Physics, Electricity, 13-14

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13.1 Electrical Power and Energy

$$\text{Power} = \frac{\text{Energy Transferred}}{\text{Time}}$$

Power is measured in watts, and energy in joules. Alternatively, one kilowatt-hour is the energy transferred in one hour from a source of power 1000W; 3.6MJ.

13.2 Electric Current

13.2.1 Charge

Current is a flow of charge. Charge itself is a fundamental property of matter. Charge can be positive or negative, and opposite charges attract. Charge itself is measured in coulombs, with the charge on one electron being -1.6×10^{-19}C.

13.2.2 Conductors and Insulators

Conduction is the flow of electric charges through a material. An insulator is a material that will not readily conduct electricity, as it has no free charges - the tightly bound electrons would require a relatively large amount of energy to be freed.

By rubbing together two insulators, electrons are transferred from one material to another, leaving neither material with a neutral charge.

Metals are good conductors due to the fact that some of their atomic electrons are free to move between atoms and carry charge.

13.2.3 Current

Electrostatic phenomena are when there is no flow of continuous charge. A continuous charge is known as a current.

$$Q = It$$

The direction of conventional current is from positive to negative. However electrons, being negatively charged, flow from negative to positive.

Current is the rate of flow of charge: With a current of one ampere, one coulomb will pass a given point every second.

13.2.4 Electric Circuits

An electric current will be set up in a conductor if there is:

- An energy source, such as a battery made up of cells
- A continuous circuit

13.2.5 Conservation of Charge

Charge is conserved wiothin a circuit. At any given point, the input and output charge must be equal - *Kirchoff's First Law*

In a series circuit, current is the same everywhere. In a parallel circuit, the sum of the current in branches is equal to the total current.

13.3 Potential Difference

The amount of energy transferred when a charge moves between points is known as the potential difference (pd), with the term voltage normally being used. This is analogous to gravitational potential difference - a larger potential difference increases the energy that is transferred by a charge moving through it.
The potential difference between two points is defined as the work done per unit charge passing between those two points

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

where W is work done. Potential difference is measured using a voltmeter connected in *parallel* (Ammeters are connected in *series*). Voltmeters are assumed to have infinite resistance, and ammeters to have no resistance.

13.3.1 Conservation of energy in a circuit

The total energy transferred by the charge must be equal to the energy it receives from the battery. The energy transferred from a battery/source is known as the electromotive force (emf).

The sum of the potential differences around a circuit is equal to the sum of the electromotive forces - *Kirchoff's Second Law*

Potential differences across a series circuit will sum to the EMF, whereas potential differences across parallel components are equal.

13.3.2 Power, Potential Difference, and Current

$$P = \frac{W}{t}$$
$$V = \frac{W}{Q}$$
$$P = \frac{QV}{t} = IV$$
$$E = VIt$$

13.4 Resistance

- Metals are the most common conductors
- Free electrons move randomly between fixed positive ions
- If a potential difference is applied, the electrons will accelerate towards the positive connection
- They then collide with the positive ions, and lose kinetic energy, which is transferred to vibrational energy in the ionic lattice

13.4.1 Resistance and Ohm's Law

$$V = IR$$

Ohm's Law: *Provided that temperature and other physical conditions remain constant, the current through an ohmic conductor is proportional to the potential difference across the conductor.*

13.5 Current-Voltage Characteristics

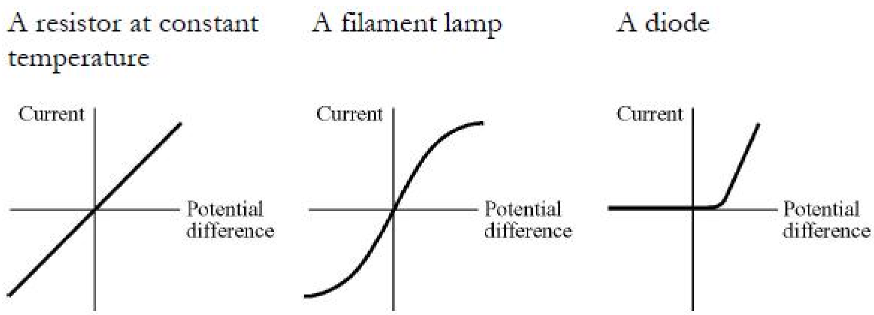

Figure 1: Common Current-Voltage graphs

Diodes have bias - they will not allow current to be transferred if placed the wrong way round. They can also be 'doped' to affect the wavelength of the light emitted.

13.6 Combining Resistors

13.6.1 Resistors in Series

$$R_T = R_1 + R_2 + ...$$

13.6.2 Resistors in Parallel

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + ...$$

13.7 Power and Resistance

$$P = I^2 R$$

$$P = \frac{V^2}{R}$$

Despite the risk of shock, a higher voltage is preferable as it is much more efficient. This favours a series circuit.

13.8 Resistance and Resistivity

$$R \propto L \text{ Doubling the length doubles the chance of collisions}$$

$$R \propto \frac{1}{A} \text{ Doubling area doubles electrons, thus doubling current, and halving resistance, to ensure } V \text{ is constant}$$

$$\therefore R \propto \frac{L}{A}$$

$$\therefore R = \rho \times \frac{L}{A}$$

$$\rho = \frac{RA}{L}$$

Resistivity is measured in Ωm. Conductivity is the reciprocal of resistance

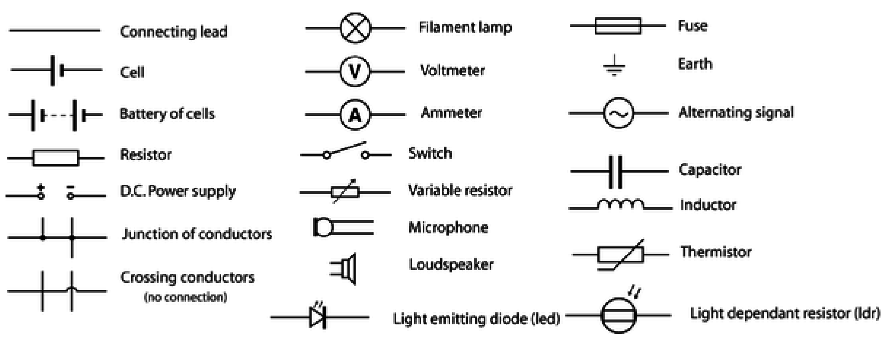

Figure 2: Circuit symbols

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14.1 EMF and Internal Resistance

All power supplies produce a potential difference between terminals.

$$\epsilon = \frac{E}{Q}$$
$$V_{term} = \epsilon - V_{inter}$$
$$V_{term} = \epsilon - I \times r_{inter}$$
$$\epsilon = V_{term} + V_{inter}$$
$$\epsilon = I(R_{circuit} + r_{inter})$$

When current passes through any power supply, it transfers some energy in heating up the internal resistance of the cell. Therefore, $V_{term} < \epsilon_{\text{,cell EMF}}$.

To measure the EMF, a voltmeter should be placed across the terminals with no current flowing. To measure the terminal potential difference, a voltmeter should be placed across the terminals when there is a current flowing.

14.1.1 Measuring the EMF of a cell

The EMF is equal the the terminal potential difference when there is no current.

14.2 Resistance and Temperature

Electrical resistance tends to increase with temperature.

- Resistivity is caused by interaction of moving electrons and positive ions
- As temperature increases, electrons lose more energy in these interactions
- Resistance increases

$$\text{Change in resistivity} \propto \text{Change in temperature}$$

14.3 Semiconductors

Semiconductors, such as silicon and germanium, are an intermediate class of materials that have a limited number of mobile charges.

As a semiconductor is heated, some of the vibrational energy is transferred to atomic electrons, which become free to move. Therefore, $R \propto \frac{1}{T}$.

14.3.1 Thermistors

Semiconductors can be used to make thermistors, resistors whose resistance changes with temperature. These can have a negative or positive temperature coefficient. NTC resistors resistance drop as temperature increases. These have several uses:

- Thermometers
- Thermostats
- Current surge protection

14.3.2 Light-dependent Resistors

Some semiconductors have a resistivity that depends on the intensity of the light that they are being exposed to. Electrons absorb energy from the light, and as intensity increases, the number of free electrons does too, reducing resistivity.

14.4 Superconductors

When a metal cools, its positive ions lose vibrational energy, and the conducting electrons lose less energy in collisions - the resistivity decreases. At a critical temperature, T_c, some materials undergo a change of phase and become a superconductor, with no electrical resistance. At this point the mechanism of conduction changes:

- Electrons move in pairs
- Energy is passed between electrons in the pairs
- They do not interact with the positive ions in the lattice
- They are not scattered by the lattice and do not transfer energy to it

14.4.1 Applications of Superconductors

Superconductors show the *Meissner effect*, whereby they exclude an external magnetic field. This in effect 'repels' a magnetic field, and can be used in magnetic levitation. This particularly useful with Maglev trains. Superconducting magnets are also used in the LHC, and MRI scanners. Coils made of a superconducting material would also be able to improve the efficiency of generators and motors.
If a room temperature super conductor was found, it could be used in power transfer cables, and reduce energy wastage hugely.

14.5 Potential Dividers

Potential dividers can be used to divert an appropriate amount of a power supply's terminal PD. Essentially, a potential divider is two resistors connected in series.

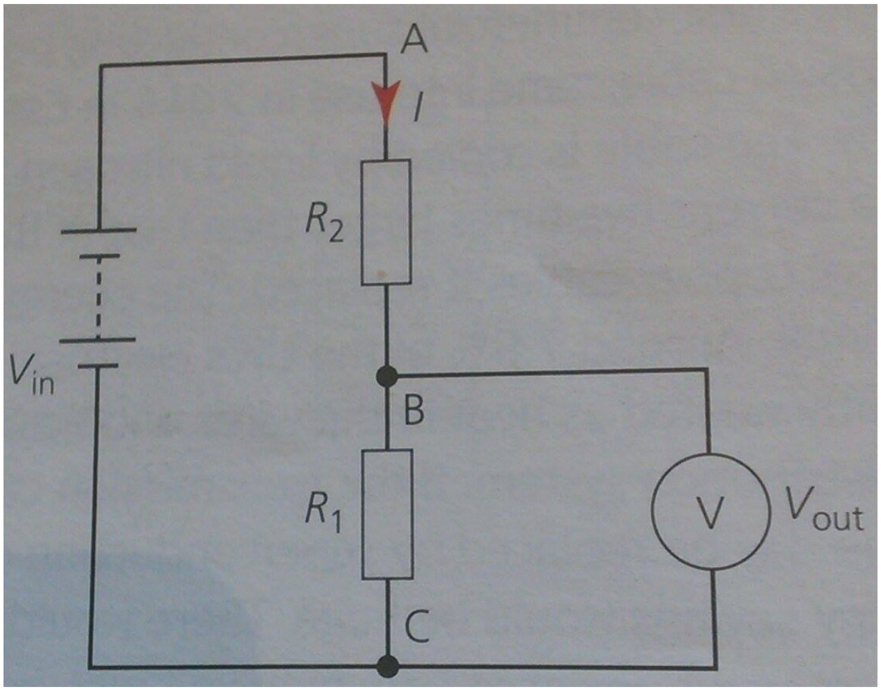

Figure 3: A potential divider

Assuming no current through the voltmeter, the same current will flow through both resistors.

$$I = \frac{V}{R} = \frac{V_{in}}{R_1 + R_2}$$
$$V_{out} = IR_1$$
$$V_{out} = \frac{V_{in}}{R_1 + R_2} \times R_1$$
$$= V_{in} \times \frac{R_1}{R - 1 + R_2}$$

Also,

$$\frac{V_{out}}{V_{in}} = \frac{\text{output resistance}}{\text{input resistance}}$$

Typically, R_2 is a *variable resistor*, which allows the output voltage to be varied, which is particularly useful with sensors - these depend on a PD. The lower the value of R_2, the greater the output voltage.

If a thermistor or similar is used as R_2, then devices can be set to turn on or off in certain circumstances. Although they have a curved resistance-temperature graph, there is a linear relation over small intervals.