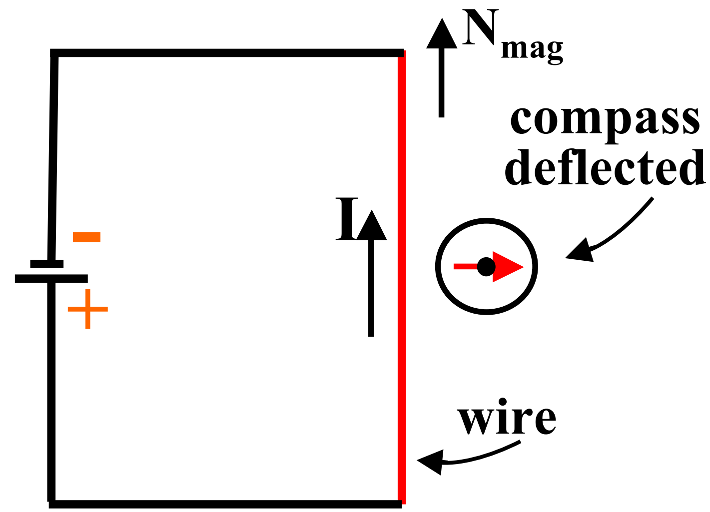
Magnetic Effects due to Electric Currents

- **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.

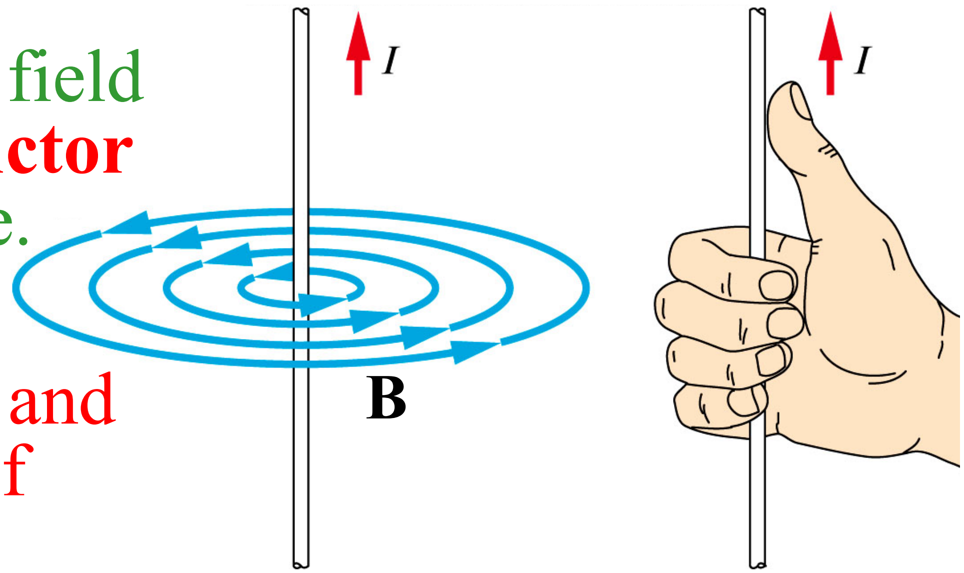
Result:

- **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.

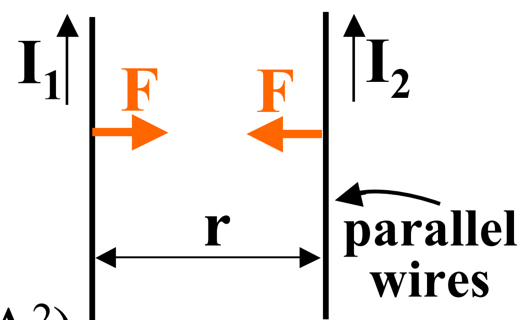


Field perpendicular to current

- **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)

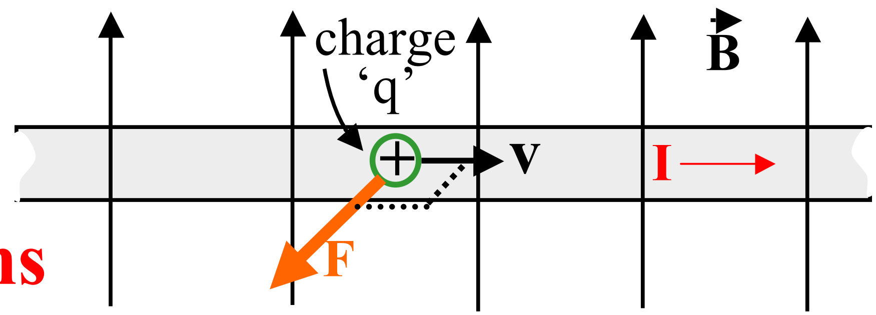


Electromagnetism 2 (Chapter 14)

Magnetic Force:

- Can be exerted by: - **O**ne magnet on another.
  - Magnets on a current carrying wire.
  - Currents carrying wires on each other.
- Magnetic force **arises** when **current** (i.e. electric **charge**) is **flowing**.
- Ampere showed force is perpendicular to the current motion.

  i.e. Force is perpendicular to velocity of charge motion.



F = q. v .B Units: **Newtons**

- Force is proportional to the **quantity** of **charge** and its **velocity** (i.e. related to **current**) and **magnitude** of **field**.

Note: Velocity must be perpendicular to the field for this equation. (Maximum force condition)

- As with the **electrostatic force**, the **magnetic force** defines the **magnetic field**.

$$B = \frac{F}{q.v}$$

$$E = \frac{F}{q} \qquad \text{(Force /unit charge)}$$

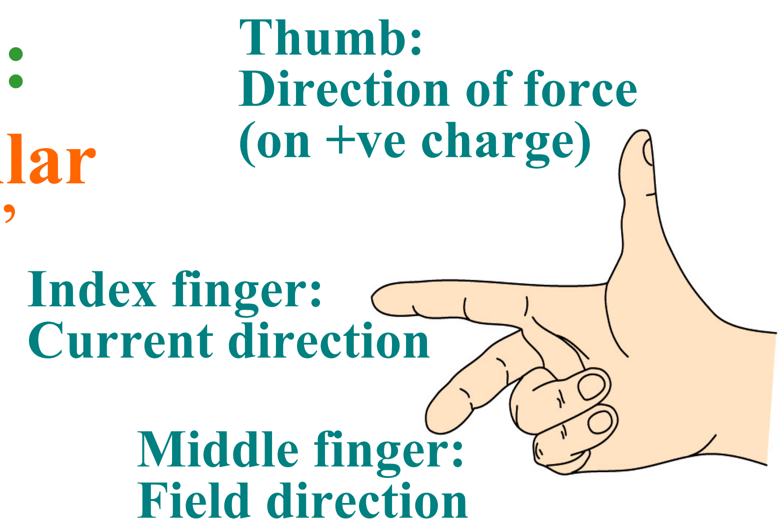
(where ‘v’ is perpendicular to ‘B’).

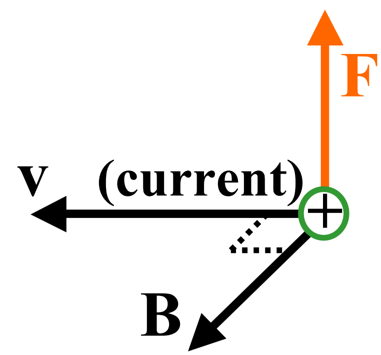
- **Units** of **magnetic field** ‘B’ are the **Tesla**.
- Thus **magnetic field strength** is **force** per **unit charge** and **unit velocity**!

❖ If **v = 0**, there is **NO** magnetic force!

Direction of force:

- **Force** is **perpendicular** to **magnetic field** ‘B’ and **current**.
- **Right hand rule:**





- For a given **length** of wire, we can **express 'B'** in terms of **current**:

$$B = \frac{F}{q.v}$$

but $I = \frac{q}{t}$, and $v = \frac{l}{t}$

Thus: $$\mathbf{B = \frac{F}{I.\,\mathit{l}}}$$

Example:

What force is acting on a 2 m long wire carrying current of 5 amps in a perpendicular magnetic field of 0.8 Tesla?

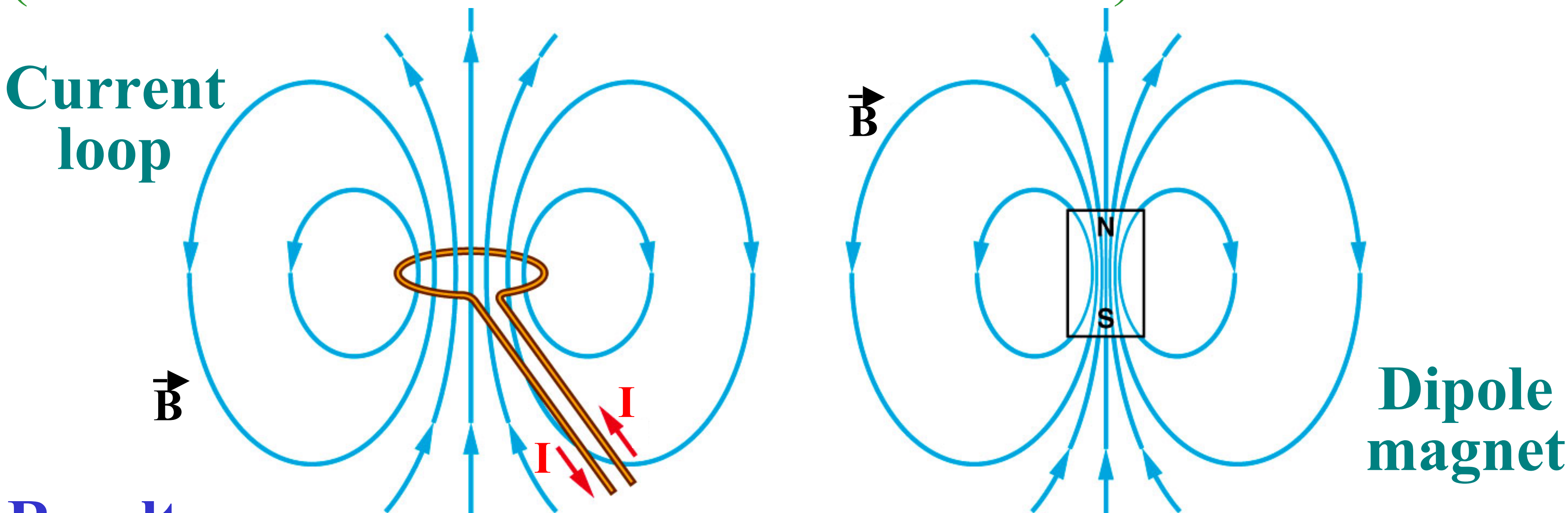
$F = B.\,I.\,l = 0.8 \times 5 \times 2 = 8\text{ N}$ (perpendicular to I and B)

Summary:

- **Magnetic force** is a **fundamental** force exerted by **moving charges**.
- Electric **currents** generate **magnetic forces** by means of **magnetic field**.
- **Magnetic field** is **force per units charge**, per **unit velocity**. If **v = 0**, **No field** and **No force**.

Current Loops

- What happens when we **bend wire** to form a **loop**? (i.e. What does the resultant field look like?)

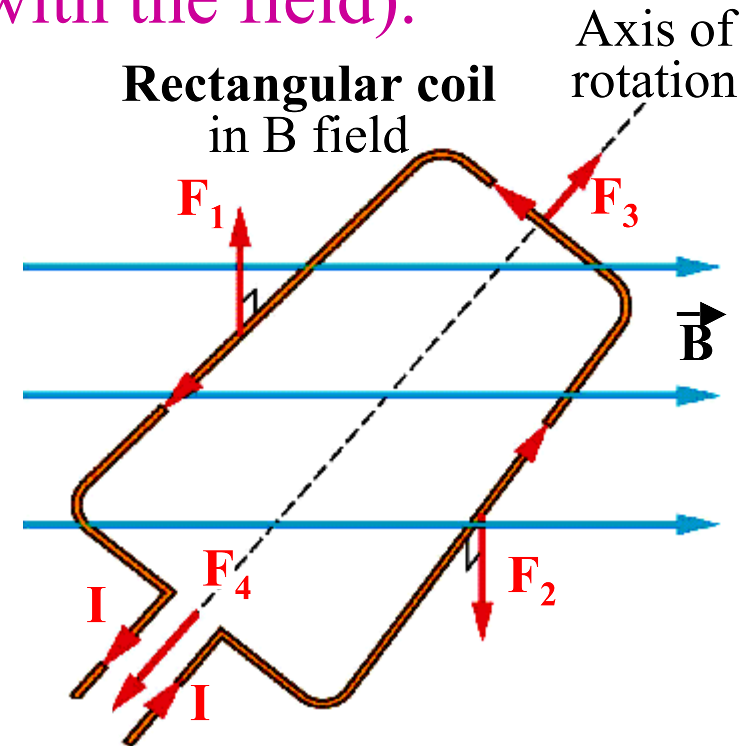


Results:

- **Magnetic field** produced by a **current loop** is **identical** to that of a **short bar magnet**.
- **Field strength** is **largest** at **center** of the **loop**.
- **Current loop** forms a **magnetic dipole field**.

Electric Motor

- If we place a **current loop** in an **external magnetic field**, it will experience a **torque**.
- This **torque** is the **same force** a **bar magnet** would **experience** (if not initially aligned with the field).
- Using **Right Hand rule** the forces ($F = B. I. l$) create:
  - · F_1 and F_2 combine to produce a **torque.**
  - · F_4 and F_3 produce **no torque** about the **axis of rotation**.

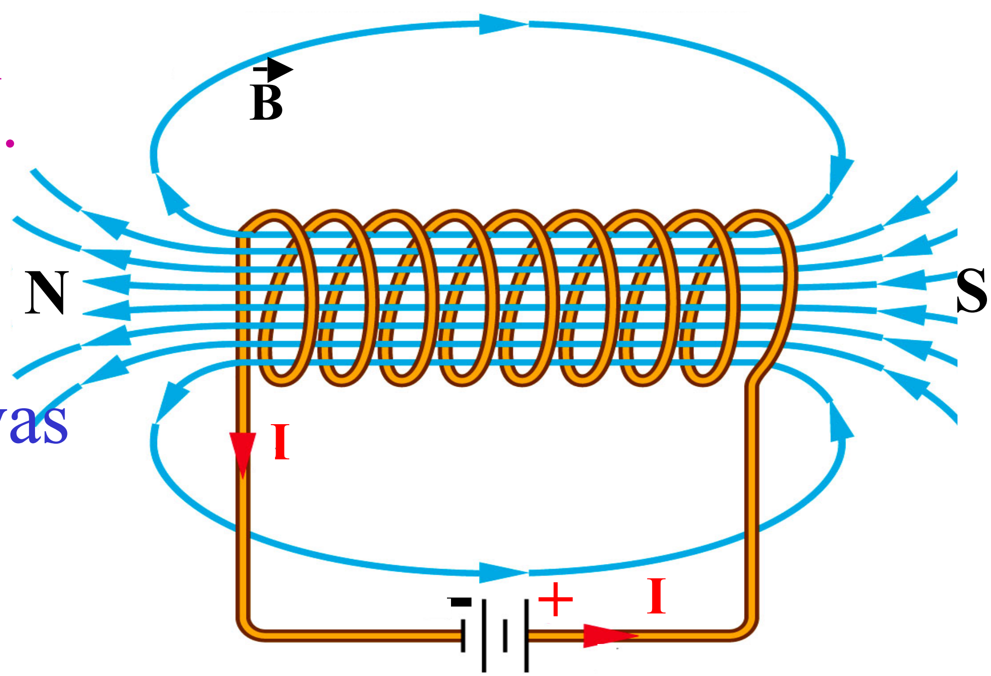


- Forces F_1 and F_2 will rotate loop until it is perpendicular to magnetic field (i.e. vertical in figure).
- To keep **coil turning** in an **electric motor** must **reverse current** direction **every ½ cycle**.
- **AC current** is **well suited** for operating electric motors.
- In a DC motor need to use a "split ring" or "commutator" to reverse current.

- **Electric motors** (AC and DC) are very common:
  Magnitude of torque is proportional to **current** flowing.
  Uses: car starter motor; vacuum cleaners; current meters
- **AC motors** run at a **fixed speed**.
- **DC motors** have **adjustable speed** (depending on applied voltage.

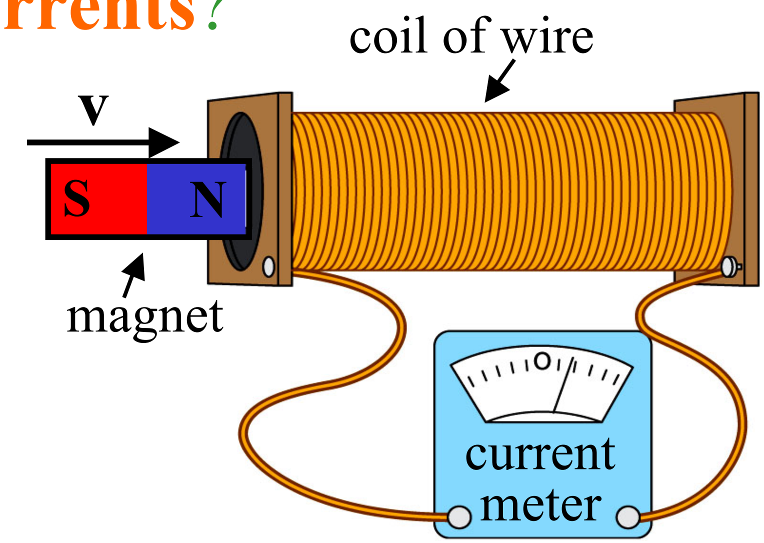
Electromagnets

- If we take a **single loop** and **extend** it into a **coil of wire** we can create a **powerful electromagnet**.
- **Magnetic field** proportional to **number of turns** on coil.
- If add iron/steel core field **strength enhanced**.
- Ampere suggested source of magnetism in materials was current loops – **alignments** of "**atomic loops**" gives a **permanent magnet**.

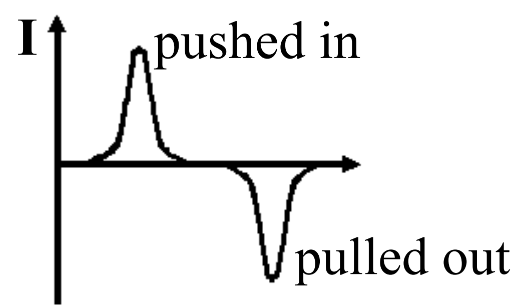


Electromagnetic Induction

- An **electric current** produces a **magnetic field** **but** can **magnetic field** produce **electric currents**?



- Magnet moved in and out of wire coil.
- **Michael Faraday** (U.K.) discovered that when **magnet** is **moved** in /out of a core a **current** was **briefly induced**.
- **Direction** of current **depended** on **direction** (in/ out) of magnet.

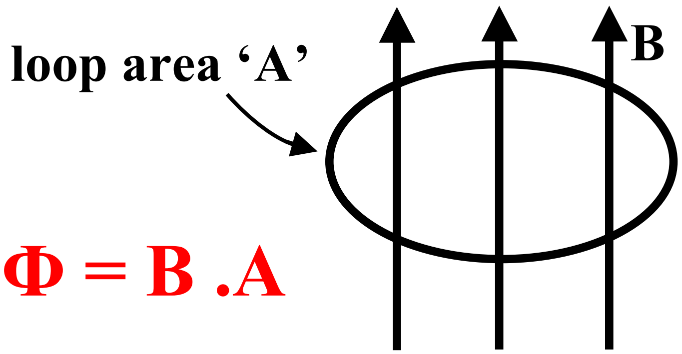


- When **magnet stationary** **no current** is **induced**.
- **Strength** of **deflection** depended on **number of turns** on coil and on **rate of motion** of the magnet.

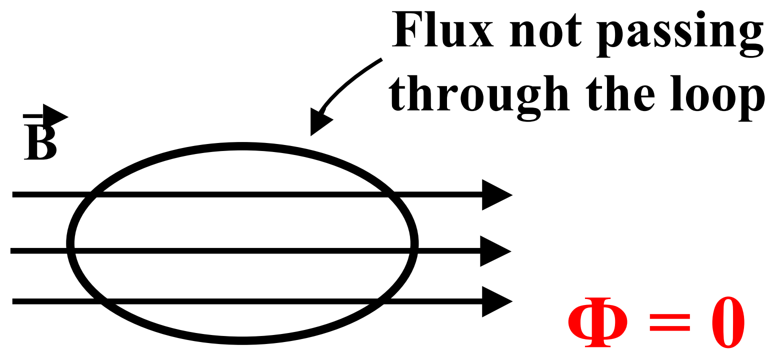
Result: **Current induced** in coil when **magnetic field** passing through coil **changes**.

Magnetic Flux

- Number of **magnetic field lines** passing through a **given area** (usually area of loop).



$\Phi = B\,.A$



$\Phi = 0$

Maximum flux is obtained when **field lines** pass through circuit **perpendicular** to coil.

If **field lines parallel** to circuit plane, the **flux = 0** as **no field lines** pass **through coil**.

❖ **Faraday's Law: A voltage is induced in a circuit when there is a changing magnetic flux in circuit.**

$$\varepsilon = \frac{\Delta\Phi}{t}$$ (electromagnetic induction)

- **Induced voltage 'ε' equals rate of change of flux.**

- $\Delta\Phi$ is **change** in flux
- More rapidly flux changes, the larger the induced voltage (i.e. larger meter swing).
- As magnetic **flux passes** through **each loop** in coil the total flux,

$$\Phi = N \cdot B \cdot A$$

- Thus the **more turns** of wire, the **larger** the **induced voltage**.

Example: Determine induced voltage in a coil of 100 turns and coil area of 0.05 m^2, when a flux of 0.5 T (passing through coil) is reduced to zero in 0.25 sec.

$$\Phi = N \cdot B \cdot A = 100 \times 0.5 \times 0.05$$

$$\Phi = 2.5 \text{ T} \cdot m^2$$

N = 100 turns
B = 0.5 T
A = 0.05 m2
T = 0.2 s

Induced voltage:

$$\varepsilon = \frac{\Delta\Phi}{t} = \frac{2.5 - 0}{0.25} = 10 \text{ v}$$

- **Question**: What is the direction of induced current?

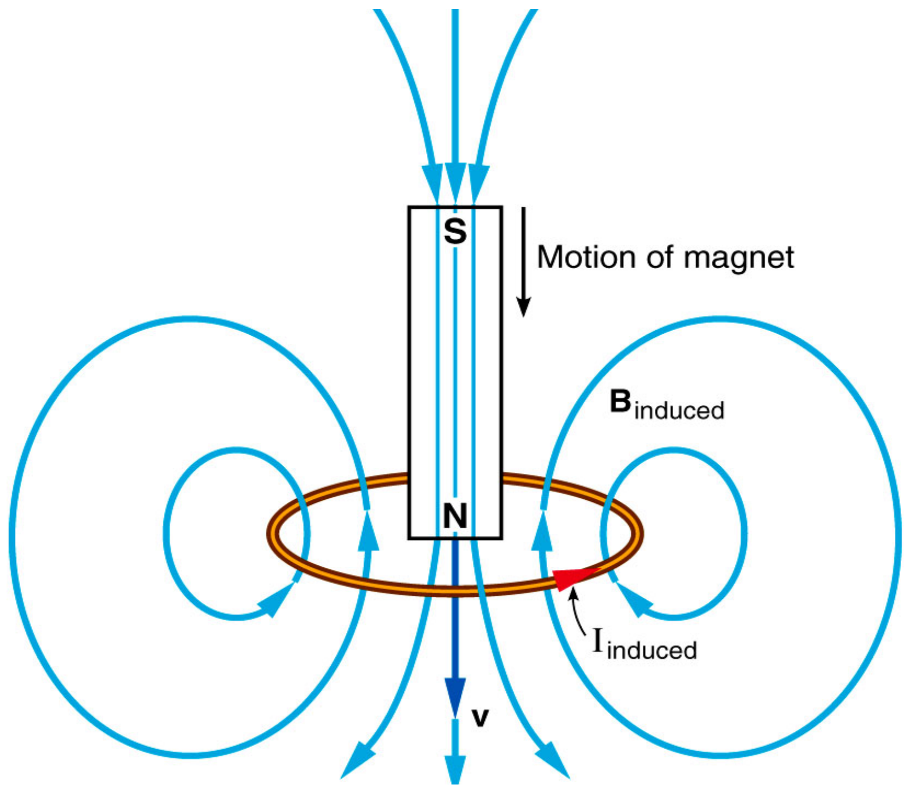
Lenz's Law (19th century):

❖ **The direction of the induced current (generated by changing magnetic flux) is such that it produces a magnetic field that *opposes* the change in original flux.**

E.g. If **field increases** with time the field produced by **induced current** will be **opposite in direction** to original external field (and vice versa).

- As magnet is pushed through coil loop, the **induced field opposes** its field.

Note: This also explains why the **current** meter needle **deflects** in **opposite directions** when magnet pulled **in** and **out** of **coil** in laboratory demonstration.



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.

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

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

- 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 $q = I \cdot t$ (Units: Coulombs, C)

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