Foundational principle.

A current carrying conductor will generate an Electromagnetic Field. Likewise a changing Electromagnetic Field will induce current flow in a conductor.

- **Magnets**
  1. Natural – metal etc. found magnetising
  2. Artificial – metal etc. that can be made to be magnetising
  3. Electromagnets – made using electricity

- **Types of Magnets Material**
  1. Ferromagnetic – materials that are relatively easy to magnetise
  2. Paramagnetic – materials that become only slightly magnetised
  3. Diamagnetic – materials that become only slightly magnetised when in a strong magnetic field. Once magnetised they are magnetised in a direction

- **Magnetic Fields**

  Area of influence around a magnet made up of magnetic flux

- **Magnetic Flux** **Φ** measured in Webbers **Wb**

  Lines of magnetism that flow from *North to South*

$$\phi = \frac{F_m}{R_m}$$

- **Magnetic Flux Density** **B** measured in Tesla's **T**

  Number of lines of magnetism in an area

- **Magneto Motive Force** **F_m** measured in Ampere turns **At**

  The magnetic force created by electron flow

$$\boldsymbol{F = I \times n}$$

F is force measured in Newtons
I is the current flowing in the conductor in Amperes
n is the number of turns in the coil

- **Magnetic Force on conductors**

  The force between two conductors running in parallel carrying current causing them to either REPEL (if the two currents are flowing in opposite directions) or ATTRACT (if the two currents are flowing in the same direction).

$$F = \frac{2\times10^{-7}\times I_1\times I_2}{d}$$

F is force measured in Newtons
I_1 is the current flowing in conductor 1 in Amperes
I_2 is the current flowing in conductor 2 in Amperes
d is the distance between the two conductors in metres

- **Electromagnetic Force**

  The force on a current carrying conductor when it is placed in a magnetic field.

$$F = B \times I \times l$$

F is force measured in Newtons
B is the flux density
I is the current flowing in the conductor in Amperes
l is the length of the conductor in metres

- **Magnetic Field Strength** **H** measured in Ampere per metre **A/m**

  The magnetic force per meter

- **Reluctance** **R_m** measured in Ampere turns per Webbers **At/Wb**

  The opposing force to the creation of magnetic flux

$$Rm = \frac{l}{\mu_r \times \mu_o \times Area}$$

- **Permeability** **μ**

    The ease with which a material allows a flux to be created

$$\mu = \mu_r \times \mu_o$$

$$\mu = \frac{B}{H}$$

Absolute permeability $\mu_o = 4 \times \pi \times 10^{-7}$

Relative permeability $\mu_r = \frac{\mu}{\mu_o}$

- **Inductance** **L** measured in Henrys **H**

    The property of a material, which enables an electromagnetic force to be generated in it.

    The factors that govern inductance are

    1. The number of turns
    2. The area of the magnetic core
    3. The relative permeability of the core
    4. The length of the inductor

- **Electromagnet**

    A magnet made using a coil carrying current, the strength of which is determined by the amount of current flowing, the number of turns in the coil and to a lesser extent the area of the magnetic core and its permeability.

$$At = I \times N$$

- **Electromagnetic Induction**

  The name given to a phenomenon, when a conductor moving across magnetic fields causes a voltage to arise in the conductor. If the conductor is also part of a circuit, current will flow.

  The amount of voltage and/or current induced is related to:

  1. Strength of the magnetic field
  2. The number of turns in the conductor
  3. The speed at which the conductor moves across the magnetic flux
  4. The angle of which the conductor moves across the magnetic flux

  The direction of current flow is dependant on the polarity of the magnetic field and can be determined by applying the **RIGHT** hand rule for generators. (Forefinger is direction of magnetic field, thumb is the direction of motion of the conductor and middle finger is the direction of electron flow.)

  The main applications for EMI are induction motors/generators and transformers.

- **Generators**

  The name given to a machine, having an external source physically move internal components, that uses the principles of EMI to create voltage and current. (See EMI for more info)

- **Motors**

  The name given to a machine that has an external electrical power source that using the principles of EMI applies a force to turn the internal components.

  The direction of force is dependant on the polarity of the magnetic field and direction of current flow, and can be determined by applying the **LEFT** hand rule for motors. (Forefinger is direction of magnetic field, thumb is the direction of motion of the conductor and middle finger is the direction of electron flow.)

  When a DC motor is started there is no back EMF to limit current flow. At start up the current is limited by the resistance of the armature winding only, resulting in a high inrush current (Approx. 20 times running current). This high current draw at start up requires the use of 'starters' to limit the current flow until the motor is spinning sufficiently to produce a back EMF. The most common method involves the use of resistors.

- **Types of DC machines (i.e. Generators and Motors)**
    1. Permanent Magnet
    2. Separately Excited
    3. Shunt
    4. Series
    5. Compound

- **Permanent Magnet Machines**

  Has a permanent magnet as either the rotor on a generator or the stator on a motor. On a generator it produces AC and so must have rectifiers to produce DC output.

  Reversing the polarity at the Armature will change the direction of the rotation of the motor.

- **Separately Excited**

  A separate DC supply feeds just the Field winding on a generator but on a motor a DC supply also feeds the Armature. On a generator the voltage generated comes from the Armature windings.

  Reversing the polarity at the Armature will change the direction of the rotation of the motor.

- **Shunt**

  The field windings are connected parallel with the armature.

  The shunt machine relies on the existence of residual magnetism. On a generator if it fails to generate a voltage when rotating the field connection may be connected so that the generated EMF is opposing the residual EMF (Changing the direction of rotation or the polarity of the field to armature windings should rectify this problem).

  A field regulator can be installed in series with the shunt field windings on a motor to control the speed by limiting the amount of current flowing through the field winding and thus limiting the field magnetic strength.

  If the field winding develops a fault and becomes open circuited it will act like a series machine and accelerate to destruction.

  Reversing the polarity at the Armature will change the direction of the rotation of the motor.

- **Series**

    The field windings are connected in series with the armature. The field winding has to carry all of the armature windings current and thus is made up of heavy gauge wire.

    Series motors are capable of high torque at low speeds. But under no load will spin to destruction.

    Reversing the polarity at the Armature will change the direction of the rotation of the motor.

- **Compound**

    A compound machine is the combination of both Shunt and Series machines in one machine and is a combination of characteristics as well i.e. it is capable of high torque at low speeds but will not spin to destruction.

    They can be connected so that the shunt and series windings assist each other this is called CUMULATIVELY compounded. They can also be connected so the shunt and series windings resist each other this is called DIFFERENTIALLY compounded.

    The series windings may be wound like follows:

    1. **Under compounded** – the series windings have only a few turns so it has a decreasing voltage under full load conditions.
    2. **Level compounded** - the series windings have enough turns to maintain a constant voltage under full load conditions.
    3. **Over Compounded** –the series windings have more than enough turns so that a higher voltage is produced under full load conditions.

    Reversing the polarity at the Armature will change the direction of the rotation of the motor.

	Series Machine	Shunt Machine	Compound Machine
Good Points	High Torque at low speeds	Constant speed with load	High Torque at low speeds Constant speed with load
Bad Points	Will spin to destruction	Low torque at low speeds	More expensive as it has two field windings
Uses	Starter Motor	Conveyer belt	Everywhere else

	Series Field Winding	Shunt Field Winding	Armature winding
Characteristics of windings	Low resistance Physically heavier gauge cable with fewer turns High current flow	High Resistance Physically lighter gauge cable with more turns Low current flow	Low resistance Physically heavier gauge cable with fewer turns High current flow
Can be identified by	Using a multimeter set to Ohm's or by using an Ohm meter and measuring a LOW resistance across the winding. *(note, reading will not change if rotor is turned)*	Using a multimeter set to Ohm's or by using an Ohm meter and measuring a HIGH resistance across the winding. *(note, reading will not change if rotor is turned)*	Using a multimeter set to Ohm's or by using an Ohm meter and measuring a LOW resistance across the winding that varies when the rotor is turned.

- **Generated Voltage**

$$V_g = \frac{P \times \Phi \times n \times Z}{60 \times a}$$

V_g is generated voltage in Volts
P is number of poles
Φ is magnetic flux per pole in Webbers
n is revolutions per minute
Z is number of effective conductors
a is number of parallel current paths

- **Torque**

  The name given to the effort required to rotate an object

$$\tau = F \times \textit{Perpendicular Distance}$$

τ is Torque measured in Nm
F is force measured in Newtons
Perpendicular Distance is length measured in meters

- **Regulation**
  - **Voltage %**

    $$V_r = \frac{(V_{no\ load} - V_{full\ load}) \times 100}{V_{full\ load}}$$

  - **Speed %**

    $$Speed_r = \frac{(Speed_{no\ load} - Speed_{full\ load}) \times 100}{Speed_{full\ load}}$$

- **Efficiency**

  The ratio between input power and output power. The difference between input power and output power is due to losses.

$$Efficiency\ (\%) = \frac{Output\ Power}{Input\ Power} \times 100$$

Where Input Power is given by:
$P = I \times V$
P is power measured in Watts (W)
I is current measured in Amperes (Amps)
V is voltage measured in Volts (Volts)

And Output Power is given by:

$$P_{Output} = \frac{2 \times \pi \times n \times \tau}{60}$$

P is power measured in Watts (W)
n is revolutions per minute (RPM)

π is Pi, which is 3.14…
τ is torque measured in Newton Meters (Nm)

- **Losses**
  - **Air Gaps**
    Due to airs low permeability the magnetic flux density is reduced which increases reluctance.

  - **Friction**

  Iron Losses
  Remain constant

  - **Hysteresis**
    The power required to reduce the residual magnetism in the core to zero is called a Hysteresis loss. The force required is known as the coercive force.
  - **Eddy Currents**
    The changing magnetic field induces current into both the core and the windings. The current in the core are known as eddy currents. Not only do they reduce efficiency (by creating an unwanted back E.M.F.) they also cause unwanted heating.

  Copper Losses
  Change with the load

  - **Resistance of windings**