Current of electricity

Content

Electric current

- Current of electricity is all about making charged particles to move.
- Whenever electric charges move, an electric current is said to exist.
- An electric current in a material is the rate of flow of electric charge through the material.

CURRENT $$I = \frac{Q}{t}$$

UNIT: Ampere = A = C/s

- 1 ampere is a flow of 1 coulomb per second
- Current is measured by ammeter connected in series with the circuit

Example 1

- The current in the filament of a torch light bulb is 0.03 A. How much charge flows through the bulb in 1 minute?

- The current in a component is reduced uniformly from 100 mA to 20 mA over a period of 8.0 s. What is the charge that flows during this time?

  A 160mC **B 320mC** **C 480mC**

  D 640mC

Example 2

- A wire carries a current of 1.5 A.

(a) How much charge pass through a point in a wire in 15 minutes?

(b) How many electrons pass the point in 15 minutes?

Example 3

- How many electrons per second pass through a particular point of wire carrying a current of 10.0 A?

Potential Difference

- The potential difference between two points is defined as the amount of electric energy changed to other forms of energy per coulomb of charge flowing between the points.
- Measured in volts
- Scalar quantity

Voltage (Volt, V)

$$V = \frac{W}{Q}$$

Amount of energy (Joule, J)

Charge (Coulomb, C)

Example 4

- What physical quantity would result from a calculation in which a potential difference is multiplied by an electric charge?

  A electric current

  B electric energy

  C electric field strength

  D electric power

- Which electrical quantity would be the result of a calculation in which energy is divided by charge?

  A current

  B potential difference

  C power

  D resistance

Example 5

- The potential difference between point X and point Y is 20 V. The time taken for charge carriers to move from X to Y is 15 s, and, in this time, the energy of the charge carriers changes by 12 J. What is the current between X and Y?

A 0.04 A B 0.11 A C 9.0 A D 25 A

Electromotive force (EMF)

- Emf is also measured in **volts, V**
- How is it different from potential difference?
- In any circuit there are components that put electrical energy **in** and those that take it **out**.
- From now on we will say any device putting electrical energy into a circuit is providing an **emf** and any device taking it out has a **p.d**. across it.
- The best way to think of them is:-

Emf – amount of *other forms of energy* converted into *electrical energy per unit charge.*

(charges gain electrical energy)

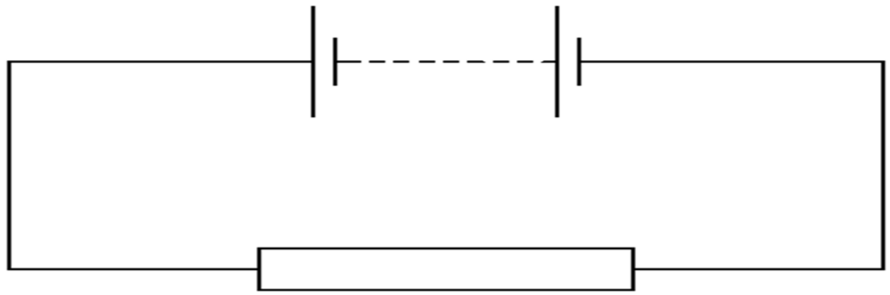
P.d. – amount of *electrical energy* converted into *other forms of energy per unit charge flow between 2 points.*

(charges lose electrical energy)

- Sources of emf : Cells, batteries, generators, dynamos.

Example 6

- In the circuit below, the battery converts an amount *E of chemical energy to electrical energy* when charge *Q passes through the resistor in time t.*



- Which expressions give the e.m.f. of the battery and the current in the resistor?

	e.m.f.	current
A	EQ	Q/t
B	EQ	Qt
C	E/Q	Q/t
D	E/Q	Qt

Resistance

- As charged particles try to make their way round a circuit they encounter resistance to their flow. This resistance is due to the frequent collision of the charged particles with the atoms of the passage/matter that it is flowing.
- The passage/matter in which the charged particles flow encounter little opposition is said to have low resistance. This matter is called conductor. (eg: copper)
- Some passages/matters strongly oppose the flow of charged particles whereby they conduct little or no current is said to have high resistance. This matter is called insulator. (eg: plastic)

- **Resistance is defined to be the ratio of the potential difference V between 2 points to the current passing through them.**

$$\boxed{R \equiv \frac{V}{I}}$$

UNIT: OHM = Ω

Ohm’s Law

Georg Ohm

- **Ohm’s law** states that ***the current flowing in a metallic conductor is proportional to the potential difference applied across it, provided that the physical conditions (such as temperature) remain unchanged / are constant.***
- Conductors ***which obey Ohm’s law*** are classified as ***ohmic conductors. Otherwise, is called non-ohmic conductors.***
- ***A resistance of a conductor that does not change with current is called ohmic conductor.***
- ***A resistance of a conductor that changes with the current is called non-ohmic conductor***.

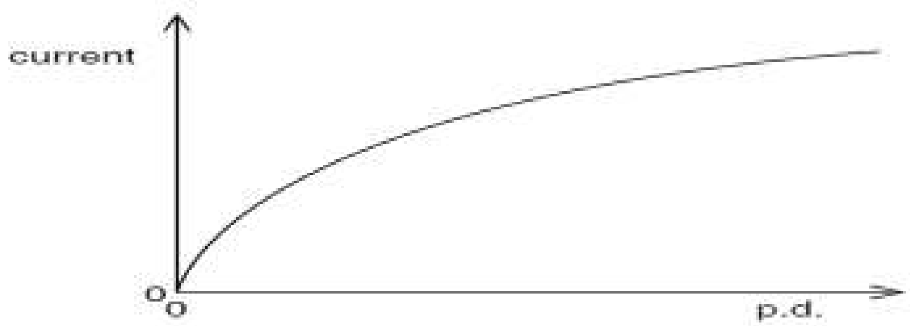
Example 7

- The current in a heater is 6.3 A when the potential difference across it is 12 V. Calculate the resistance of the heater.

- A small torch has a 3.0 V battery connected to a bulb of resistance 15Ω. Calculate the current in the bulb.

Example 8

- The graph shows how the current through a lamp filament varies with the potential difference across it.



Which statement explains the shape of this graph?

A As the filament temperature rises, electrons can pass more easily through the filament.

B It takes time for the filament to reach its working temperature.

C The power output of the filament is proportional to the square of the current through it.

D The resistance of the filament increases with a rise in temperature.

I-V characteristic curves of various conductors

- ***A resistance of a conductor that does not change with current is called ohmic conductor.***

- ***A resistance of a conductor that changes with the current is called non-ohmic conductor***. These materials include semiconductors (e.g. diode, thermistor) and lamp filament.

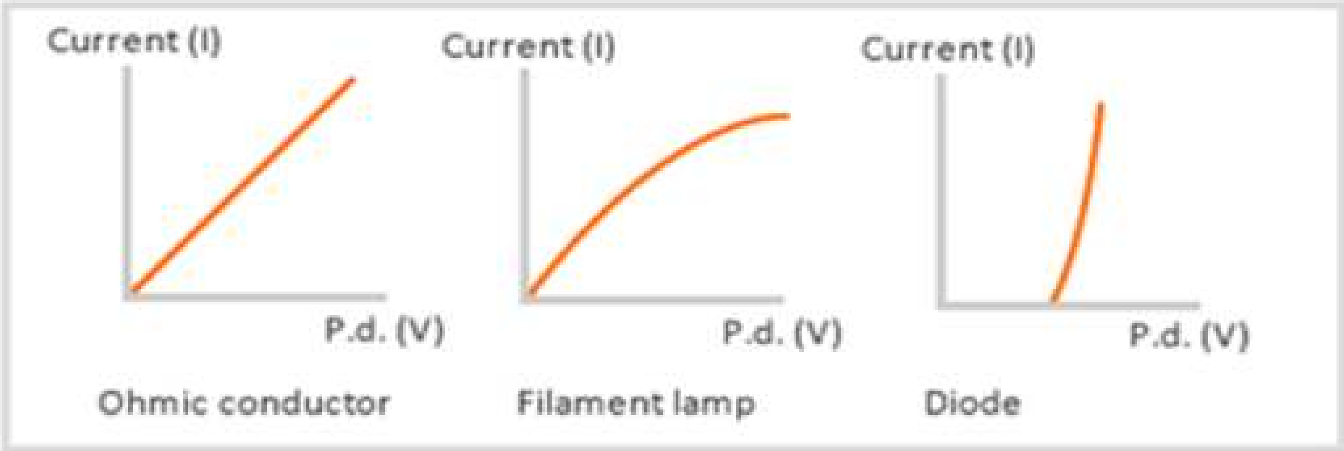
- We will look at the I-V characteristics for:

  1.) Conductor with constant temperature.

  2.) Semiconductor Diode.

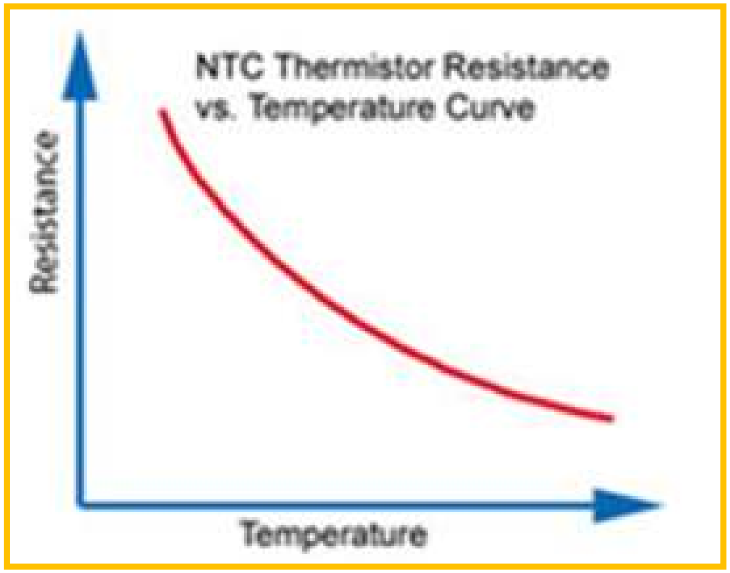
  3.) Filament Lamp / Bulb.

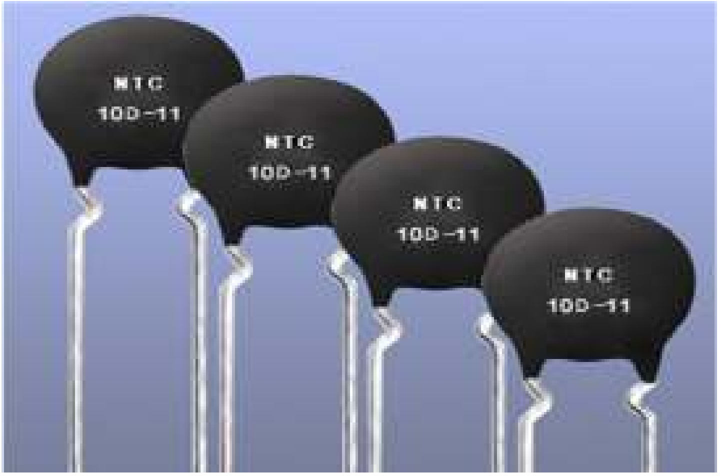
I-V characteristic curves of various conductors



- **An ohmic conductor** has an I-V graph which is just a straight line through the origin. This shows that the current flowing through them is directly proportional to the p.d. across them. Obeys ohm law.
- **A filament lamp** does not obey ohms law as the resistance does not remain constant to due an increase in heat at higher voltages. However, for small voltages and currents, the graph is approximately a straight line.
- **A diode** only allows current to flow in one direction and only then it will only let current pass until a certain minimum voltage has been reached. However small increases in voltage after the minimum voltage result in large increases in current.

Temperature characteristic of thermistors





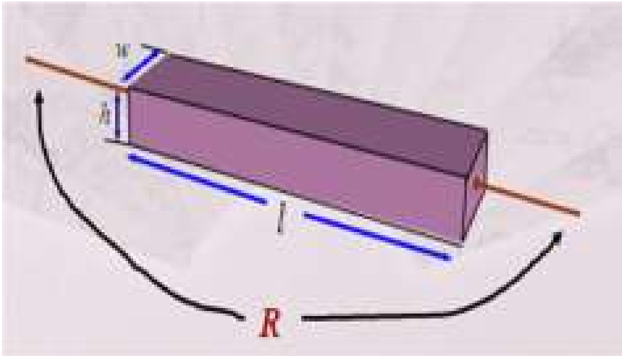
- Also known as thermal resistor.
- This device is designed to have a resistance which changes rapidly with temperature.
- One of the common type of thermistor is called negative temperature coefficient (NTC) thermistors.
- The resistance of the NTC thermistor decreases approximately exponentially with increasing temperature.

Resistivity

- All materials have some resistance to the flow of charge, but depends on the type of material.

- The ***longer a wire***, the ***greater the resistance*** as the charges have to go through a greater path. i.e. resistance is proportional to the length of wire or $\boldsymbol{R \propto L}$

- The ***thicker a wire*** is, the ***smaller its resistance*** since there is a bigger area for the charges to travel through. i.e. resistance is inversely proportional to the cross-sectional area of the wire or $\boldsymbol{R \propto 1/A}$



- Putting it all together gives the expression, $\mathbf{R = \rho L/A}$ where ρ is a constant for a particular material at a particular temperature called the **resistivity.**

Resistivities ρ, of some materials

Metals

- Silver = $1.6 \times 10^{-8}\ \Omega m$
- Copper = $1.7 \times 10^{-8}\ \Omega m$
- Gold = $2.4 \times 10^{-8}\ \Omega m$
- Aluminium = $2.8 \times 10^{-8}\ \Omega m$
- Iron = $9.8 \times 10^{-8}\ \Omega m$
- Constantan = $49 \times 10^{-8}\ \Omega m$ *, **alloy 60/40 Cu/Ni***
- Mercury = $96 \times 10^{-8}\ \Omega m$

Semiconductors

- Germanium = $0.6\ \Omega m$
- Silicon = $2.3 \times 10^{3}\ \Omega m$

Insulators

- Pyrex = $1 \times 10^{12}\ \Omega m$
- Glass = about $10^{12}\ \Omega m$

Example 9

- What length of constantan wire of diameter 0.40 mm has a resistance of 10.0 ohms? Assume that the resistivity ρ of constantan is 5.0×10^{-7} Ωm.

Example 10

- Determine the resistance of a 12.0 m copper wire that has a cross-sectional area of $3.31 \times 10^{-6}\ m^2$ [ρ Cu : $1.7 \times 10^{-8}\ \Omega m$]

- A 10.0 m long wire has a cross-sectional area of $3.3 \times 10^{-5}\ m^2$ and resistance of 5 mΩ. Determine the resistivity of the material of the wire.

Example 11

- When a potential difference V is applied between the ends of a wire of diameter d and length l , the current in the wire is I. What is the current when a potential difference of 2V is applied between the ends of a wire of the same material of diameter 2d and the length $2l$? Assume that the temperature of the wire remains constant.

Electrical power

- Power is the rate of doing work or of transferring energy
- Earlier we defined potential difference $V = W/Q$
- Dividing each term on the right by t, becomes $V = (W/t)/(Q/t)$
- But W/t is power P, and Q/t is current I. Thus $V = P / I$

- Rearrange the equation, we have $\mathbf{P = VI}$
- **This equation is commonly use to calculate power input / generated / supply.**

- By substituting $V = IR$, $\rightarrow$ $\mathbf{P = I^2R}$

  $I = V/R$, $\rightarrow$ $\mathbf{P = V^2/R}$
- **These 2 equations are commonly use to calculate power output / dissipated / loss.**

- By using a voltmeter to measure the potential difference across a component and an ammeter to measure the current through it, we can then calculate power dissipated in that component too. ($\mathbf{P = VI}$)

Example 12

- The current in a heater in a school experiment is 6.3 A when the p.d. across it is 12 V. Calculate the power of the heater.

- Determine the resistance of the heating element of an electric oven designed that produces a 4.0 kW of heat when connected to a 240 V source.

Example 13

- An electric iron absorbs 1100 W of power when a potential difference of 240 V is applied across it. Calculate the resistance of the electric current.

- Find the power dissipated in a 5 Ω resistor connected to a 12 V battery

Example 14

- How much power is dissipated in a a resistance of 10 ohm when a current of 0.10 A flows through it?

- A p.d. of 10 V falls across a resistance of 10 ohm. What is the power dissipated?

Internal Resistance, r & Terminal Potential Difference, V_t

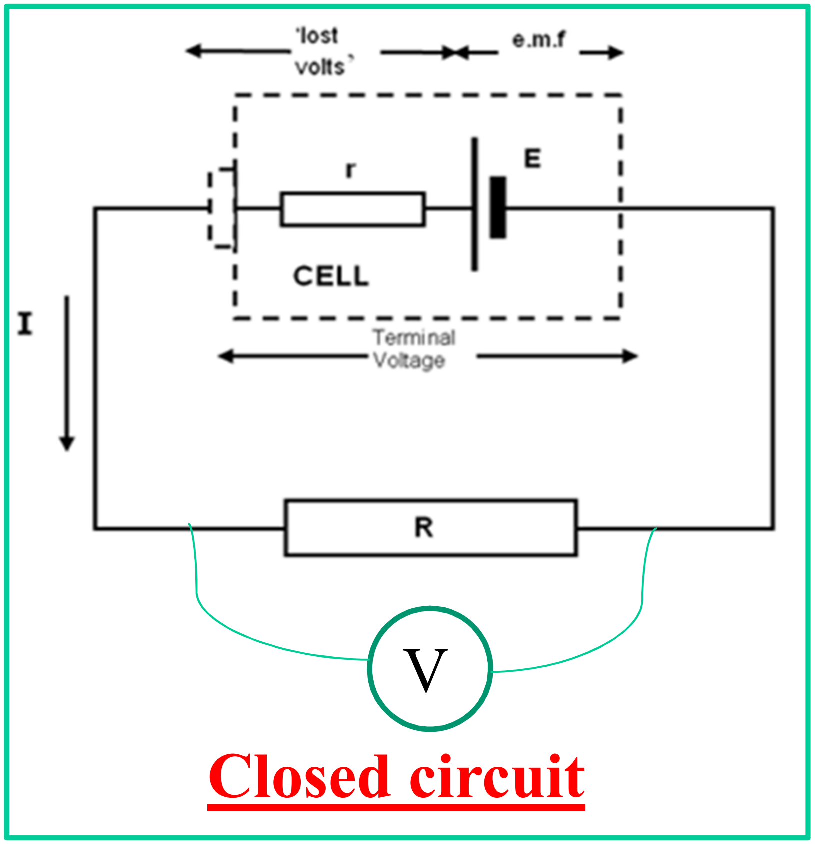
- All power supplies have some resistance between their terminals. The resistance within a source of emf is called its internal resistance.

  *Often the internal resistance in problems is assumed to be negligible.
- As charges travel through the source emf, it gains a lot of energy but loses some of it to this internal resistance.
- Due to internal resistance, the ***terminal potential difference is always lesser than the emf.***
- Hence $\boldsymbol{E = IR + Ir}$

$$\boldsymbol{E = V_t + V_r}$$

where R = total external resistance, V_t = terminal p.d.
r = internal resistance, V_r = p.d. across internal resistance.

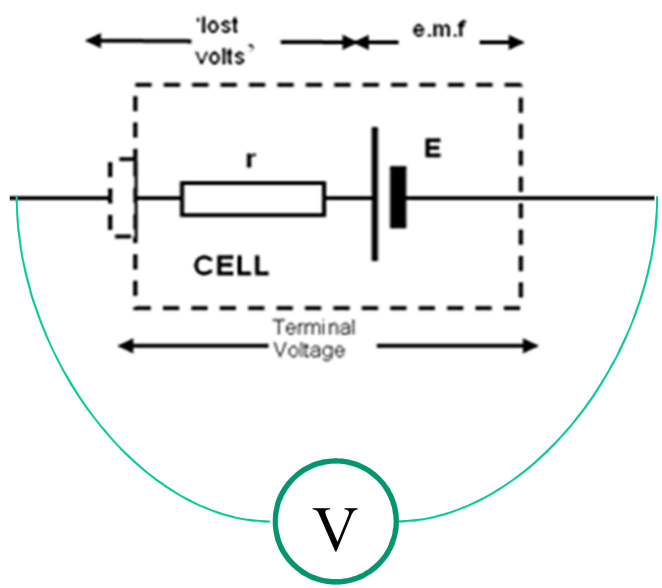
Internal Resistance, r &
Terminal Potential Difference, V_t



- Connecting a voltmeter across the resistor will give a reading of the potential difference across the resistor when a current flows in the circuit.
- $E = V_t + V_r \quad \longrightarrow \quad V_t = E - V_r$
- The terminal p.d. value, V_t is less than the emf, which means not all energy supplied per coulomb by the cell is available to the external circuit.
- Some energy has been "lost" in driving the current through the source's internal resistance (r)
- Some voltage has drop or fall, V_r

- For each coulomb of charge,
  (energy supplied by cell) = (energy dissipated in R) + (energy dissipated in cell)
  i.e : (emf) = (terminal p.d.) + (lost volts)

Internal Resistance, r & Terminal Potential Difference, V_t



Open circuit

- Connecting a voltmeter across the terminal of the cell in an open circuit will give a reading of the potential difference which is same as the emf.
- There is no current flows in an open circuit.
- $V_t = E - V_r \quad ; V_r = Ir \quad ; I = 0\ A$
  $V_t = E - (0)r$
  $V_t = E$

Example 15

- A battery of e.m.f, 1.50 V has a terminal p.d. of 1.25 V when a resistor of 25 Ω is connected to it.

  Calculate the (a) current flowing,

  (b) the internal resistance *r*

  (c) the terminal p.d. when a resistor of 10 Ω replaces the 25 Ω resistor.

Example 16

- A battery of emf 12.0 V and internal resistance 0.50 Ω maintains a steady current of 1.0 A in a circuit. Find the terminal voltage of the battery

- A dry cell delivering 0.5 A current has a terminal voltage of 1.47 V. What is the internal resistance of the cell if its open circuit voltage is 1.50 V?

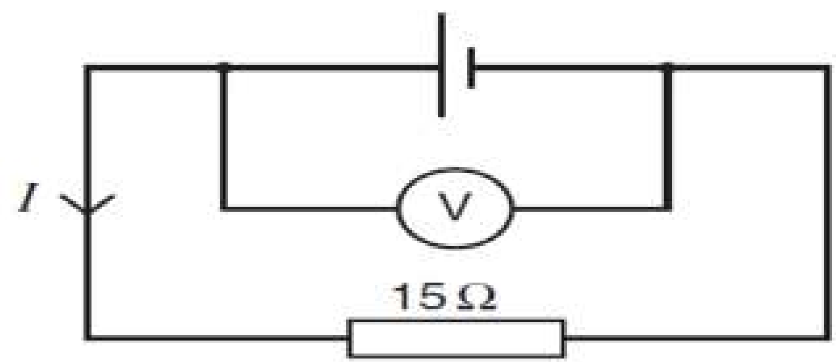
Example 17

- A 9.0 V battery is connected to a 10 Ω resistor. A voltmeter placed across the resistor measures 8.50 V. Determine the internal resistance of the battery.

- What is the terminal p.d. for a cell of emf 2V and internal resistance 1 ohm when it is connected to a 9 ohm resistor?

Example 18

- The e.m.f. of the cell in the following circuit is 9.0V. The reading on the high-resistance voltmeter is 7.5V.



- What is the current *I* ?

A 0.1A B 0.5A C 0.6A D 2.0A

Example 19

- The terminal voltage of a battery is observed to fall when the battery supplies a current to an external resistor. What quantities are needed to calculate the fall in voltage?

  A the battery's e.m.f. and its internal resistance

  B the battery's e.m.f. and the current

  C the current and the battery's internal resistance

  D the current and the external resistance

Effect of internal resistance on output power, P_o

- The **output power** P_o or **power dissipated** in a device when a current I flows across it is given by $\boldsymbol{P_o = VI}$

  where V = potential drop across the device

- The source **input power** P_i from the cell is given by $\boldsymbol{P_i = IE}$

- The **efficiency** $\boldsymbol{\varepsilon}$ in % is the energy conversion given by

  $$\boldsymbol{\varepsilon = P_o / P_i = IV / IE = V / E = (IR) / (IR + Ir)}$$

  $$\boldsymbol{\varepsilon = R / (R + r)}$$

- To obtain a higher efficiency, the total external resistance R should be very much greater than the cell's internal resistance r.

- Therefore ε tends towards 1 when R»r.

Example 20

- A battery of e.m.f. 9.00 V and internal resistance 0.50 Ω is connected to a 8.36 Ω resistor.

  Determine

  (i) the current in the circuit,

  (ii) the potential difference across the 8.36 Ω resistor,

  (iii) the power supplied to the 8.36 Ω resistor.