EDEXCEL NATIONAL CERTIFICATE/DIPLOMA
SCIENCE FOR TECHNICIANS

OUTCOME 2 - ELECTRICAL PRINCIPLES

TUTORIAL 1 – ELECTRICAL ENERGY

2 Electrical principles

Electrical energy: electric charge, charged conductors, conductors and insulators, resistivity and resistance, potential difference, electro-motive force, voltage, current

Dc circuits: Ohm's law, current, voltage and resistance in a simple circuit, series and parallel circuits, combined series/parallel circuits, Kirchoff's laws, elementary electrical power formulae

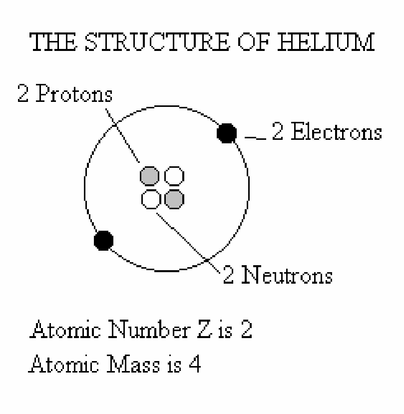
Magnetism: permanent magnets and magnetic fields, magnetic effect of a current, electromagnets, electro-magnetic induction, transformers, Lenz's and Faraday's laws, generator principle, motor principle

You should judge your progress by completing the self assessment exercises. These may be sent for marking at a cost (see home page).

On completion of this tutorial you should be able to do the following.

- Explain Electric Charge.
- Define Current.
- Define Power
- Define Voltage, Potential Difference and Electro Motive Force
- Define Resistance and Resistivity
- Define Conductance and Conductivity

1. CHARGE AND ENERGY



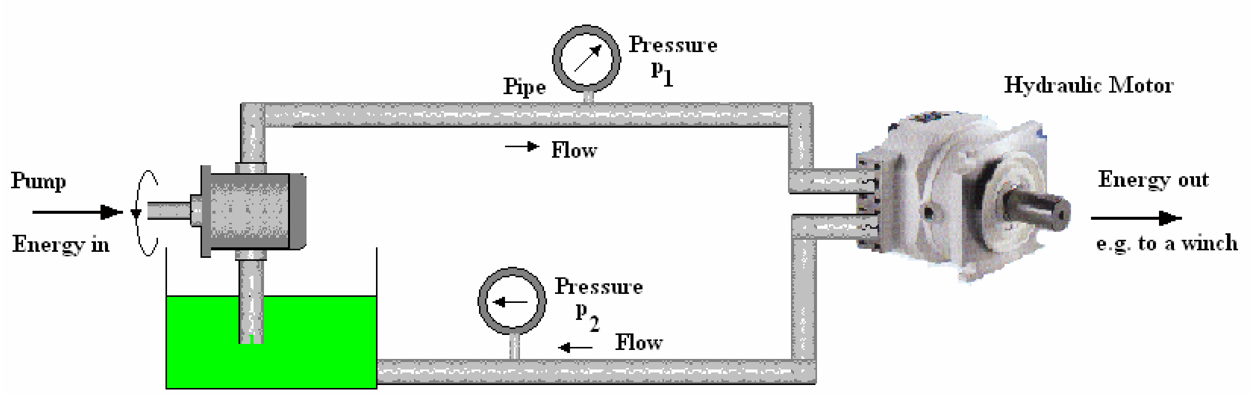
All substances are made up from atoms. An atom is made from three sub-atomic particles called electrons, protons and neutrons. The protons and neutrons are large compared to the electrons and clumps together to form a nucleus. The protons carry a positive charge of electricity. The electrons carry a negative charge of electricity and they orbit the nucleus at various distances and form spherical shells.

The electrons can be made leave the atoms and flow either through a vacuum as in a Cathode Ray Tube or they can be made to jump from one atom to another and flow through a material as in a copper conductor. A flow of electrons is called an electric current.

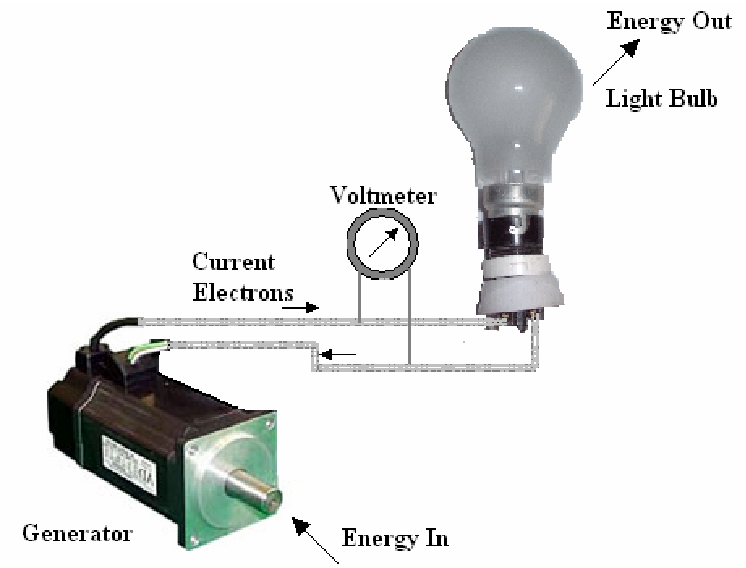
Each electron carries a small amount of energy equal to 160.25×10^{-21} Joules per Volt. The flow of electricity transfers energy from one place to another rather like how a flow of liquid can transport energy from one place to another. It is useful to make an analogy with fluid flow here.

ANALOGY

The hydraulic system shown has a pump that requires energy to drive it. The pump drives liquid along a pipe to a hydraulic motor where the energy is given up for example to drive a winch. The energy has been transported along the pipe. The pump has to overcome pressure p_1 in order to drive the motor. The amount of energy delivered depends both on the pressure and the flow rate. In fact the hydraulic energy is given by E = pressure x volume of liquid.



Now consider the electrical system. A generator drives a current of electrons along the conductor to the light bulb where the energy is converted into heat and light. Energy must be put into the system at the shaft of the generator and this is carried through the conductor to the light bulb. The generator (could be a battery) must produce a voltage to overcome the resistance of the light bulb. The amount of energy transported depends on both the voltage V and the quantity of electrons Q (called the charge).



Note the analogy:- Voltage with Pressure and Current with Flow rate.

The total energy per volt is called the CHARGE (Q) and this is measured in Coulombs.
Electrical energy = Charge x Volts = Q V

The charge transferred per second is called the CURRENT (I) and this is measured in Amperes (A).
Current = Charge/second = Q/time = I Amps. 1 Amp = 1 Coulomb per second.

The energy transferred per second is the power so electric power measured in Watts. It follows that electric power is given by:
P = Q V/time = Voltage x Current = V I

WORKED EXAMPLE No. 1

A current of 5 Amperes flows in a conductor at 12 volts.
Calculate the power transfer and the charge used in 60 seconds.

SOLUTION

P = V I = 12 x 5 = 60 Watts
Q = I x time = 5 x 60 = 300 Coulombs

SELF ASSESSMENT EXERCISE No. 1

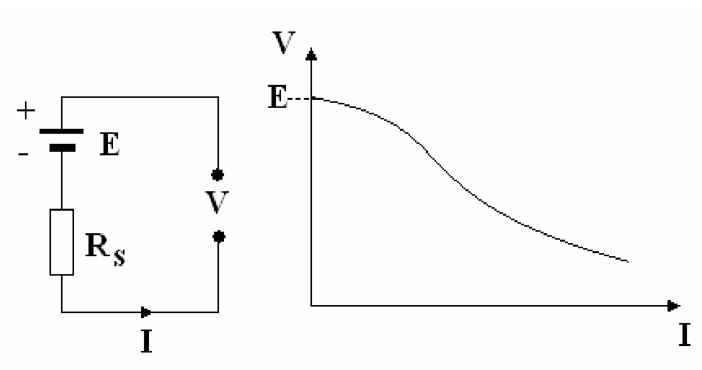
1. A charge of 500 Coulombs flows through a conductor in 200 seconds. What is the average current? (2.5 A)
2. A Battery holds a charge of 2000 Coulombs at a potential of 12 Volts. What is the energy stored? (24000 Joules)
3. A light bulb consumes 100 Watts of power at 24 Volts. What is the current? (4.17 A)

2. **ELECTRO MOTIVE FORCE - E**

When direct current is supplied to a circuit, it must come from a source. This will be a battery, mains power supply or a generator. The current flowing from the terminals must pass through the internal parts of the source and this will have a resistance called the internal resistance R_s. When a current I flows, there will be a voltage drop inside the source given by I R_s.

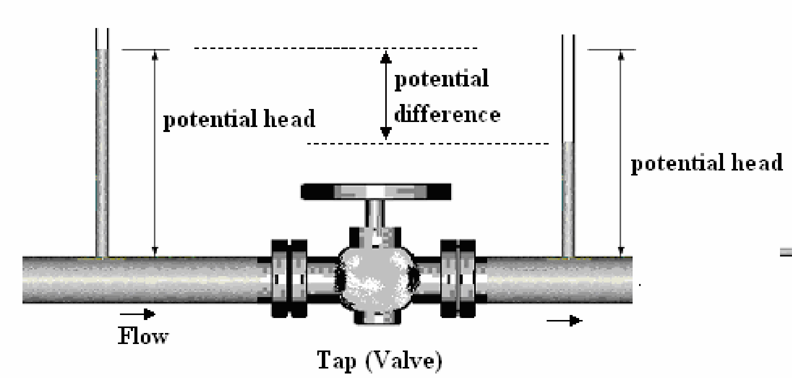
When the current is zero, the terminal voltage will be the maximum possible from the source and this is the Electro-Motive Force (e.m.f). The symbol used is E. We define the e.m.f. as the ideal voltage of the source. We can measure the e.m.f. by measuring the terminal voltage with a volt meter that draws negligible current.

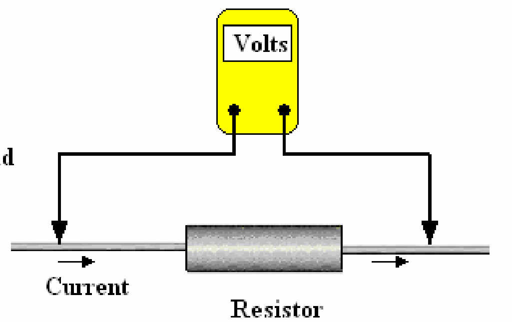
If the e.m.f. is E then the terminal voltage will be $V = E - I\,R_s$. If we measure the terminal voltage of a battery for various currents and plot the results we get something like the graph shown. E is the value at zero current. The graph may not be straight and this indicates that the internal resistance is not constant. A good quality battery will have a low internal resistance and is capable of delivering high currents.



3. **POTENTIAL DIFFERENCE - p. d.**

This is another term for voltage difference and it comes about by analogy with a hydraulic system. The diagram shows how potential difference can measured over a tap with fluid flowing through it. The vertical tubes measure the potential height and the difference is the potential difference. In the same way the voltage difference can be measured between two points in an electric circuit such as either side of a resistor as shown. The term potential difference or p.d. is often used to mean the voltage difference.





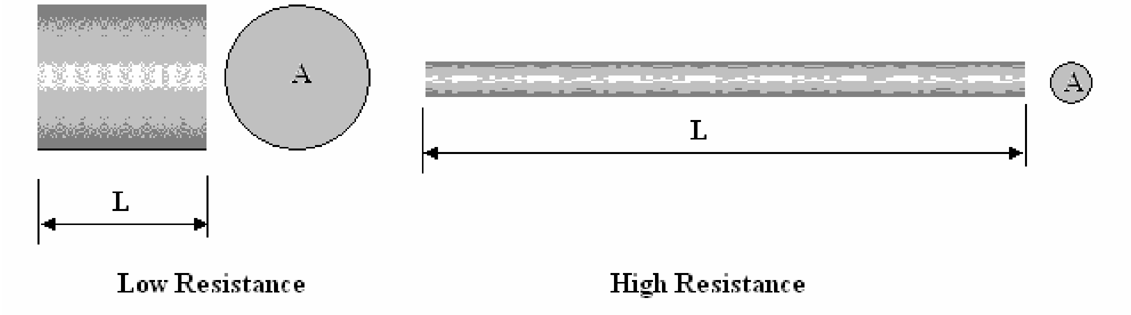
4. RESISTANCE AND CONDUCTION

Some materials such as copper have atoms with a large number of orbiting electrons so electrons jump easily from one to another. Silver is the best conductor but too expensive to use for wires. Other materials have few electrons (e.g. polymers and glass) so they do not conduct electricity very well. In order to make electricity flow along a conductor, a force is needed to make them jump from one atom to another. This is the voltage or potential difference.

The resistance of a conductor increases with length L and decreases with cross sectional area A so we may say R is directly proportional to L and inversely proportional to A.

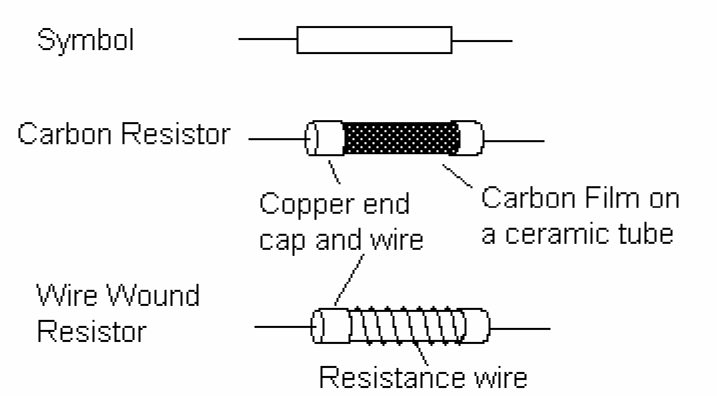
R = Constant x L/A   measured in Ohms Ω
The constant is the resistivity of the material ρ hence:-   **R = ρL/A Ohms.**
The diagram illustrates the difference between a short fat conductor and a long thin conductor.
In terms of conductance
G = Constant x A/L measured in Siemens (S)
The constant is the conductivity of the material σ hence:-   **G = σ A/L   Siemens.**
It follows that G = 1/R and σ =1/ρ

The diagram illustrates the difference between a short fat conductor and a long thin conductor.



RESISTORS

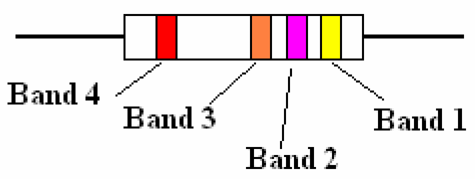
Electrical resistance is rather like friction and it causes energy to be lost as heat since voltage is wasted in overcoming it. This is put to use in things like the heating element of an electric fire or kettle. Electrical conductors need to have the lowest resistance possible so copper is commonly used as Silver is too expensive. Resistors are components deliberately made to have specified resistance for use in electronic circuits. The following is a brief description of resistors.



The most common form of construction is a ceramic tube coated in a resistor material. This may be a carbon film, a metal oxide film or a metal film. The resistors are generally larger for higher wattage ratings. The wire wound resistor is generally used for high heat dissipation rates. The heat produced by resistors may cause the resistance value to change and affect the electronic circuit of which it is a part. The type and size must be chosen carefully to suit the application.

COLOUR CODE

Band 1 represents the first digit.
Band 2 represents the second digit.
Band 3 represents the number of zeros following the second digit.
Band 4 represents the tolerance and has the following codes.



Black	0	Green	5
Brown	1	Blue	6
Red	2	Violet	7
Orange	3	Grey	8
Yellow	4	White	9

None ±20% Silver ±10% Gold ±5% Red ±2%

For example a colour code of yellow, Violet and Orange would translate into 47000 Ω or 47 kΩ.

WORKED EXAMPLE No. 2

Calculate the resistance of an Aluminium wire 0.2 mm diameter and 20 m long given the resistivity is $2.65 \times 10^{-8}\ \Omega$ m

SOLUTION

$A = \pi D^2/4 = \pi \times 0.0002^2/4 = 31.42 \times 10^{-9}\ m^2$
$L = 20$ m
$\rho = 2.65 \times 10^{-8}\ \Omega$ m

$R = \rho L/A = 2.65 \times 10^{-8} \times 20/31.42 \times 10^{-9} = 16.87\ \Omega$

SELF ASSESSMENT EXERCISE No. 2

1. Calculate the resistance of a copper wire 5 m long and 0.3 mm diameter. The resistivity is 1.7×10^{-8} Ohm metre. (Answer 1.202 Ω)

2. Calculate the resistance of a nichrome wire 2 m long and 0.2 mm diameter given $\rho = 108 \times 10^{-8}$ (Answer 68.75 Ω)