Unit V – Electricity & Magnetism

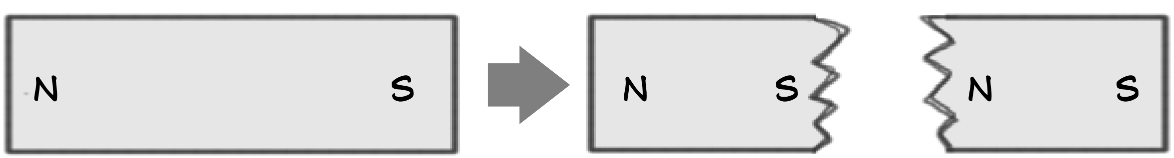
Topics covered:

- Magnetism
- Magnetic Fields, Magnetic Field Lines
- Domain Theory
- Electromagnetism
  - RHR#1 straight conductor
  - RHR#2 solenoids
  - RHR#3 magnetic force
- The Electric Motor
- The Electric Generator

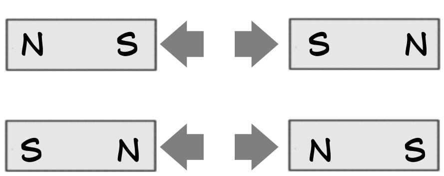
Magnets

Magnets are objects that exhibit magnetic phenomena. They consist of a ***North (N)*** pole at one extreme and a ***South (S)*** pole at the other.

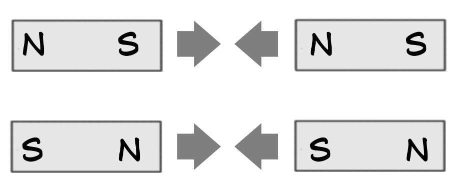
Magnetic monopoles do not exist – every magnetic object has opposite poles at opposite extremes. If a magnet is broken in half, each new fragment will have both a North and a South pole at its extremes.



When two objects are placed near each other, like poles will attract, and opposite poles will repel each other.



repulsion (like poles)



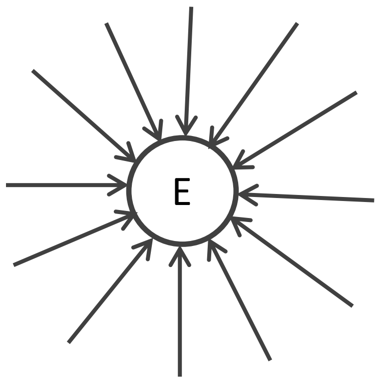
attraction (opposite poles)

Magnetic Fields, Magnetic Field Lines

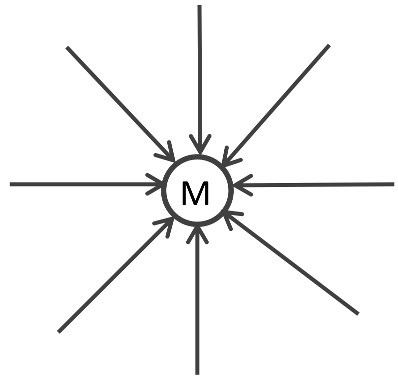
Force Field - a 3-dimensional space in which a force can be applied.

Gravitational Fields & Gravitational Field Lines

- Since all masses are attracted to other masses (Newton's law of universal gravitation), if we wanted to draw the gravitational field strength of the Earth, we would draw lines that show the direction of the force experienced by any object that happens to be near the Earth.
- The higher the density of lines at one location (e.g. closer to the surface), the stronger the force experienced there.
- Objects that have a stronger gravitational field are drawn with more field lines.



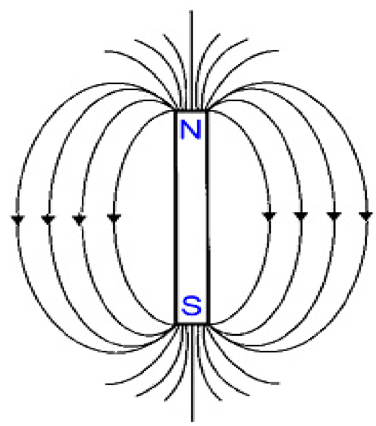
Gravitational field of earth



Gravitational field of the moon

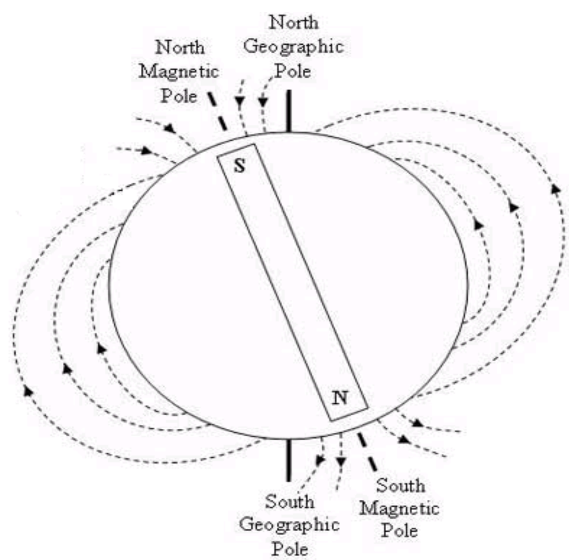
Magnetic Fields & Magnetic Field Lines

- Are always directed from north (N) to south (S), *outside* of the magnet.
- Are continuous (go from South to North *inside* the magnet)
- Never cross each other.
- A higher density of lines means a stronger magnetic field at the poles.



Magnetic Field of the Earth

Due to the Earth's molten iron core, it has a magnetic field. The geographic North pole is actually the magnetic South pole. Geographic North is referred to as *North* because all magnets point their magnetic north poles towards it (i.e. a compass!).

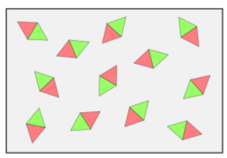


Domain Theory

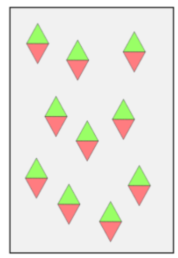
Dipoles – All atoms behave like tiny magnets, each with North and South poles. Since they are so small, they are little else than these two poles, and so are called ***dipoles***. When dealing with large (macroscopic) materials, we find that dipoles close to each other tend to act similarly, and we call these groups of dipoles ***domains.***

In a **non-magnetic substance**, all the domains are arranged randomly, and in doing so cancelling themselves out such that there is no net magnetic field.

Permanent Magnets have all their domains lined up in the same direction, which reinforce each other and create a net, macroscopic magnetic field.

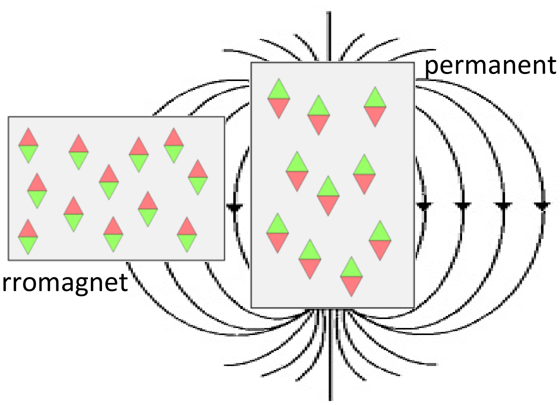


domains random (not magnetic)



domains aligned (magnetic)

Ferromagnets are substances that, under 'normal' circumstances, have their magnetic domains aligned randomly, so are not magnetic. But, if they are placed in an *external* magnetic field, their domains while align themselves accordingly. Once the external field is removed, the domains return to their random orientation.



Electromagnetism

In 1819, the principle of electromagnetism was discovered (and by accident!), which demonstrates that electricity and magnetism, previously thought to be completely separate phenomena, where in fact the same thing:

> *A changing electric field (i.e. electricity) creates a magnetic field, and a changing magnetic field creates an electric field (i.e. electricity).*

<u>Right Hand Rule of Electromagnetism #1 - Straight Conductor</u>

When a current flows through a straight conductor, a magnet field is produced is the space around the conductor:

Thumb: placed in the direction of the electric current (I).
Curled Fingers: Indicate the direction of the magnetic field ($\vec{B}$) produced by the current in the wire. (*The strength of the magnetic field depends on the amount if current through the wire).

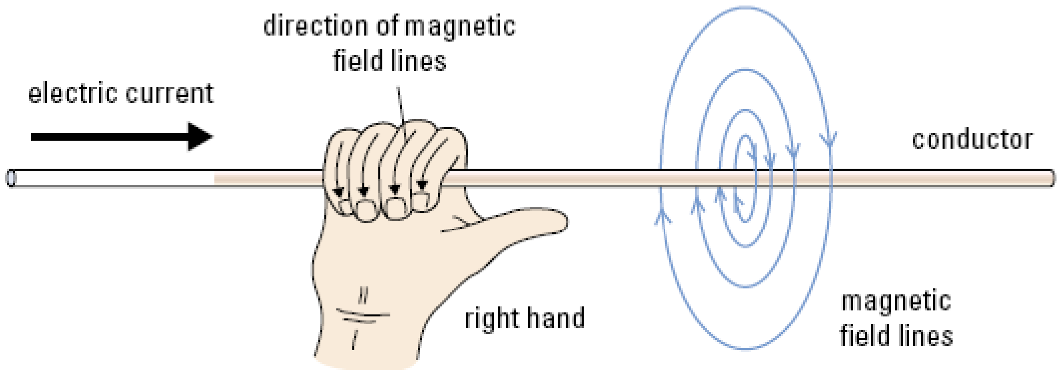
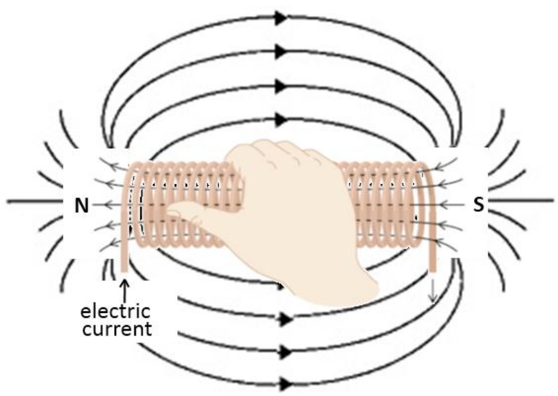


*image courtesy of *Nelson Physics11*

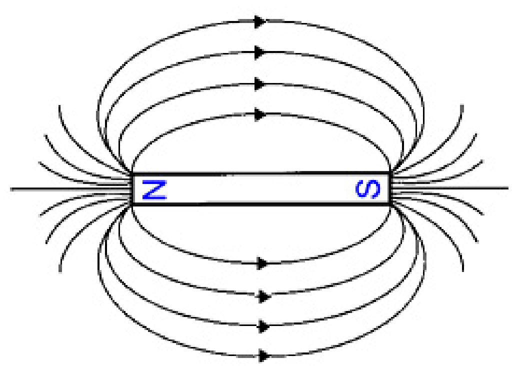
<u>Right Hand Rule of Electromagnetism #2 - Solenoids</u>

When a current flows through a solenoid (a conducting wire that has been wrapped in a circular spiral that gradually progresses from one end to the other), a magnet field is produced is the space around the conductor (n.b. the pattern of this field is identical to that produced by a bar magnet):

Curled Fingers: Placed in the direction of the current (I)
Thumb: Indicates the direction of the magnetic field ($\vec{B}$) produced *inside* the solenoid



Solenoid



Bar Magnet

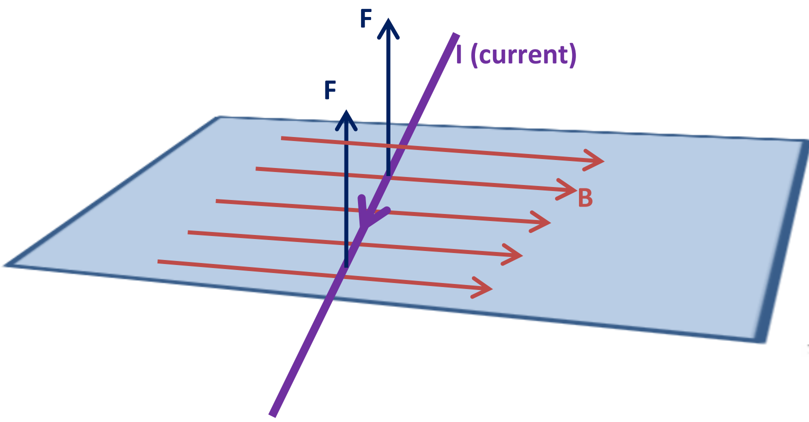
Factors Affecting the Magnetic Field of a Solenoid

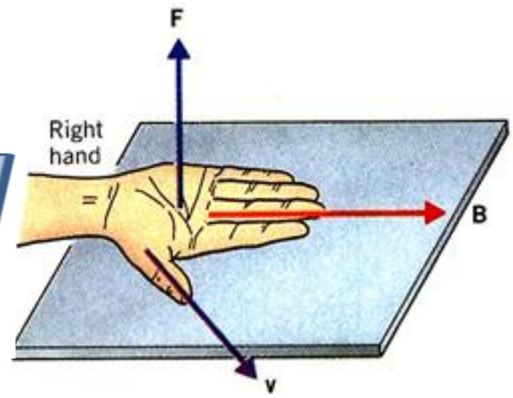
- **Current** - The stronger the current, the stronger the magnetic field produced.
- **Number of loops** - The more loops of wire that exist, the stronger the magnetic field produced.
- **Core Material** - If a ferromagnetic material is placed inside the coil, it can greatly increase the strength magnetic field (the material becomes magnetized and adds to the field of the solenoid).

Right Hand Rule of Electromagnetism #3 – Magnetic Force from External Field

When a current or an electrically charged particle flows through an *external* magnetic field, a force is exerted *on* the current/particle *by* the external field:

> **Flat Fingers**: Indicates the direction of the external magnetic field ($\vec{B}$).
> **Thumb**: Indicates the direction of *conventional* current / *positively* charged particle.
> **Open Palm**: Indicates the direction of the force *on* the current/charge *by* the external field.





The Electric Motor

Electric motors, large and small, are found everywhere, from handheld electric fans to electric cars. If there are moving parts in a device that needs to be run on batteries or plugged in, there's an electric motor inside.

The magnetic force that acts on a wire from an external magnetic field from RHR#3 is all that is required to operate an electric motor – that and some clever design:

> A loop of wire is placed inside an external magnetic field, as shown below. If the current is connected, what will happen? Segment ***A*** of the wire will experience an upward force, and segment ***B*** will experience a downward force, causing the whole loop to rotate clockwise.

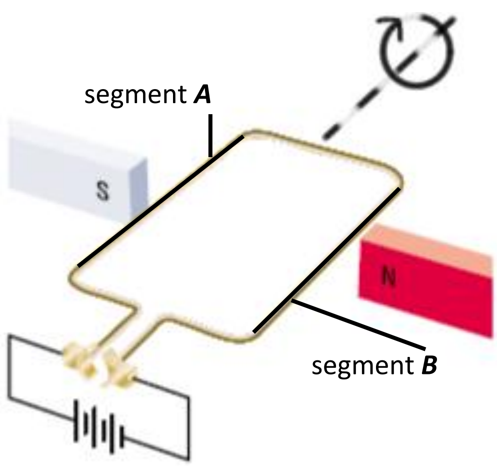
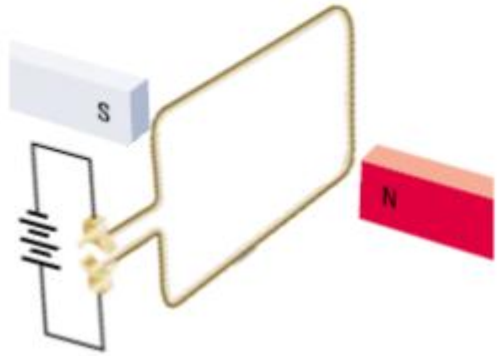


*image courtesy of *Nelson Physics11*

> However, once the loop passes the vertical position (after it rotates by 90°), the upwards force will cause it to rotate counter-clockwise. The loop will oscillate back and forth from its vertical position until it finally comes to rest there.



Not a very useful motor if can only, at the most, rotate for one half cycle. However, if the current in the loop changed direction after passing the vertical position, the direction of the force would also change, and the rotation would continue. If the current could change direction halfway through each cycle, it would then keep spinning indefinitely. This is how an electric motor works.

Below is a diagram of an electric motor as it completes one full rotation, changing the direction of its current along the way (between (b) and (c)). The loop of wire has been replaced by an electromagnet (solenoid), and motion is dictated by its poles. Upon careful analysis, however, the electromagnet experiences forces in the exact same manner as the loop of wire:

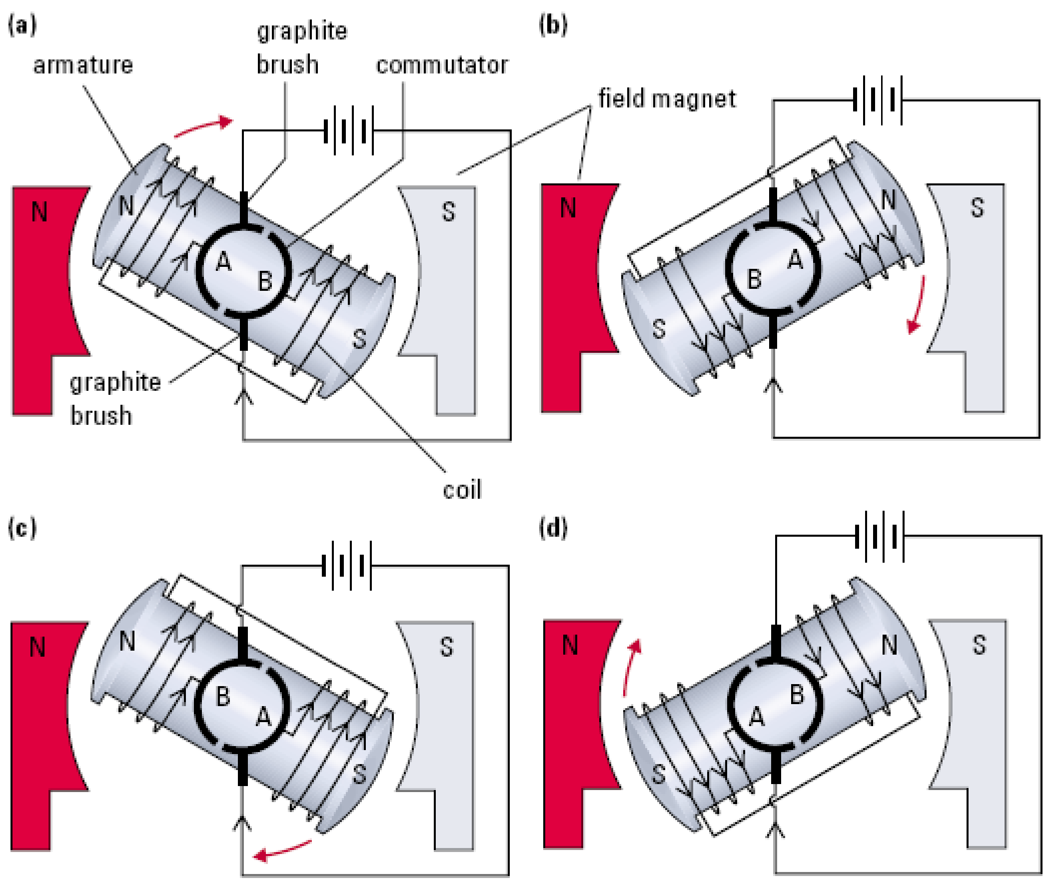


*image courtesy of *Nelson Physics11*

Notice also that exactly between (b) and (c) the current stops flowing, but the rotational momentum keeps the armature keeps it spinning to reconnect again, now with the current flowing in the opposite direction.

The Electric Generator

An electric generator acts in the exact opposite way as an electric motor. If you can get a magnetic field to change (e.g. by spinning a magnet) near an electric conductor, a current will flow through the conductor. Most electricity is produced by simply getting a magnet to spin:

i) **Coal / Nuclear / Oil and Gas / Geothermal:**
Heat is used to boil water, to produce steam (1), which rises to spin a turbine (2), which spins a magnet (3) to produce electricity.

ii) Hydroelectric / Tidal Energy:
Water falls from a high position and enters the turbine (1), turning the blades (2) in the turbine , which spins a magnet in the generator (3) to produce electricity.

iii) Wind:
Wind turns the blades (1), which turns a turbine (2) which spins a magnet (3) to produce electricity.

i)

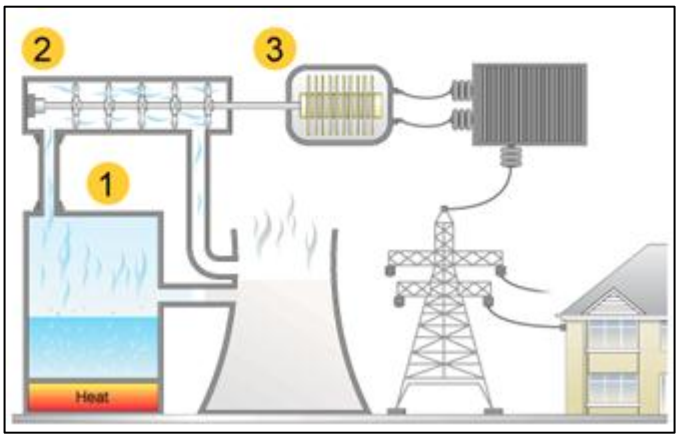


*image courtesy of *The BBC* KS3 Bitesize

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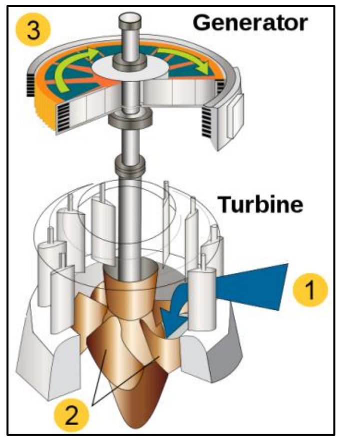

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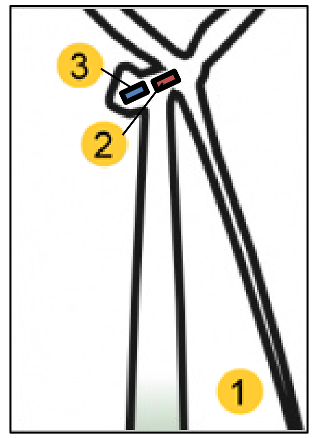
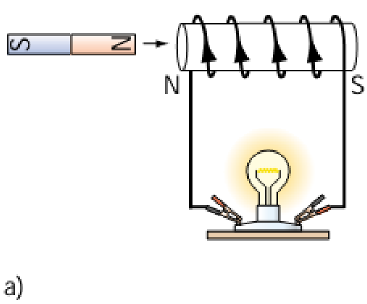


Lenz's Law

A changing magnetic field near a conductor will create a current in the inductor (an *induced* current). This induced current will create its own magnetic field, and Heinrich Lenz determined that:

The magnetic field of an induced current always opposes the change in magnetic field that is causing the induced current

Notice in a) below, as the bar magnet is pushed towards the solenoid, a current is produced such that the bar magnet is repelled, which resists this change. In b), the opposite occurs when the bar magnet is taken away, where a current is produced such that the bar magnet is attracted, again, resisting the change.



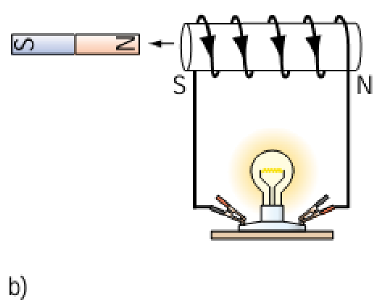


*image courtesy of *Addison Wesley Physics 11*