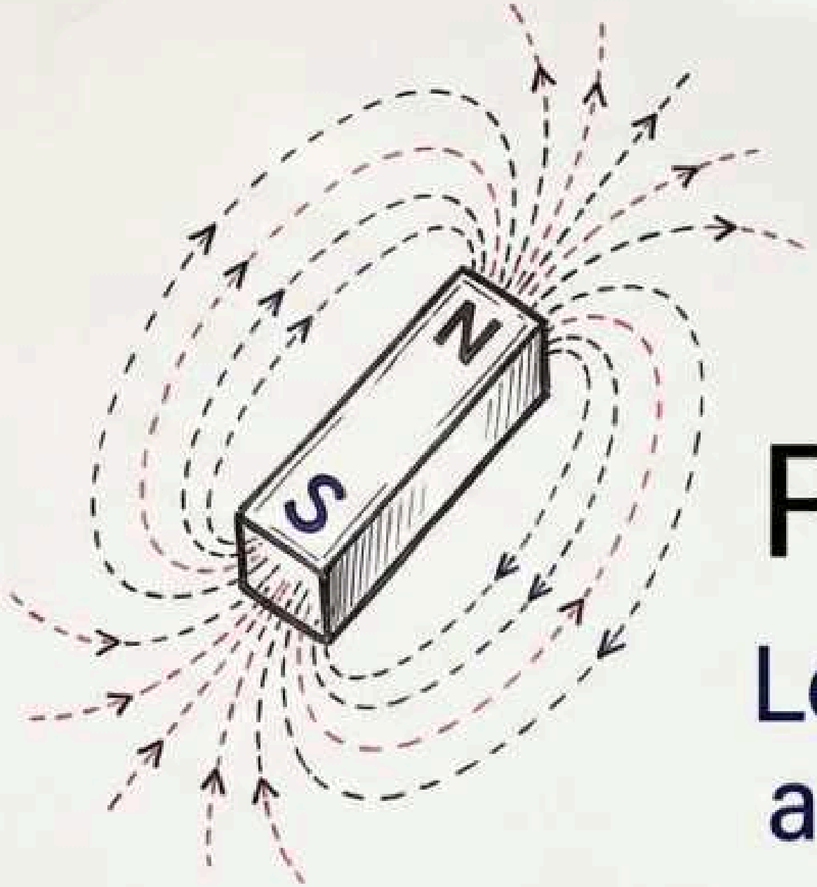
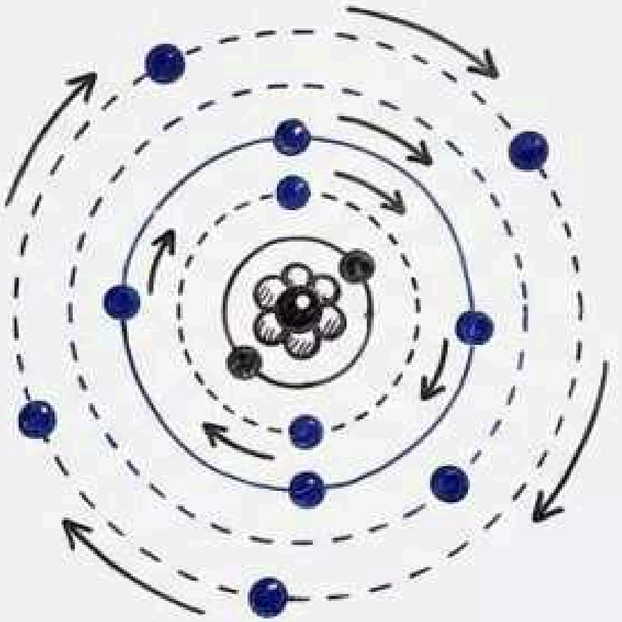
¶ 4.1



Physics 102 B

Lecture 4: Magnetism and Magnetic Forces



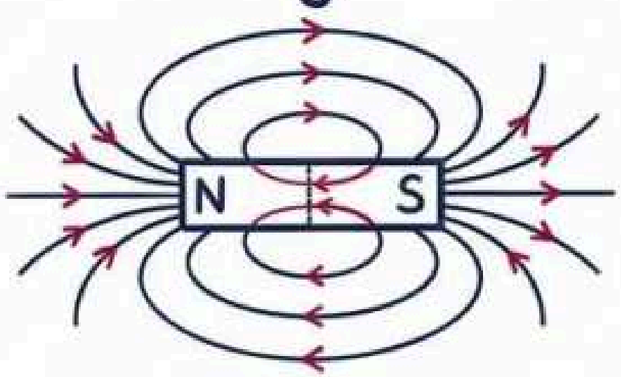
Welcome to Lecture 4.

Gemini Notebook

Magnetism: The Second Half of Electromagnetism

¶ 4.2

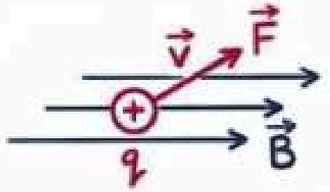
1. Describe Magnetic Fields

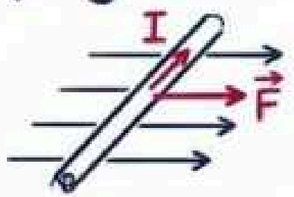


1 1

2. Calculate Forces

- (moving charges & current-carrying wires)



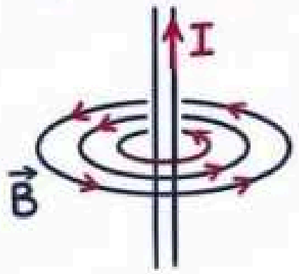


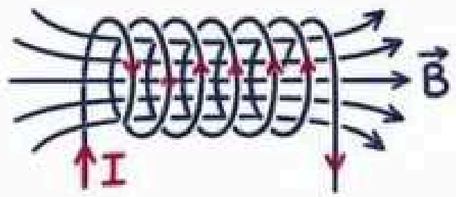
2 2

3. Find Fields

3

- (wires & coils)

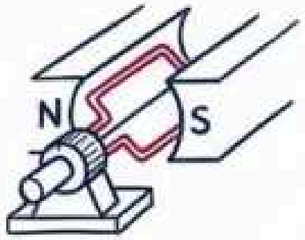


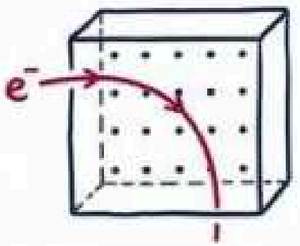


4. Applications

4

- (motors & particle detectors)





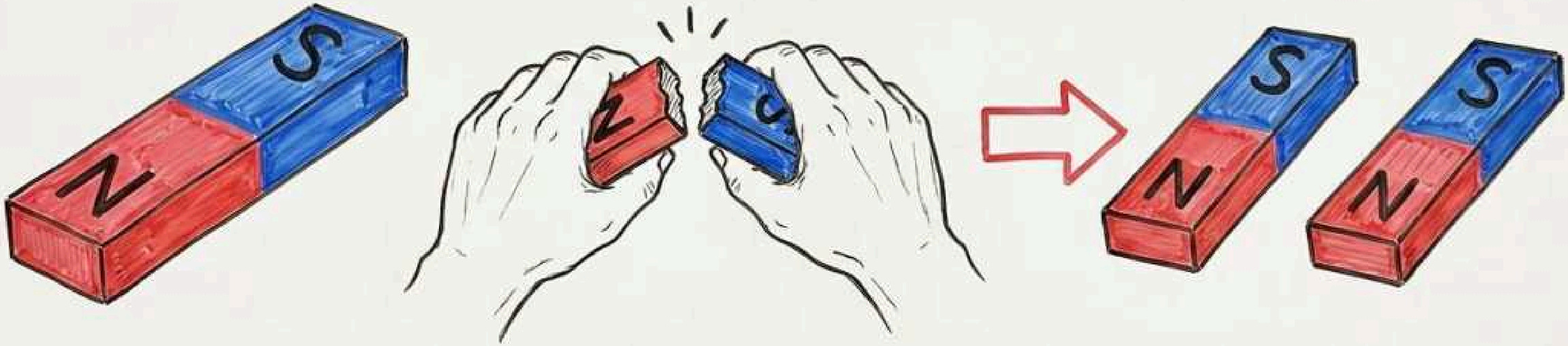
Core Insight: Magnetism is caused by moving charge.

Gemini Notebook

Poles: North (N) and South (S)

¶ 4.3

Like poles repel, opposite poles attract.



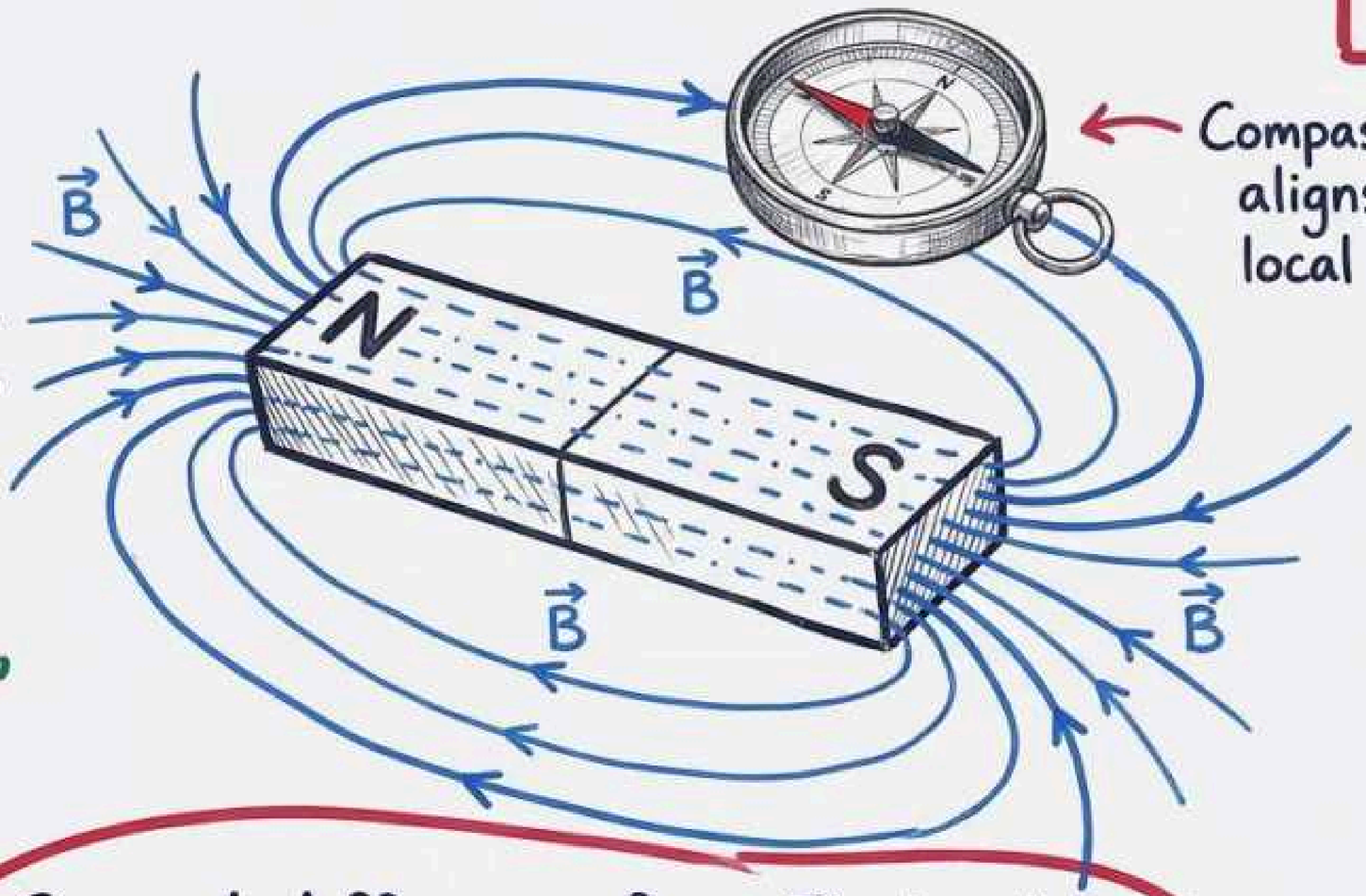
The Monopole Rule: Cut a magnet in half → get two smaller magnets. No isolated magnetic monopoles exist.

Gemini Notebook

¶ 4.4

Magnetic Field = $\vec{B}$
(Unit: Tesla, T)

Lines leave North, enter South.

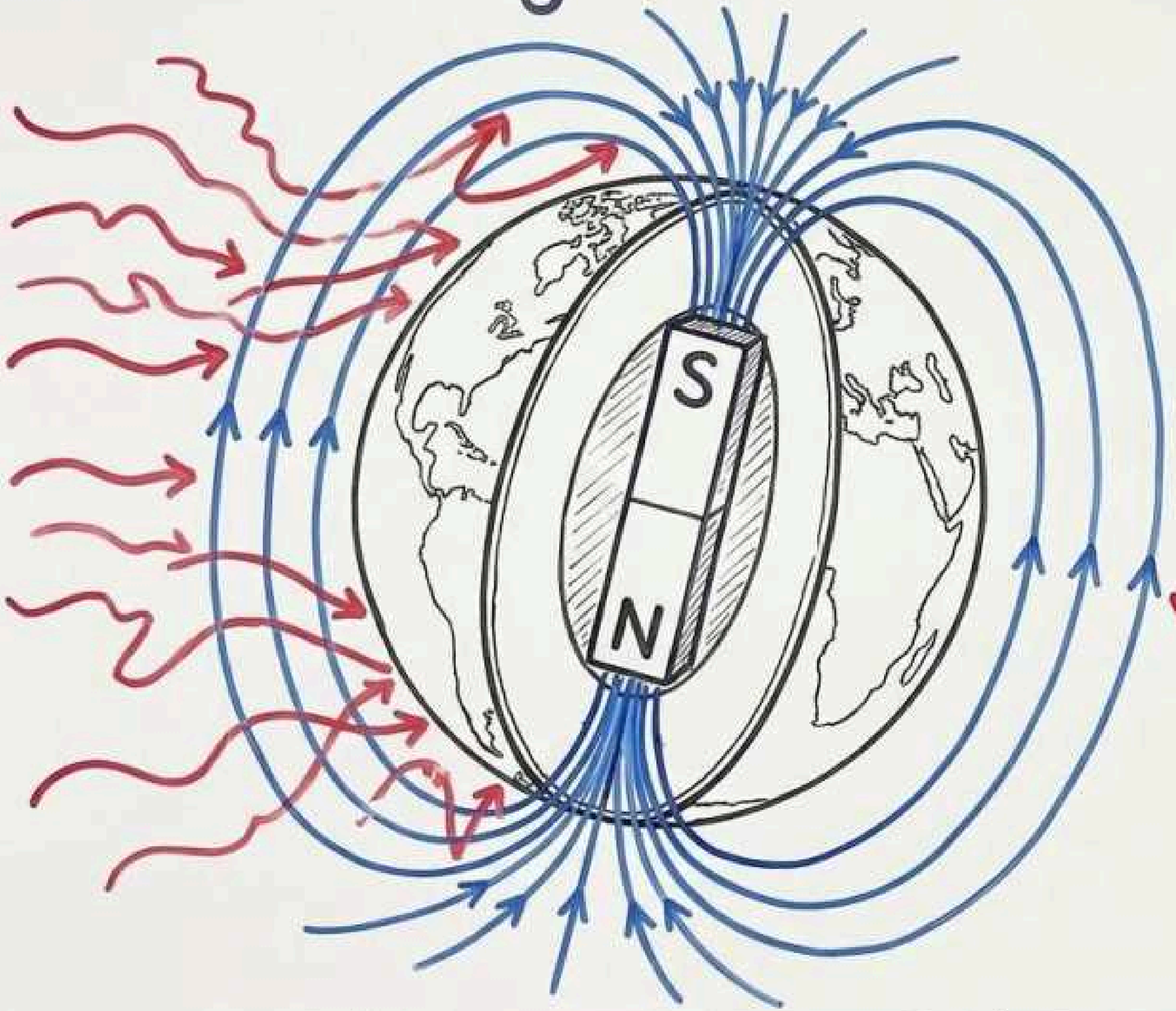


Crucial difference from Electric lines:
Magnetic lines form closed loops continuing inside the magnet.

Gemini Notebook

Earth's Magnetic Field

¶ 4.5



- Surface Strength: ~50 μT (5×10^{-5} T)
- Geographic Arctic = Magnetic South Pole

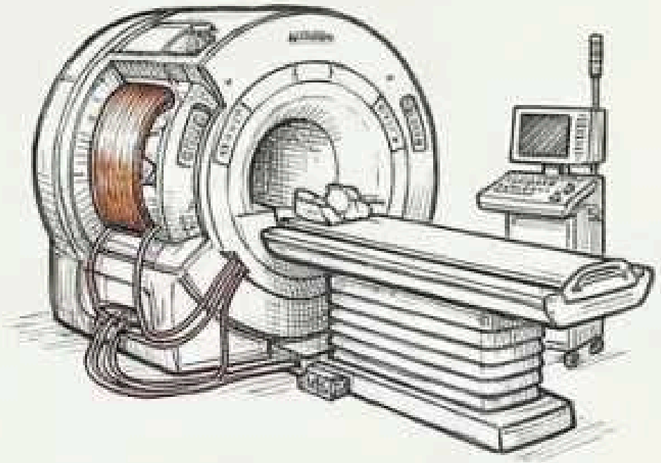
← Shields us from solar charged particles → Result: The Aurora.

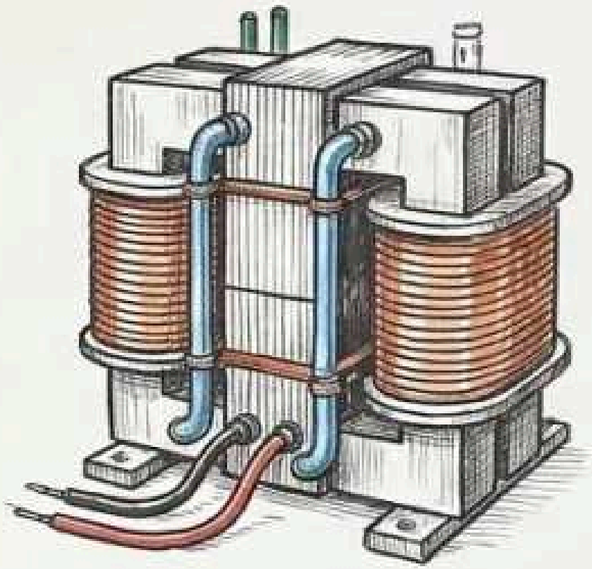
Gemini Notebook

¶ 4.6









Earth:
0.00005 T
(50 μT)

Refrigerator
Magnet:
0.005 T

Hospital MRI
Scanner:
1.5 to 3.0 T
(30,000x Earth's field)

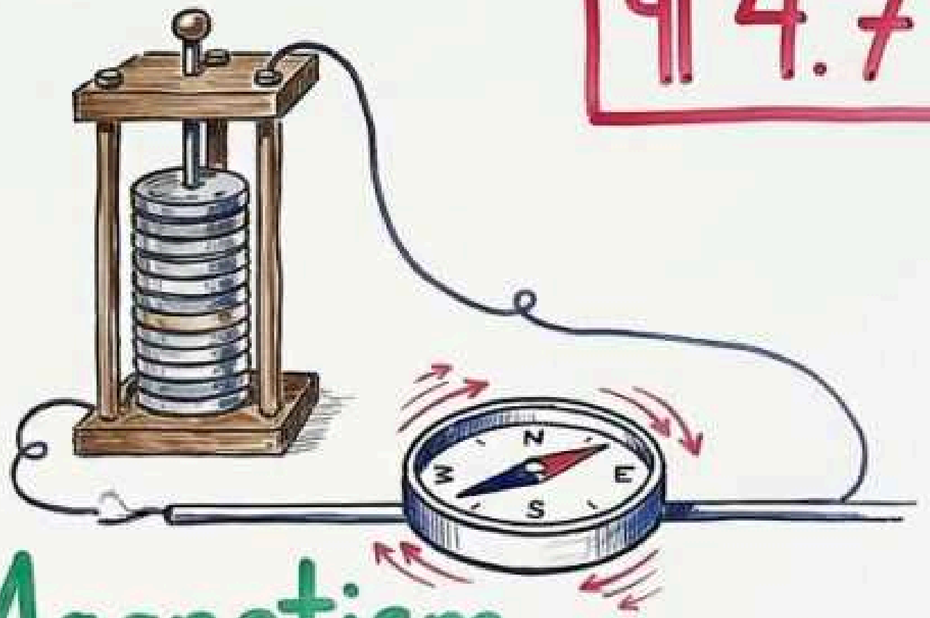
Strongest Steady
Lab Magnets:
> 40 T

Gemini Notebook

§ 4.7



The Grand Connection



Electricity ⟷ Magnetism

1820

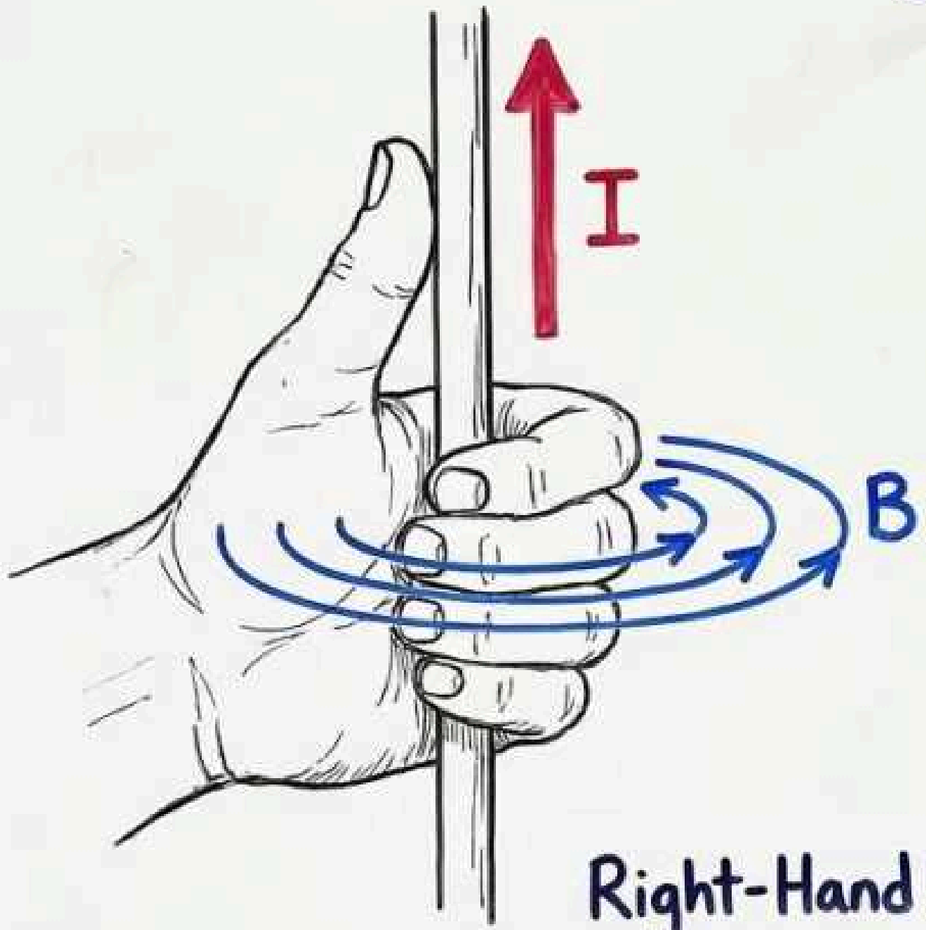
Oersted discovers a current-carrying wire makes a compass twitch.

Core Principle: Moving charge is the true source of every magnetic field (even in bar magnets).

Gemini Notebook

Field around a long straight wire

¶ 4.8



$$B = \frac{\mu_0 I}{2\pi r}$$

Current

Distance from wire

$$\mu_0 = 4\pi \times 10^{-7}$$

Right-Hand Rule:

Thumb = Current (I)

Curled Fingers = Field (B)

Gemini Notebook

Try a Number:

¶ 4.9

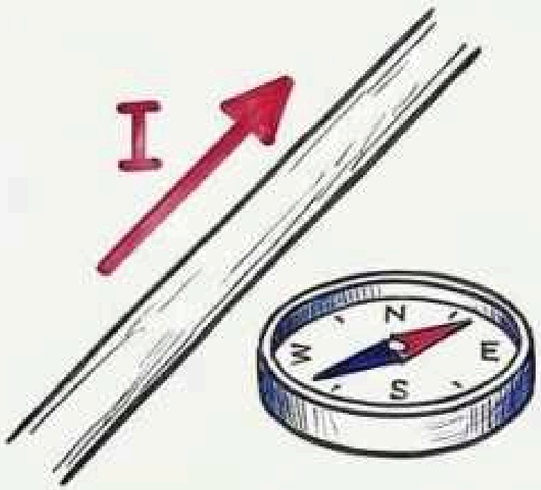
Given

$I = 10\,A$

$r = 5\,cm = 0.05\,m$

$$B = \frac{(4\pi \times 10^{-7}) \times 10}{2\pi \times 0.05}$$

$$B = \frac{(2 \times 10^{-7}) \times 10}{0.05} = 40\,\mu T$$

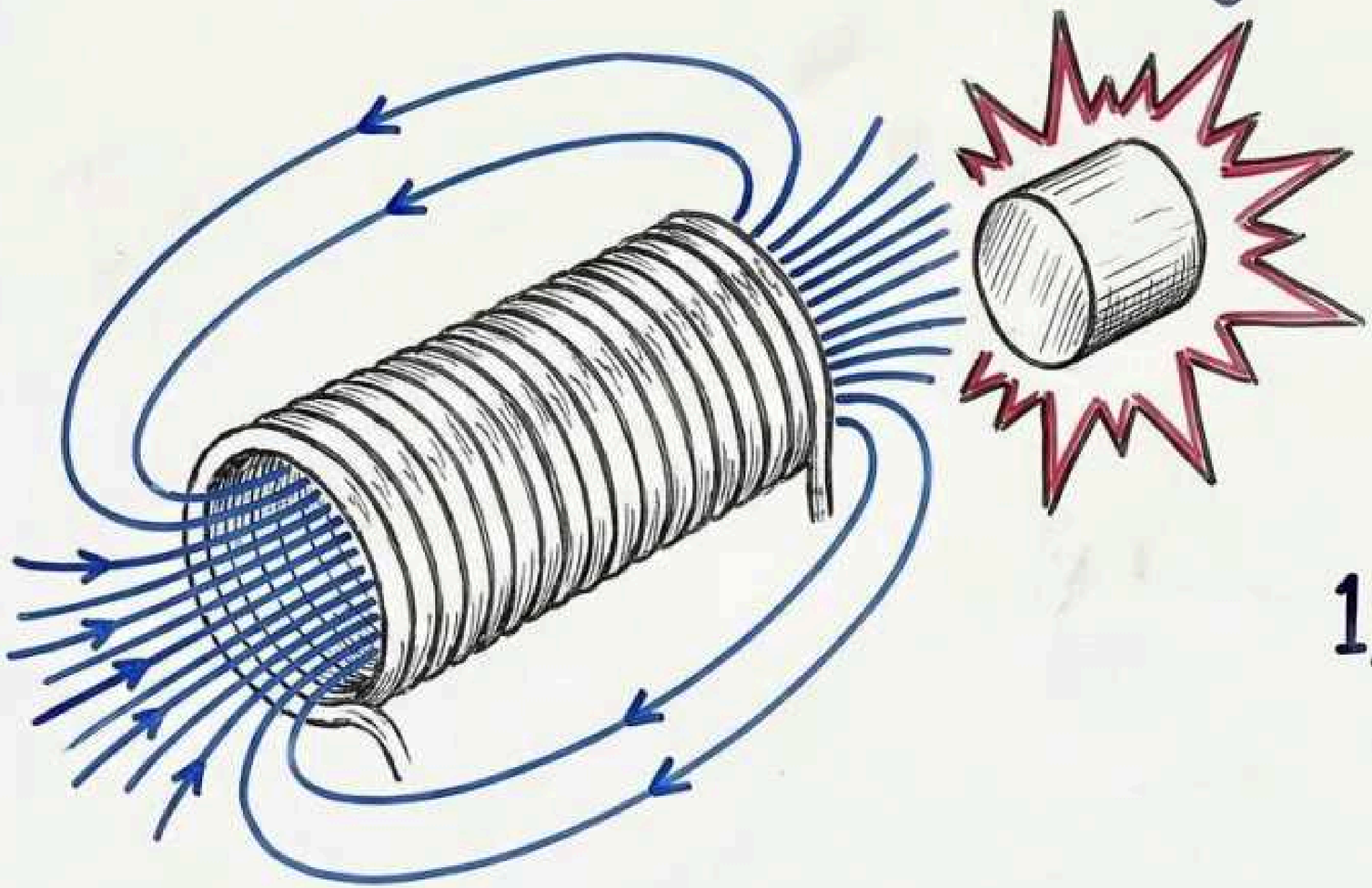


Result: $40\,\mu T$ is almost the same as Earth's field.
Heavy currents can make a compass point wrong!

Gemini Notebook

Solenoid (Coil): Concentrates magnetic field inside.

¶ 4.10



$$B = \mu_0 n I$$

n = turns per meter

1,000 turns/m at 2 A

→ $B \approx 2.5\ mT$

Pro Tip: Adding an iron core multiplies the field by hundreds.

Gemini Notebook

¶ 4.11

The Magnetic Force:

$$F = q v B \sin(\theta)$$

- q = Charge
- v = Velocity
- B = Magnetic Field
- q = Charge
- θ = Angle between velocity and field

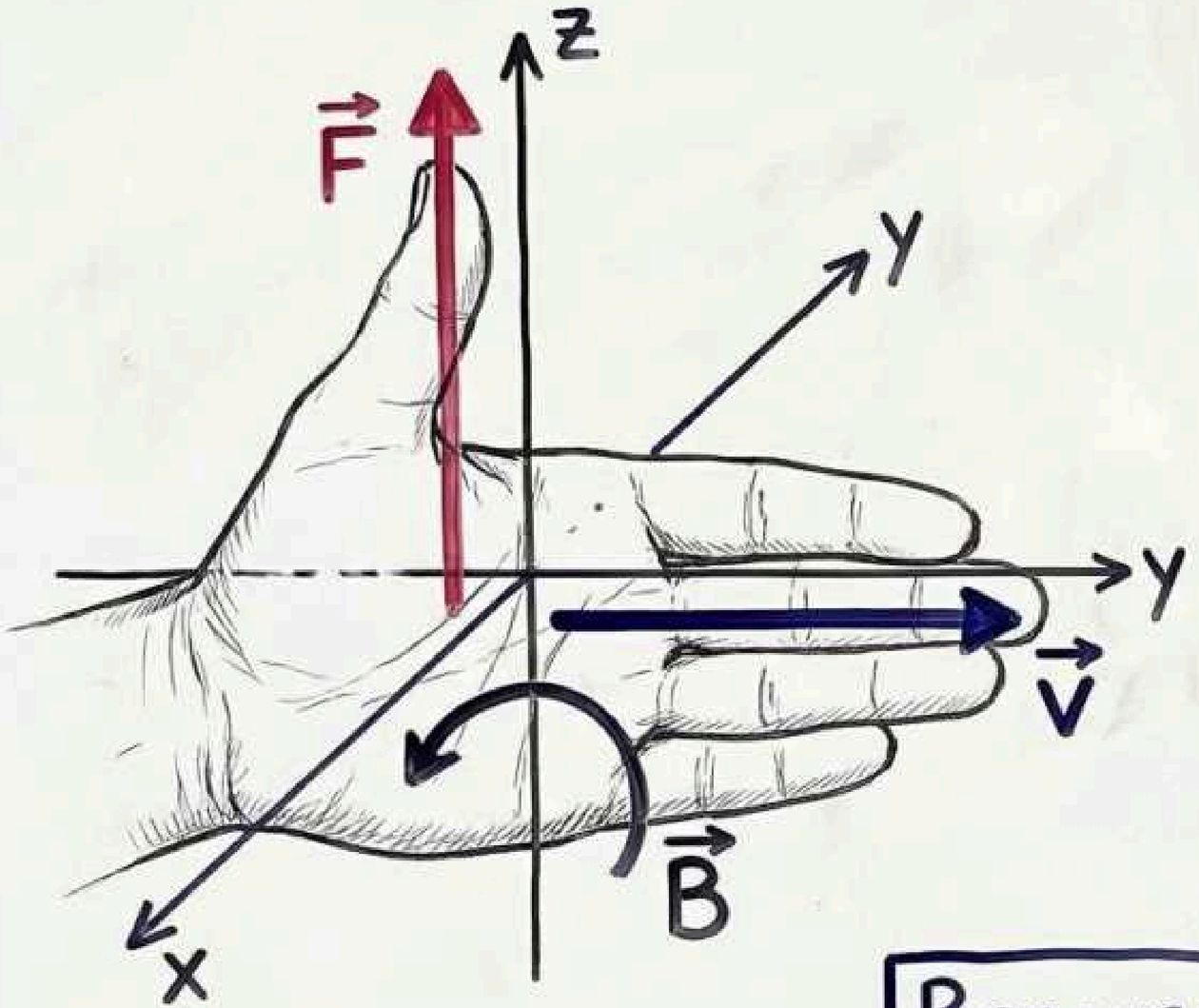


- Max force across the field.
- Zero force along the field.
- Charge at rest feels NO magnetic force.

$v=0 \rightarrow F=0$

Gemini Notebook

¶ 4.12



Force is perpendicular to both velocity and field.

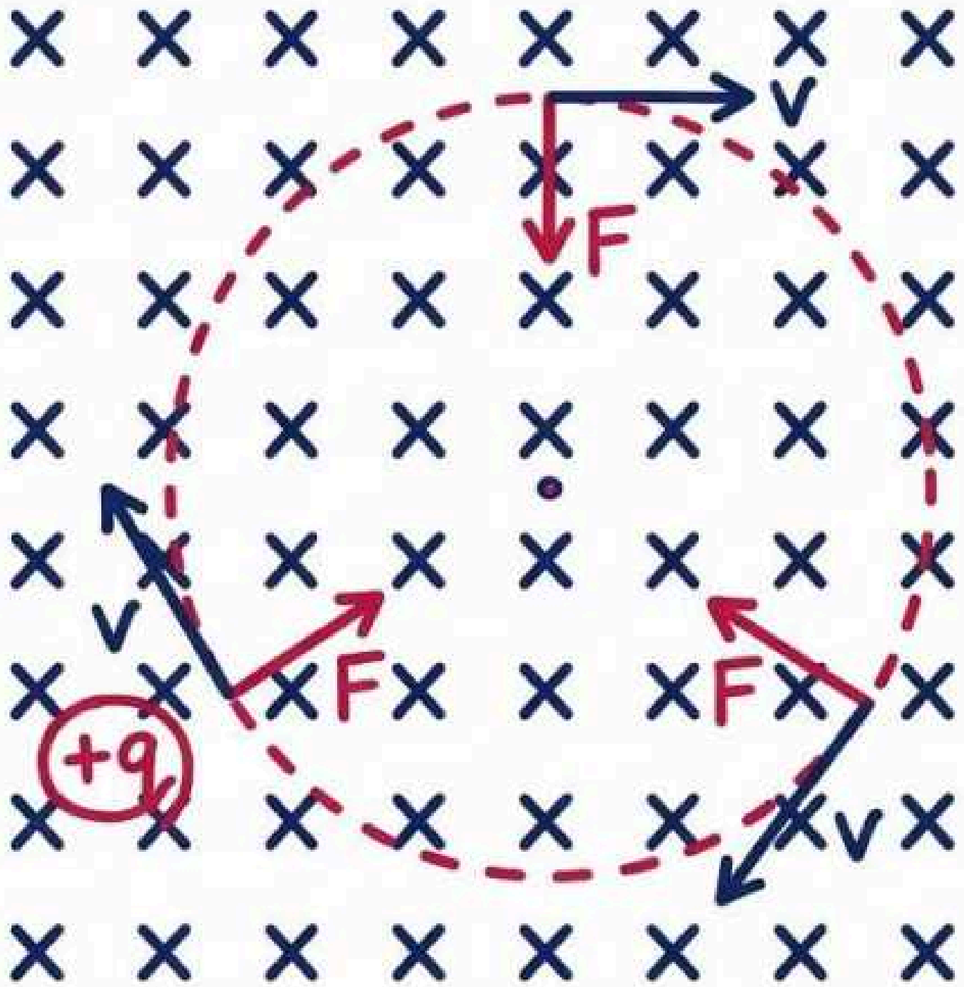
Right-Hand Rule 2:
Fingers along $\vec{v}$, curl to $\vec{B}$
→ Thumb is Force on a positive charge. (Reverse for negative).

Because force is sideways to movement, magnetic fields do no work.

Gemini Notebook

Force does no work = changes direction, not speed

¶ 4.13



Charge entering uniform field at right angles → Circular Path

Equating forces: $F_c = F_m$

$$\rightarrow \frac{mv^2}{r} = qvB$$

$$r = \frac{mv}{qB}$$

Gemini Notebook

Electron Path Calculation:

¶ 4.14

Electron speed (v): 1,000,000 m/s

Field (B): 0.01 T

Force: $F = 1.6 \times 10^{-15}$ N



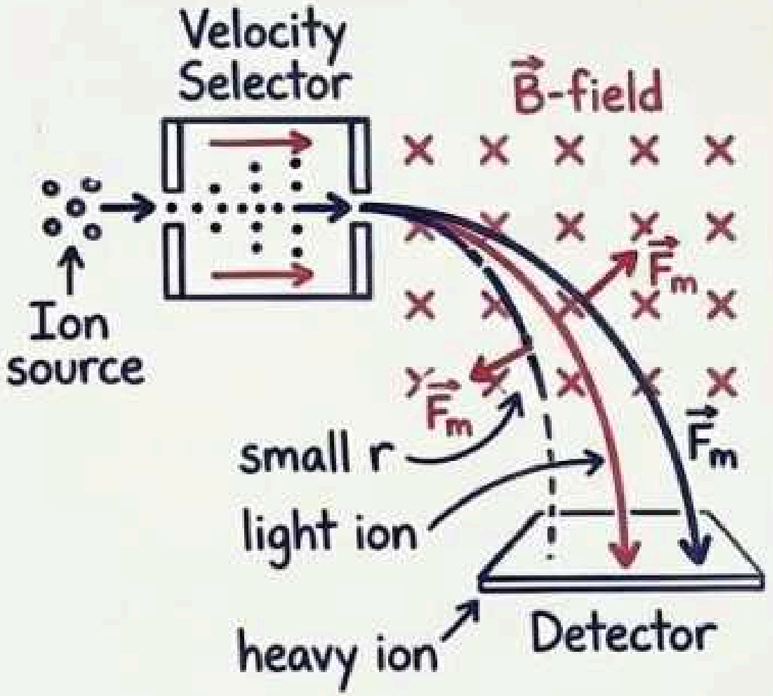
$$r = \frac{(9.11 \times 10^{-31}) \times 10^{6}}{(1.6 \times 10^{-19}) \times 0.01}$$

$$\underline{r = 0.57 \text{ mm}}$$

Gemini Notebook

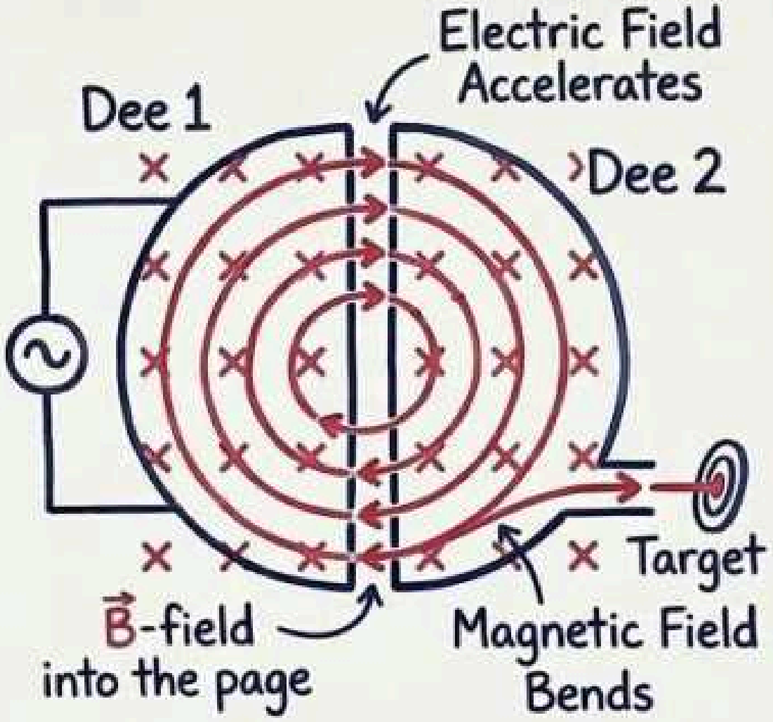
Putting Circular Motion to Work:

¶ 4.15



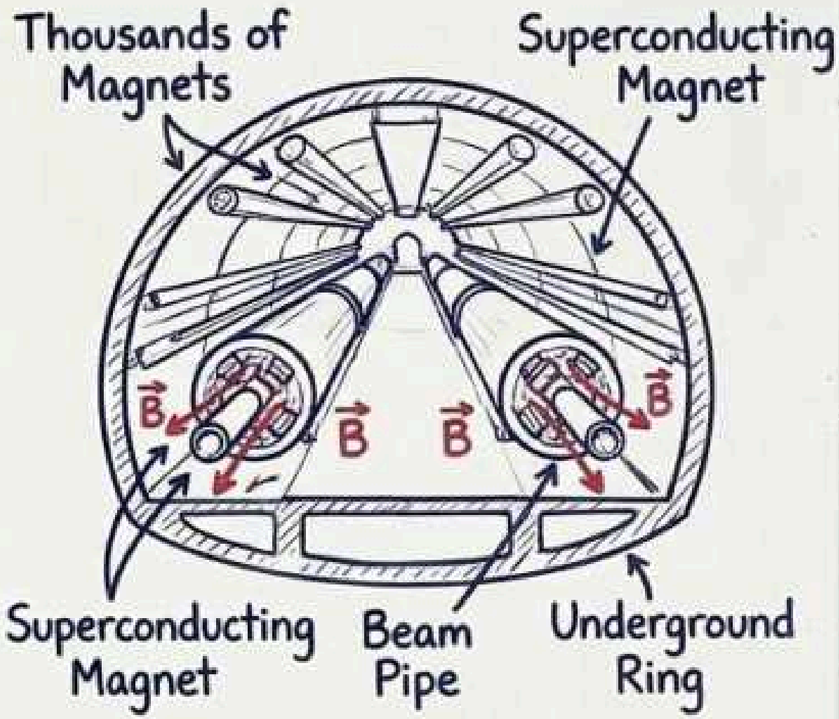
Mass Spectrometer:

Radius of path reveals ion mass.



Cyclotron:

Magnetic field bends particles; electric field accelerates them.



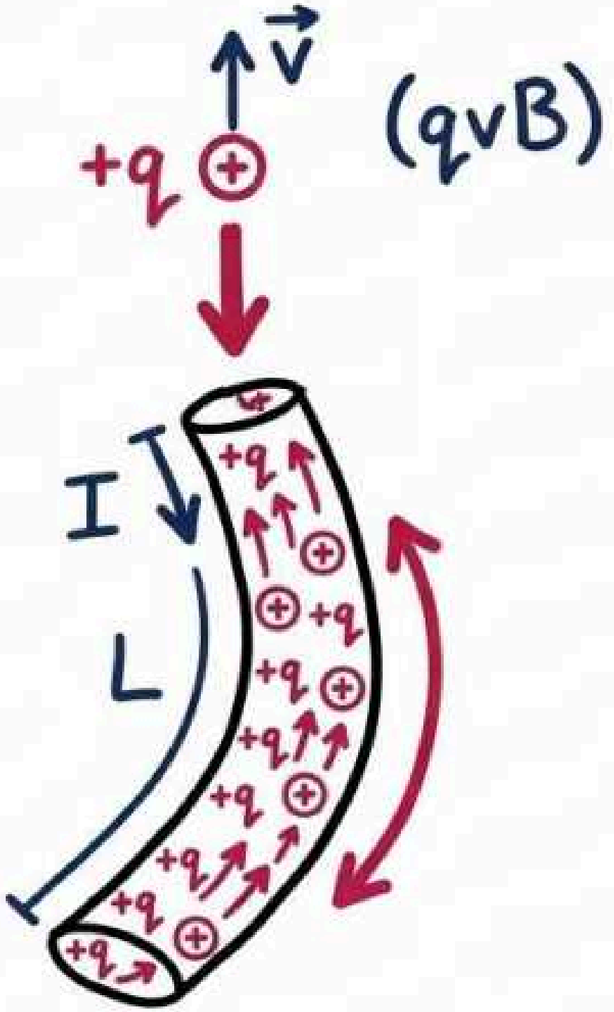
Particle Colliders:

Thousands of superconducting magnets steer beams.

Gemini Notebook

Current = Moving Charge.
Therefore, fields push on wires!

¶ 4.16



$$F = BIL \quad (L = \text{length across field})$$

Example:

$L = 2\,m,\ I = 5\,A,\ B = 0.3\,T$

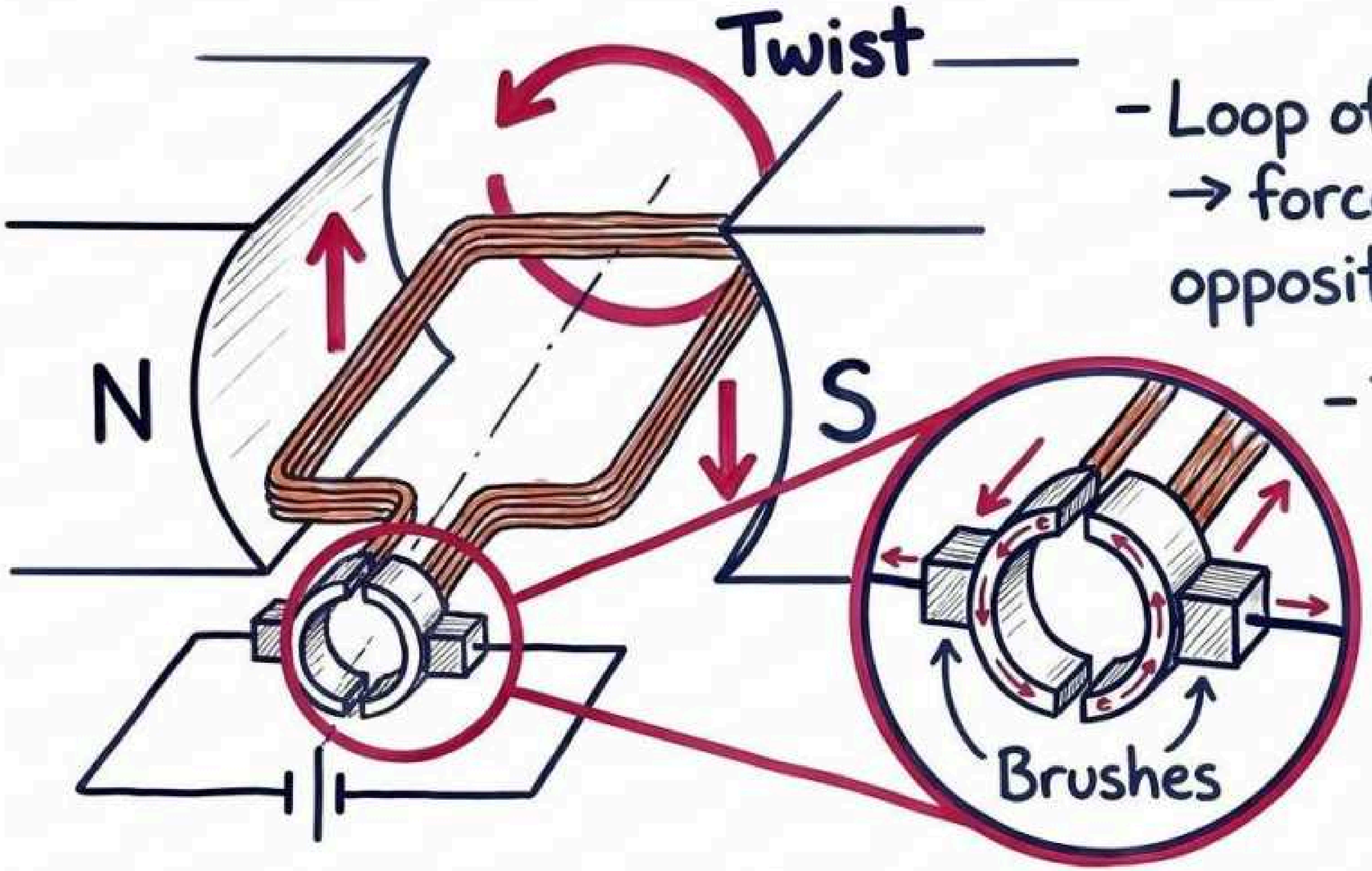
$F = 0.3 \times 5 \times 2 = 3$ Newtons

(Noticeable movement)

Gemini Notebook

The Heart of the Electric Motor:

¶ 4.17



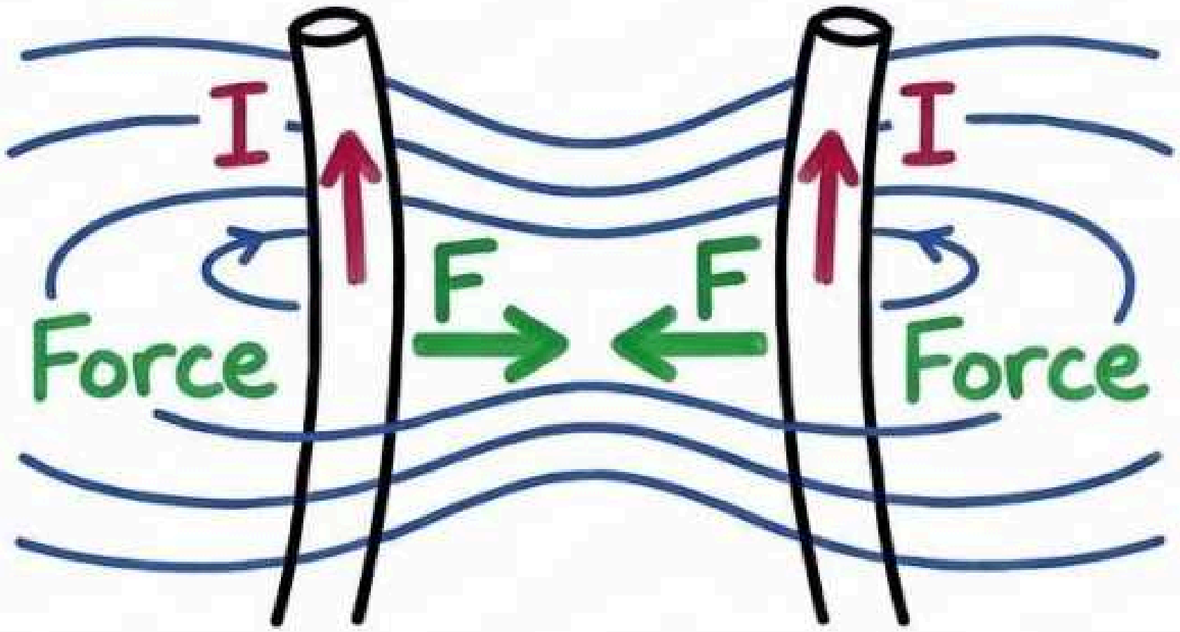
- Loop of wire in a B-field → forces on sides push opposite ways → Twist.
- The Commutator: Reverses current each half-turn to keep the twist going in one direction.

Drives: Fans, trains, drills, electric cars.

Gemini Notebook

¶ 4.18

Two parallel wires interact with each other's magnetic fields.



Rule: Currents in the same direction attract.

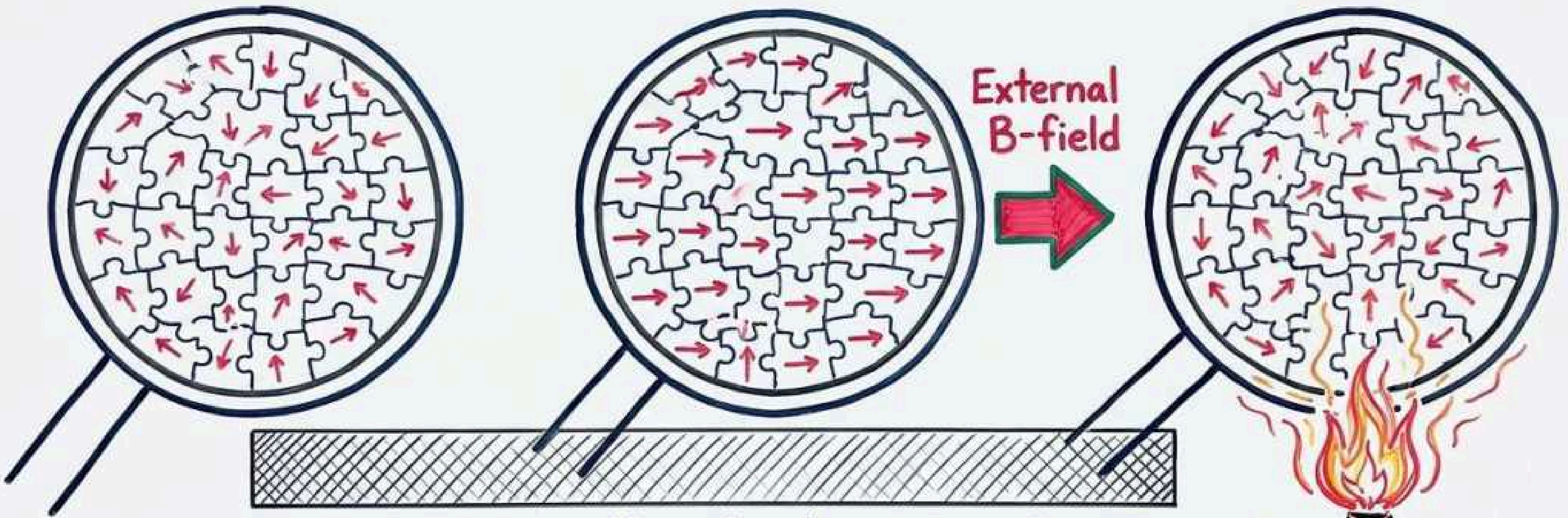
Historical Definition of the Ampere: 1 Ampere in two wires 1 meter apart produces exactly 2×10^{-7} N of force per meter.

Gemini Notebook

Magnetic Materials (Iron, Nickel, Cobalt):

¶ 4.19

Driven by tiny electron currents in atoms lining up in domains.



Unmagnetized:
Domains point randomly, cancel out.

Magnetized:
External field aligns domains permanently.

Curie Temperature:
Heating scrambles the alignment.



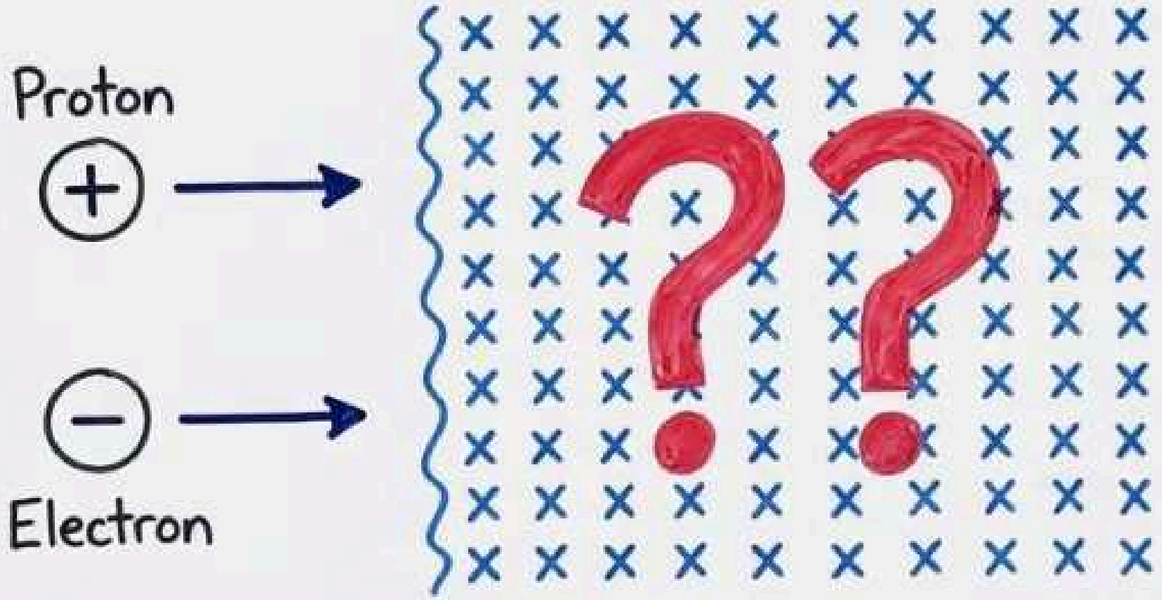
Gemini Notebook

Lecture Question:

¶ 4.20

A proton and an electron enter the same magnetic field at the same speed, at right angles.

Which has the larger radius?
Which direction does each circle?



Hint: $r = \frac{mv}{qB}$. A proton is ~1,800x heavier than an electron. (Proton radius is 1800x larger; they circle in opposite directions due to opposite charge).

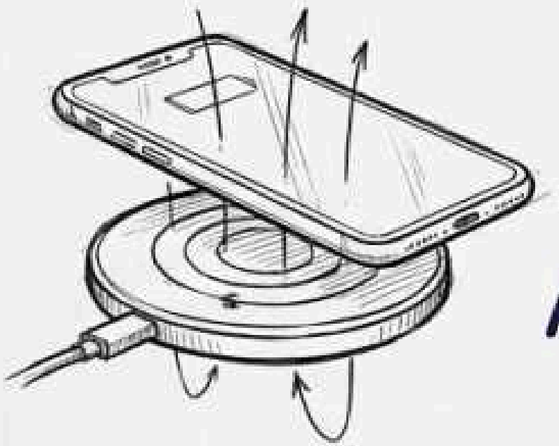
Gemini Notebook

¶ 4.21

Coming in Lecture 5:

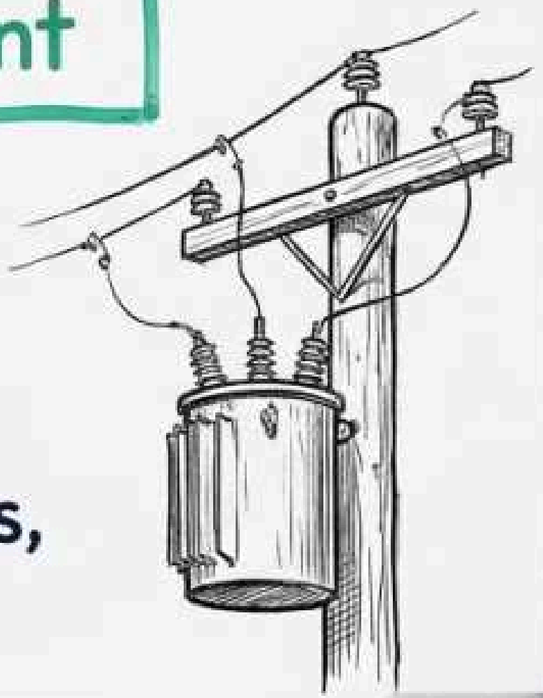
Can magnetism create electricity?

Changing Magnetic Field → **Electric Current**



Yes: A changing magnetic field creates an electric current.

Applications: Generators, transformers, and wireless charging.



Gemini Notebook