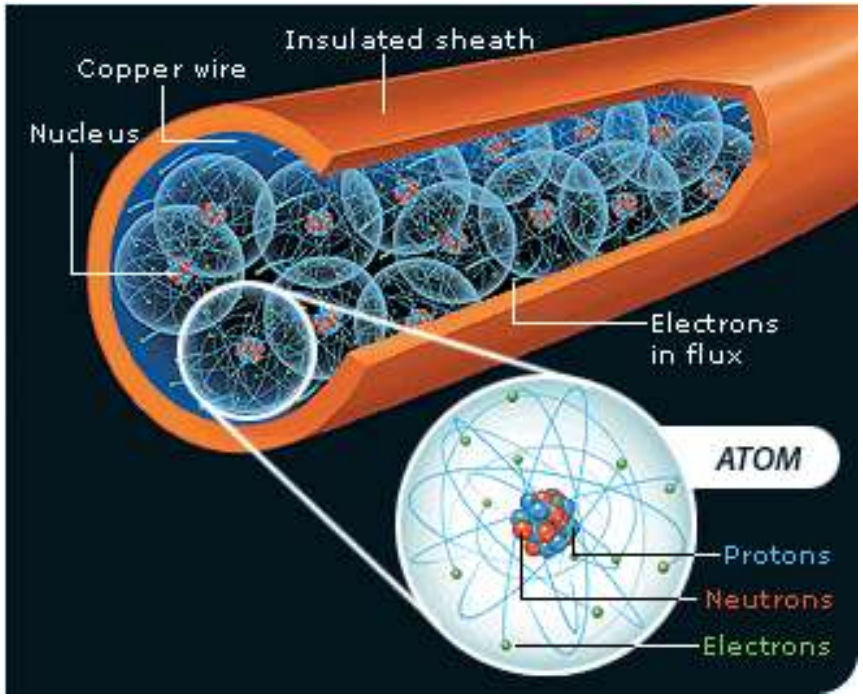
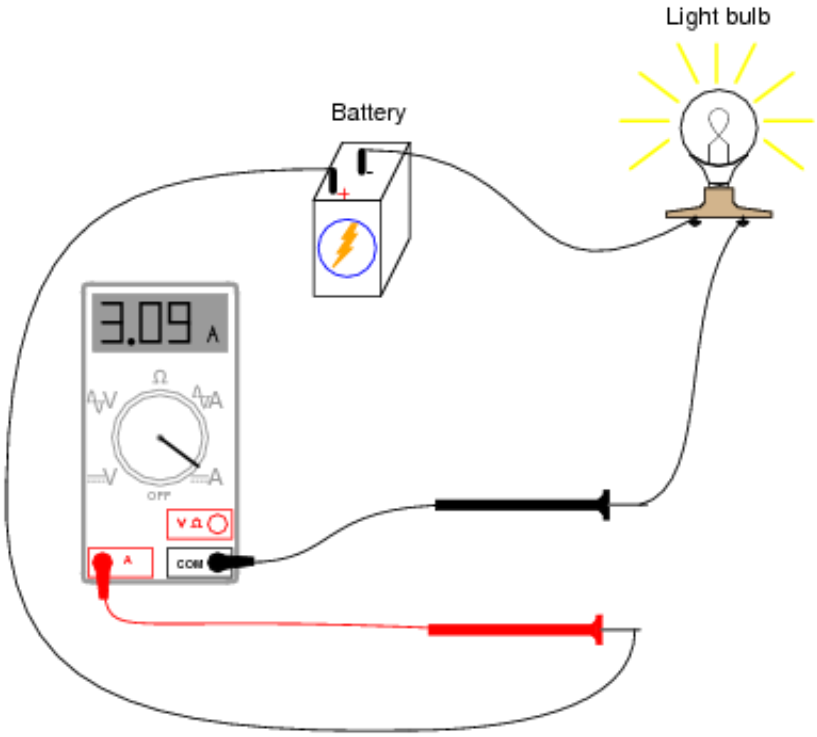
Moving charges: electric current



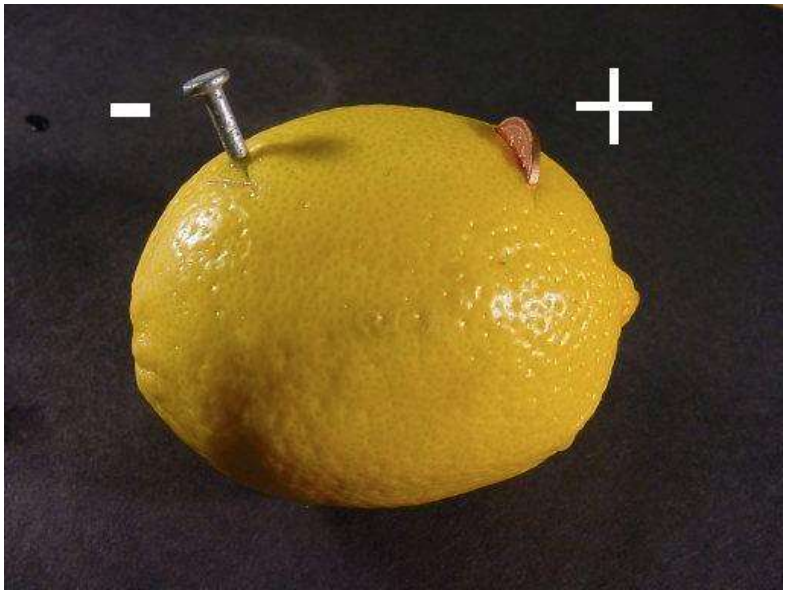
- Some atoms/molecules/materials hold on to their electrons tightly.
  - Insulators: plastic, rubber
- Some let their charges roam about freely
  - Conductors: most metals
- Units of electric current: Coulombs/sec = Ampere

Toll plaza counts
Cars per second

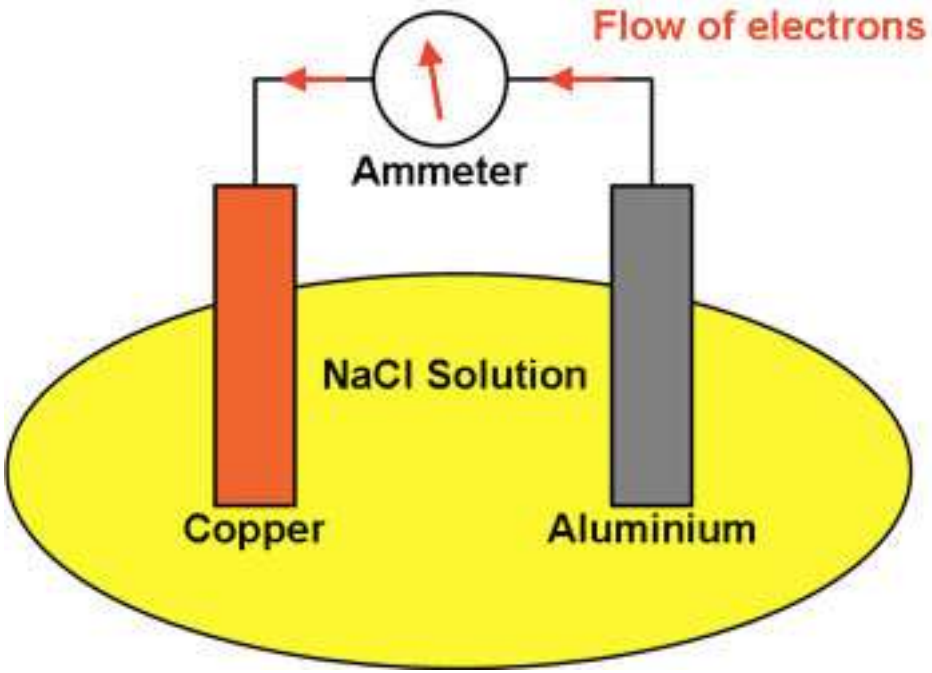


Amp-meter counts
Coulombs per second = Amperes

Batteries



Batteries



Constant flow of current!

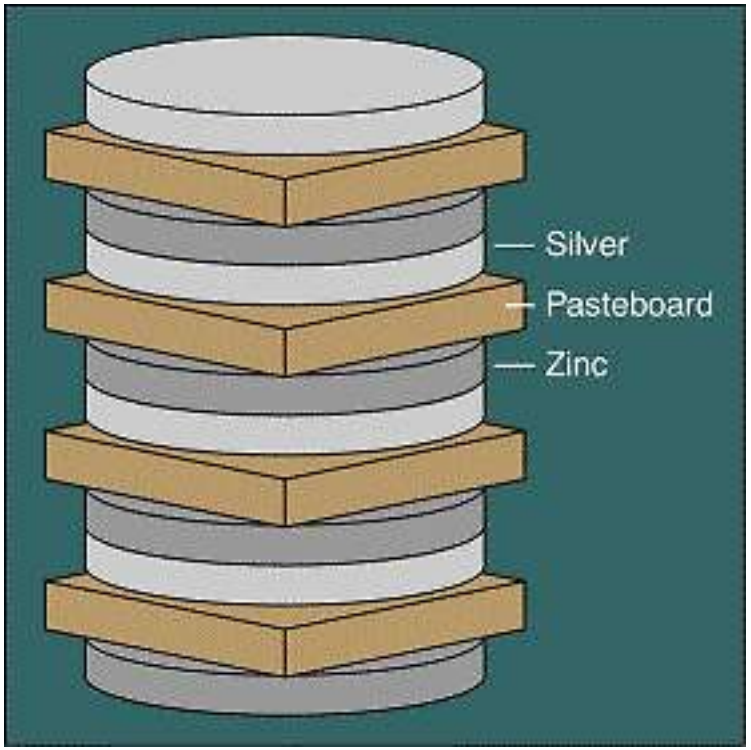
Voltage

- When charges move in an electric field, the electrostatic force does WORK on the charge.
- Moving from point A to point B, the work done per unit charge would be measured in Joules/Coulomb.
- This is called the potential difference between the points A and B. It is measured in Joules/Coulomb, also called Volts.
- Therefore, a potential difference is also called a voltage.

Units of VOLTS = Joules/Coulomb

Alessandro Volta (1745-1827)
(Padua, Italy)

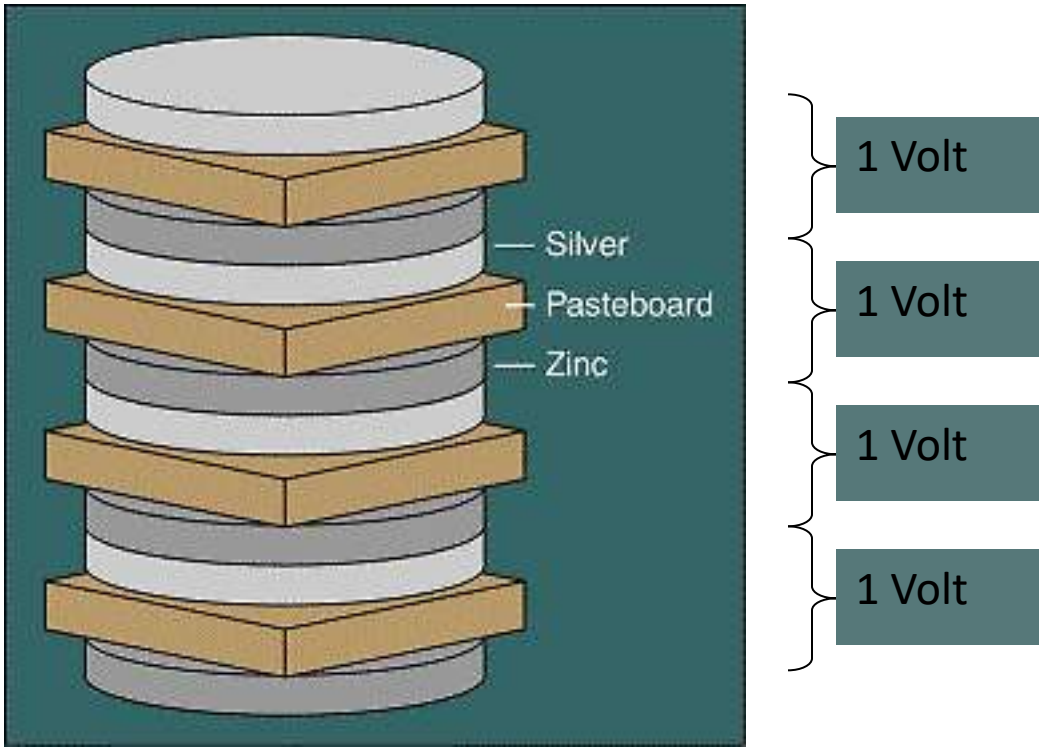
Volta invented a practical way of producing electricity: Electrochemistry



Soaked in saltwater

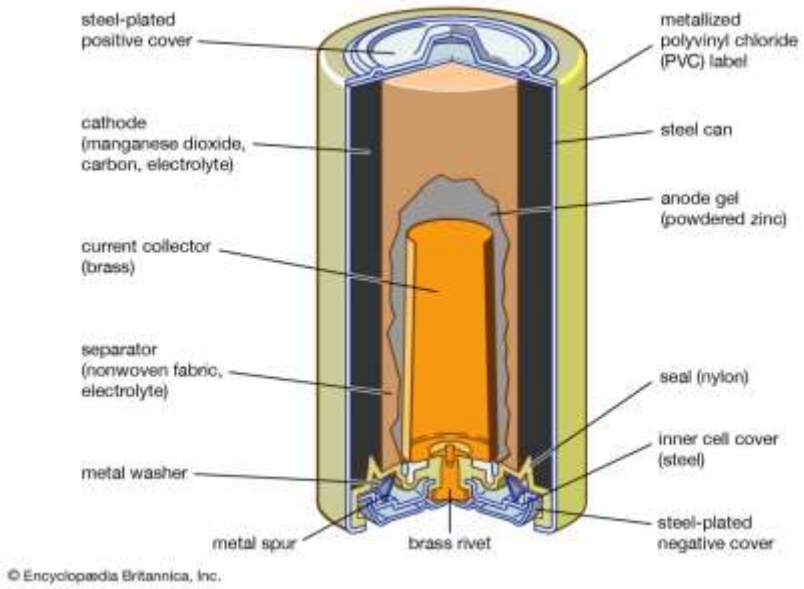
1 Volt

- 4-Volt “Voltaic pile” = 4-Volt “battery”
- A single one of the sandwich structures is called an “electrochemical cell”, or just “cell”.
- A battery is a stack of cells.

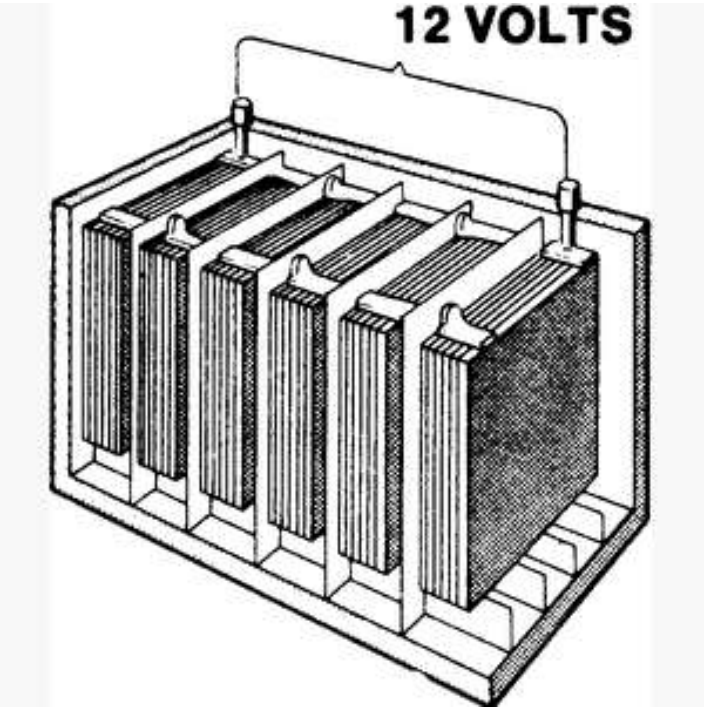


- 4-Volt “Voltaic pile” = 4-Volt “battery”
- A single one of the sandwich structures is called an “electrochemical cell”, or just “cell”.
- A battery is a stack of cells.
- The voltages of the stacked cells add up.

Batteries

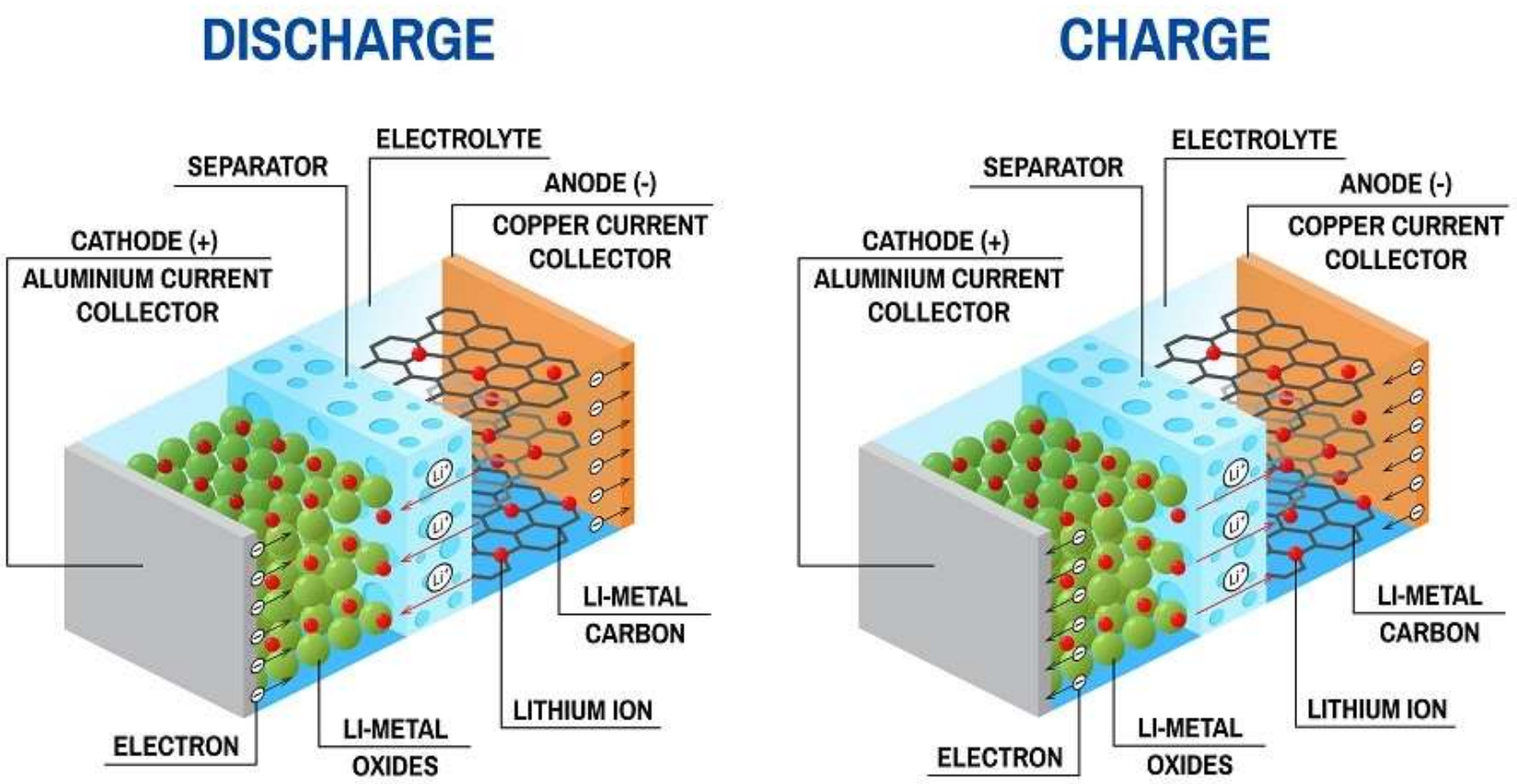


- Single-cell flashlight battery 1.5 V
- Alkaline battery

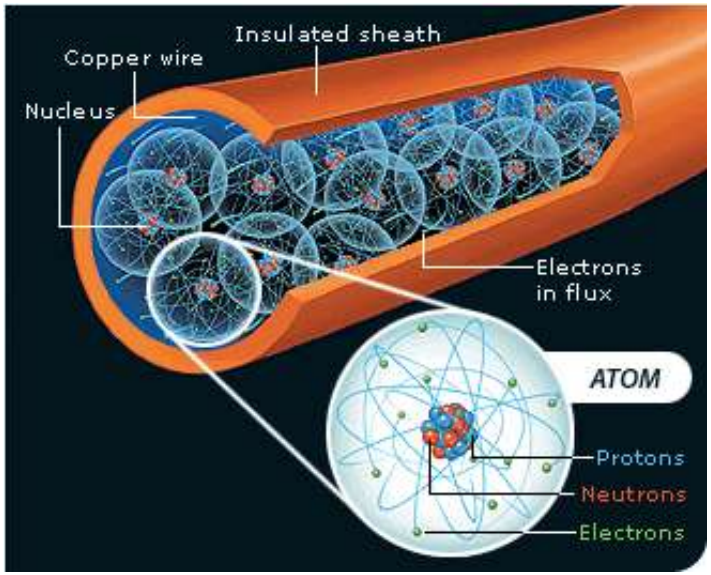


- Auto battery: 6 cells x 2 V = 12 V
- Lead acid battery
- Rechargeable!

Lithium Ion Battery



Ohm's law of conductivity

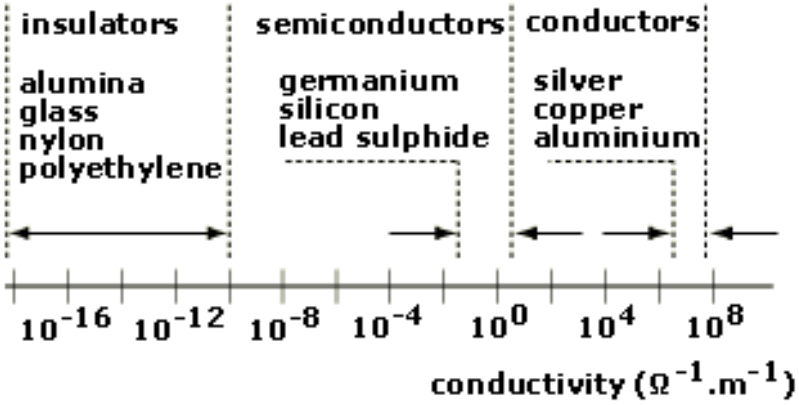


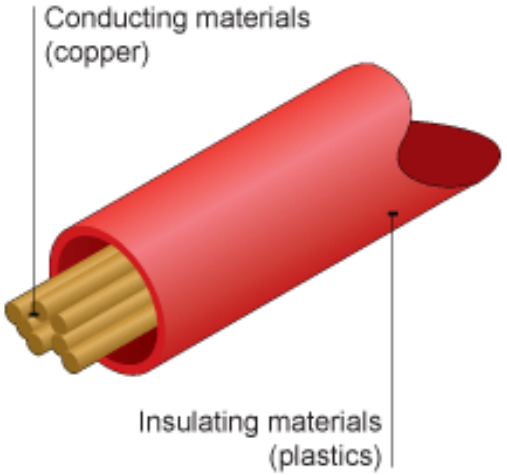
$$I = \frac{V}{R}$$

I = current, in amperes

V = applied voltage

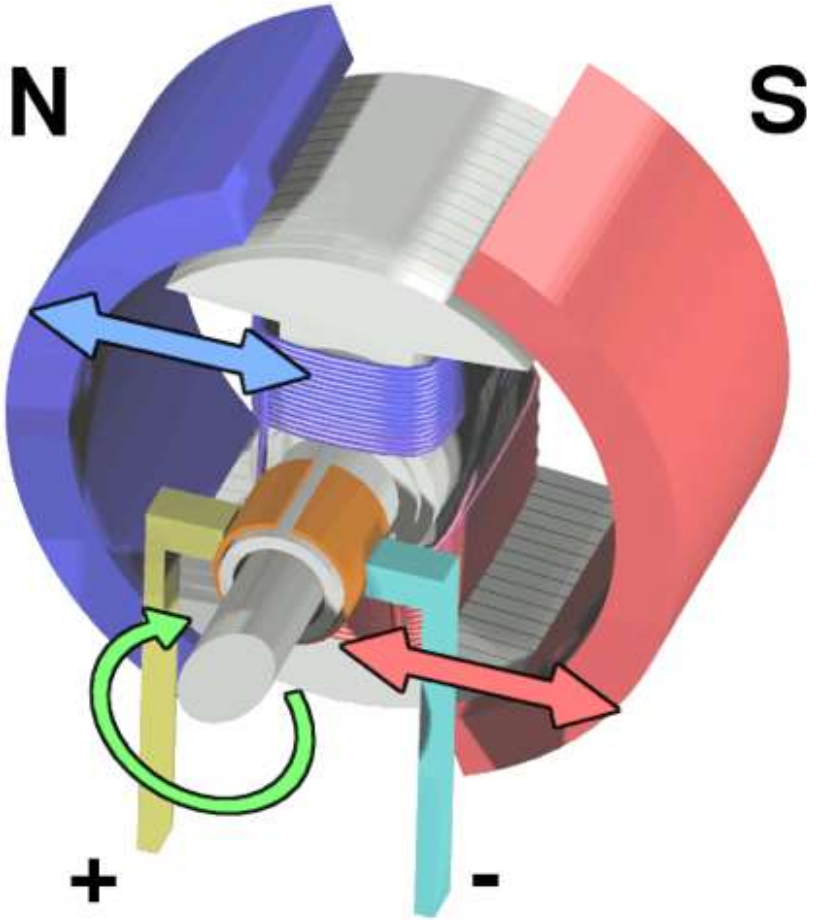
R = resistance, in ohms





- So is the difference between conductors, semiconductors, and insulators one of degree, or is it qualitative?
- In other words, the dividing line is chosen arbitrarily?
- No: At zero temperature, the resistance of insulators becomes infinite, while the resistance of conductors remains finite.
- Semiconductors (if pure) behave like insulators at zero temp. If impure (doped), they behave like conductors.
- Another class of materials has zero resistance at low temperatures. They are called superconductors.

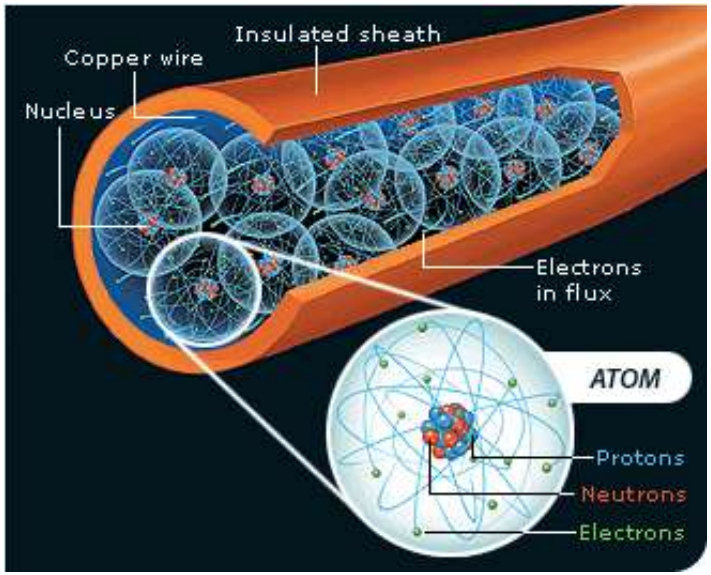
Electromagnetism, Motors, and Generators (Chapter 8)



Outline

- Last time: Motionless charges: *Electrostatics*
- Today:
  - Motionless magnets: *Magnetostatics*
  - Moving charges: *Electrodynamics*
    - Moving charges feel magnetic force
    - Moving charges generate magnetic field
    - Electric motors
    - Magnetic induction and electric generators

Ohm's law of conductivity

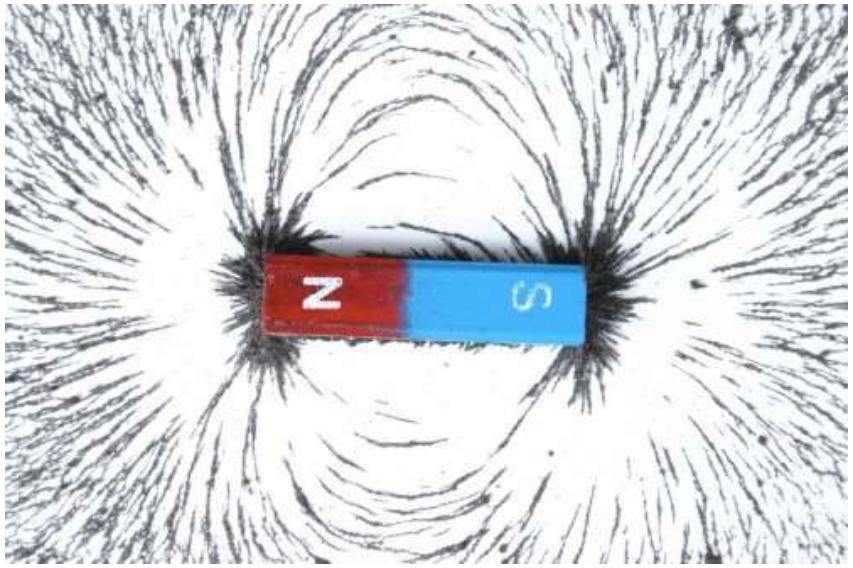


$$I = \frac{V}{R}$$

I = current, in amperes
V = applied voltage
R = resistance, in ohms

Resistance: opposition of flow of electric current

Magnetism

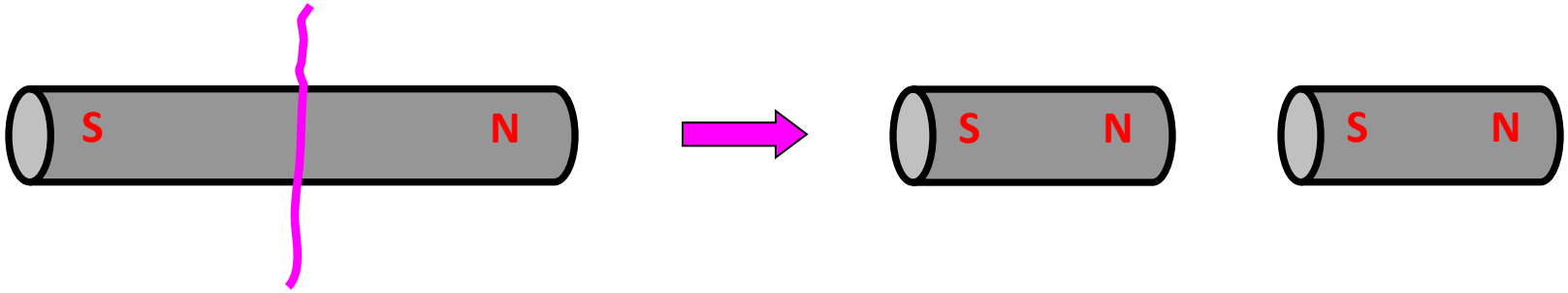


Known since ancient times (lodestone = magnetite)

Sir William Gilbert (circa 1580) believed moon and earth are held in orbit by magnetic forces

Magnetism

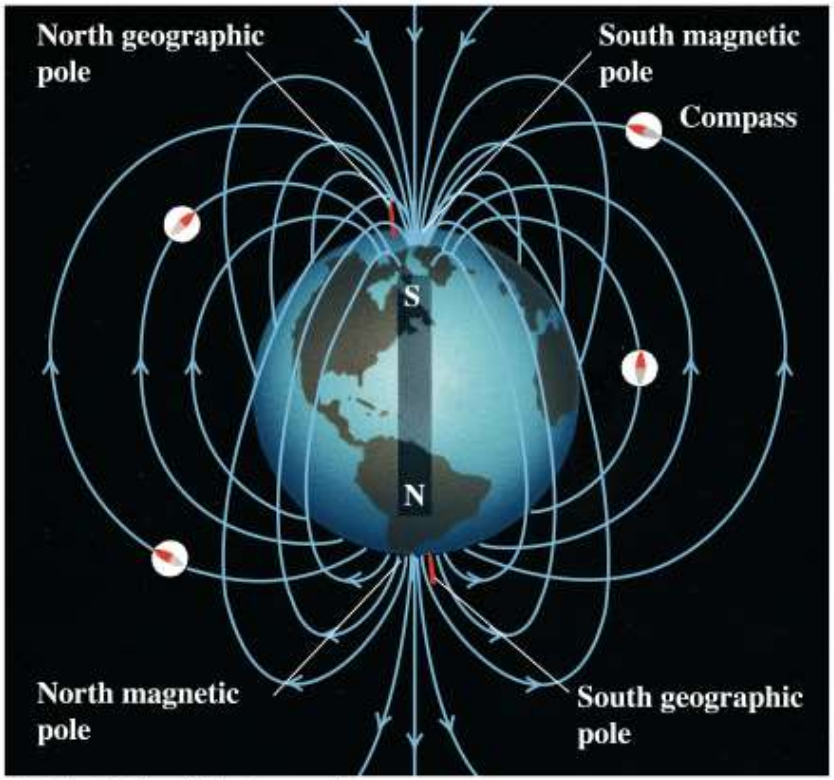
- North poles repel
- South poles repel
- Opposite poles attract
- Poles cannot be isolated
- Break a dipolar magnet and you get two dipolar magnets



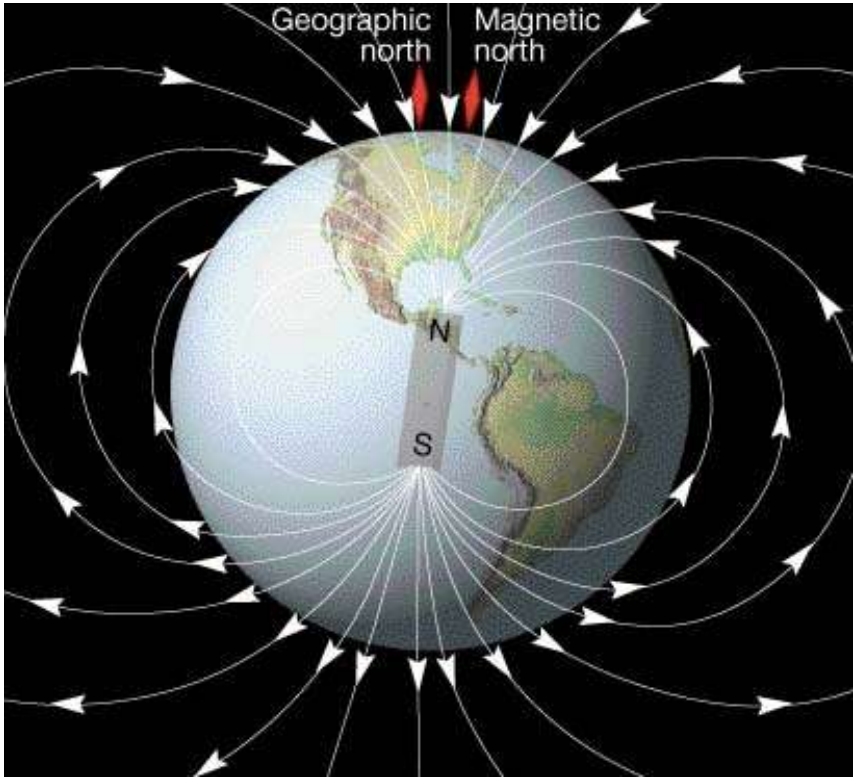
Magnetism

- North poles repel
- South poles repel
- Opposite poles attract
- Poles cannot be isolated
- Break a dipolar magnet and you get two dipolar magnets
- Magnetic materials lose their magnetism above a certain temperature

What you can find on the internet



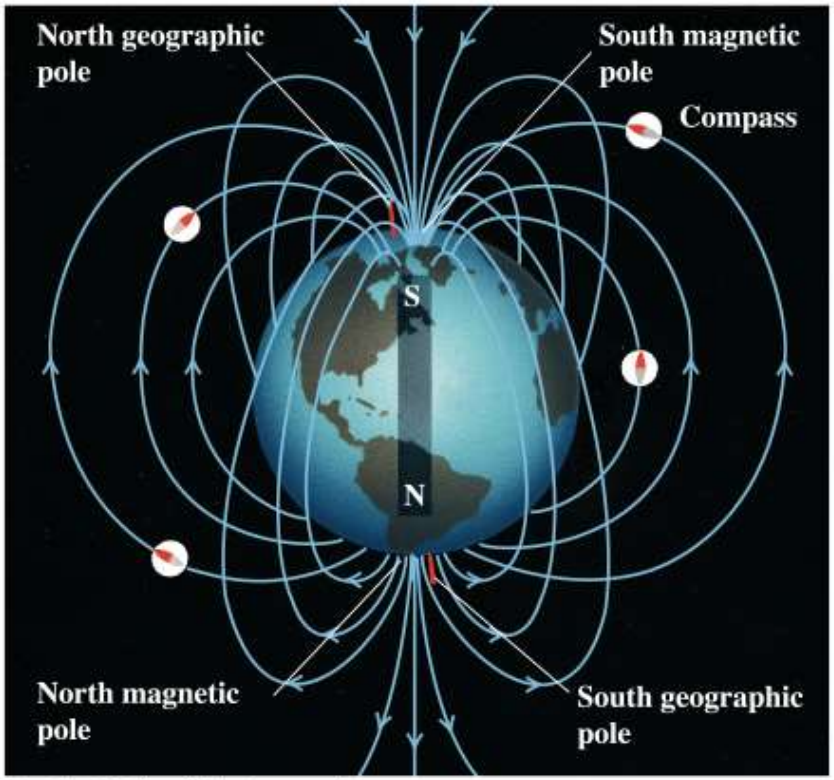
(A)



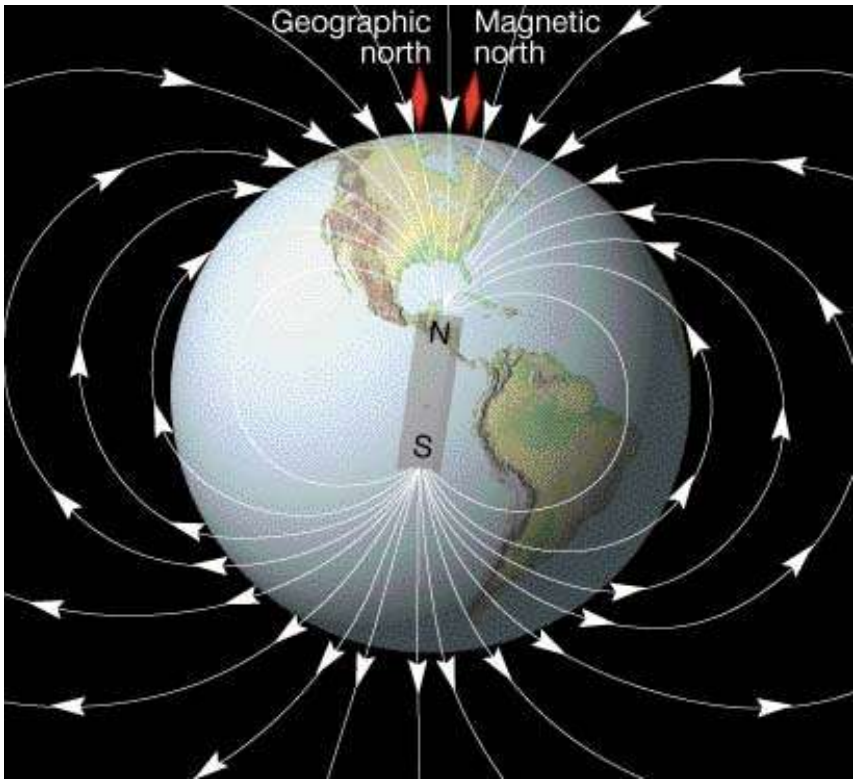
(B)

Which is correct?

What you can find on the internet

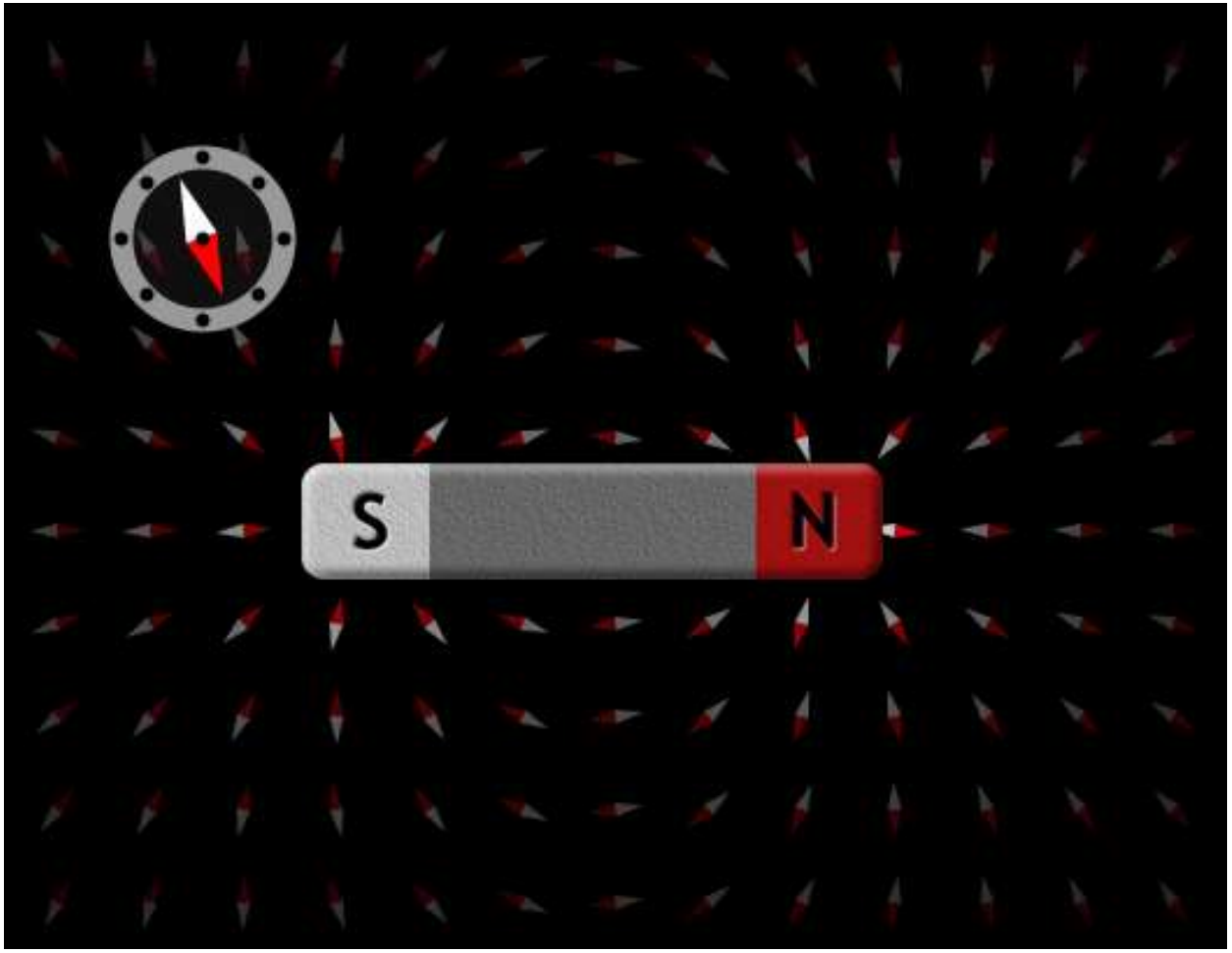


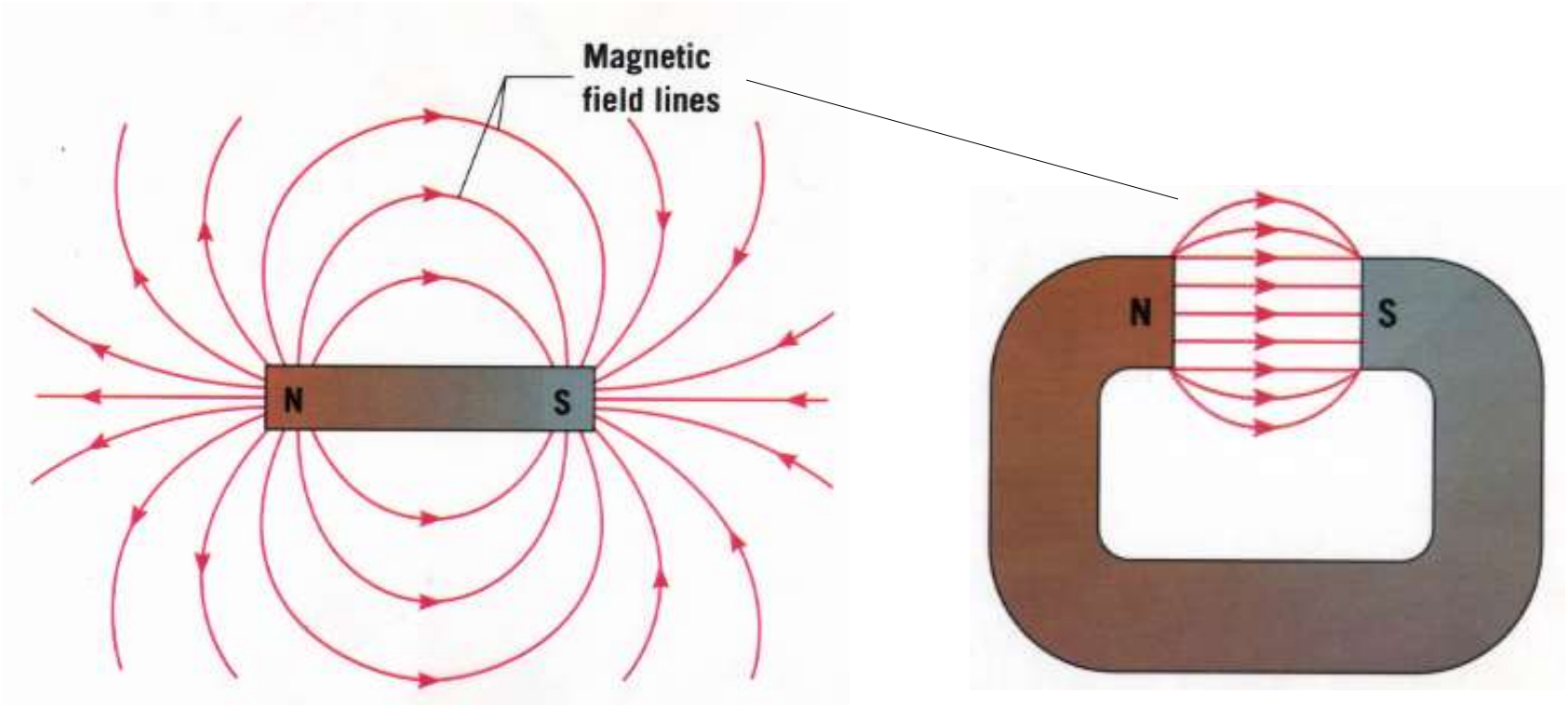
Right !



Wrong !

Simulation




Magnetic
field lines
N
S
N
S

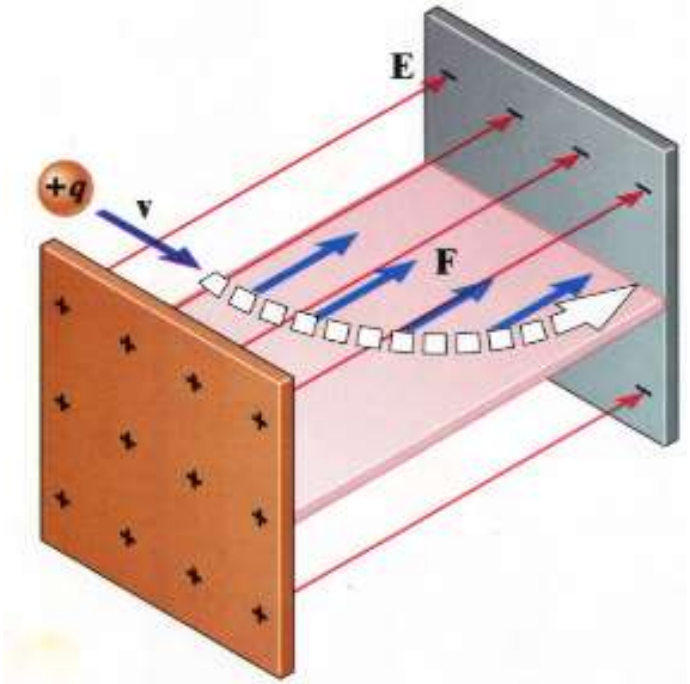
Connections between electric and magnetic forces

Is there one?

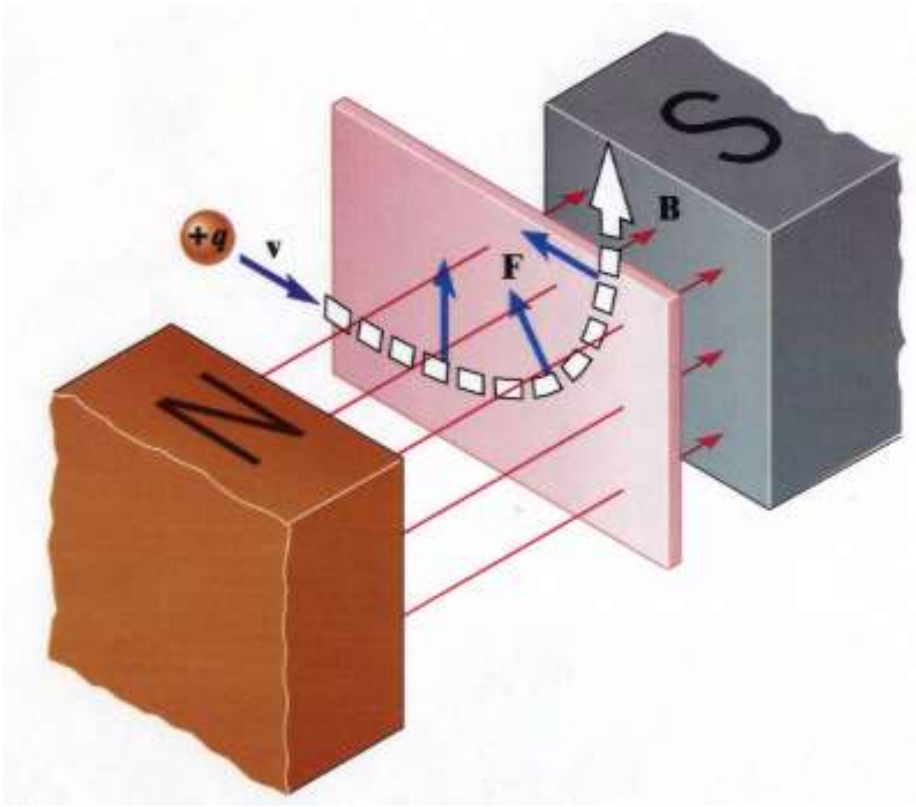
Electrodynamics

- Moving charges feel magnetic force
- Moving charges generate magnetic fields
- Electric motors
- Magnetic induction and electric generators

Force on a moving charge

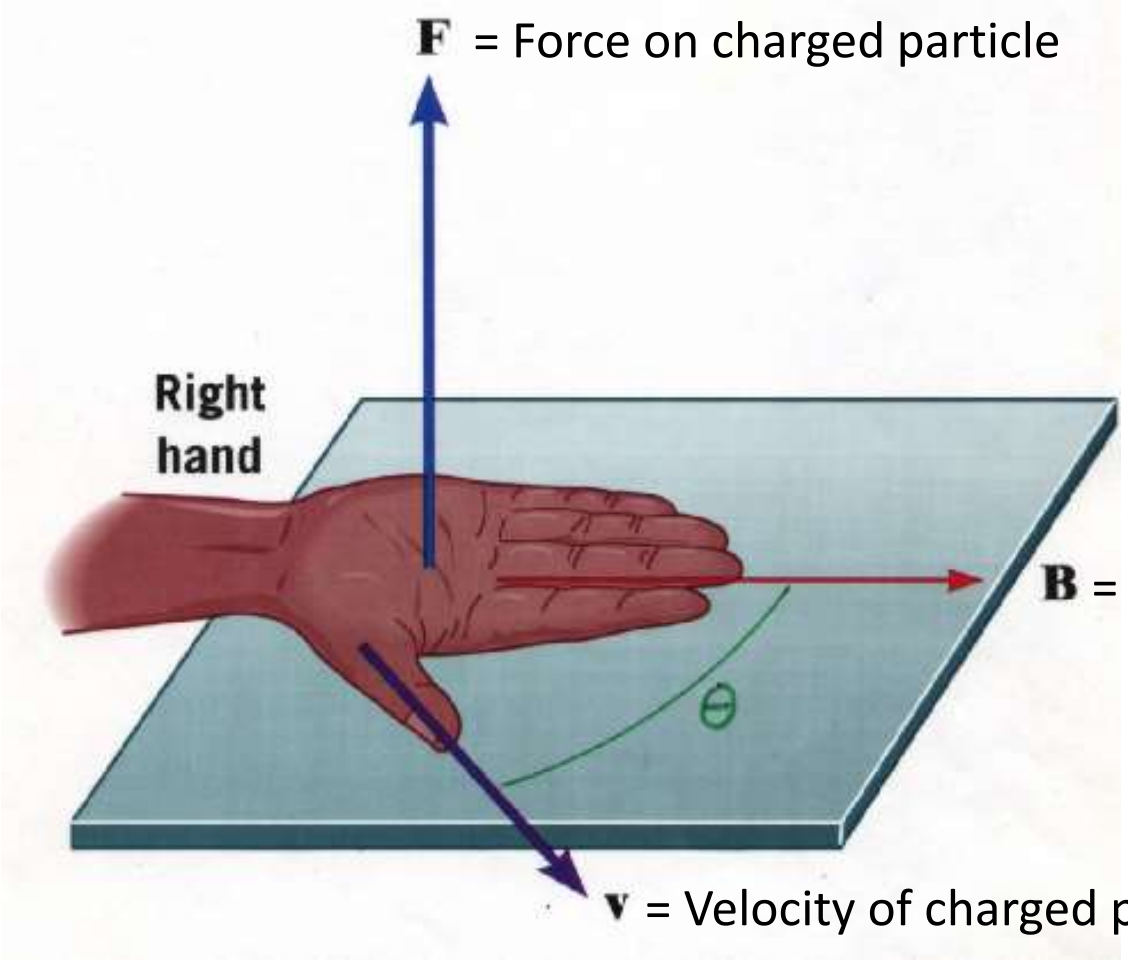


Electric force



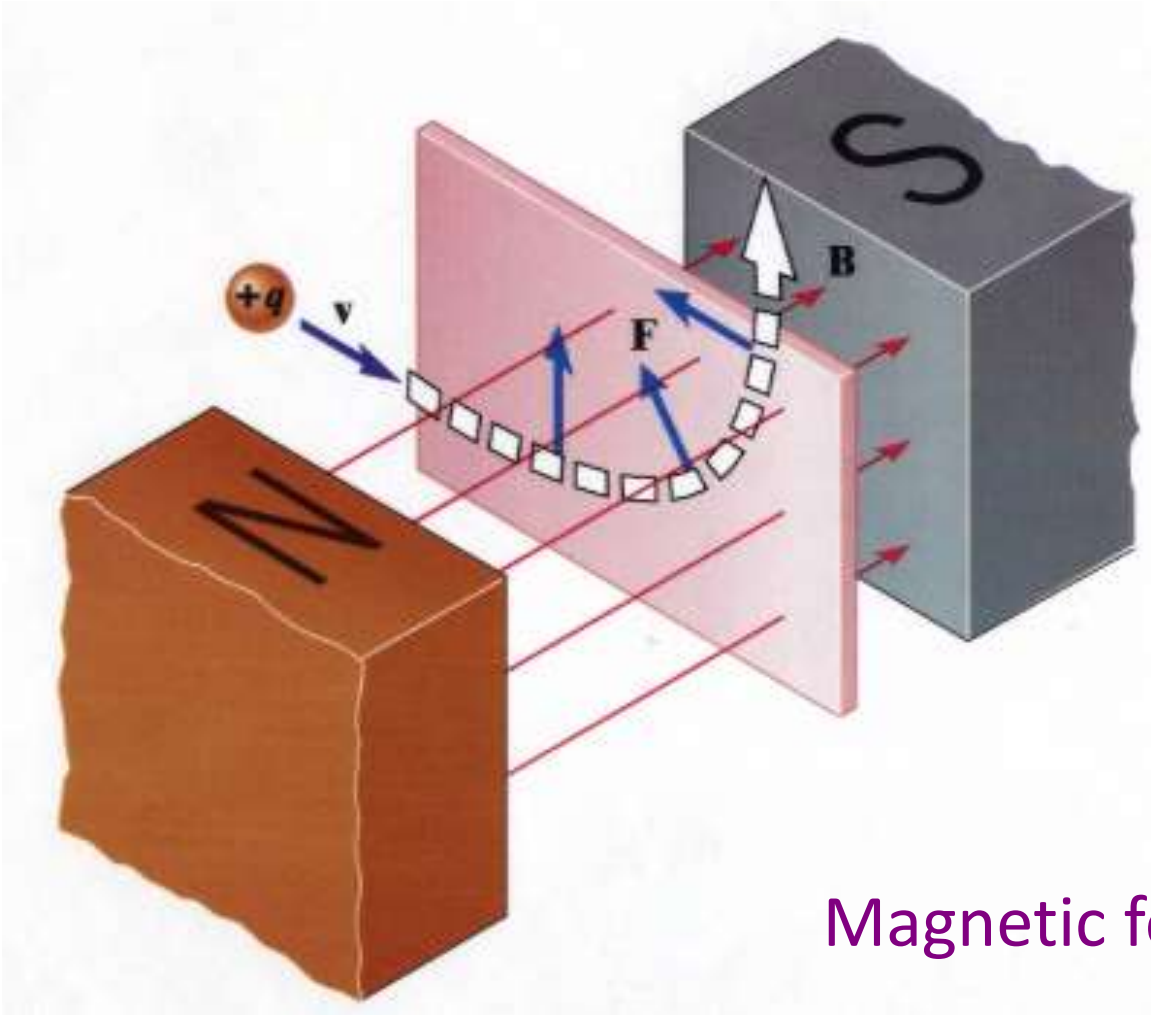
Magnetic force

Force on a moving charge



The “right hand rule” (for positive charge)

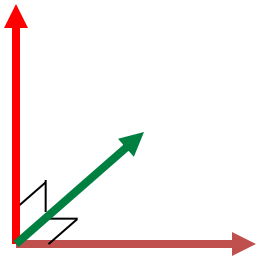
Force on a moving charge



Magnetic force

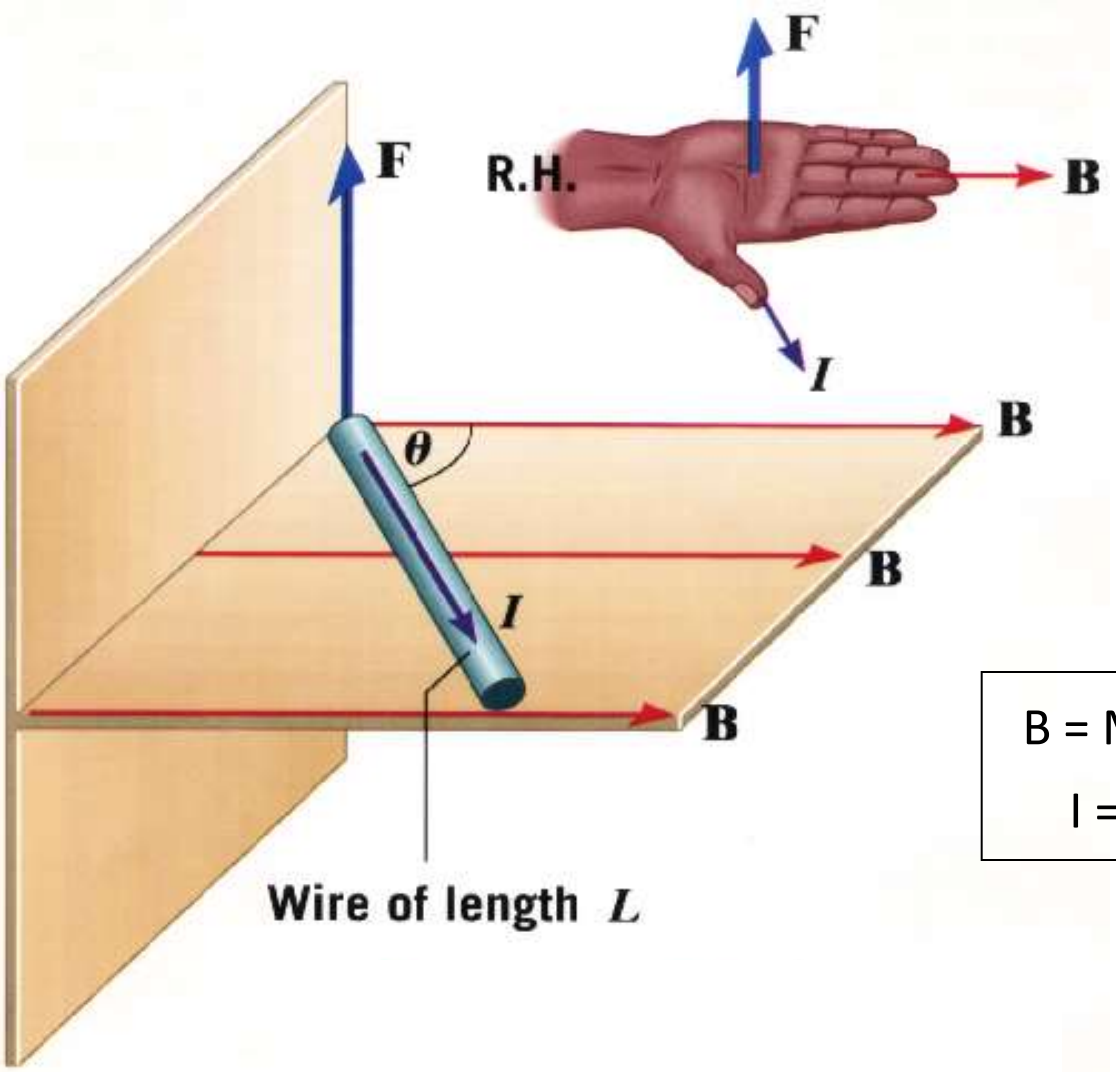
Magnetic forces: Principles

- Three-way rule:
  - Force is perpendicular to magnetic field and to current (or particle velocity)



- Reversal rule:
  - Flip of charge, current, velocity, field, … flips resulting force

Force on a current-carrying wire



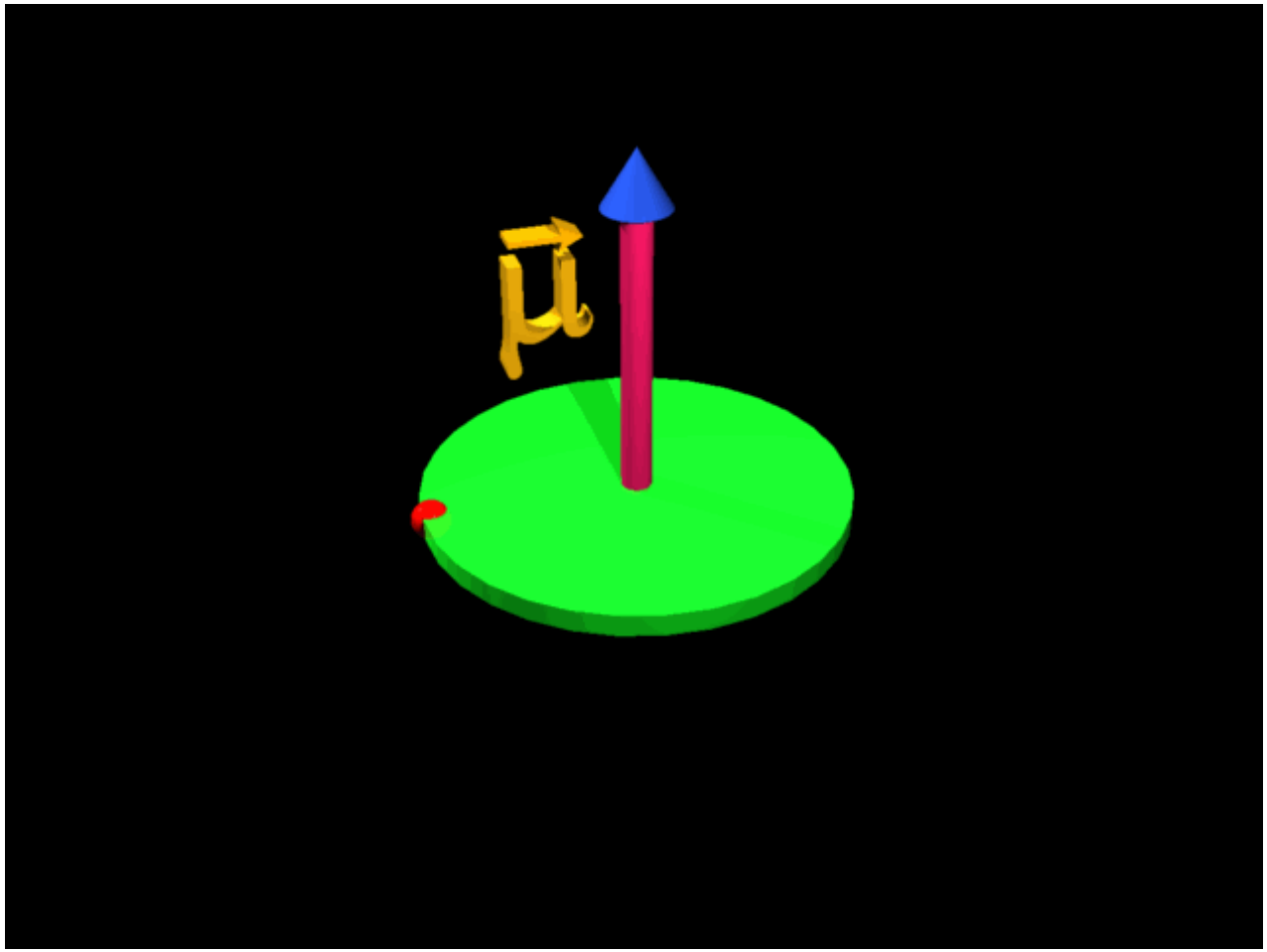
B = Mag. Field

I = current

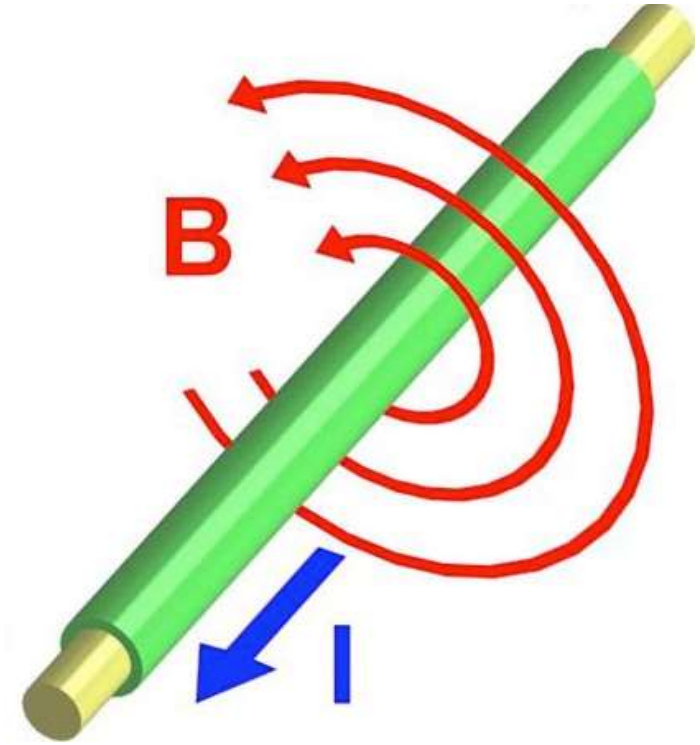
Electrodynamics

- Moving charges feel magnetic force
- Moving charges generate magnetic fields
- Electric motors
- Magnetic induction and electric generators

Actually, all magnetism comes from moving charges, at atomic level! (animation)



Magnetic field around a current carrying wire



B = Mag. Field

I = current

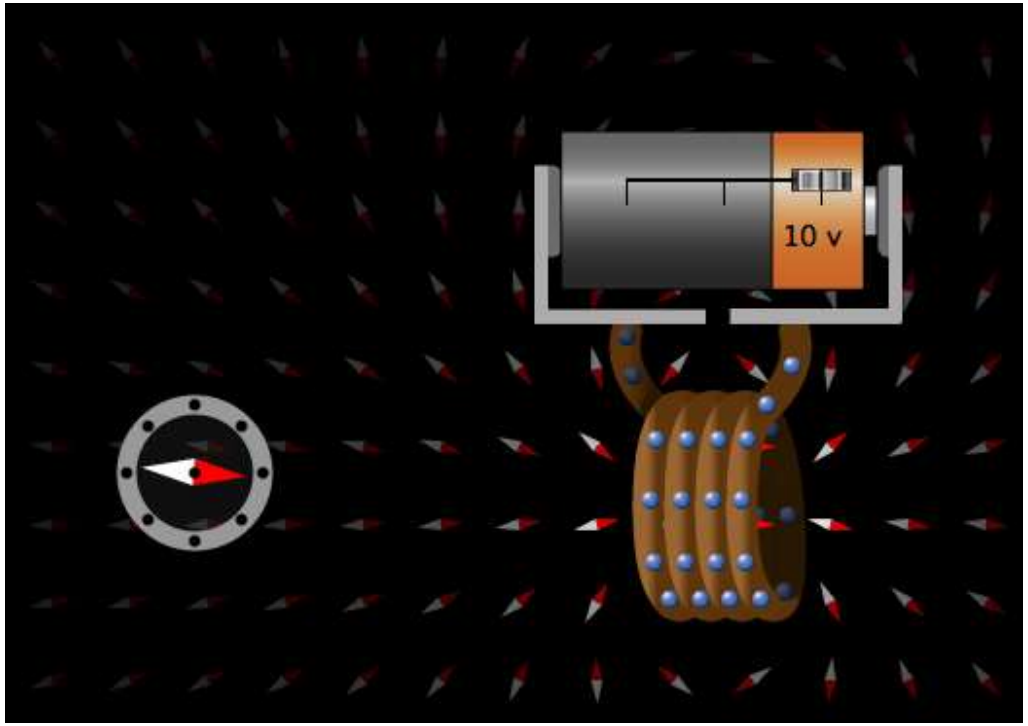
Alternate “right hand rule”

Demos: Magnetic field around a current carrying wire

Simulation: Electromagnet

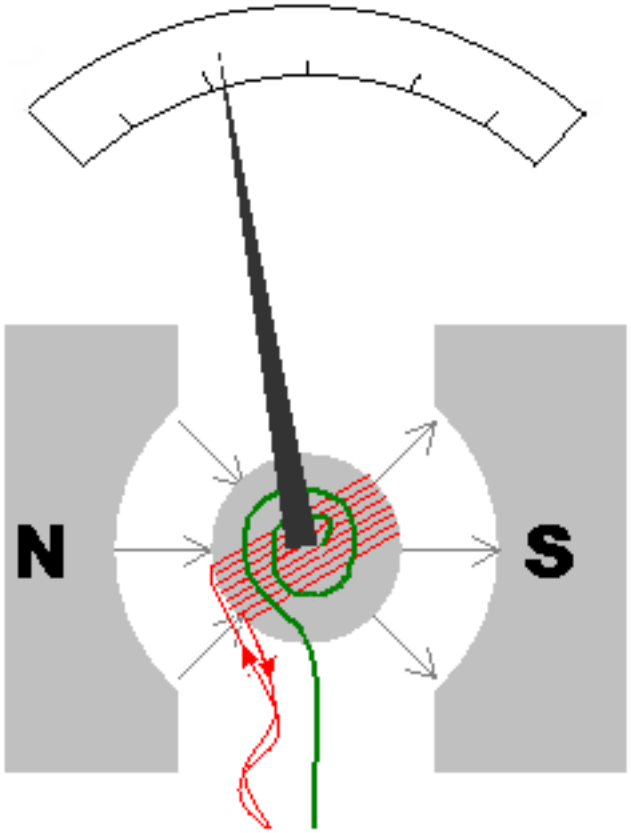
What if we loop wire into a coil?

We get a magnetic field produced by the electric current!



Galvanometer (current meter)

Galvanometer measures current



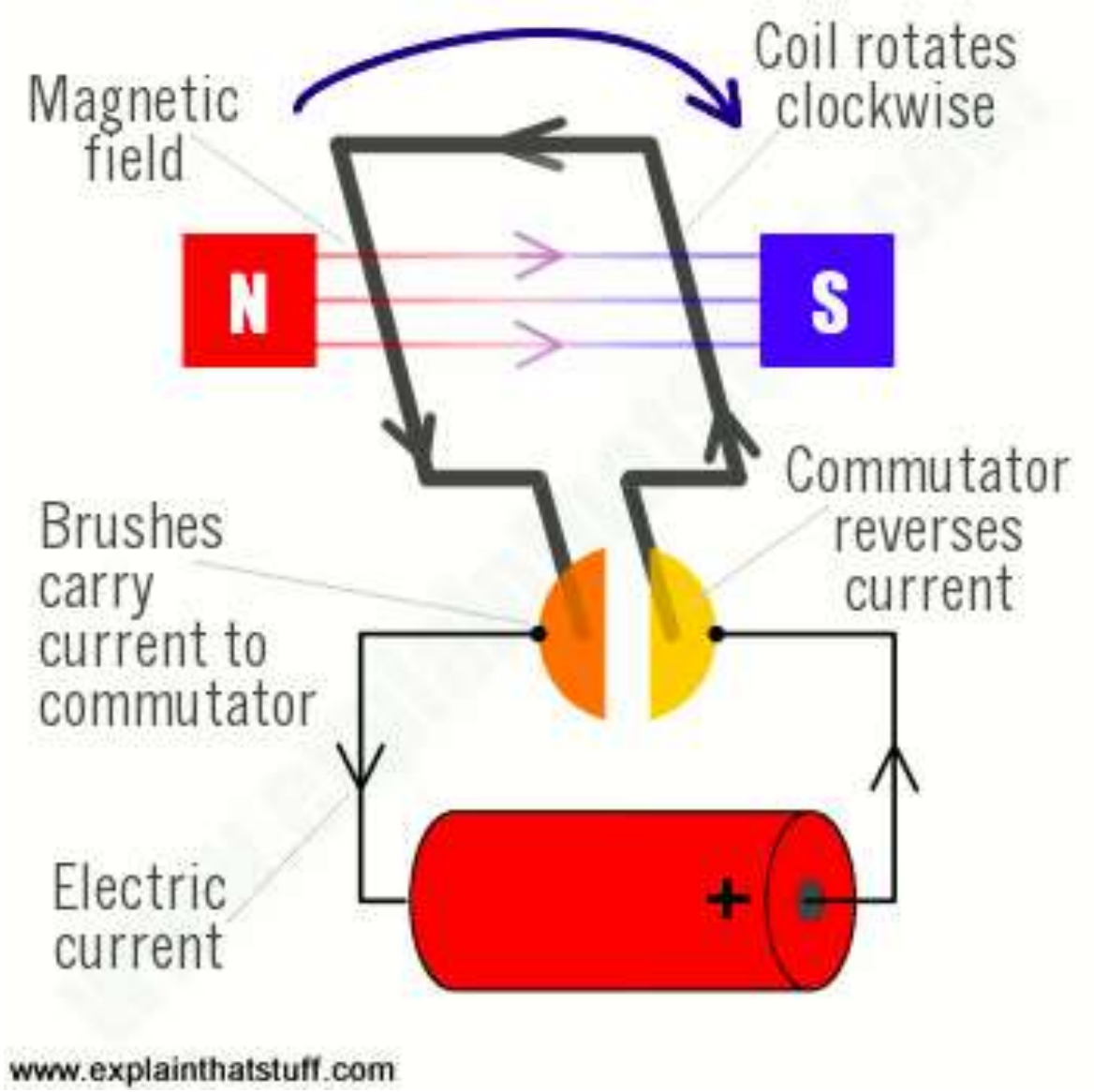
What happens if we move a bar magnet through a coil?

Demo: Galvanometer with Coil

Electrodynamics

- Moving charges feel magnetic force
- Moving charges generate magnetic fields
- Electric motors
- Magnetic induction and electric generators

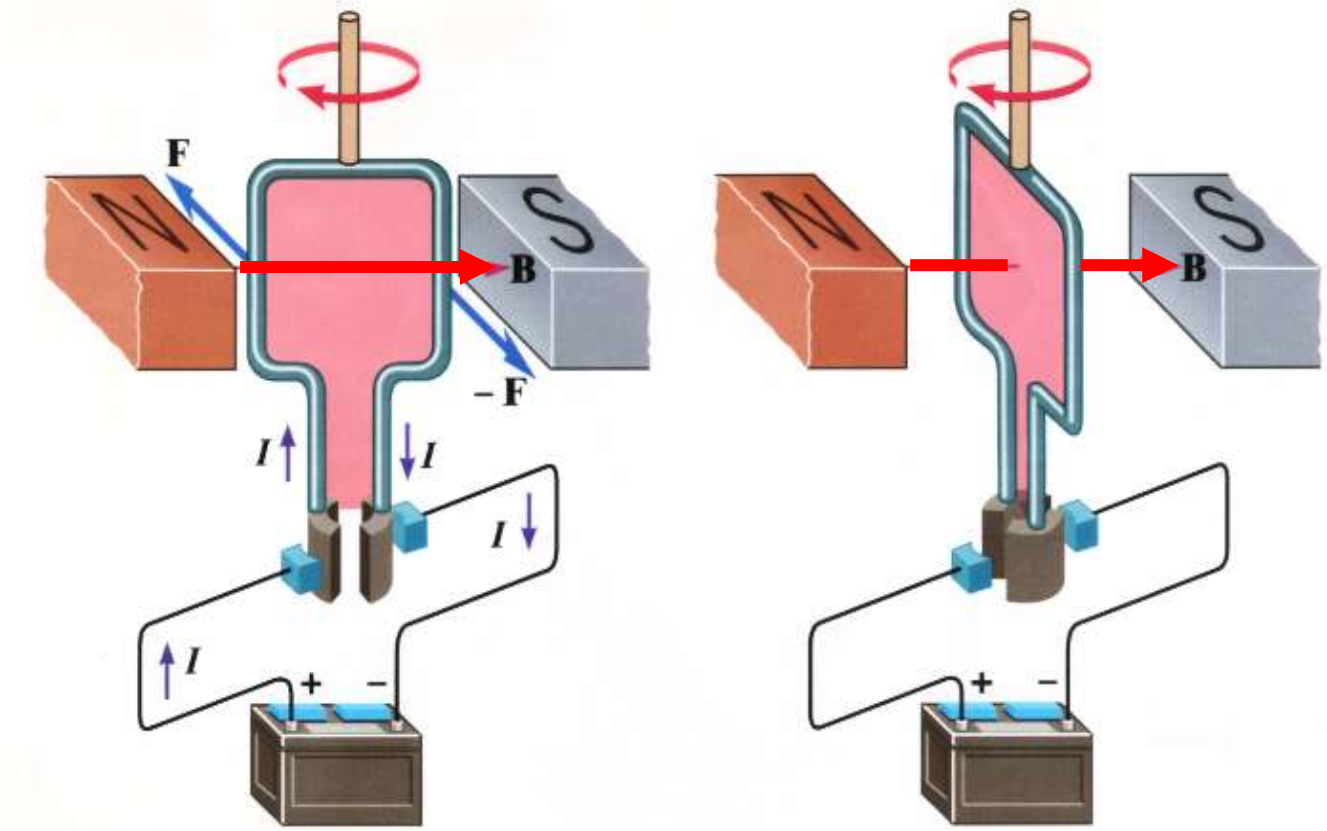
Electric Motor



Electric motors involve rotating coils of wire which are driven by the magnetic force exerted by a magnetic field on an electric current.

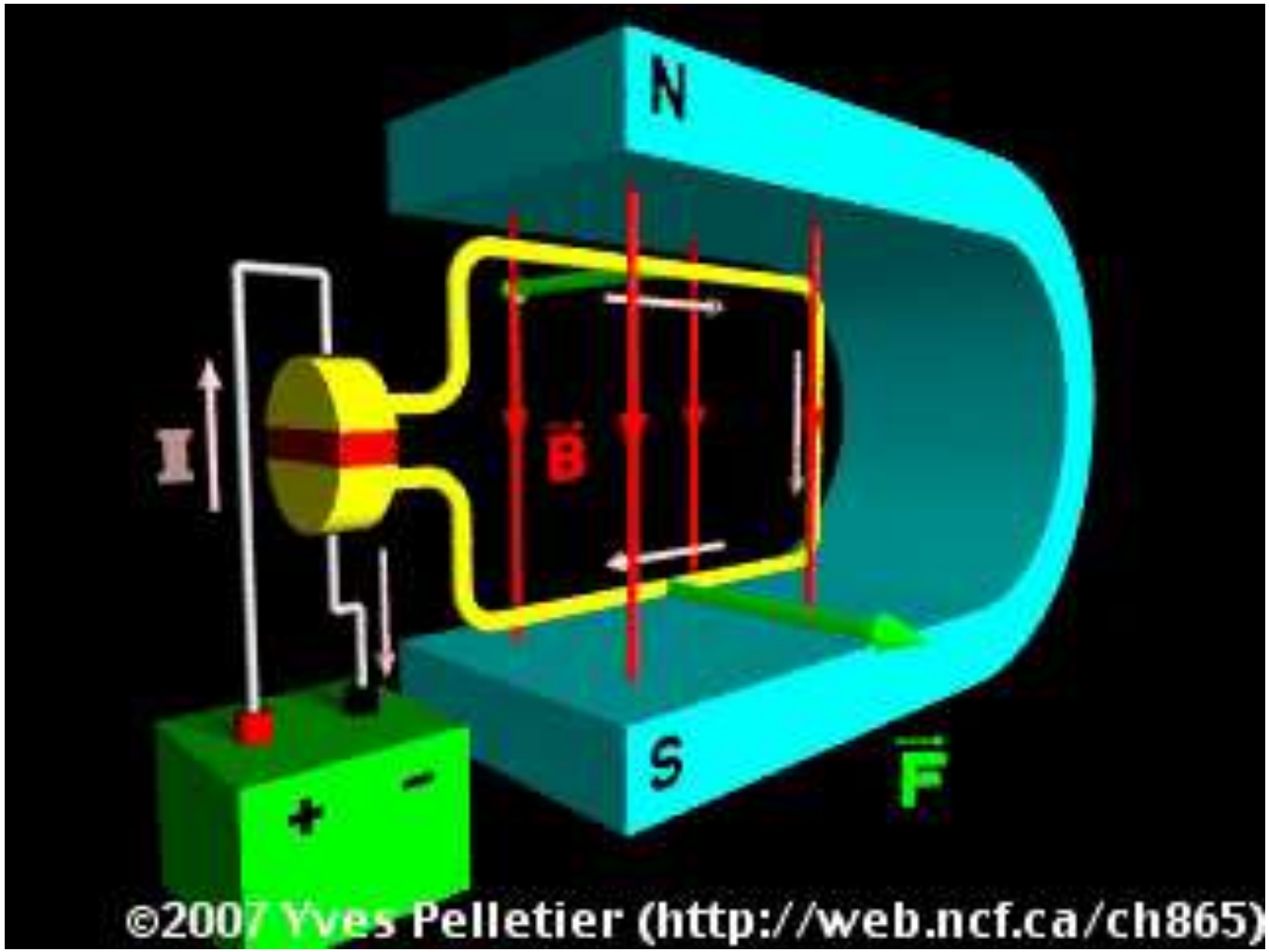
Energy transformation: electrical energy → mechanical energy

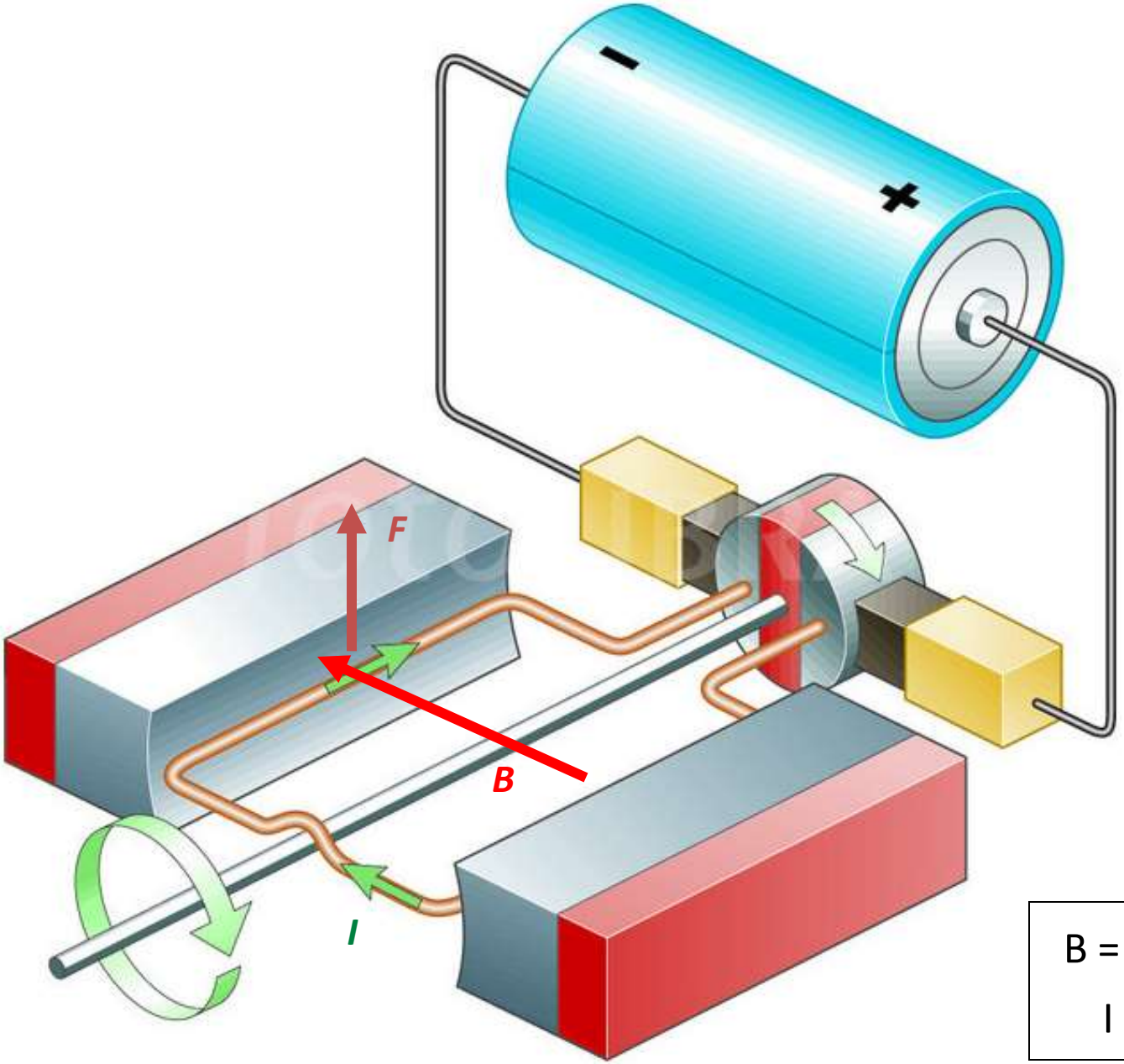
Electric motors



- When electric current passes through a coil in a magnetic field, the magnetic force produces a *torque* which turns the motor
- Electric current is supplied externally (through a commutator)
- The magnetic force acts perpendicular to both the wire (direction of current) and the magnetic field

Electric motor video





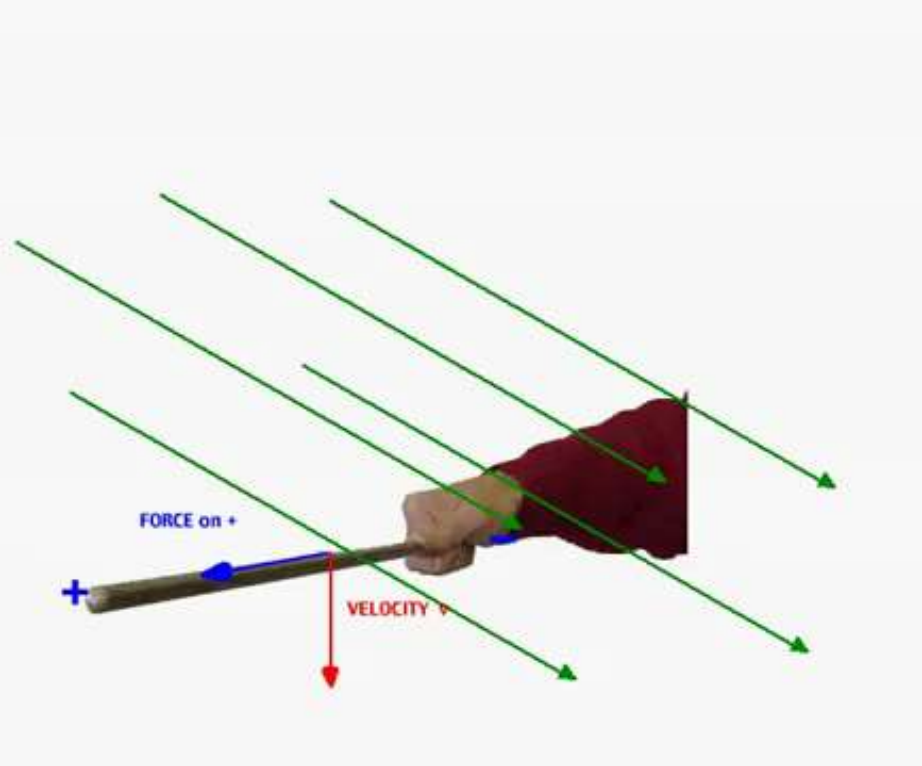
B = Mag. Field

I = current

Electric generators

- Moving charges feel magnetic force
- Moving charges generate magnetic fields
- Electric motors
- Magnetic induction and electric generators

Induction of current in moving wire (animation)



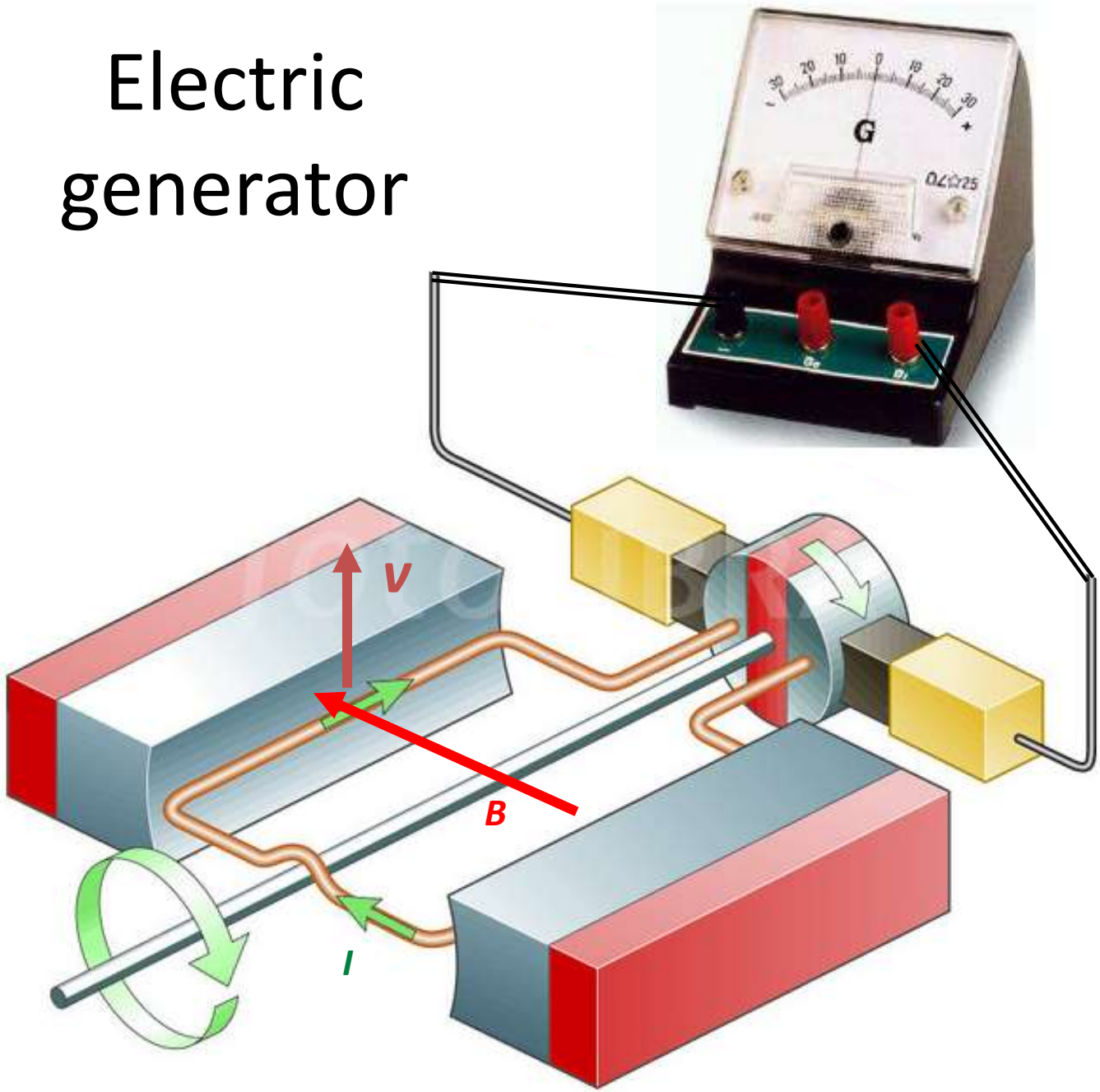
If charge in a wire is moving *perpendicular* to a magnetic field, then the force on the charge is along the wire.

This force does work, and work per unit charge is voltage.

Therefore, any change in the magnetic environment of the wire will cause a voltage (and current) to be "induced" in the wire.

Discovered by Michael Faraday!
(mathematically described by James Maxwell)

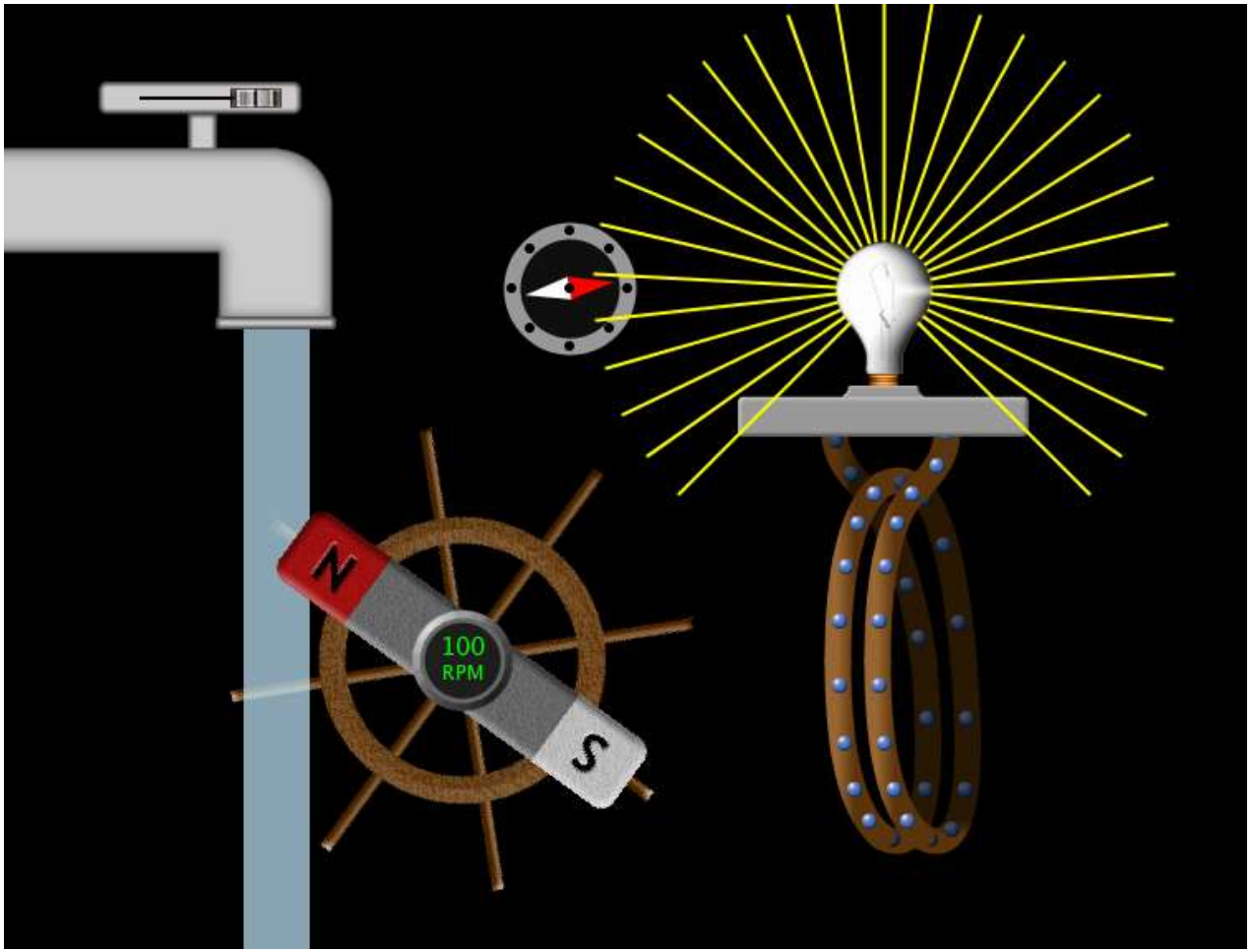
Electric generator



If the movement of the wire is in the form of a rotating coil, then the two sides of the coil move in opposite directions.

Since the rotation produces different directions of motion at different points on the circle of rotation, the voltage generated is sinusoidal – produces an alternating current (AC).

Simulation: Generator



https://phet.colorado.edu/en/simulation/legacy/faraday

Efficiency of motors and generators

Energy conversions:

Electrical ⇒ Mechanical: Motor

Mechanical ⇒ Electrical: Generator

$$\text{Max Efficiency} = \frac{T_{in} - T_{out}}{T_{in}}$$

(Temperatures measured in K)

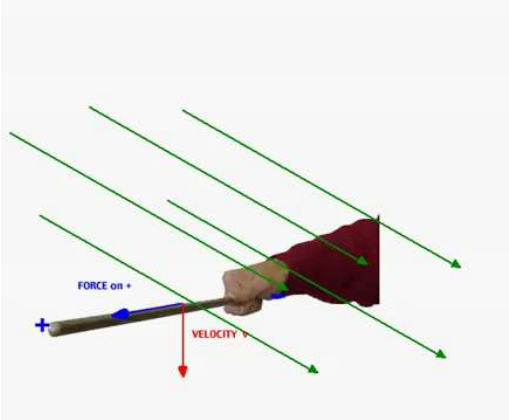
Does it apply?

No!

NOT A THERMAL ENGINE!

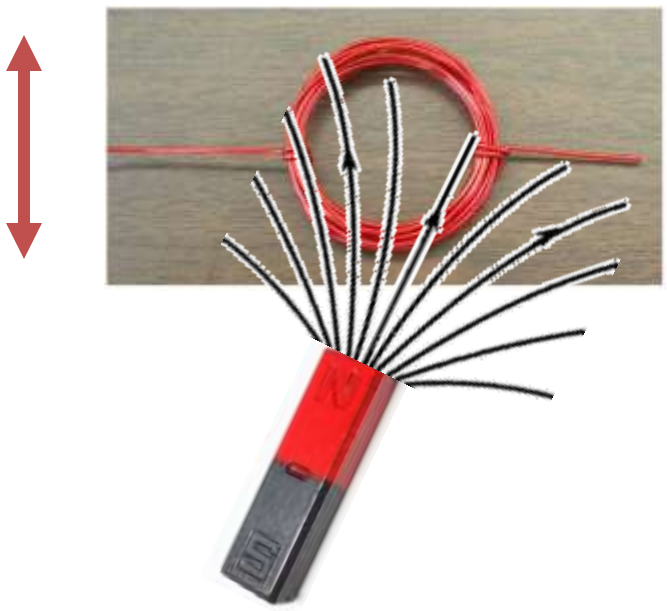
Types of magnetic induction

- Induction of current in a moving wire

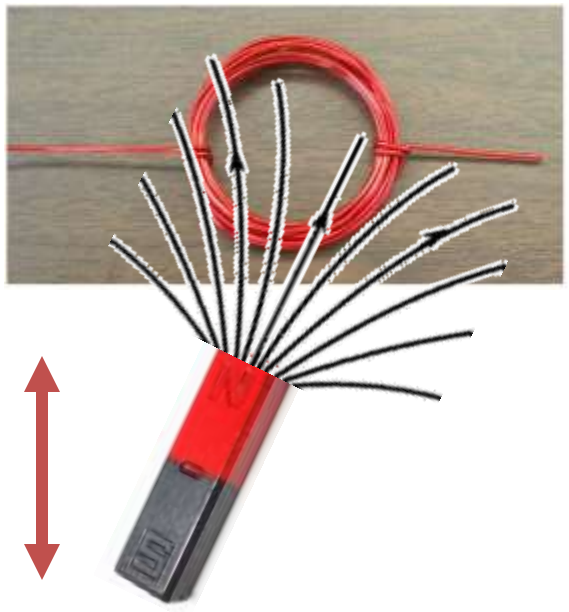


- Induction by moving magnet and stationary wire
- Induction with nothing moving!

Types of magnetic induction

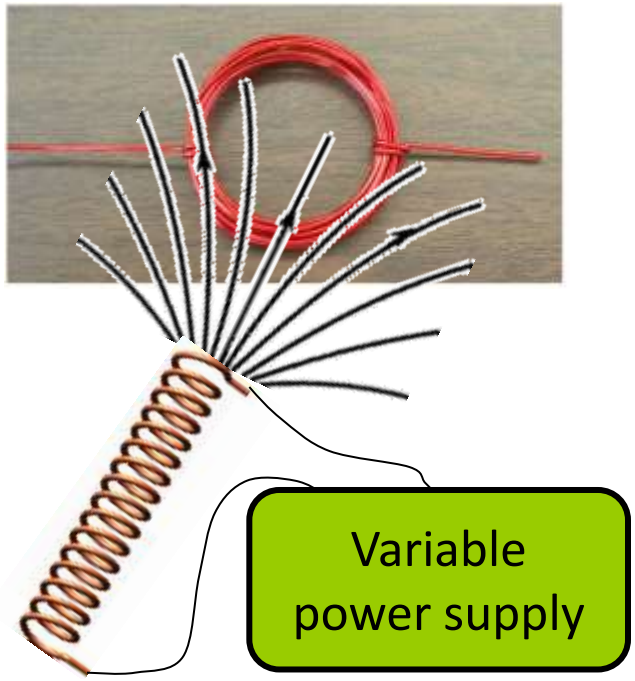


Moving wire, stationary magnet



Stationary wire, moving magnet

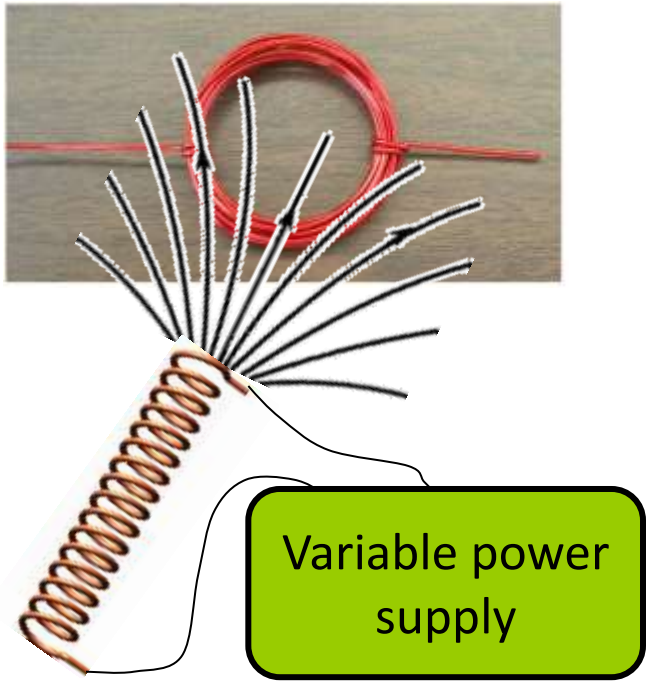
Types of magnetic induction



Stationary wire,
stationary magnet!

Faraday principle

- Induced voltage depends only on the rate of change of the magnetic field through the loop
- Changing magnetic fields generate circulating electric fields



Demo: Copper Tube

Faraday principle

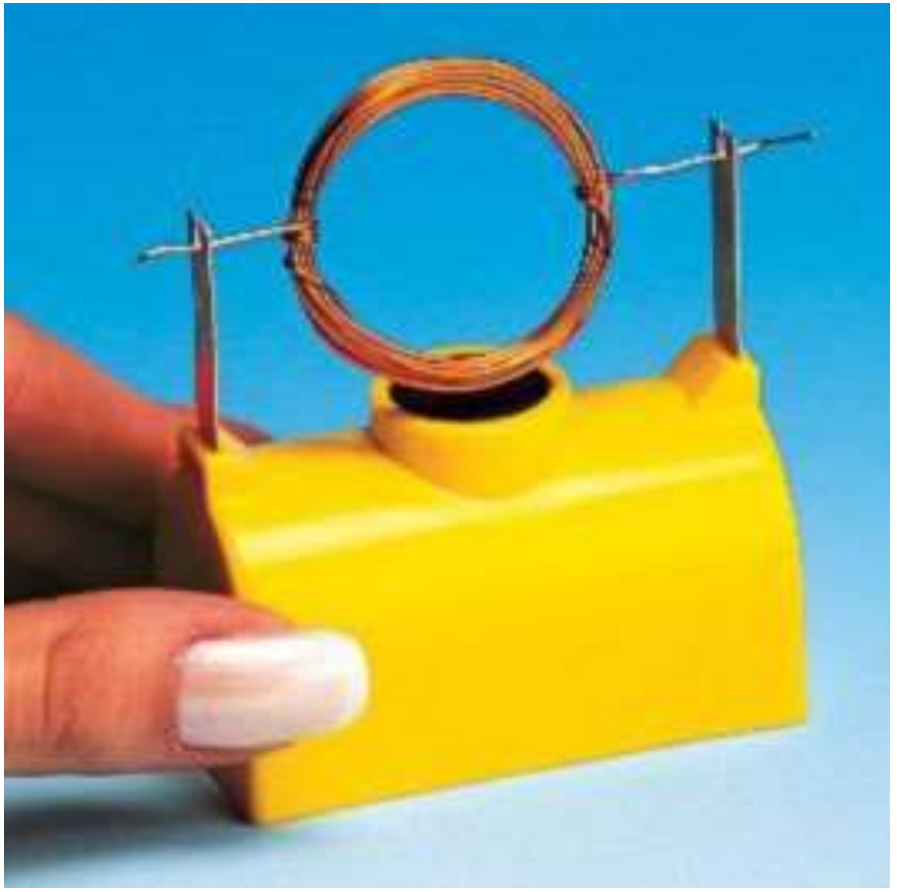
Maxwell principle

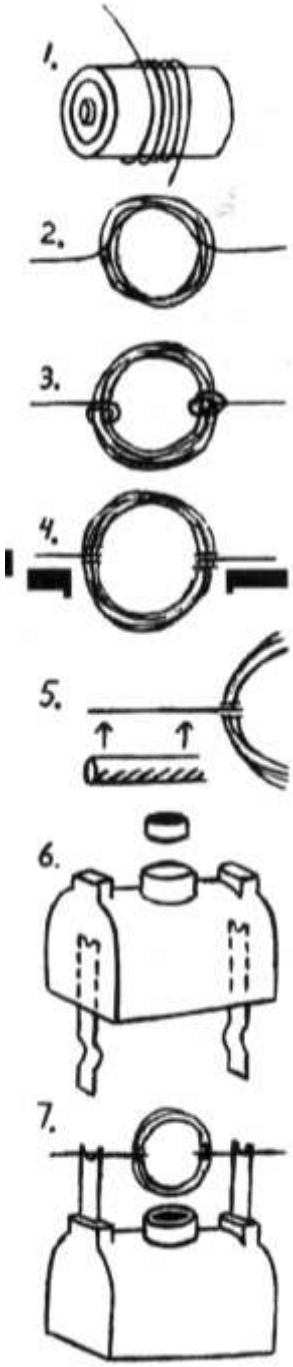
Changing magnetic fields generate circulating electric fields

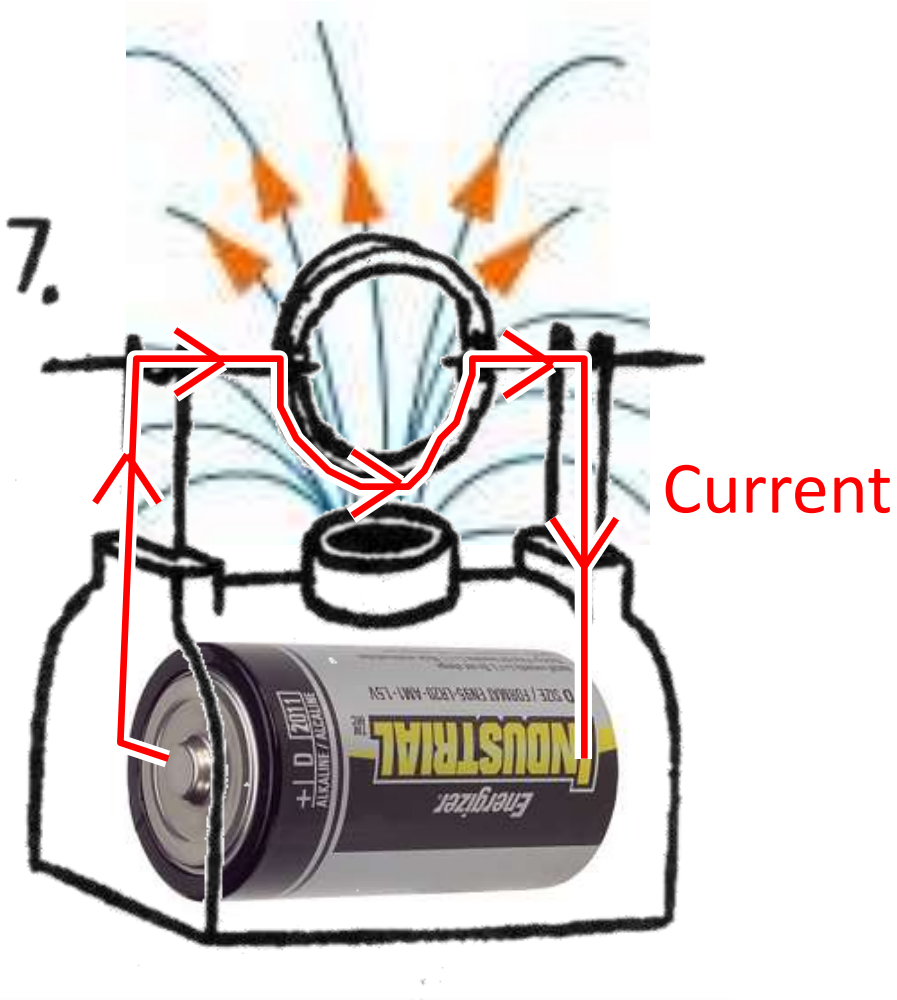
Changing electric fields generate circulating magnetic fields

Electromagnetic waves!

Lab: Electric Motor







See Electric Motor Kit video on Canvas under "Media Gallery"

Next Time

- Next time: Chapter 9 (Electromagnetic Waves)

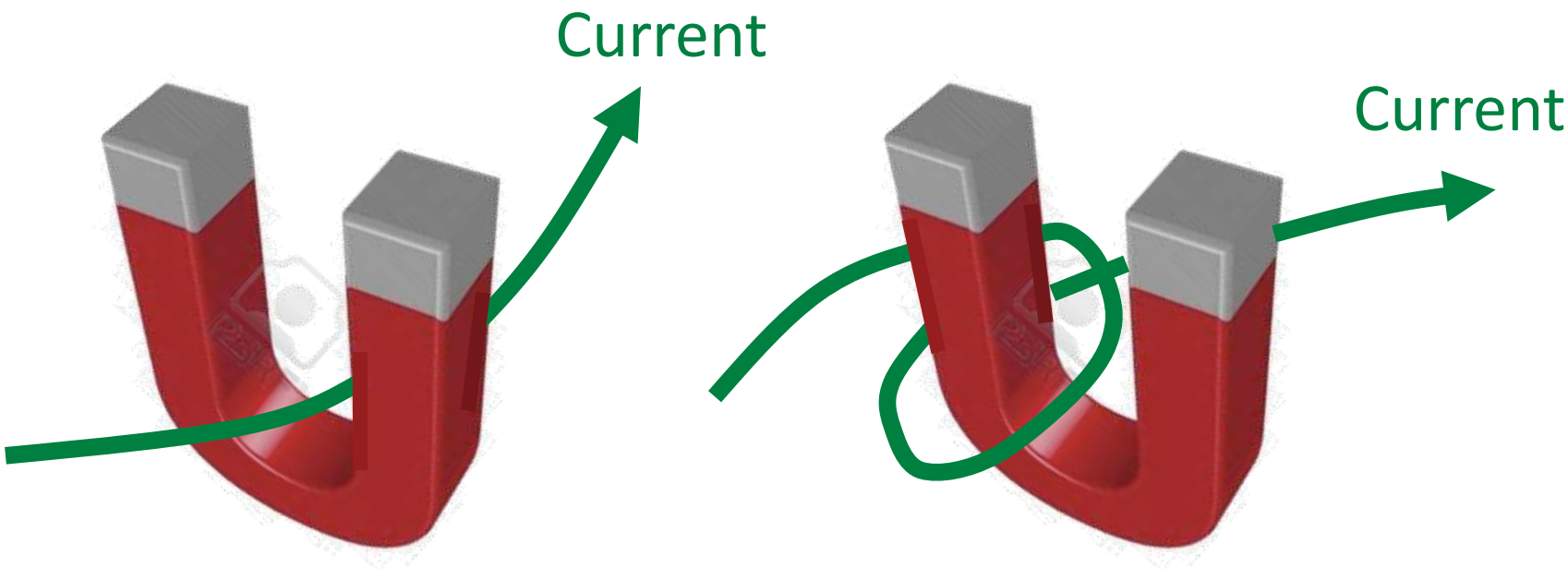
Next HW

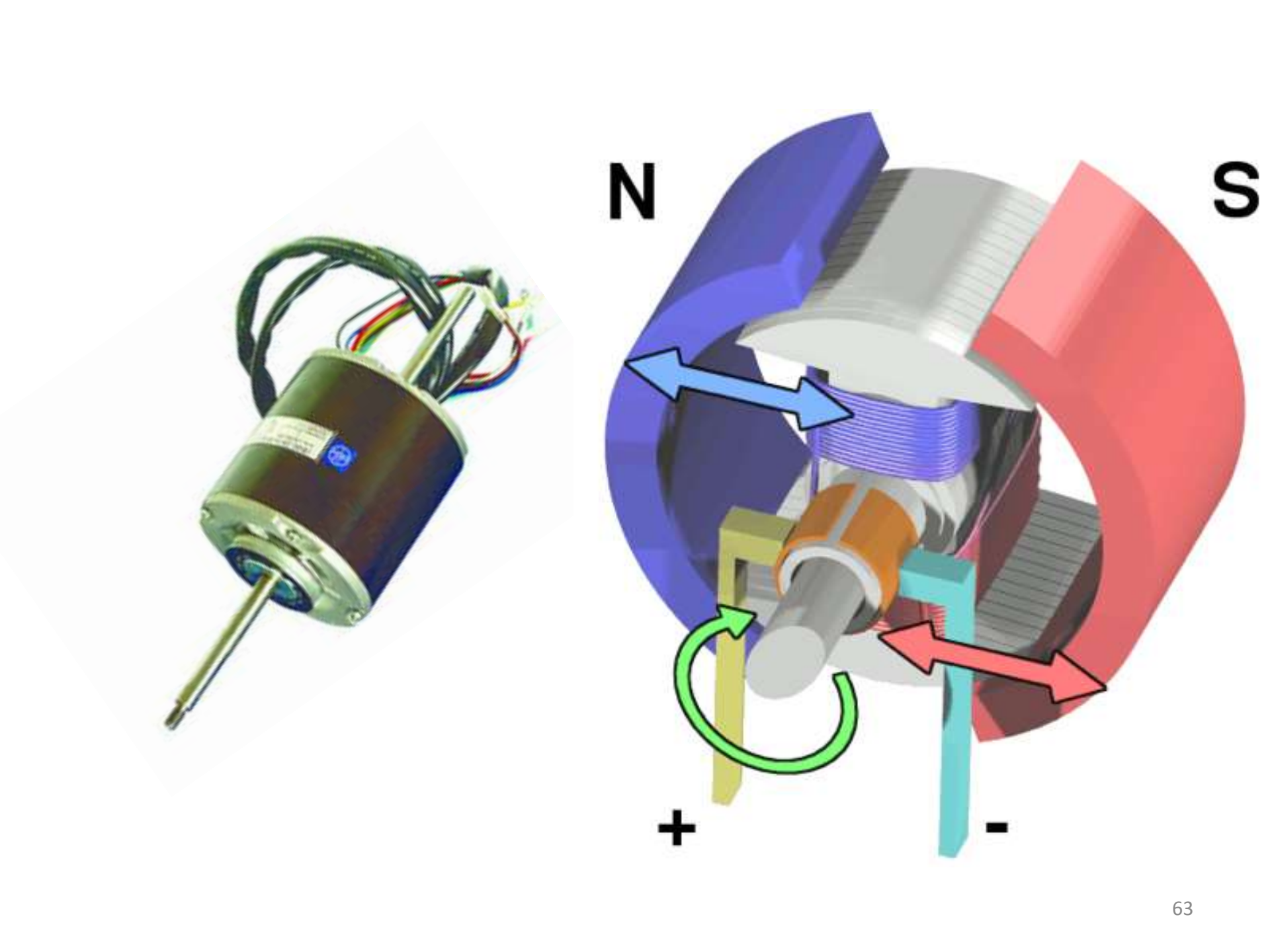
- HW#7 due March 30

Skip

Which way will it jump?

https://www.youtube.com/watch?v=tUCtCYty-ns

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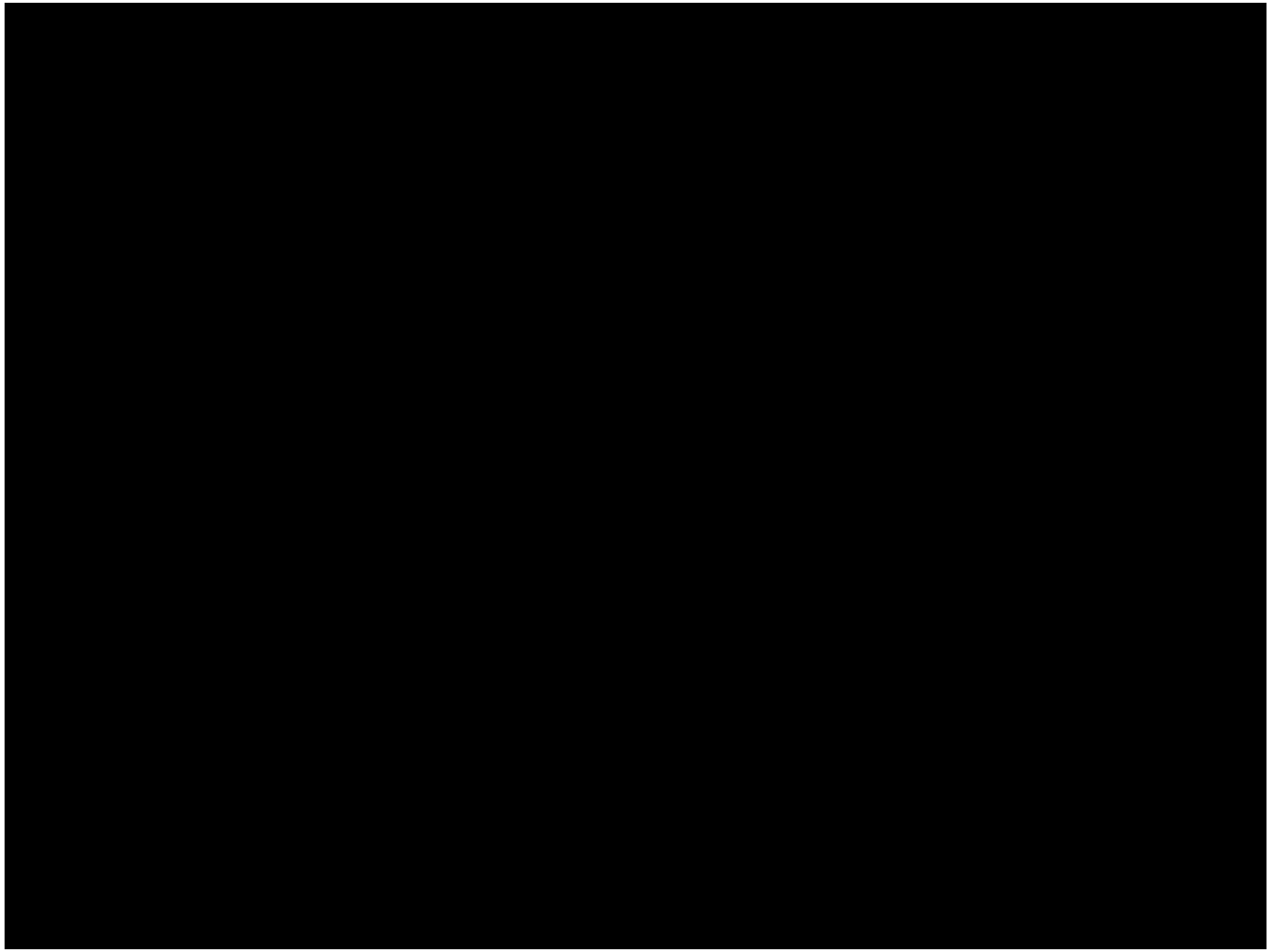
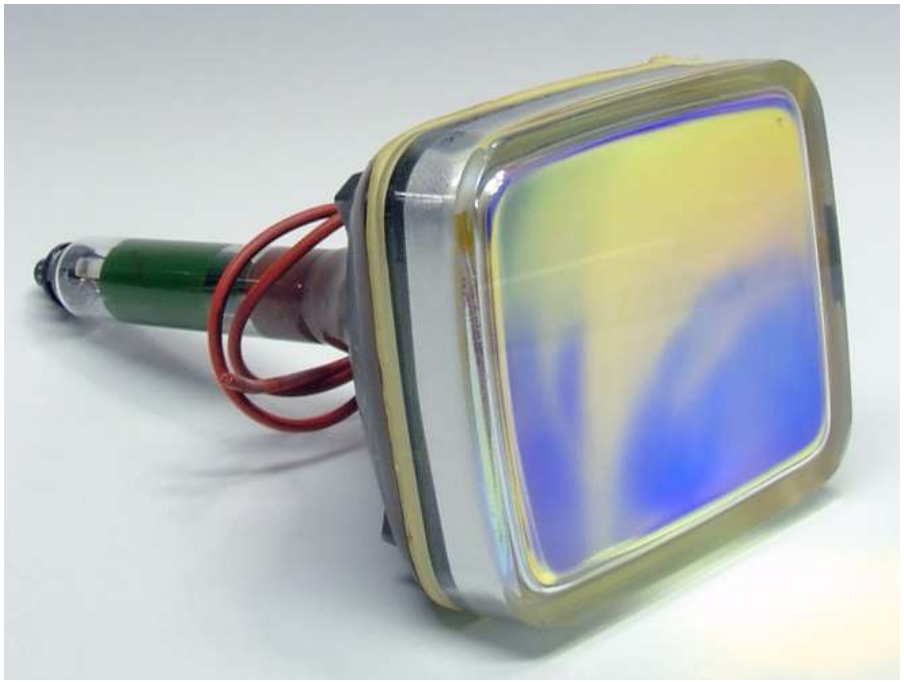
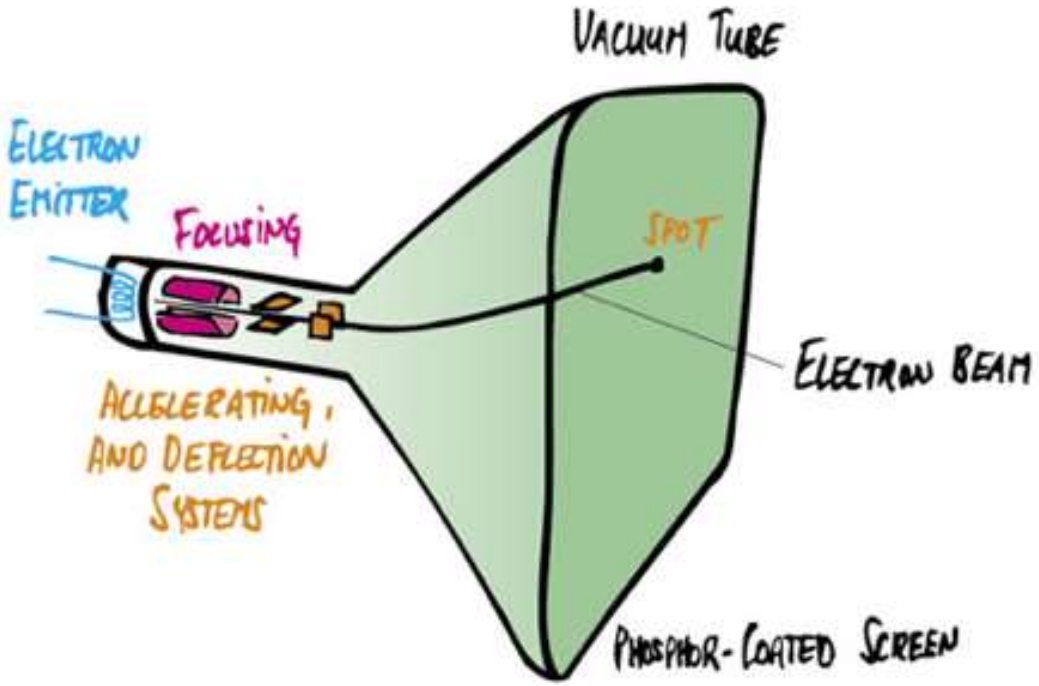
Motor Kit Video

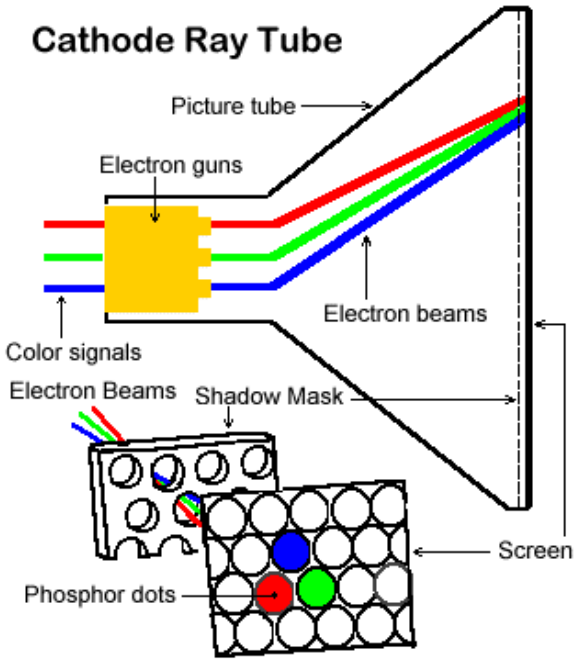


CRT = Cathode Ray Tube



CRT = Cathode Ray Tube





Black and White **Color**

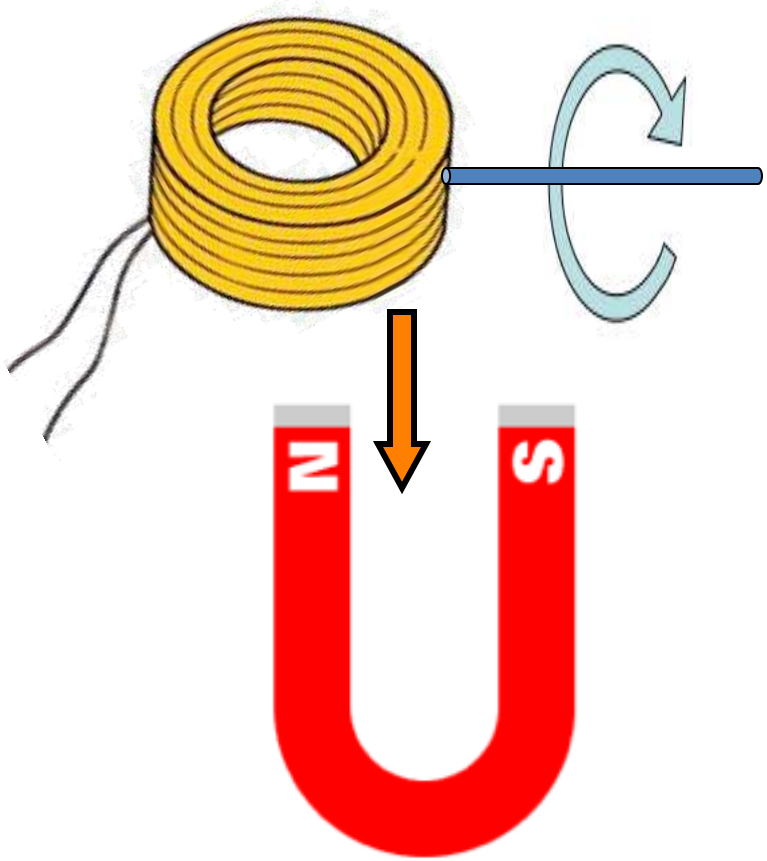
Faraday Coils

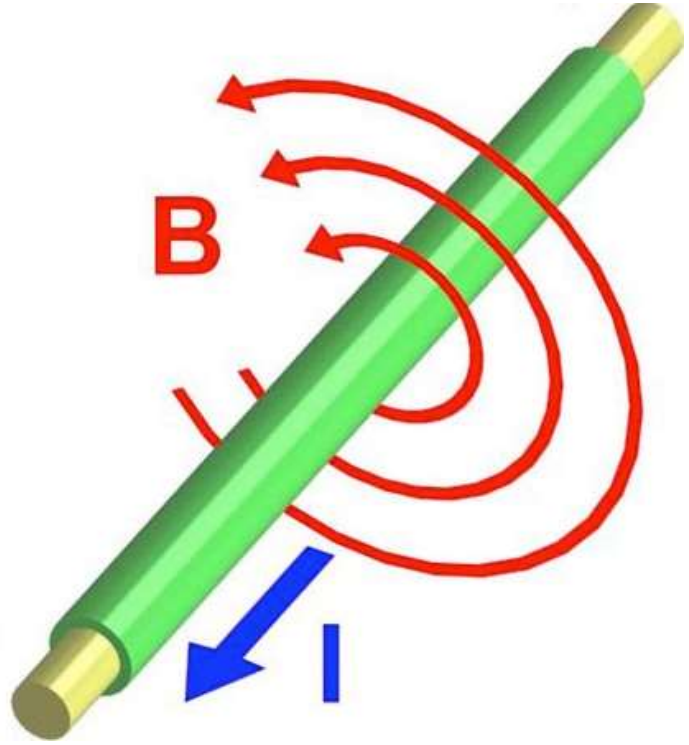
If the coil is flipped upside down before lowering onto the magnet, the meter deflection will:

A) Reverse direction

B) Stay in the same direction

C) Go to zero





B = Mag. Field

I = current

Electromagnet

Animation

Phet Applet: Earth's magnetic field

https://phet.colorado.edu/en/simulation/legacy/magnet-and-compass

Reverse magnet?

Reverse battery?

Hold magnet in hand: above? To side?

Efficiency of motors and generators

Energy conversions:

Electrical ⇒ Mechanical: Motor

Mechanical ⇒ Electrical: Generator

NEMA Design B Electrical Motors

Electrical motors constructed according NEMA Design B must meet the efficiencies below:

Power (hp)	Minimum Nominal Efficiency[1)]
1 - 4	78.8
5 - 9	84.0
10 - 19	85.5
20 - 49	88.5
50 - 99	90.2
100 - 124	91.7
> 125	92.4

Clicker

Which way will the spot move?

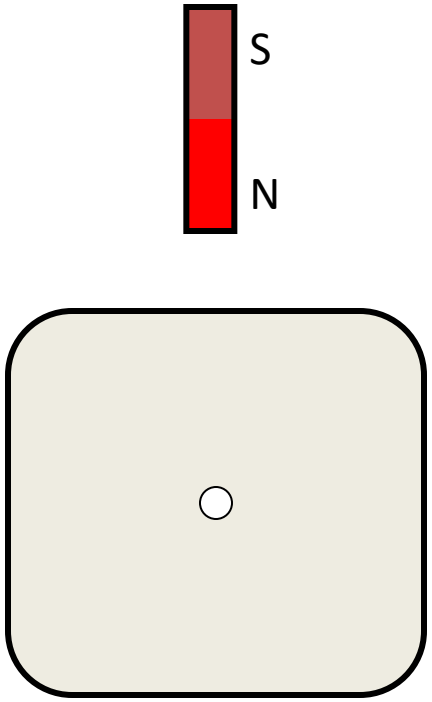
A) Up

B) Down

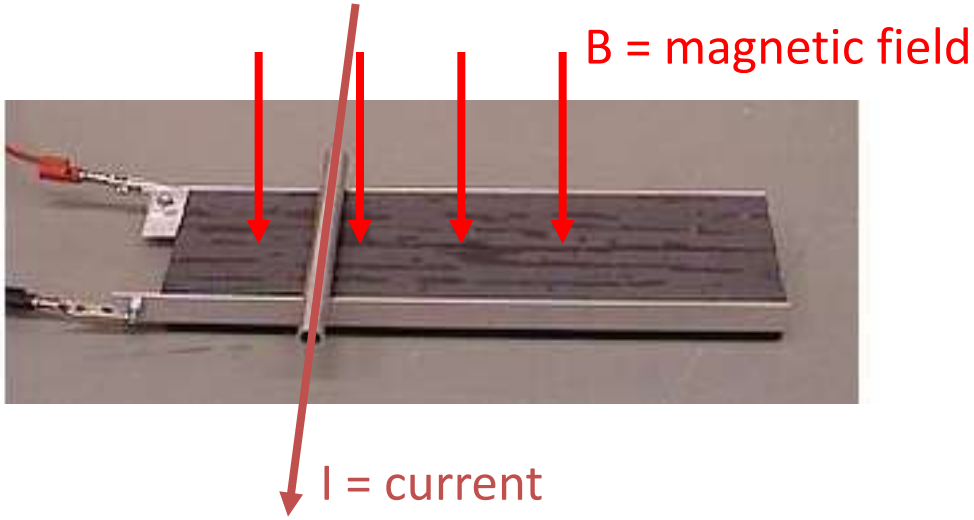
C) Left

D) Right

E) None of the above



Ampere motor demo



Clicker

If the metal cylinder is reversed, the force on the cylinder will:

A) Reverse direction

B) Stay in the same direction

C) Go to zero