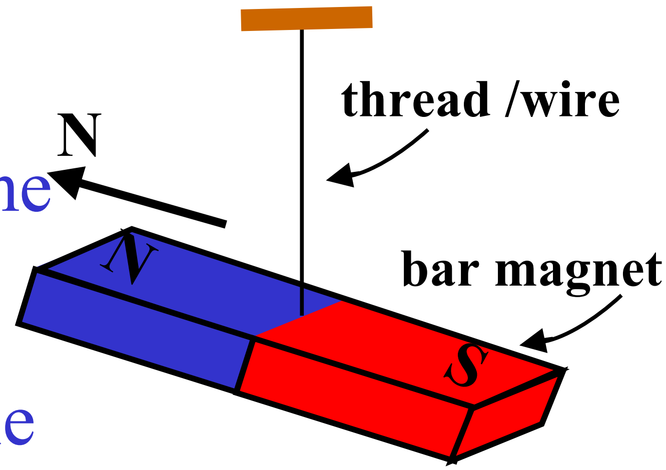
Electromagnetism 1 (Chapter 14)

Magnets:

- Very **familiar** objects but **mysterious** too.
- Uses:
  - Compass
  - Electric motors
  - Electric generators
  - Transformers
- Like **gravitational** and **electrostatic** forces, **magnets** also exhibit "long range force".
- Three common magnetic elements are the metals:
  - Iron
  - Cobalt
  - Nickel
- Most magnets are made of a **combination** of **these three metals**, plus other compounds.
- **First** known **magnets** were made of **naturally** occurring **iron ore** called **magnetite** which is often **weakly magnetized**.

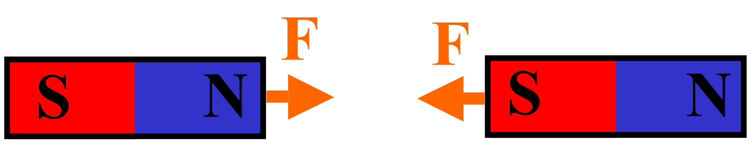
- Magnets **attract** certain metals (made of iron or steel) but not others (e.g. silver, copper, aluminum) and most non metal materials.
- Magnets can **attract** or **repel** each other (depending on their alignment).

Magnetic Poles:

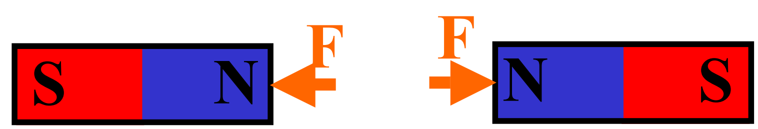


- If a magnet is suspended on a wire, one end will point approximately northwards.
- This is called the "North seeking" pole and is labeled 'N'.
- The other end, "South seeking" pole is labeled 'S'.

Attraction



Repulsion



❖ **Like poles repel** one another and **unlike poles attract** each other.

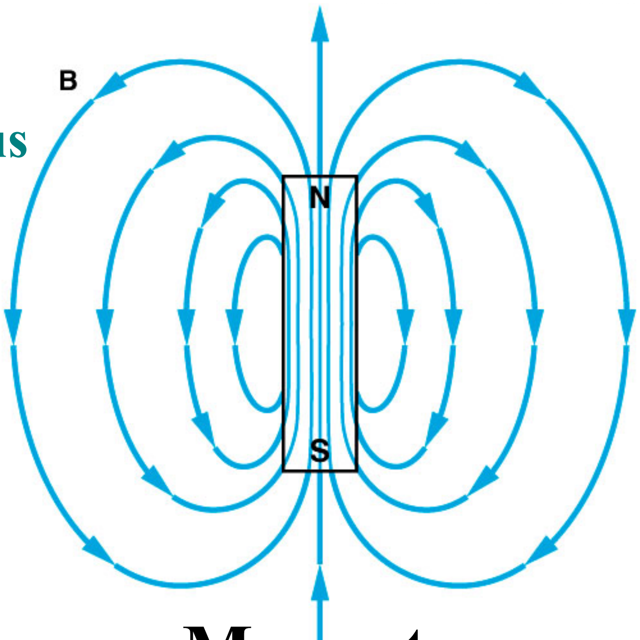
Comparison of Magnetic and Electrostatic Forces (Coulomb's Law)

- **Both** exhibit **attractive** and **repulsive** forces.
- **Both** are "**long range**" forces (like gravity).
- **Both** magnetic and electrostatic forces **decrease** as $\frac{1}{r^2}$.
- **Both** forces depend on the **product** of "**charges**" (electrostatic) or "**pole strengths**" (magnetic).
- **Both** exhibit "**field lines**" that indicate magnitude and direction of forces.
- However, **unlike** an **electrostatic** charge, a magnet is always **at least** a **dipole**.
- A **dipole** consists of **two opposite poles** separated by a distance.
- **Cutting** a magnet **in half** will produce **two dipoles**.
- The search for a magnetic monopole continues (i.e. particles consisting of single isolated pole).

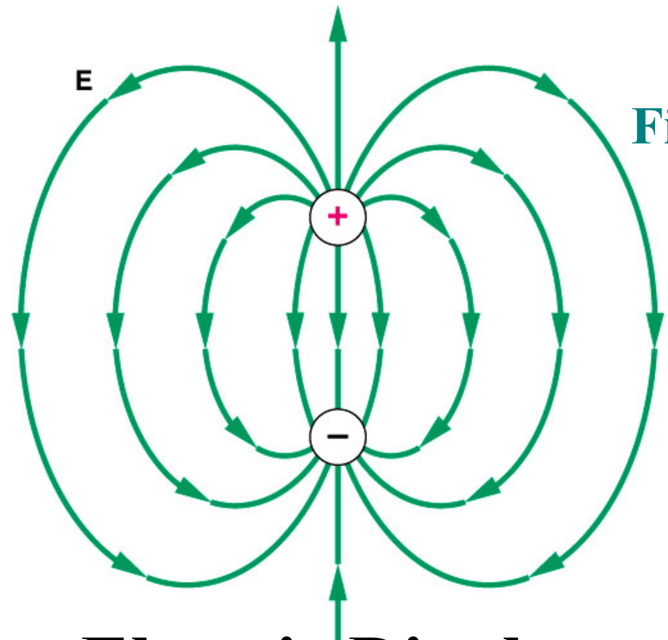
Magnetic Field Lines

- Magnetic field lines of a **simple dipole magnet** are **similar** (but not identical) to **electric field lines** of an **electric dipole**.

Continuous loops



Magnet



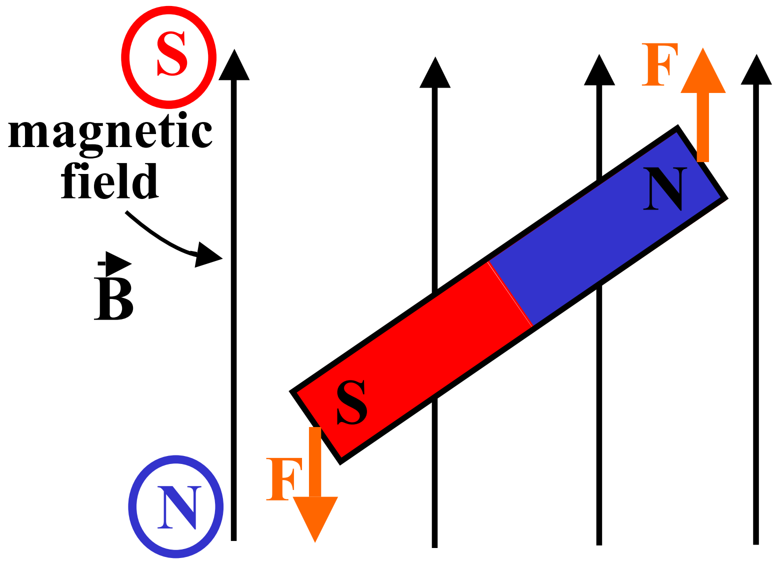
Electric Dipole

Field lines end on charges

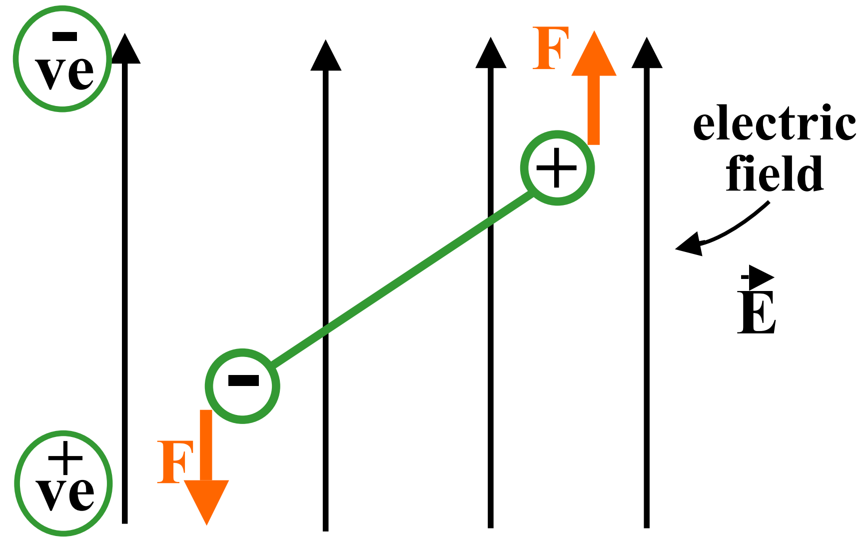
- Magnetic field lines **emerge** from **North** pole and **go to South** pole… (like electric field from +ve to –ve).
- However, unlike electric field lines, magnetic lines are **continuous loops**.
- Magnetic field strength is **very high within** the magnet.

Influence of an External Field

- Question: **What happens** when we place a **magnetic dipole** (or an **electric dipole**) in an **externally made field**?



Magnetic Dipole

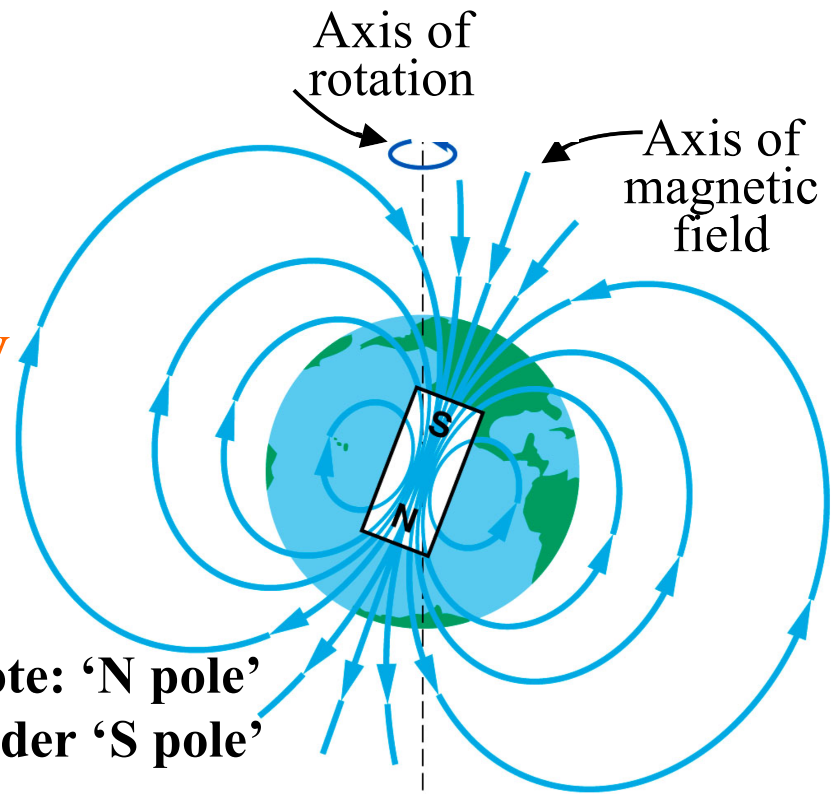


Electric Dipole

- **Both** experience a **torque** causing the **magnetic** (and **electric**) **dipoles** to **align** with the **external field** (i.e. the **two fields** align together).
- **Reason** why **iron filings line up** with **field** around a **magnet** – as they become **tiny magnetic dipoles** (in presence of a magnetic field).

Earth's Magnetic Field

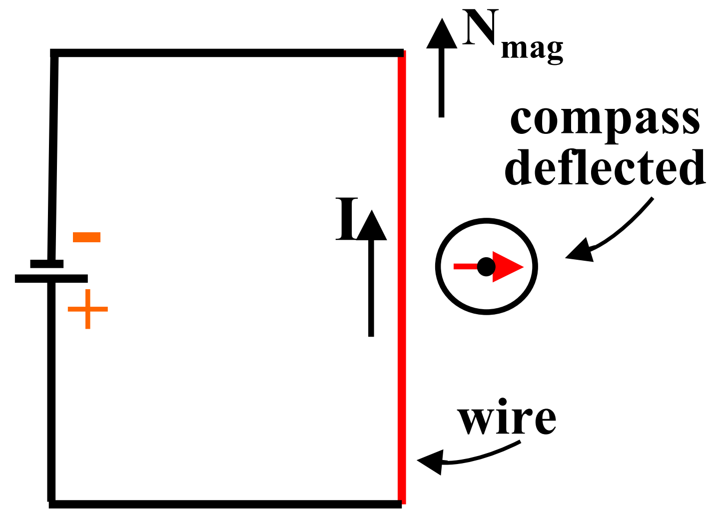
- **Compass** invented by Chinese – discovered **magnetite crystals** would point approximately **N-S** when free to turn.
- **Compass** permitted **ocean navigation** even when no Sun or stars to plot position by!
- **Gilbert** (16th century) suggested **Earth's magnetic field** like a large "**bar magnet**" (i.e. **dipole field**).
- **North seeking pole** of compass **aligns** itself along **Earth's magnetic field**, pointing roughly **northwards**.
- **Axis** of magnetic **field not** exactly **aligned** with **rotation axis**.
- **Earth's magnetic field** probably produced by electric **currents** flowing in molten **core**.
- Polarity reversals ~10,000 yrs.



Note: 'N pole' under 'S pole'

Magnetic Effects due to Electric Currents

- **Volta** (1800) invented the **battery** and enabled the first measurements with **steady electric currents**.
- **Oersted** (1820) **discovered** the **magnetic effects** of an **electric current** (by accident!).



- Discovered that a **compass** positioned **close** to a **current carrying wire** was **deflected**.
- **Maximum** effect when **wire magnetic N-S aligned.**
- When **current flows** compass **needle deflects away** from N.

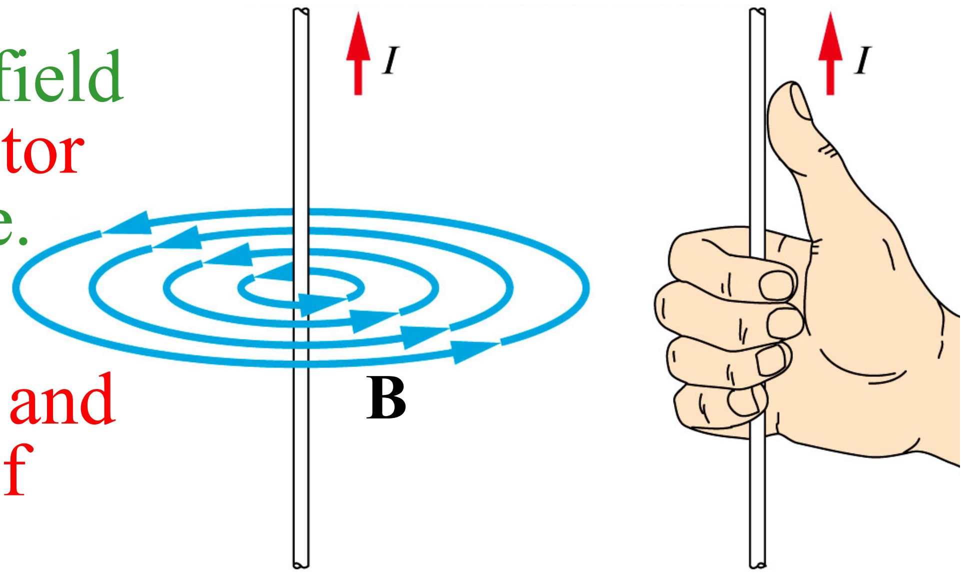
Result:

- **Magnetic field produced** by **current flowing** in **wire. Field is perpendicular** to **direction** of **current**.
- Need several amps to produce an observable deflection and effect decreases with distance from wire.

- Oersted discovered magnetic field produced by a straight conductor forms **circles** centered on wire.

Right hand rule:

- Thumb in direction of current and curled fingers give direction of magnetic field lines.

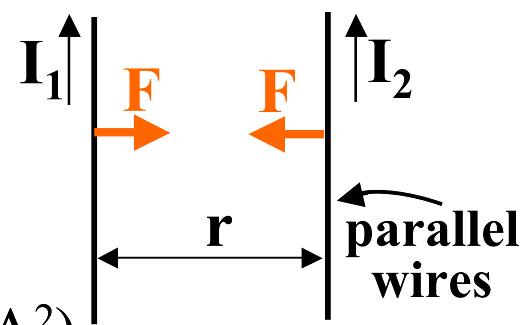


Field perpendicular to current

- Question: Does an electric current experience a magnetic force in presence of a magnet or another current carrying wire?
- Ampere (1820's, France) discovered there is a **force** exerted on one current carrying wire by another.
- Two parallel currents:

$$\frac{F}{l} = \frac{2k' I_1 I_2}{r}$$

(where $k' = 1 \times 10^{-7}\ N/A^2$)



Ampere's Law: $\frac{F}{l} = \frac{2k' I_1 I_2}{r}$

- Force is proportional to product of both **currents**.
- Force is inversely proportional to **distance** (r) between wires.
- Force is proportional to **length** (l) of wires.
- Force is **attractive** when currents in **same direction** and **repulsive** if current in **opposite direction**.
- Example: Determine force between two wires 1 m in length, separated by 1 m and carrying 1 amp each.

$$F = \frac{2 \times 10^{-7} \times 1 \times 1}{1} = 2 \times 10^{-7}\ N$$

$k' = 1 \times 10^{-7}\ N / A^2$
$r = 1\ m$
$I_1 = I_2 = 1\ A$

- This is the **definition of the ampere** which is the basic unit of electromagnetism.

❖ 1 amp is current required to produce a force of 2×10^{-7} N per meter on 2 parallel wires separated by 1 m.

Definition of Charge

- Electric charge is measured in Coulombs.
- The **Coulomb** is **defined** from the **ampere** as:
- Current I is the rate of flow of charge 'q'

$$\text{Current} = \frac{\textbf{Charge flow}}{\textbf{time}} \quad \text{or} \quad I = \frac{q}{t}$$

- Thus, Charge $q = I \,.\, t$ (Units: Coulombs, C)

❖ **One Coulomb equals one ampere in one second.**