any two points of the circuit.
4	It is greater than the potential difference between any two points in a circuit.	However, p.d. is greater than emf when the cell is being charged.

Internal Resistance of a cell:

The opposition offered by the electrolyte of the cell to the flow of electric current through it is called the internal resistance of the cell.

Factors affecting Internal Resistance of a cell:

i) Larger the separation between the electrodes of the cell, more the length of the electrolyte through which current has to flow and consequently a higher value of internal resistance.

ii) Greater the conductivity of the electrolyte, lesser is the internal resistance of the cell. i.e. internal resistance depends on the nature of the electrolyte.

iii) The internal resistance of a cell is inversely proportional to the common area of the electrodes dipping in the electrolyte.

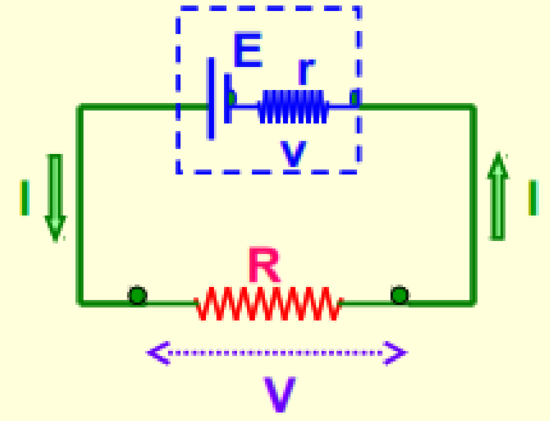
iv) The internal resistance of a cell depends on the nature of the electrodes.

$$E = V + v$$

$$= IR + Ir$$

$$= I\,(R + r)$$

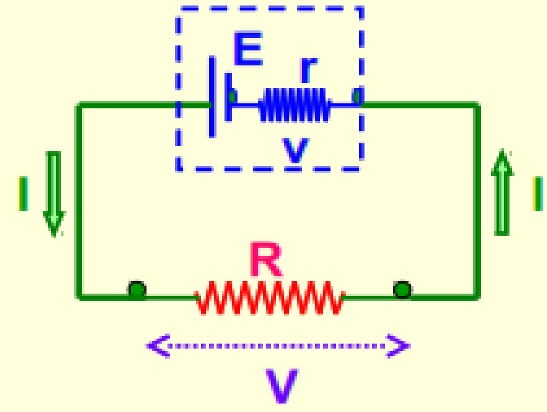
$$\boxed{I = E / (R + r)}$$



This relation is called circuit equation.

Internal Resistance of a cell in terms of E,V and R:

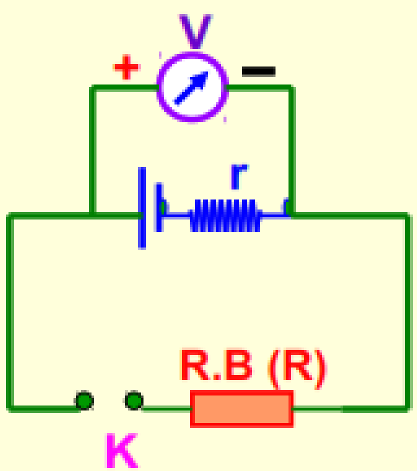
$$E = V + v$$
$$= V + Ir$$
$$Ir = E - V$$



Dividing by IR = V,

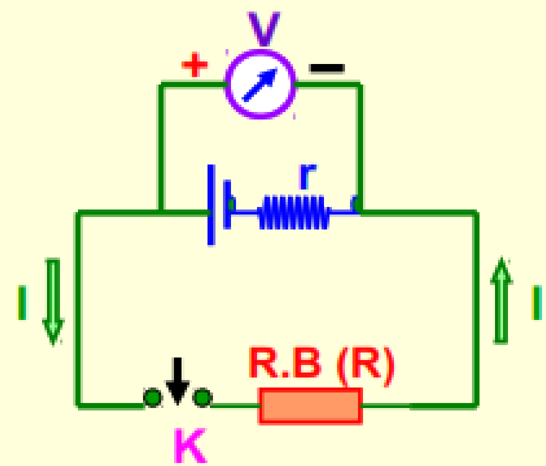
$$\frac{Ir}{IR} = \frac{E - V}{V} \Longrightarrow \boxed{r = \left(\frac{E}{V} - 1\right) R}$$

Determination of Internal Resistance of a cell by voltmeter method:



Open circuit (No current is drawn)

EMF (E) is measured



Closed circuit (Current is drawn)

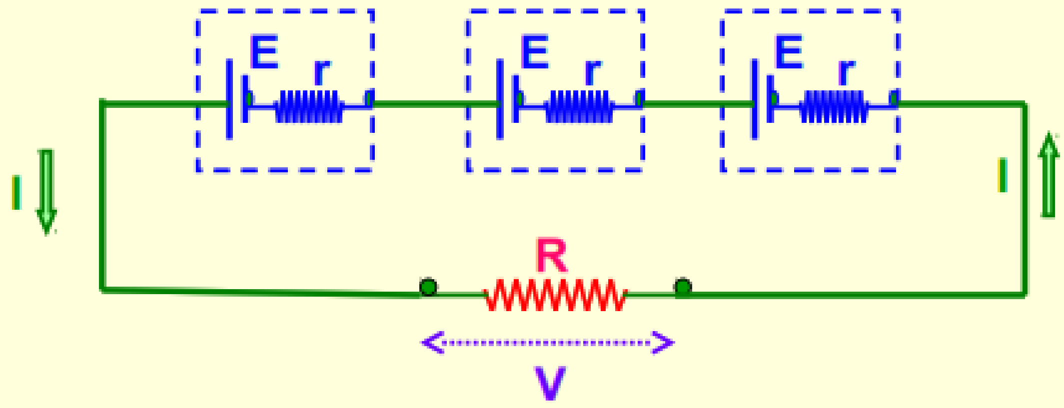
Potential Difference (V) is measured

Cells in Series combination:

Cells are connected in series when they are joined end to end so that the same quantity of electricity must flow through each cell.

NOTE:

1. The emf of the battery is the sum of the individual emfs
2. The current in each cell is the same and is identical with the current in the entire arrangement.
3. The total internal resistance of the battery is the sum of the individual internal resistances.



Total emf of the battery $= nE$ (for n no. of identical cells)

Total Internal resistance of the battery $= nr$

Total resistance of the circuit $= nr + R$

(i) If $R \ll nr$, then $I = E / r$ (ii) If $nr \ll R$, then $I = n\,(E / R)$

$$\text{Current } I = \frac{nE}{nr + R}$$

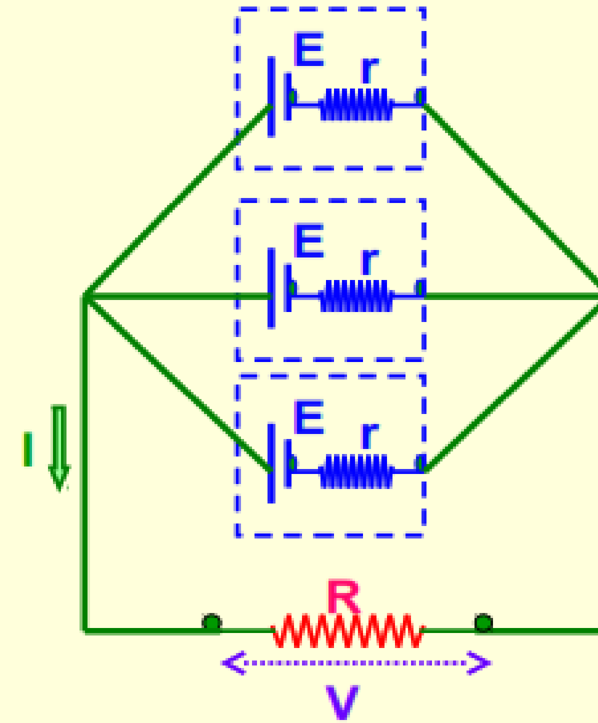
Conclusion: When internal resistance is negligible in comparison to the external resistance, then the cells are connected in series to get maximum current.

Cells in Parallel combination:

Cells are said to be connected in parallel when they are joined positive to positive and negative to negative such that current is divided between the cel

NOTE:

1. The emf of the battery is the same as that of a single cell.
2. The current in the external circuit is divided equally among the cells.
3. The reciprocal of the total internal resistance is the sum of the reciprocals of the individual internal resistances.



Total emf of the battery = E

Total Internal resistance of the battery = r / n

Total resistance of the circuit = (r / n) + R

$$\text{Current } I = \frac{nE}{nR + r}$$

(i) If R << r/n, then I = n(E / r) (ii) If r/n << R, then I = E / R

Conclusion: When external resistance is negligible in comparison to the internal resistance, then the cells are connected in parallel to get maximum current.

What is emf of a cell?

Ans. Emf is the potential difference between the positive and negative electrodes in an open circuit. i.e. when no current flowing through the cell.

Define internal resistance of a cell.

Ans. The finite resistance offered by the electrolyte for the flow of current through it is called internal resistance.

Give the expression for the potential difference between the electrodes of a cell of emf E and internal resistance r?

Ans. The potential difference **V=E – I r.**

Write the expression for equivalent emf when two cells of emf's $E1$ and $E2$ connected in series.

Ans. E **eq = E 1 + E 2**

Write the expression for equivalent emf when two cells of emf's $E1$ and $E2$ connected in series such that negative electrode of $E1$ to negative electrode of $E2$ ($E1 > E2$)

Ans. **Eeq = E1 - E2**

Write the expression for equivalent emf of n cells each of emf E connected in series.

Ans. **Eeq = nE**

Write the expression for equivalent internal resistance of n cells each of internal resistance r connected in series.

Ans. **req = n r**

- Terminal potential difference is less than the emf of a cell. Why?

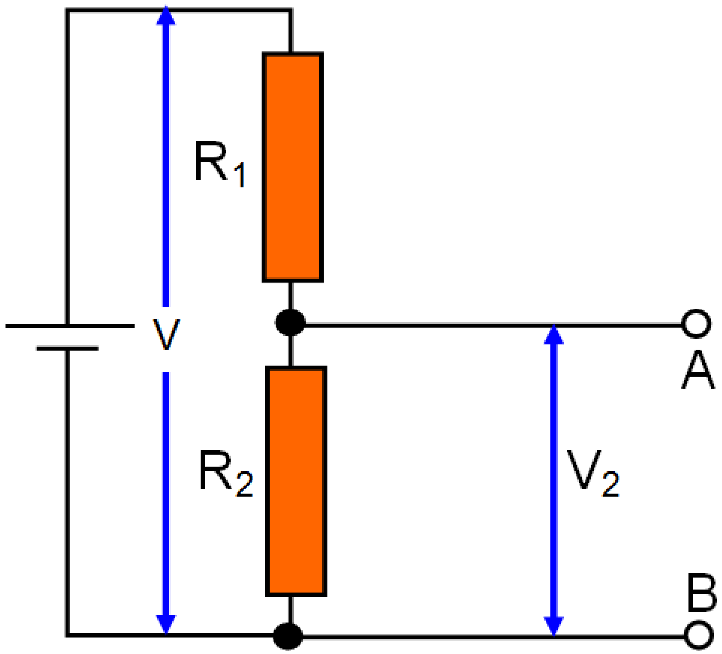
- Ans.When circuit is open,the terminal potential difference is equal to emf of the cell . When current is drawn from the cell, some potential drop takes place due to internal resistance of the cell. Hence terminal potential difference is less than the emf of a cell and is given by

Potential divider

The output voltage across AB is given by:

Output voltage (V_2) = (R_2/[R_1 + R_2])V

The input voltage (V) in this case is supplied by the battery and is constant. The current flowing through both resistors is the same (series circuit) and so the output voltage across one of them depends simply on the two resistance values and the input voltage.



Electrical energy and thermal energy.

- The resistor represents a *load* on the battery because the battery must supply energy to operate the device.
- The potential difference across the load resistance is
- **ΔV = IR and**

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

- **The total power output $I\varepsilon$ of the battery is delivered to the external load resistance in the amount I^2R and to the internal resistance in the amount I^2r.**

$$I\varepsilon = I^2R + I^2r$$

Example 28.1 Terminal Voltage of a Battery

A battery has an emf of 12.0 V and an internal resistance of 0.05 Ω. Its terminals are connected to a load resistance of 3.00 Ω.

(A) Find the current in the circuit and the terminal voltage of the battery.

Solution Equation 28.3 gives us the current:

$$I = \frac{\mathcal{E}}{R + r} = \frac{12.0\ \text{V}}{3.05\ \Omega} = \boxed{3.93\ \text{A}}$$

and from Equation 28.1, we find the terminal voltage:

$$\Delta V = \mathcal{E} - Ir = 12.0\ \text{V} - (3.93\ \text{A})(0.05\ \Omega) = \boxed{11.8\ \text{V}}$$

- Calculate the power delivered to the load resistor of 3 ohm when the current in the circuit is 3.93 A.

Solution The power delivered to the load resistor is

$$\mathcal{P}_R = I^2 R = (3.93\ \mathrm{A})^2\,(3.00\ \Omega) = \boxed{46.3\ \mathrm{W}}$$

Q. Which of the following occurs when part of an electric circuit is connected to ground?

a) The ground acts like a battery, so the current in the circuit increases.

b) Any current in the circuit flows to the ground.

c) The electric potential at the connection point is equal to zero volts.

d) The electric potential difference across the terminals of any batteries in the circuit is equal to zero volts.

e) The ground provides a source for more electrons to flow into the circuit.