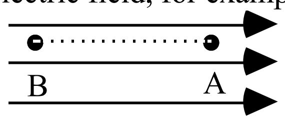
TOPIC 5— ELECTROSTATICS AND MAGNETISM:

- Charge of 1 electron = – 1.6 x 10^{-19} C.
- 1 C of charge = 6.25 x 10^{18} electrons.
- $\boxed{E = \frac{F}{q}}$ — electric field acting on objects with charge.
    - F = Force (N)
    - q = Magnitude of Charge (C)
    - E = Electric Field Strength (NC^{-1})

Electrical potential difference (V) is related to the work (W) done to move a charge (q) as follows:

$$\boxed{V = \frac{\Delta \text{P.E.}}{q} = \frac{W}{q}} \quad \text{or} \quad \boxed{W = qV}$$

Work is done, for example, when an electric charge is move against the electricity in an electric field, for example, to move a positive charge from A to B:

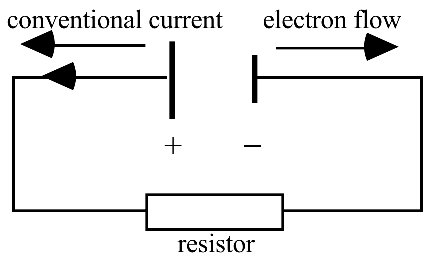


$PE_A > PE_B$

- Electrical potential difference is also called voltage and is measured in volts.
- $\boxed{F = \frac{k\,Q_1\,Q_2}{r^2}}$ — Coulomb's Law— determines the force between 2 charges at a stated distance. $k = \frac{1}{4\pi\varepsilon_0}$ and is constant of proportionality. Its value is 9.0 x 10^9 $N.m^2.C^{-2}$.
- Electric Fields for Some Charge Distributions:

{SORRY THIS IMAGE CANNOT BE REPRODUCED}
{Check your textbook.}

- $\boxed{E = \frac{k\,Q_2}{r^2}}$ — The electric field strength due to an isolated point charge.
- $\boxed{I = \frac{\Delta q}{\Delta t}}$ — Current— the rate of flow of charge in an electric circuit. Measured in amperes (A), or coulombs of charge per second.
- Conventional Current and Electron Flow:



- $V = IR$ — Ohm's Law— current is proportional to the applied voltage.

- $R = \rho \frac{L}{A}$ — The resistance of a wire is directly proportional to its length L, and its cross-sectional area A. The constant of proportionality is ρ, and is called the resistivity. It changes depending on the material used. (NB. When L increases, there are more obstacles to electron flow. When A increases, there is more space in which electrons can travel). The units of resistivity are Ωm.

  The resistance of a conductor depends on the following:
  ❶. Length
  ❷. Cross-sectional area
  ❸. Resistivity
  ❹. Temperature

  - The increase in resistance in a material can be shown as:

    $R_f = R_0(1 + \alpha t)$

    where:
    R_0 is the resistance at some reference temperature, say 0ºC.
    R_f is the resistance at some temperature, t ° C, above the reference temp.
    α is the temperature coefficient for the material being used.

- **εmf**— the work per unit charge made available by an electrical source.
  - $\text{emf} = \frac{\text{energy supplied}}{\text{charge}}$,

    BUT
  - $\text{PD} = \frac{\text{energy dissipated}}{\text{charge}}$
  - $\Delta V = \frac{\Delta W}{I\Delta t}$ — potential difference in external circuits is the power, dissipated (released) per unit current.

Series & Parallel Circuits:

Series:

- $I = I_1 = I_2 = I_3 = \ldots$
- $V = V_1 + V_2 + V_2 + \ldots$
- $R = R_1 + R_2 + R_3 + \ldots$

Parallel:

- $I = I_1 + I_2 + I_3 + \ldots$
- $V = V_1 = V_2 = V_2 = \ldots$
- $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$

- Galvanometers, Ammeters, & Voltmeters:
  - Galvanometers:
    - Used to detect electric currents.
    - Use a property of electromagnetism that a coil with a current flowing in it experiences a force when placed in a magnetic field.
    - Most non-digital ammeters and voltmeters consist of a moving coil connected to resistors.
  - Voltmeters:
    - Always connected across a device (in parallel).
    - Have a very high resistance so that it does not take current from the device whose potential difference is being measured.
    - Have a high resistor connected in series with a galvanometer.
  - Ammeters:
    - Always connected in series with a circuit.
    - Have a very low resistance so that they do not alter the current flowing in the circuit.
    - Have a low resistor connected in parallel with a galvanometer.

- Power— is the rate at which energy is supplied to a device.

- $\boxed{P = IV}$
- $\boxed{P = \frac{W}{t}}$
- $\boxed{P = I^2 R}$
- $\boxed{P = \frac{V^2}{R}}$

Magnetism:

- Two types of magnets:

- Temporary/Soft magnets— lose their magnetic properties easily, eg. iron magnets. Are the basis of electromagnets.
- Permanent/Hard Magnets— do not lose their magnetism, eg. steel, and alnico. Retain magnetic properties over long periods of time.

Magnetic Fields and Patterns:

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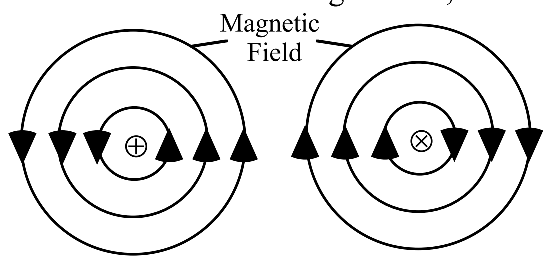
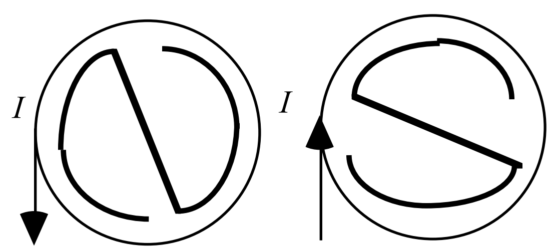
- When a current flows through a wire, it causes a magnetic field like such:



Current into page   Current out of page

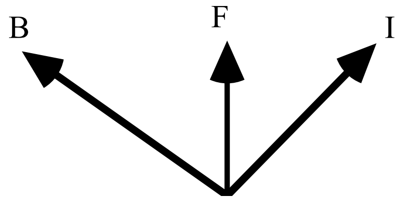
We use the "right-hand grip rule" to determine the direction of the current and field.

- A solenoid has a magnetic field like the one shown on page 397 (IB Text). The polarity is thus:



North End   South End

➨ The strength of a solenoid can be increased by:
  - ♥. Increasing the current flowing.
  - ♥. Increasing the number of coils.
  - ♥. Using a soft iron core in the coil.
- When a charged particle is placed in a magnetic field, it experiences a force. This force on this current-carrying conductor can be found by the right-hand palm rule:



The fingers point along the lines of the magnetic field, the force comes out of the palm, and the thumb points in the direction of the current.

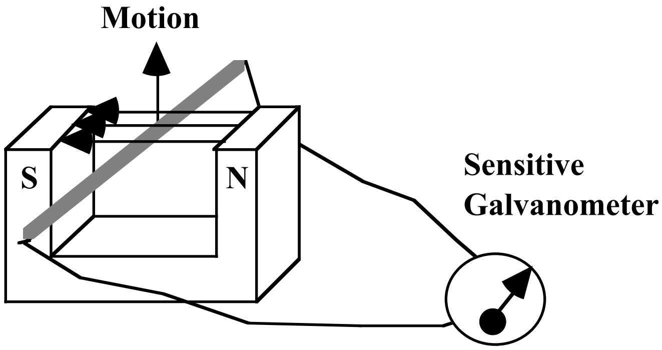
- $\boxed{\mathbf{F} = I\,\ell\,\mathbf{B}\,(\sin\theta)}$ — relates force in conductor to the current flowing, the length of the conductor, and the strength of the magnetic field. (Sometimes it is not perpendicular, in which case we use sin θ).
- $\boxed{\mathbf{F} = q\,V\,\mathbf{B}\,(\sin\theta)}$ — relates force in conductor to charged particle moving in magnetic field. (Sometimes it is not perpendicular, in which case we use sin θ)
- $\boxed{r = \frac{m\,v}{q\,\mathbf{B}}}$ — The spiral motion that a charged particle follows when it enters at 90º and the magnetic field is uniform. The radius can be determined from this.

- <u>DC Motors:</u>
  - Use parts such as **armature** (rectangular coil of wire mounted in magnetic field produced by curved magnets), **brushes** (connect coil to the terminals of a battery, make contact with **split-ring commutator**.)
  - Force can be determined by right-hand palm rule.

- <u>Force Between 2 Parallel Wires:</u>
  - 2 unlike wires repel, 2 like wires attract.
  - Magnetic Field Strength (B) can be determined by right-hand grip rule. Force can be determined by right-hand palm rule.
  - For magnetic fields resulting, see p.408 (IB Text).

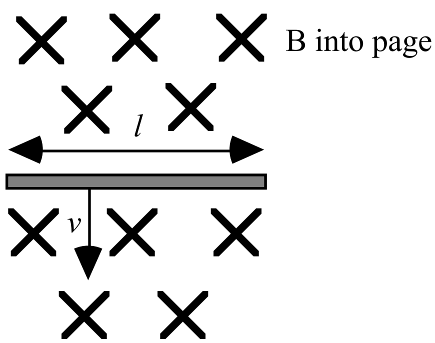
<u>Electromagnetic Induction:</u>

Faraday's Law of Magnetic Induction:
Experiment to Produce Induced Current:



- Found that the strength of the induced εmf was dependent upon:
    1. The speed of the movement
    2. The strength of the magnetic flux density
    3. The number of turns on the coil
    4. The area of the coil
- Found that the magnitude of the induced εmf was not proportional to the rate of change of the magnetic field **B** but rather proportional to the rate of change of magnetic flux **Φ** for a straight conductor or flux linkage N.Φ.

Induced EMF in a Conductor:

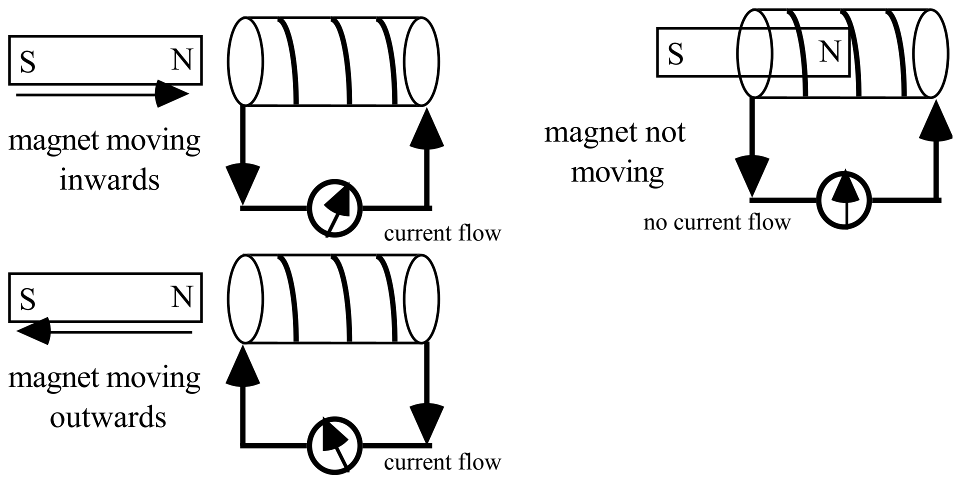


- For a conductor of length *l* that moves with velocity *v* perpendicular to a magnetic flux density of induction **B** as shown above, when the wire conductor moves in the magnetic field, the free electrons experience a force as the conductor moves in the field. This force causes the electrons to drift from one to the other, and eventually the emf becomes large enough to balance the magnetic force and stop the electrons from moving. Thus:
- $\varepsilon = \mathbf{B}\, l\, v$
- $\varepsilon = \frac{\Delta(A\mathbf{B})}{\Delta t}$ where A is the area in m2.
- Magnetic flux **Φ** through a region— a measure of the number of lines of magnetic force passing through that region:
- $\mathbf{\Phi} = A\,\mathbf{B}\cos\theta$— where A is the area of the region and q is the angle of movement between the magnetic field and a line drawn perpendicular to the area swept out. Unit of magnetic flux is the Weber (Wb).
- For N number of conductors as in the case for a solenoid, the term **flux-linkage** is used: $\varepsilon = -N \times \frac{\Delta\Phi}{\Delta t}$.— (Newmann Equation)

- **Faraday's Law— the magnitude of the induced emf in a circuit is directly proportional to the rate of change of magnetic flux or flux linkage.**

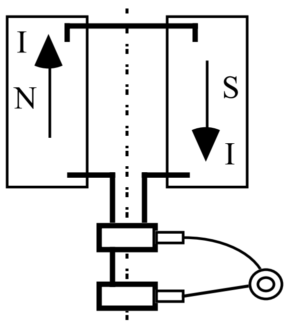
Lenz's Law of Electromagnetic Induction:

- In diagram below, when north pole is moved toward core of solenoid, induced current flows in external circuit, anti-clockwise to end of solenoid nearest magnet. This end acts like north pole. When magnet stationary induced current is zero. When bar magnet is removed from solenoid, induced current flows in opposite direction, and south pole is created in end that was previously north pole.
- **Lenz's Law - The direction of the induced εmf is such that the current it causes to flow opposes the change producing it.**
- Combining two laws above gives Newmann Equation.



9.4 Generators and Alternating Current:

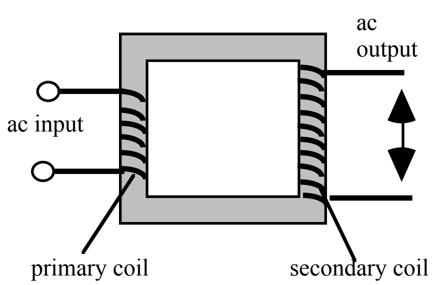
- Most important practical application of Laws of electromagnetic induction was development of electric generator or dynamo. On a C.R.O, the induced emf is of a sinusoidal nature, when graphed as a function of time.
- A.C. generator: uses mechanical rotational energy to provide the force to turn a coil of wire called an armature in a magnetic field. As armature cuts magnetic flux, εmf's are induced in the coil. As the sides of the coil reverse direction every half turn, the εmf's alernate in polarity. If there is a complete circuit, alternating current A.C. is produced. The induced currents are conducted in and out by way of slip-rings and carbon brush contacts.



AC Generator

- Direction of emf can be found by applying the right hand palm rule for electromagnetic induction— for left side of coil.
- Magnitude of emf can be found by the following formula:
  $\varepsilon = 2\pi f N A \mathbf{B} \sin(2\pi f t)$— where the coil has N turns, has an area A, and is in the magnetic field **B**.

- Alternating current can be represented by the equation $I = I_P \sin(\omega t)$, where Ip is the maximum current called the peak current. Alternating currents are expressed by their r.m.s (root-mean-square) or effective current and voltage, which can be found by: $I_{rms} = I_0 \times \sqrt{2}$ and $V_{rms} = V_0 \times \sqrt{2}$
- **The Transformer**— This is a useful device that makes use of electromagnetic induction, which is used for increasing or decreasing a.c. voltages.



A simple Transformer

- It is found that: $\frac{V_p}{V_s} = \frac{N_p}{N_s} = \frac{I_s}{I_p}$ where N is equal to the number of turns on a designated coil.
- If N_s is greater than N_p then the transformer is a **step-up transformer**.
- If the reverse occurs and N_s is less than N_p the it is a **step-down transformer**.
- If the voltage is stepped up by a certain ratio, the current in the secondary coil is stepped-down by the same ratio.

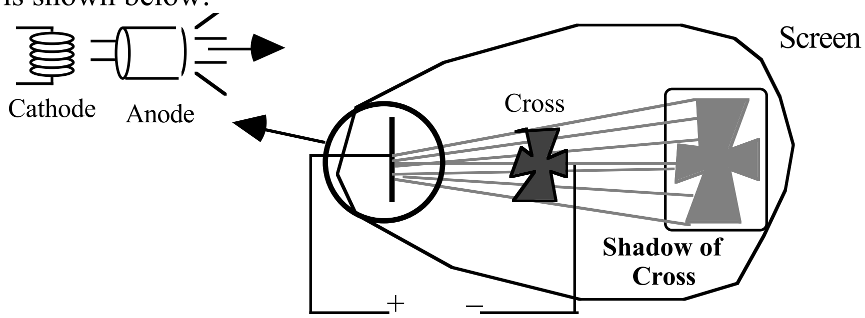
- **Power Transmission**— high voltage transmission is used in power transmission rather than high current trnasmission. This minimises energy and heat losses because of the resistance in the wires. Transformers are used until the required voltages are reached.
- **Cathode Ray Oscilloscope**— Used to display electrical signals.
  - Uses: d.c or a.c voltmeter, displays waveforms, measures time intervals, displays pahse relationships, compares frequencies, displays hysteresis loops.
  - Consists of sophisticated cathode ray tubel; consists of electron gun, deflecting system and flourescent screen.
  - Electrons pass through control grid and anode system that control and focus the electrons. Electrons then accelerated to high velocities— electron gun. X and Y plates put them on a certain part of the screen. Time-base control applies steadily changing voltage to X-plates so beam is swept over screen from left to right. Controls beam from dot/straight line to straight line/waveform.

TOPIC 6— ATOMIC & NUCLEAR PHYSICS:

- Milikan's Experiment— Robert Milikan carried out experiment to try to quantify the elementary charge. Passed oil droplets of uniform size through charged plates, so that a uniform electric field with a known potential difference. By knowing the magntude of the potential difference, distance between the plates, and acceleration due to gravity (in this case equal to electric force), he was able to calculate charge on individual oil drop. He found the following equation:

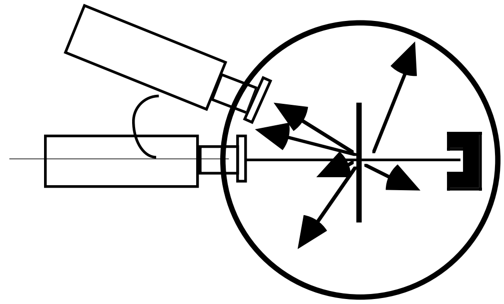
  $q = \frac{mg}{E}$ OR, when the equation $E = \frac{V}{d}$ is used (magnitude of electric field), $q = \frac{mgd}{V}$

  .
- Milikan was able to calculate that the charge on each oil drop was a multiple of the elementary charge, which he found to be $e = 1.602 \times 10^{-19}$ C.
- Thermionic Emission and Cathode Rays— Physicist Heinrich Geissler, and later Sir William Crookes, used experiment with electron guns in discharge tubes and in doing so discovered the "cathode ray". The process by which this is done, thermionic emission, is shown below:



- Cathode rays are named thus because they originate from the cathode and are attracted to the anode. They are thus negatively charged, and they can be deflected by magnetic and electric fields.
- Sir John Joseph Thomson was also able to determine the nature of cathode rays, and thus determine the ratio of charge to mass: $\frac{e}{m} = \frac{v}{Br}$.

  OR because $v = \frac{E}{B}$, therefore $\frac{e}{m} = \frac{E}{2B^2r}$. .He was able to then determine the charge to mass ratio of cathode rays = 1.76×10^{11} kg.



- Rutherford's / Geiger and Marsden's Alpha Scattering Experiment: Bombarded thin sheet of gold foil with alpha-particles (positively charged particle). Most passed through foil, thus they concluded that atoms consist mostly of empty space. Also some particles were deflected off the foil— they were directed straight at a dense, positive nucleus. Determined existence of nucleus, and was basis for new model of atom (nuclear model).
- Equations from experiment: If *r* is closest approach distance, then potential energy at distance *r* is equal to $U = Fr$. However, given that the force *F* is the coulomb force of repulsion between the alpha particle and gold nucleus, $F = \frac{kq_1q_2}{r^2}$. Therefore $U = \frac{kq_1q_2}{r}$. Rutherford was able to find approximately the radius of the gold nucleus— less than 2.94×10^{-14} m.
- From this the new planetary, or nuclear model of the atom, consisting of a dense positive nucleus surrounded by electrons which orbit the nucleus. His research continued after this with Niels Bohr and answered some of Rutherford's unanswered questions, including a hypothesis for neutrons.

Nuclear Physics:

- Use of ${}^{A}_{Z}X$ nomenclature:
  - Z is atomic (proton) number of a nuclide— number of protons found in the nucleus of the isotope. In electrically neutral isotope, also number of electrons.
  - A is mass (nucleon) number of an isotope— number of nucleons (protons & neutrons). Number of neutrons = $A – Z$.
- Artificial transmutation— the change of one element to another through the bombardment of a nucleus.(Rutherford).
- Rutherford determined through cloud chamber experiment that the alpha particle was absorbed when it collided with a nitrogen nucleus:

  $${}^{4}_{2}He + {}^{14}_{7}N \rightarrow {}^{17}_{8}O + {}^{1}_{1}H$$

  Other equations can thus be determined, eg. O_{16} bombarded with neutrons:

  $${}^{16}_{8}O + {}^{1}_{0}n \rightarrow {}^{15}_{7}N + {}^{2}_{1}H$$

- Radioactive Decay:

Type:	Alpha (α)	Beta (β)	Gamma (γ)
Description:	Helium Nucleus: $({}^{4}_{2}He)$	Fast-moving electron $({}^{0}_{1}e)$	Electromagnetic radiation with short wavelength (λ) and high frequency.(f).
Charge (q) and Mass (m):	$q = +2e$ $m = 4u$	$q = -e$ $m = \frac{1}{1850}u$	$q = 0$ $m = 0$
Energy (E) and Speed (v)	Kinetic ($E = \frac{1}{2}mv^2$) $v \sim 0.05c$	Kinetic ($E = \frac{1}{2}mv^2$) v = (0–99%) of c.	Photon ($E = hf$) $v = c$
Penetration (range)	Stopped By a sheet of paper (a few centimetres)	Stopped by a few millimetres of Al (a few metres)	Stopped by many centimetres of Pb. (no max range).

- Ionising power of alpha-particles is the greatest.
- Radioactive Decay:

Alpha Decay: $${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$

Beta (β⁻) Decay: $${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e + \overline{v}$$

Positron (β⁺) Decay: $${}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}e + v$$

Electron Capture: $^{A}_{Z}X + e^{-} > ^{A}_{Z-1}Y + v$

Gamma Decay $^{A}_{Z}X^{*} \rightarrow ^{A}_{Z}Y + \gamma$

- Radiation ionises gases— use is made of this in the Geiger-Müller detector, which uses Argon gas at low presure in a cathode metal tube, connected to an anode wire, and a loudspeaker.

- Radioactive decay is a random process for individual atoms, but the average rate of decay is exponential, and is independent of physical & chemical conditions. The 'half-life' is the time it takes for half the number of unstable atoms in a sample to decay.

  Model of decay is $\boxed{N = N_0 e^{-\lambda t}}$

  Activity in SI units is measured by the Becquerel = 1 event/s.
  Therefore,

  - $\boxed{\lambda = \frac{\log_e 2}{t_{1/2}}}$ or $\boxed{\lambda = \frac{0.693}{t_{1/2}}}$