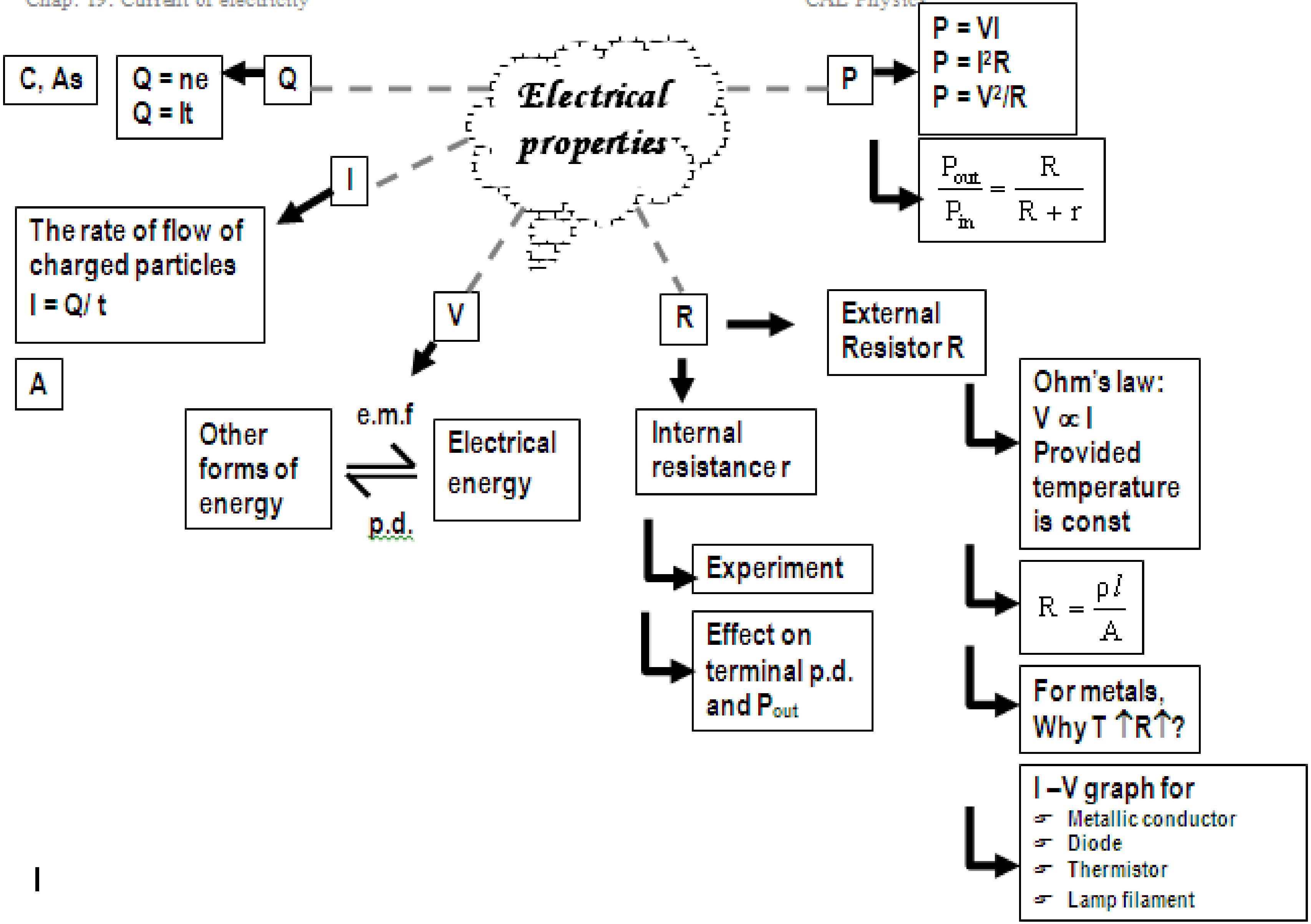
Chap 19 Current of Electricity

Lim WH 2012


Electrical properties
C, As
Q = ne
Q = It
Q
P
P = VI
P = I²R
P = V²/R
$\frac{P_{out}}{P_{in}} = \frac{R}{R + r}$
I
The rate of flow of charged particles
I = Q/ t
A
V
R
External Resistor R
e.m.f
p.d.
Other forms of energy
Electrical energy
Internal resistance r
Experiment
Effect on terminal p.d. and P_{out}
Ohm's law:
V ∝ I
Provided temperature is const
$R = \frac{\rho l}{A}$
For metals, Why T ↑R↑?
I –V graph for
Metallic conductor
Diode
Thermistor
Lamp filament

I

Current I

- It is defined as the rate of flow of charged particles.

$$I = \frac{dQ}{dt}$$

- Unit : Ampere (A)

➢ In metals, the majority charge carriers are __________. As they are delocalised and free to move. In electrolytes, e.g. salt solution, the carriers are ________ and ________ ions and in insulators, there is ____ charge carriers.

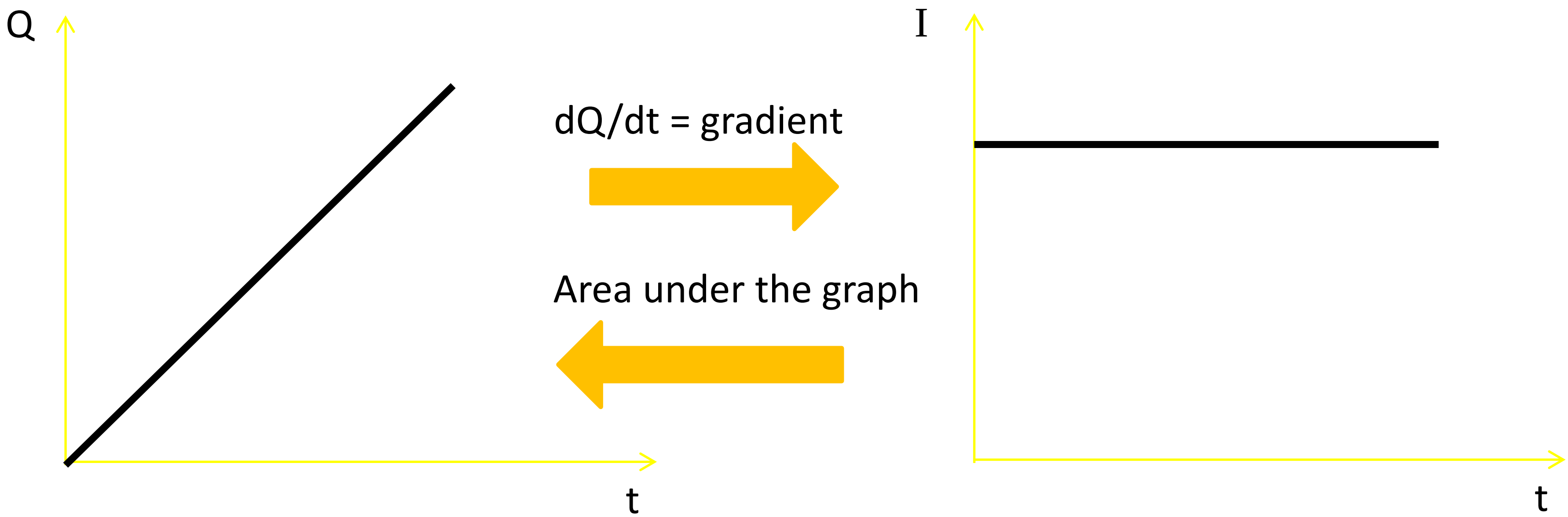
➢ The conventional current is in the __________ direction to the electron flow.

Charge Q

- Magnitude of charge Q flows past a point in a electric circuit in the time t when there is a steady/constant current I is given by the equation $Q = It$
- One coulomb is the charge crosses a section of a circuit in one second in which there is a current of one ampere.
- Elementary charge e = 1.6 x 10^{-19} C. It is the magnitude of charge on an electron or a proton.
- The magnitude of charge Q carried by n electrons is given by

  $Q = ne$.
- One coulomb of negative charge contains _________electrons.

Q & I



Examples

1. In 0.2 μs time, 3×10^6 electrons pass through uniformly a cross-sectional area of a conductor. Calculate the steady current flows through the conductor. [2.4μA]
2. A car battery supplies an electric current of 6 A for 1200 s.
   i. Assuming a steady current is supplied, find the total charge, which flows from the battery. [7200C]
   ii. An electron carries charge -1.6×10^{-19}C.
3. Determine the number of electrons passing through the battery during the 1200s. [4.5×10^{22}]
4. The current in a conductor is reduced uniformly from 90 mA to 60 mA over a period of 5.0 s. What is the charge that flows during this time? [375 mC]
5. An alpha particle consists of two protons and two neutrons. A given narrow beam of alpha particles carries a current of 4.5×10^{-7} A. calculate the number of alpha particles passing any point in the beam in one second. [1.41e12]

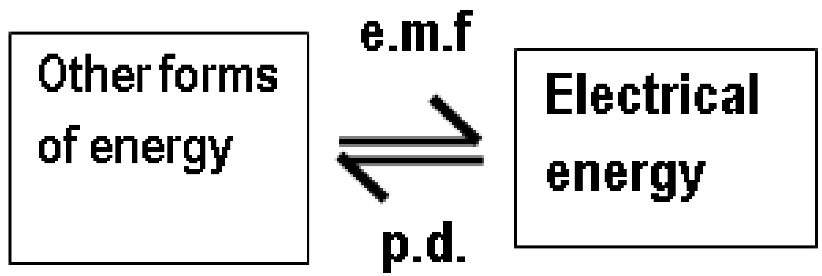
Potential difference p.d.

- **Potential difference (p.d),** V between two points in a circuit is defined as the energy per unit charge converted from electrical energy, W to other forms of energy when the unit charge Q passes from one point to other, i.e. $V=W/Q$
- OR work done to move a unit charge from one point to other.
- **A p.d. of 1 volt** is the electrical energy of 1 Joule per coulomb charge converted into other forms of energy when the unit charge Q passes from one point to other.

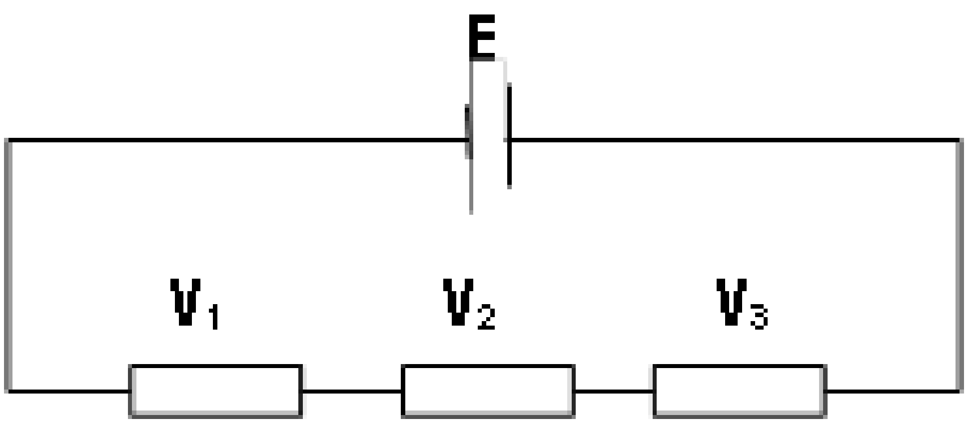
Electromotive force, e.m.f.

- **Electromotive force (e.m.f.),** E is defined as the energy per unit charge converted from other forms of energy to electrical energy when the unit charge Q passes through the whole circuit.
- OR work done to move a unit charge through the whole circuit.
- **An e.m.f. of 1 volt** is the electrical energy of 1 Joule per coulomb charge converted into other forms of energy when the unit charge Q passes from one point to other.
- In an open circuit, terminal p.d. ***V* = e.m.f.**

E.m.f. vs p.d.



energy per unit charge converted from …… to…….



Whole circuit	Between two points
e.m.f	p.d.

Examples

1. When a charge of 3000 C is supplied to a heater, all of its energy of 1500J is converted into heat. Calculate the p.d. across the heater. [0.5V]
2. 1.65×10^{19} electrons flow through a resistor that is connected to a 6 V accumulator. Find the electrical energy that is converted to heat energy in the resistor. [15.8J]
3. A cell of e.m.f. *E* delivers a charge *Q* to an external circuit. Which statement is correct?

   A. The energy dissipation in the external circuit is *EQ*

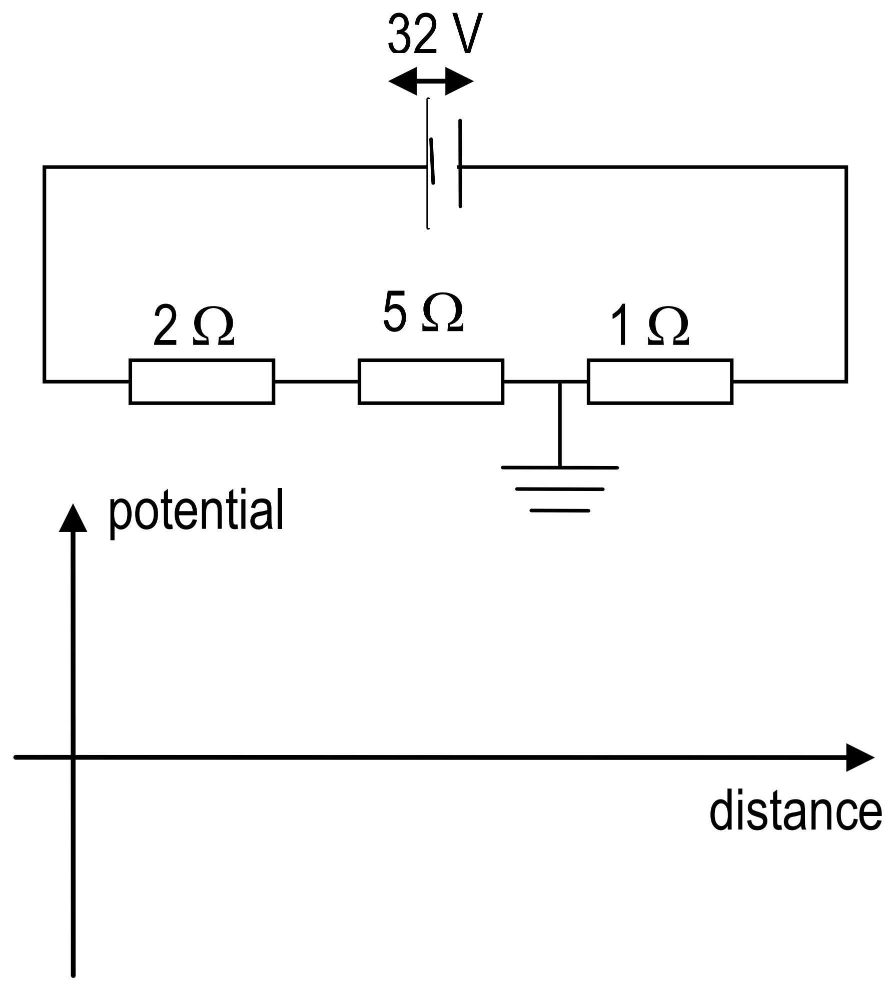
   B. The energy dissipation within the cell is *EQ*

   C. The external resistance is *EQ*

   D. The total energy dissipation in the cell and the external circuit is *EQ*

Potential vs potential difference

Sketch a graph to show the variation of potential along the resistors



Resistance R

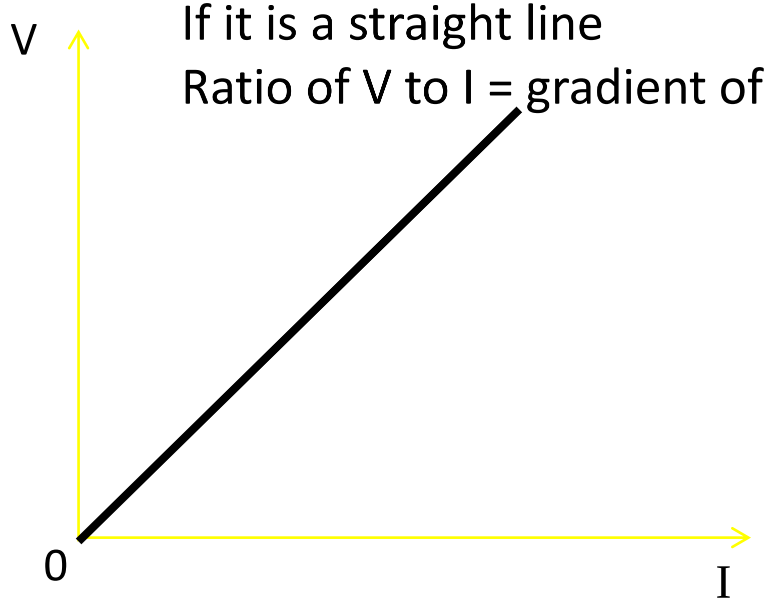
Ohm's law: p.d. across a conductor is ___________________________ to the current flows through it provided __________________ is constant.

Resistance of a material, R is the ratio of _____________________ across the material to the ______________ flowing through it, i.e. R=V/I

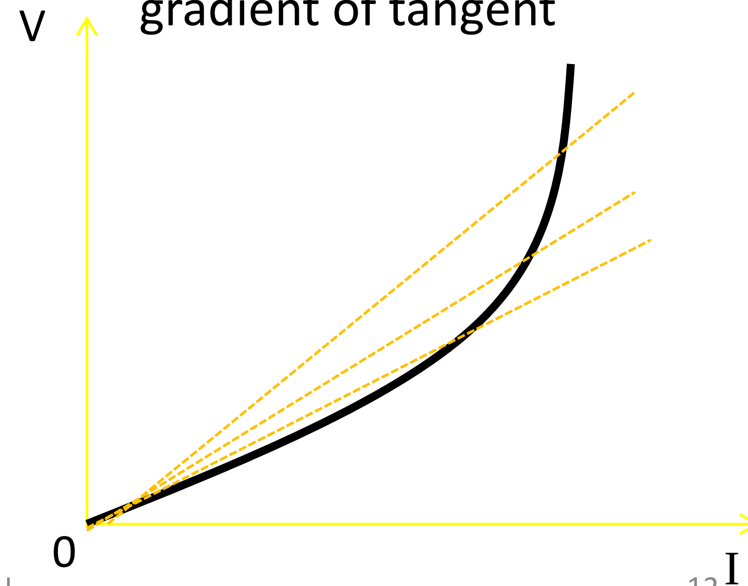
Unit :

If it is a straight line

Ratio of V to I = gradient of the line



$R \neq dV/dI$, not the gradient of tangent



For conductors, T↑ R↓

Temperature ↑
lattice absorbs KE and hence vibrates vigorously

The movement of the delocalised electrons is obstructed and hence is slowed down

The rate of flow of the electrons decreases

Current decreases or in other words resistance to the current increases.

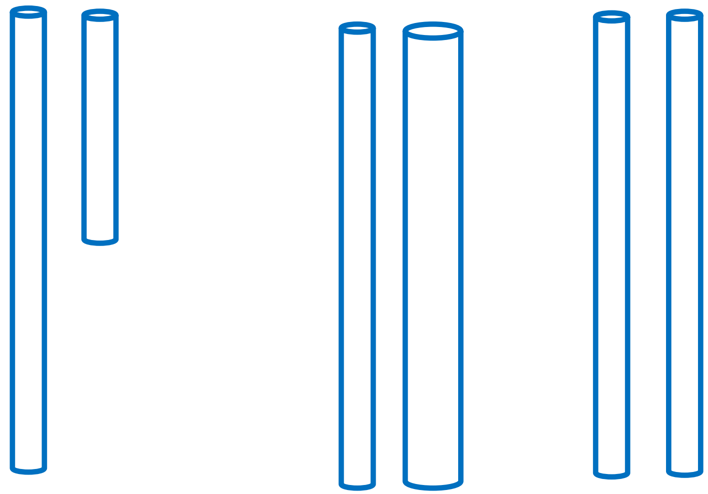
Resistance R

$$R = \frac{\rho l}{A}$$

Same material and diameter but different lengths

Same material and length but different diameters

Same length and diameter but different materials



examples

1. What length of a constantan wire of diameter 0.40mm has a resistance of 10.0 Ω?

   Taking the resistivity of the constantan wire as $5.0\times10^{-7}\,\Omega$m. [2.51m]

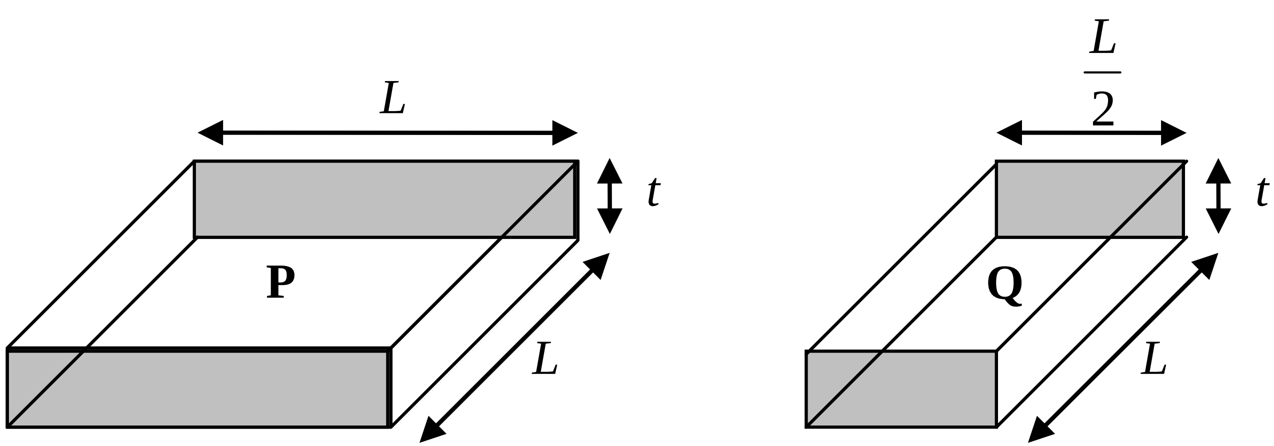
2. A metal wire is L metres long and has a diameter of d metres. Its resistance is measured as 100 Ω. What is the resistance of the same wire if its:
   i. length is halved, A const. [50]
   ii. diameter is halved, *L* const [400]

3. A conductor has a constant volume. What happens to its resistance R when it is rolled out such that its length is doubled?

example

Two conductors, **P** and **Q**, cut from a sheet of metal. **P** and **Q** have dimensions as shown in the diagram. The resistances of the conductors, R_P and R_Q, are measured between the opposite faces shaded in the diagram.

What is the value of R_P / R_Q?



Power, P

- The rate of energy conversion
- Or Work done W per unit time
- P = dW/dt
- Unit : Watt (W)
- Power P supplied by a generator or battery, P =VI
- Heat power P dissipated due to resistance R P = V^2/ R or P= I^2R

$$P = \frac{W}{t}$$

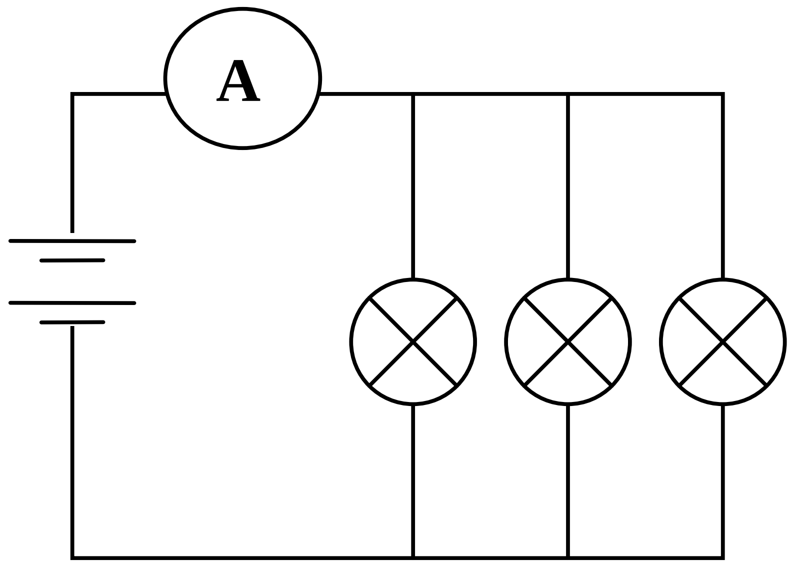
$$= \frac{VQ}{t}$$

$$= \frac{V(It)}{t}$$

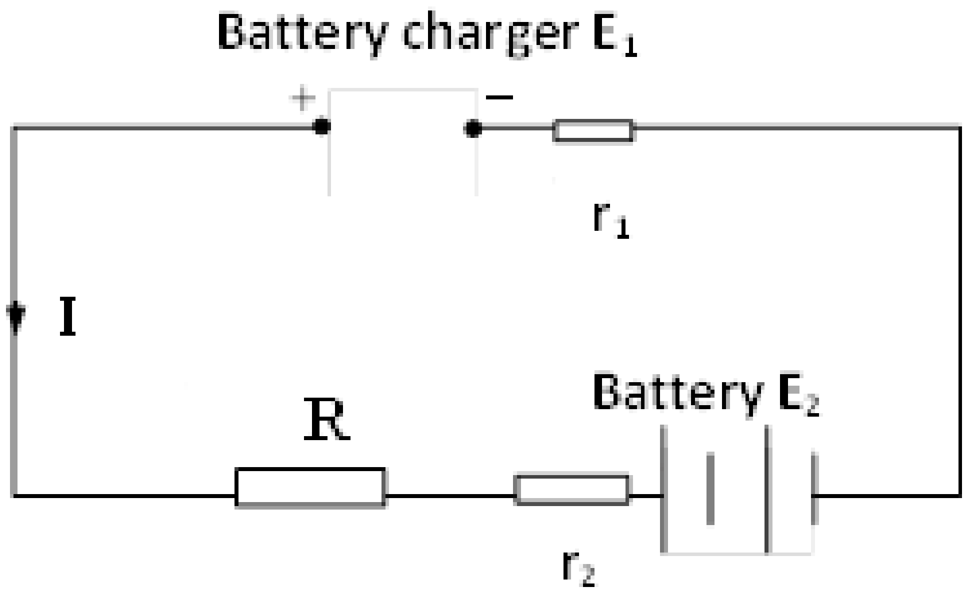
$$= VI$$

Example

Three identical bulbs are connected in parallel to a constant voltage. What happens on the brightness of the remaining bulbs and ammeter reading when the filament of one of the bulbs breaks?



Charging circuit



Power supplied by charger

$P = VI = E_1 I$

Power dissipated by all resistance

$P = I^2 R_T$

Chemical power stored

= power supplied – eat power dissipated

$= E_2 I$

Examples

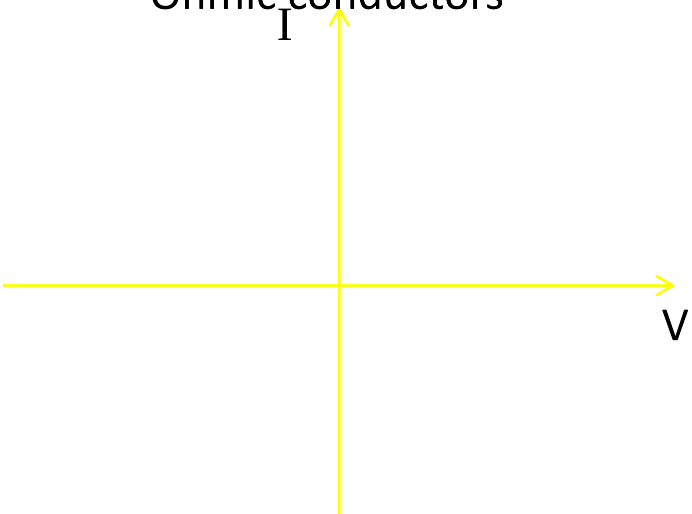
1. A light bulb is marked “ 240V, 60W ” it is switched on for 5000s.
   i. Explain the label of “ 240V, 60W ”.

   Assuming the bulb is being used correctly, calculate:
   i. the total energy converted by the bulb from electric energy [300kJ]
   ii. charge supplied to the bulb [1250C]
   iii. the steady current [0.25A]

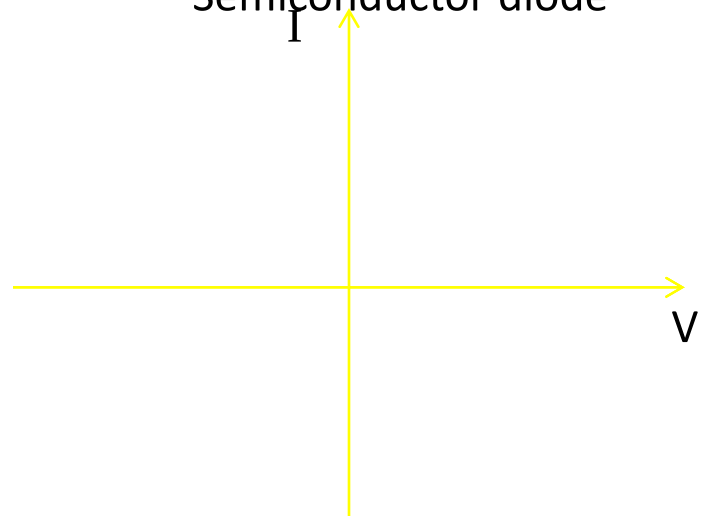
2. A battery of e.m.f. 12.0 V and internal resistance 0.60 Ω is connected to a resistor of 7.4 Ω. Determine:
   i. The current in the circuit [1.5A]
   ii. The potential difference across the 7.4Ω resistor [11.1V]
   iii. The power supplied to the external resistor [16.7W]
   iv. Fraction of the total power is delivered to the resistor [0.925]
   v. What is the value of the external resistance if the power delivered is to have a maximum value? [0.60Ω]

I-V graphs

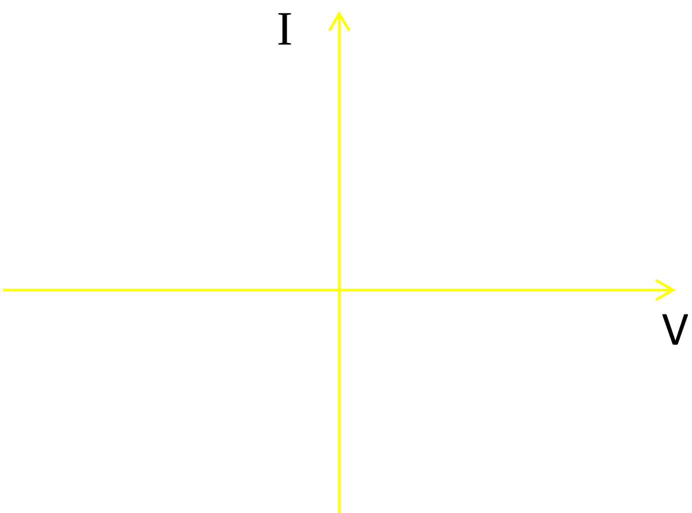
Ohmic conductors



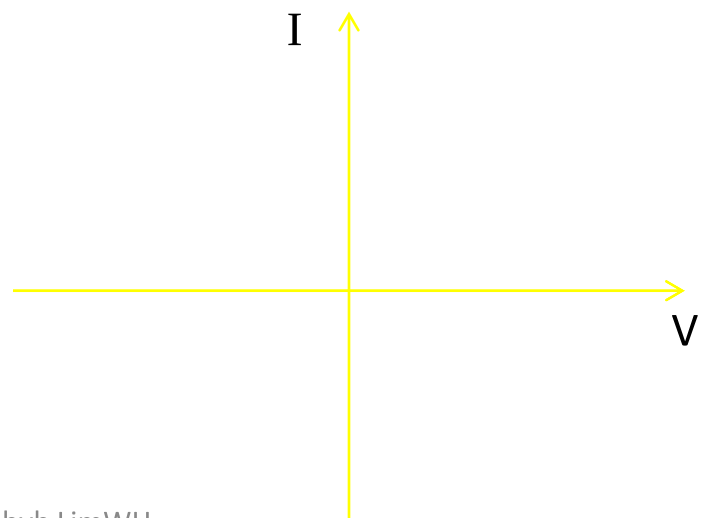
Semiconductor diode



thermistor



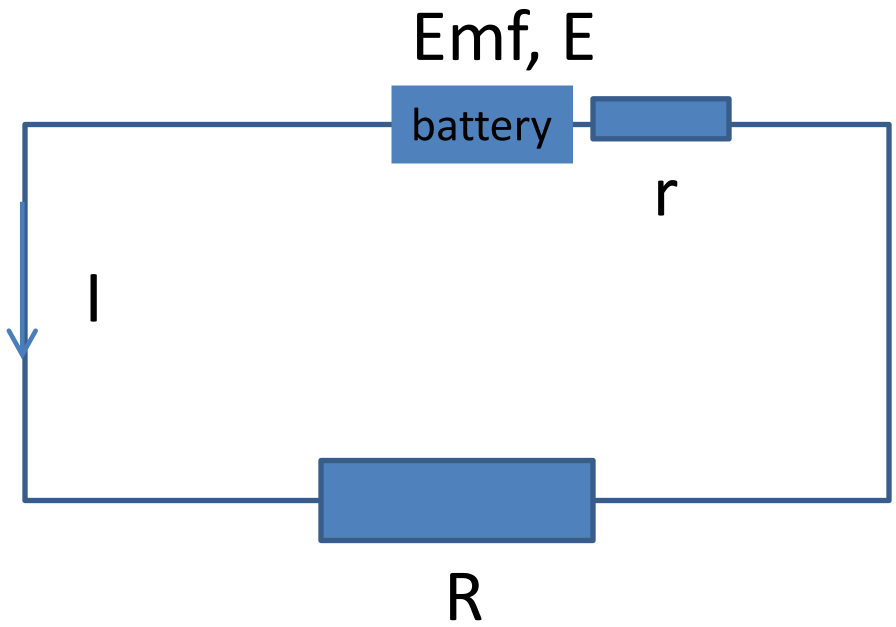
Lamp filament



Internal resistance, r

- **Internal resistance**, *r* is electrical resistance due to the __________ between the electrons (charge carriers) and particles in the chemical mixture of a cell/ battery when the electrons are re-supplied energy and being brought from negative to positive terminals.
- Therefore, not all the energy supplied to an electron inside the battery is delivered to the external circuit. A portion of energy is dissipated as __________ due to the resistance in the battery.
- Therefore, the terminal potential difference of a battery ***V*** is normally _______than the battery's e.m.f. ***E***

$$V = E - I\,r$$



$P_{\text{supplied by battery to all resistance}} = I^2 (R+r)$

$P_{\text{delivered to R}} = I^2 R$

$P_{\text{delivered to r}} = I^2 r$

Fraction of power input delivered to R = R/ (R+r)

Internal resistance, r

- Because of the internal resistance, power delivered to the external resistor is reduced. The fraction of power input bing delivered to the external resistance R is given by _________.
- Thus, with the internal resistance r, the output voltage & the output power are lower hence a lower efficiency.
- Power output is max when R =___ .

Experiment to measure internal resistance r & emf E

1. A cell under test is. connected in series with an ammeter, a fixed resistor R and a rheostat.
2. A high-resistance voltmeter is connected across the terminals of the cell to measure the terminal p.d. of the cell.
3. The rheostat is adjusted to alter the current I in steps.
4. For a particular current I, terminal p.d. V is recorded from the voltmeter.
5. Steps 3 – 4 are repeated until six sets of data are obtained.
6. A graph of V vs. I is plotted

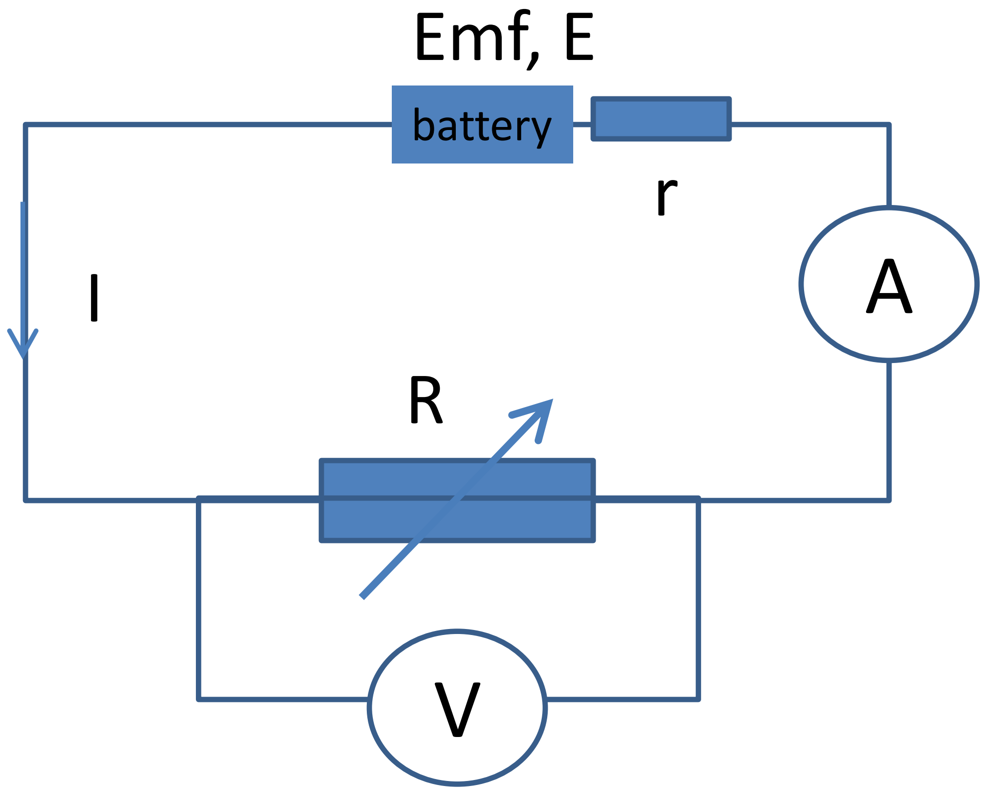
Questions

1. Explain how the e.m.f. E and the internal resistance r of the cell can be determined from this experiment.
2. If a voltmeter is connected across the fixed resistor R, sketch a graph to show the variation of the reading from this voltmeter with current.
3. Suggest a reason why a fixed resistor is included in the circuit.
4. Show that Fraction of power input being delivered to the external resistance R is given by R/(R+r).
5. Show that the power output across the fixed resistor R is the max when …… (not in syllabus)

Power output is max when R=r

the derivation is not in the syllabus

- $P_{\text{delivered to R}} = I^2 R$; where $I = E/(R+r)$
- with the same emf, higher R, lower I.
- Since Both R and I are variable, so I is replaced with $E/(R+r)$
- $P_{\text{delivered to R}} = [E/(R+r)]^2 R$; where E and r are constants.
- $P_{\text{delivered to R}} = [E/(R+r)]^2 R$
- Solve $dP/dR = 0$, one will get $R=r$



- R is increased, voltmeter V and ammeter I readings are taken for each R.
- power output P= VI is calculated.

- A graph of output power P vs. R is plotted.