Electric Circuit Model

5.2.1 Describe a simple model of electrical conduction in a metal

A metal can be viewed as lattice of positively charged ions in a sea of negatively charged electrons. Some of the electrons in a metal are free to move, the electrons that are free to move are the electrons that form an electrical current.

The free electrons are moving in the metal at high speeds, as high as 106 ms−1, as they move they also collide with the positively charged ions. The net of effect of all the collisions is zero electron movement, i.e. no current.

When there is a potential difference across a conductor the result is an electric current, i.e. a net flow of electrons in the conductor. Due to all the collisions the actual speed of an average electron though a conductor is very low. It has been estimated that the average speed for an electron is on the order of 10−4 ms−1. The speed of an electron through a conductor is called the drift velocity. As the electron collides with the positive ions it gives up its energy and the conductor heats up.

5.2.2 Define electric current

An electric current is a net flow of electrically charged particles, it can occur in solids, liquids, or gases. Electric current is a fundamental unit in physics. Current is measured in Amperes and is defined as:

"One ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed one meter apart in vacuum, would produce between these conductors a force equal to 2 × 10−7 Newton per meter of length"

How’s that for a definition?

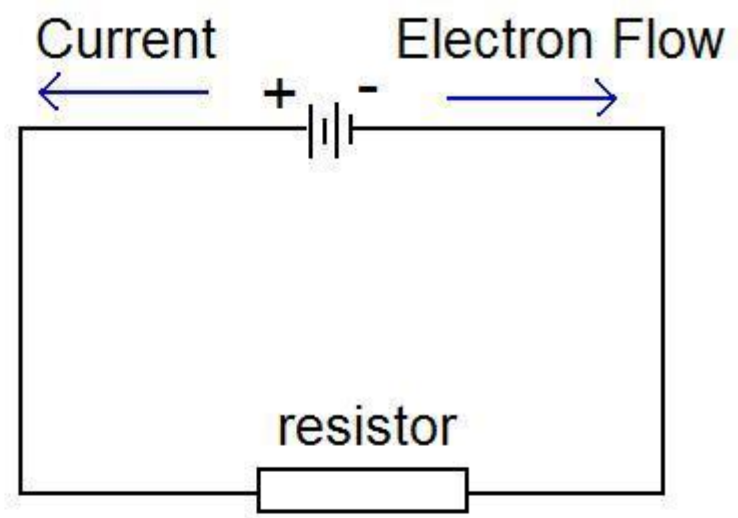
In general current is defined as the rate as which charge flows:

(1)

$$I = \Delta q / \Delta t$$

Where I is the current, q is the charge and t is time. Current is defined as flowing from positive to negative potential, this is a bit unfortunate because electron flow is from negative to positive…

For example in a simple circuit with a battery and a resistor:



5.2.3 Define and apply the concept of resistance

Some materials allow current to flow more easily than others. The measure of how easily current flows is called**resistance.** The resistance is defined as:

(2)

$R = V / I$

Where V is the potential voltage across an object and I is the current passing through he object. This is a general definition of resistance and is not a restatement of Ohm's Law that will be described below.

5.2.4 State Ohm's law

5.2.5 Compare ohmic and non-ohmic behavior

"Provided the physical conditions such as temperature are kept constant, the resistance is constant over a wide range of applied potential differences, and therefore the potential difference is directly proportional to the current flowing"

Mathematically this is represented as:

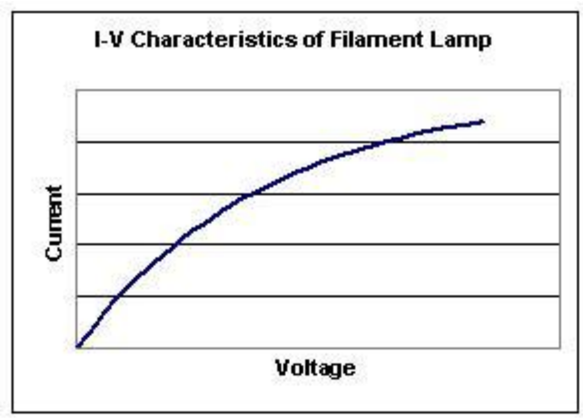
(3)
$V / I = constant$

This relationship is a generalization and does not apply to all materials. A material that obeys Ohm's law is called an ohmic material, if a material does not obey Ohm's law it is called a non-ohmic material.

Ohmic behavior is defined as a linear relationship between the potential across an object and the current flowing through it. If the relationship is not linear, then the behavior is non-ohmic.

Example of Non-Ohmic Behavior:

Current vs. Voltage for a filament lamp



As the voltage across the filament lamp increases the current increases, but it does not do so linearly. You need to know this and be able to sketch this graph for the IB exam!

5.2.6 Derive and apply expressions for electrical power dissipation in resistors

All electrical components use energy, the rate at which they use energy is said to be the electrical power used by the device or component.

Starting with the basic definition of power:

(4)
$P = W / t$

Then using the previous result for the work done:

(5)
$W = Vq$

We know that current is charge per unit time:

(6)
$I = q / t$

So we can say:

(7)
$P = Vq / t = IV$

Using the definition of resistance:

(8)
$R = V / I$

We can define power in a total of three different ways:

(9)
$P = IV = I^2 R = V^2 / R$

This last formula is in your IB formula handbook. The unit of electrical power is the same for mechanical power, the Watt, defined as one Joule per second.

5.2.7 Define electromotive force

Electromotive force is a deceptive term. It refers not to a force but to the voltage or potential provided by a electrical source. If a question asks for the e.m.f. of a battery or power source, it is simply asking for the potential difference generated, created by, or across the leads of the source.

The term electromotive force is historical, so just remember the name and don't think of it as a force.

5.2.8 Describe the concept of internal resistance

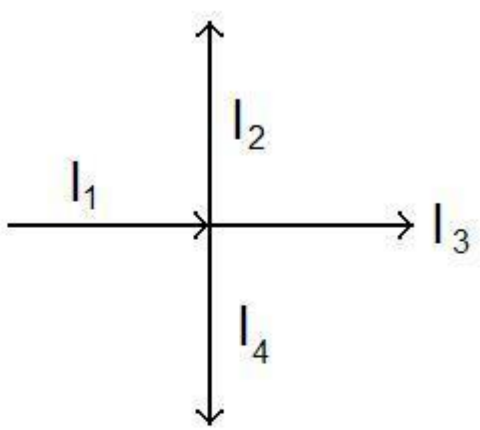
Every electrical element no matter how well made is not perfect and has some resistance, or internal resistance. We most often refer to the internal resistance of a battery. As a battery ages, it chemically degrades and the internal resistance of the battery increases, this causes the e.m.f. of the battery to decrease, i.e. the voltage decreases.

The one exception is superconductors which have exactly zero internal resistance!

5.2.9 Derive and apply the equation for equivalent resistances of resistors in series and in parallel

5.2.10 Draw circuit diagrams

Kirchoff's Current Law – Junction Rule:

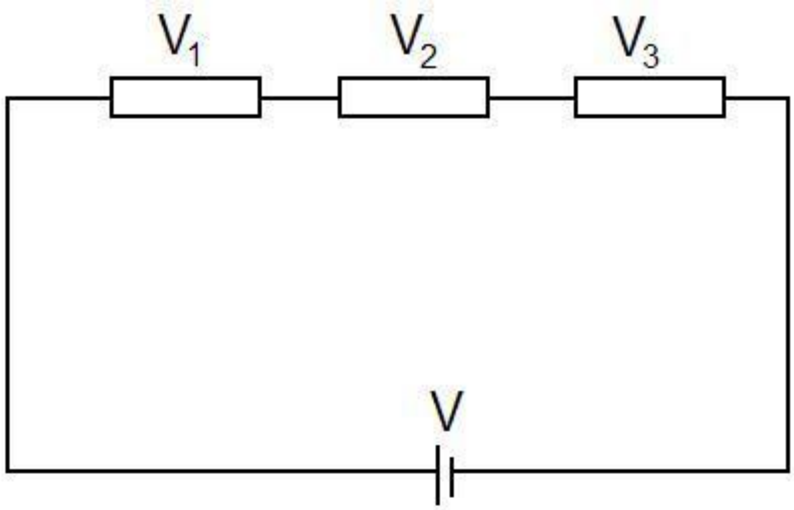


$$I_1 = I_2 + I_3 + I_4$$

The sum of the currents flowing into a point (or junction) in a circuit equals the sum of the currents flowing out at that point (or junction).

Kirchoff's law is a result of the law of conservation of charge. The current can not pile up or disappear.

Kirchoff's Voltage Law – Loop Rule:



$$V = V_1 + V_2 + V_3$$

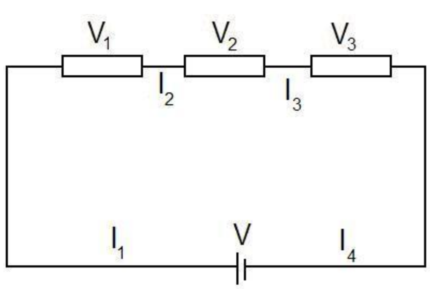
In a closed loop, the sum of the e.m.f.s equal the sum of the potential drops.

The loop rule is a result of energy conservation, the energy supplied to the circuit is equal to the energy released or used, the energy can not pile up or disappear.

Resistors in Series:

In a series circuit:

1. All the components have only one current pathway
2. All components have the same current through them
3. The sum of the potential drop across each component is equal to the e.m.f. of the cell



$$V = V_1 + V_2 + V_3$$

$$I_1 = I_2 = I_3 = I_4$$

From Kirchoff’s laws we have:

(10)
$I1 = I2 = I3 = I4$

and

(11)
$V = V1 + V2 + V3$

From the definition of resistance:

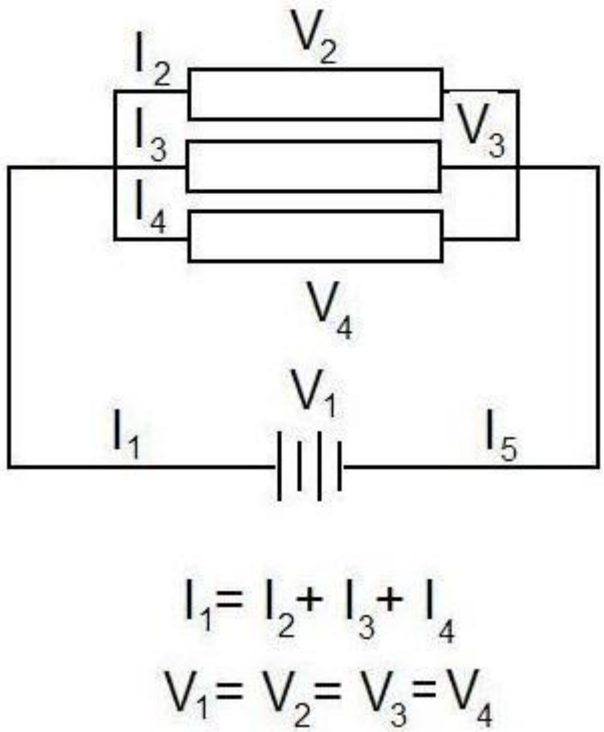
(12)
$R = V / I = V1 + V2 + V3 / I$

(13)
$R = V1 / I + V2 / I + V1 / 2 = R1 + R2 + R3$

Resistors in Parallel:

In a parallel circuit:

1. There is more than one current pathway
2. All components have the same potential difference across them
3. The sum of the currents flowing into any point is equal to the sum of the currents flowing out at that point.



From Kirchoff's Laws:

(14)

$$I = I_1 + I_2 + I_3$$

(15)

$$V = V_1 = V_2 = V_3$$

From the definition of resistance:

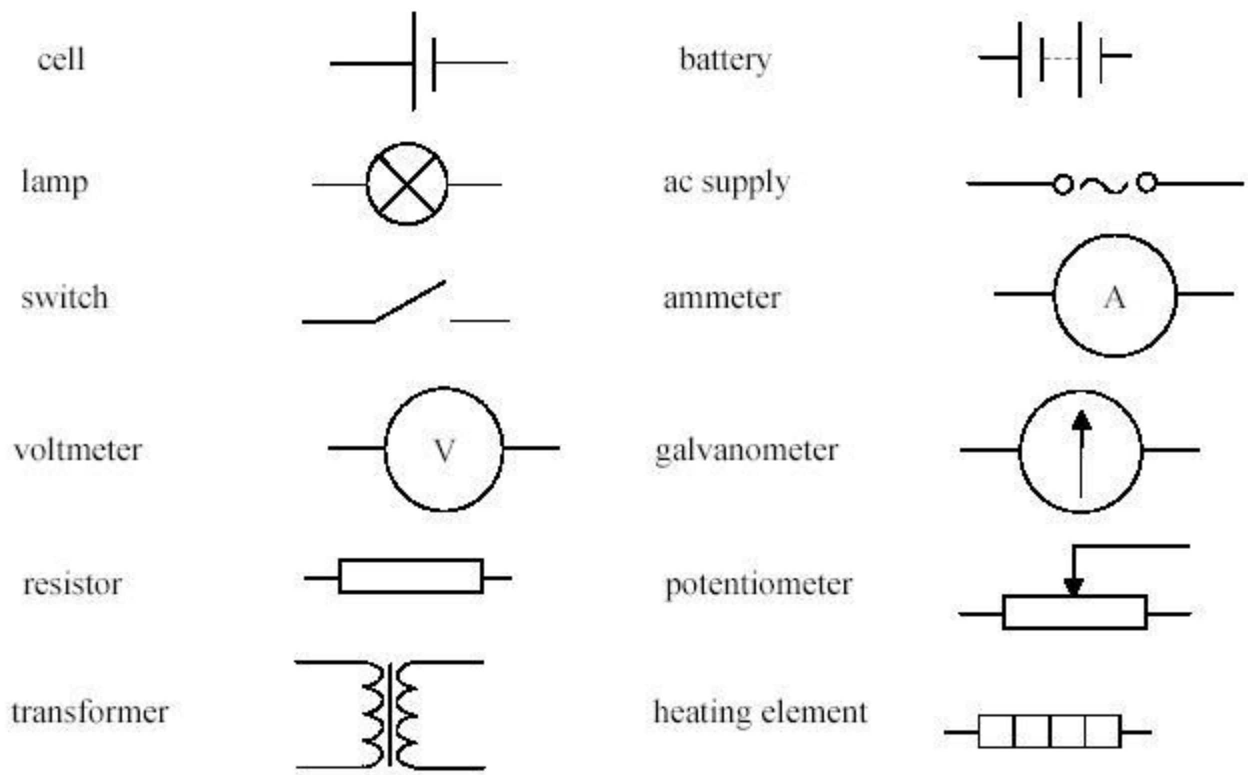
(16)

$$R = V/I = V/(I_1 + I_2 + I_3)$$

(17)

$$1/R = (I_1 + I_2 + I_3)/V = 1/R_1 + 1/R_2 + 1/R_3$$

Electrical Circuit Symbols



Definitions:

Cell: Basically a battery
Battery: A DC supply of voltage and current, usually made of many cells.
Lamp: A light bulb!
AC Supply: This is what the plugs in the wall are, AC stands for alternating current. In an AC circuit the electrons have no net motion, they simply slosh back and forth.
Switch: If you don't know what this is drop out and be a government employee.
Ammeter: A device used to measure the current flowing through a circuit, must be put in series.
Galvanometer: A historic name given to early simple ammeters.
Voltmeter: A device used to measure potential difference, must be put in parallel.
Resistor: Plays no role except to resist the flow of a current, i.e. removes energy from the circuit or there is a potential drop or difference across the resistor.
Potentiometer: Is an electric element that has a variable resistance that can be controlled by the user.
Transformer: An element used to change the voltage an current in a electric circuit. In

an ideal transformer energy is conserved. So if the voltage goes up the current goes down and vice versa.

Heating Element: see switch

5.2.11 Describe the use of ammeters and voltmeters

Voltmeters:

1. Always connected across the device or in parallel.
2. Has a very high internal resistance, so as not to draw a large current from the circuit.

Ammeters:

1. Always connected in series with a circuit
2. Has a very low internal resistance, so as not to generate a drop in potential.

Source: http://ibphysicsstuff.wikidot.com/electric-circuits