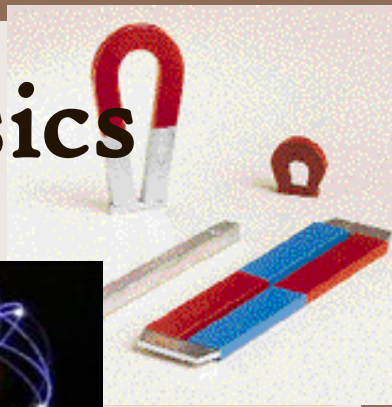


Magnetism Basics

- **Source:** electric currents (electron spin)



- **Magnetic Domains:** atomic regions of aligned magnetic poles

Random Alignment



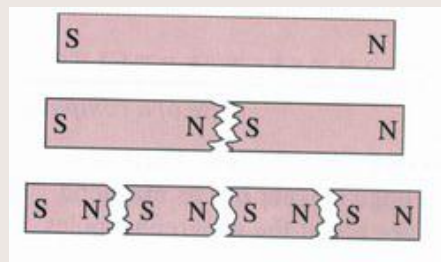
Net Effect = Zero!

Ferromagnetic Alignment



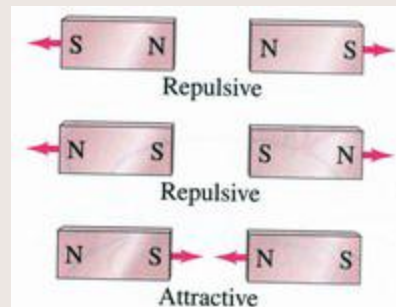
Net Effect = Additive!

- **Bipolar:** all magnets have a North Pole & South Pole—natural monopoles do not exist! Splitting a magnet results in bipolar “mini-magnets!”

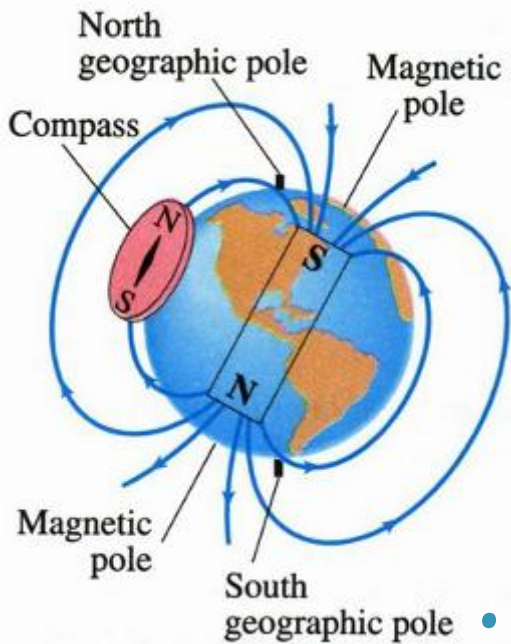


- **Magnetic Forces:** like electric forces

- Likes Repel
- Opposites Attract



The Earth: A Natural Magnet

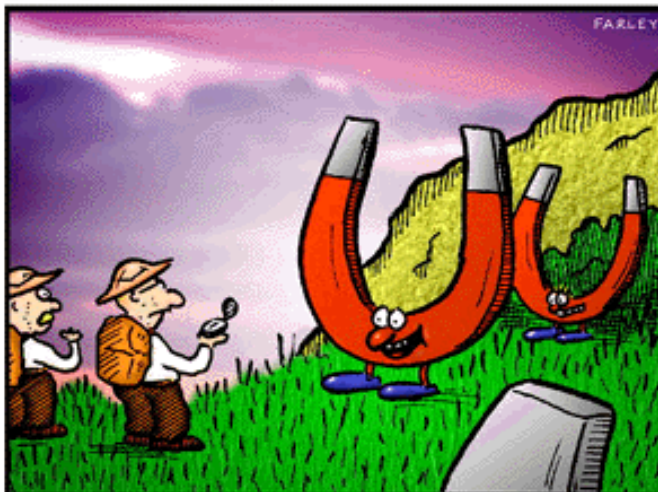


- Earth's Magnetic Poles shift with time—even reversing direction!



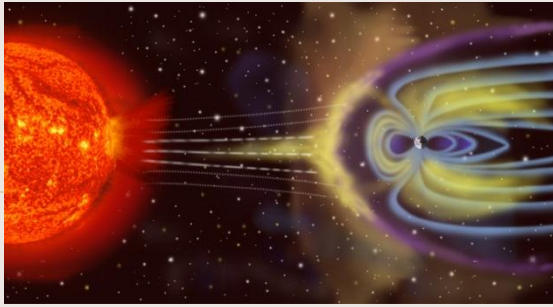
- Magnetic Field is *3-Dimensional* and deflects downwards at the poles—a compass would be totally useless!

DOCTOR FUN



"Ho ho, foolish explorers - your compasses are useless here!"

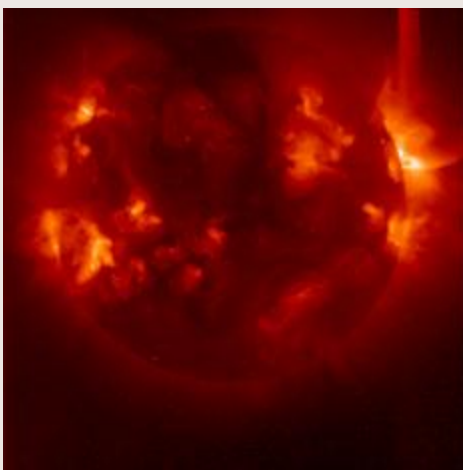
Astronomical Effects



Magnetic Shielding:

Earth's B field naturally shields and bottles high-energy cosmic radiation from the sun towards the poles

- **Aurora Borealis:**
(*Northern Lights*)
Due to shielding effect, cosmic radiation interacts with the atmosphere lighting up the night sky @ poles.

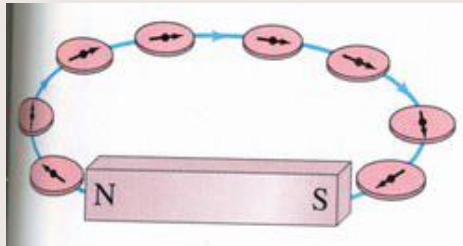


- **Solar Flares:**

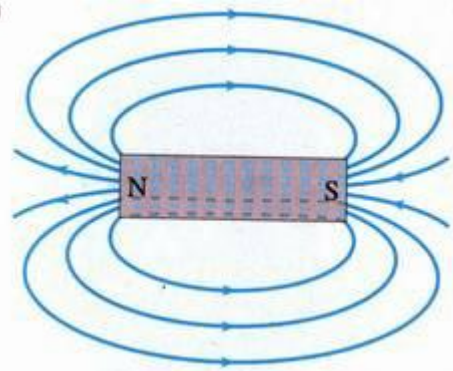
~11 years the Sun experiences large-scale fluctuations in it's B field-
-kicking out gases and intense radiation enough to disrupt radio communications on Earth!

Magnetic Fields \vec{B}

- **Magnetic Fields (B):** Force Field acting on magnetic domains like Electric Fields acting on electric charges

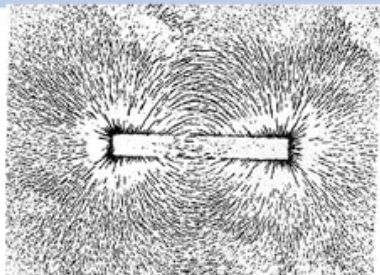


- **Direction:** points from North to South Poles and flows through interior of magnet or coil

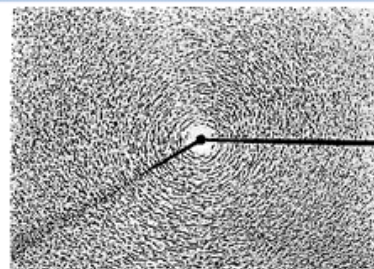


- **Strength:** like Gravity, obeys Inverse Square Law: Force $\sim 1/d^2$. Unlike gravity, a medium (i.e. iron) can alter strength. Density of **B** field strongest at poles.

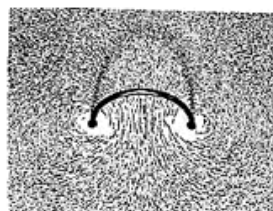
Examples of Iron Filings Defining Magnetic Field Lines



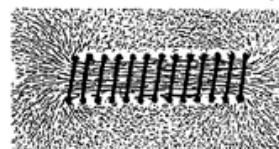
bar magnet



wire



current loop



solenoid

ElectroMagnetic Induction



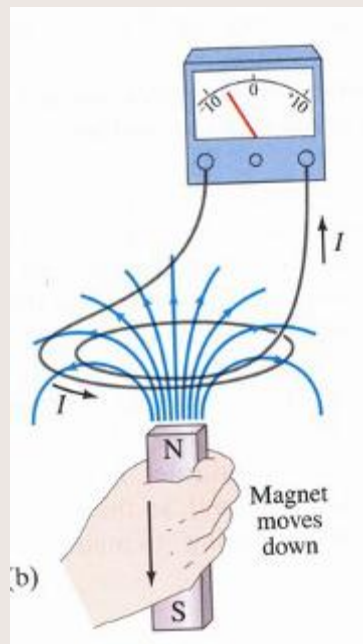
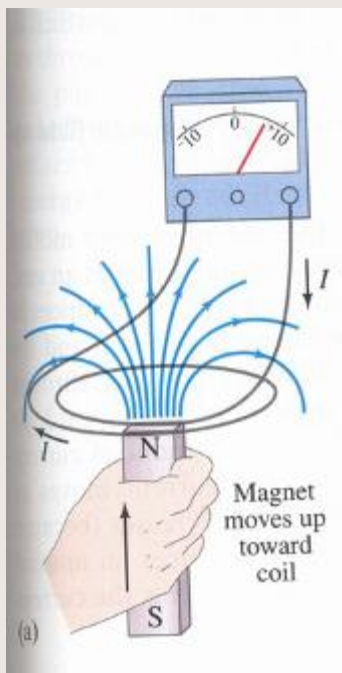
- **The Missing Link:**

-Oersted discovered *Electric Currents* produce Magnetism. Will Magnetism produce Currents?

- **Lenz's Law:**

-A **CHANGING B** field through a circuit will induce an **OPPOSING B** field.

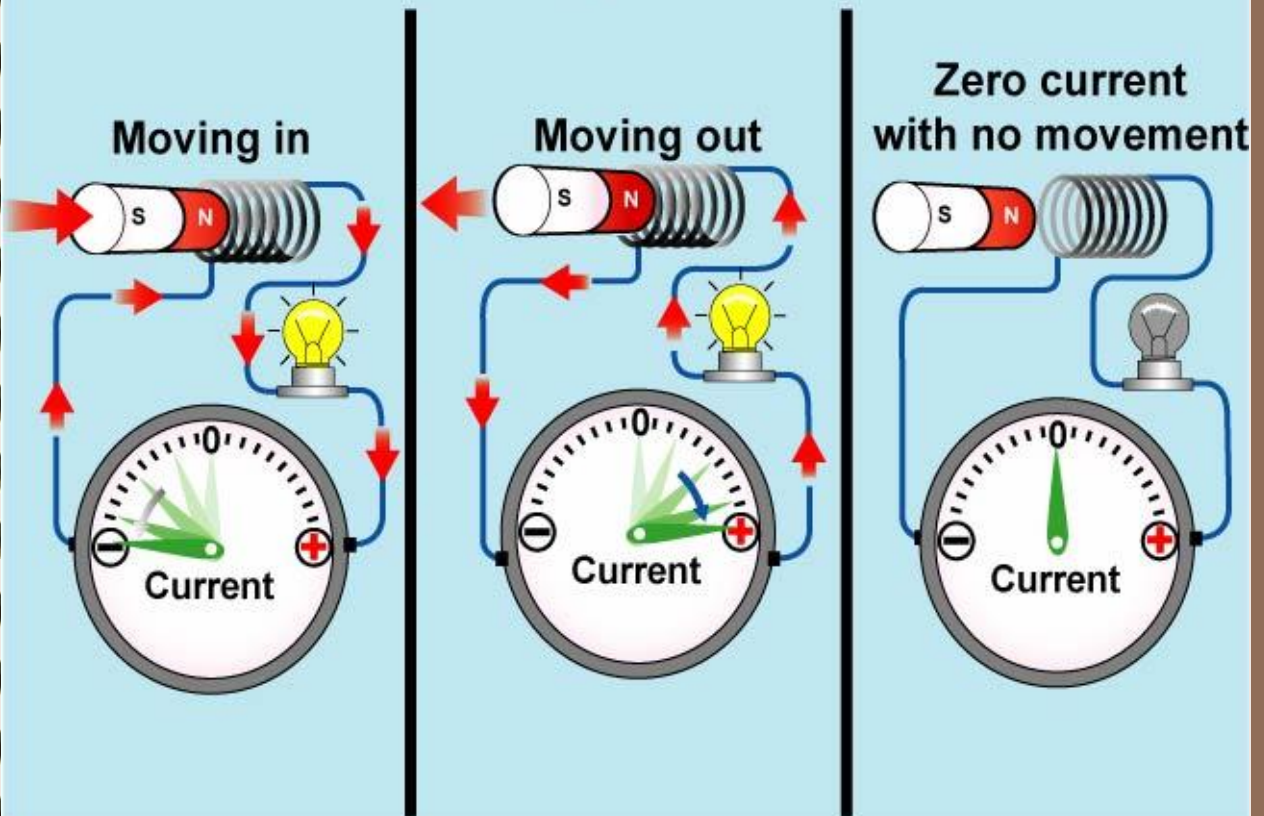
- Why *opposing*? Mechanical energy to change **B** will result in electrical energy! Energy is conserved! Otherwise, infinite free energy!



Induction Secrets:

Changing & Opposing Fields

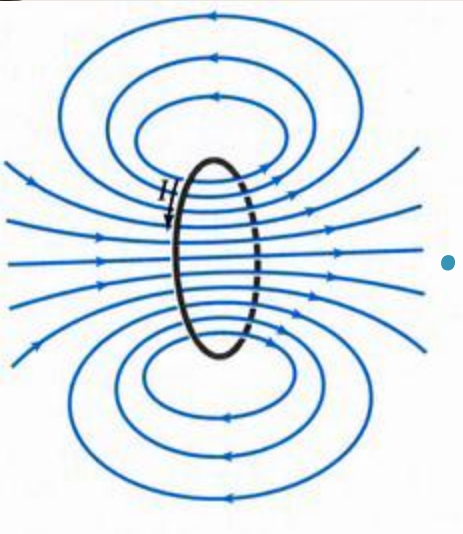
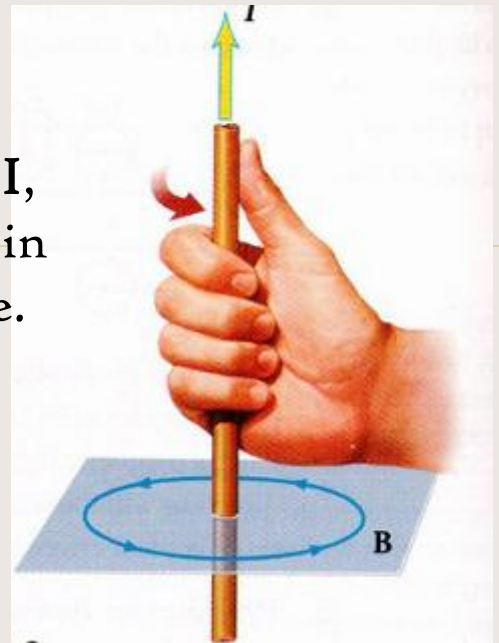
Electromagnetic Induction



Right-Hand Rules

- **Current-Carrying Wire:**

Thumb: points in direction of I ,
Fingers: curl in direction of B in concentric circles around wire.



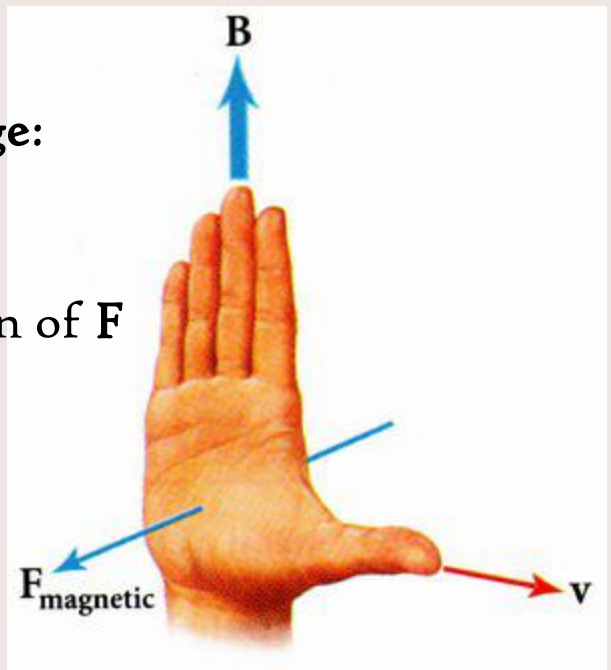
- **Loop:**

Fingers: curl in direction of current
Thumb: points in direction of B .

- **Force on Moving Charge:**

Thumb: direction of v
Fingers: direction of B
Palm: pushes in direction of F

- Note all 3 Quantities are at 90 degrees!



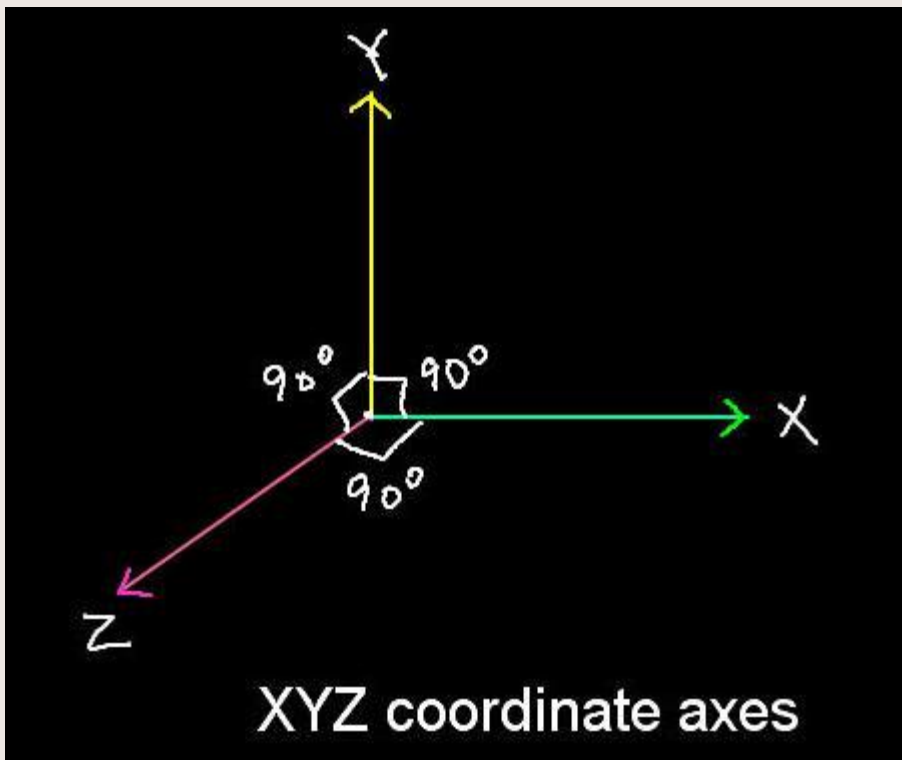
Right-Hand Rule Practice



= into page (tail feathers of arrow)

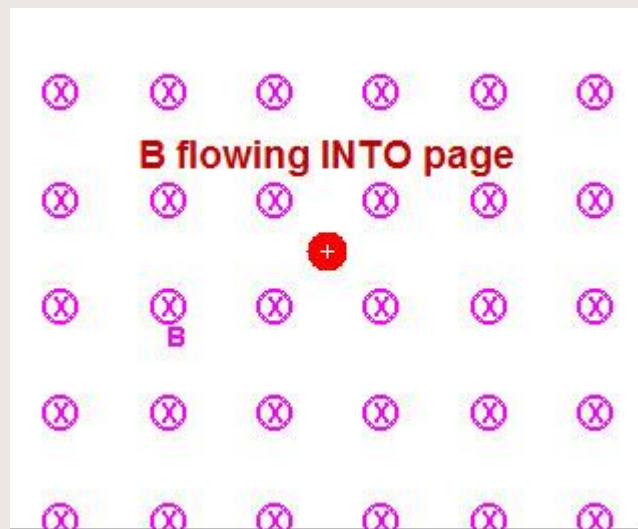


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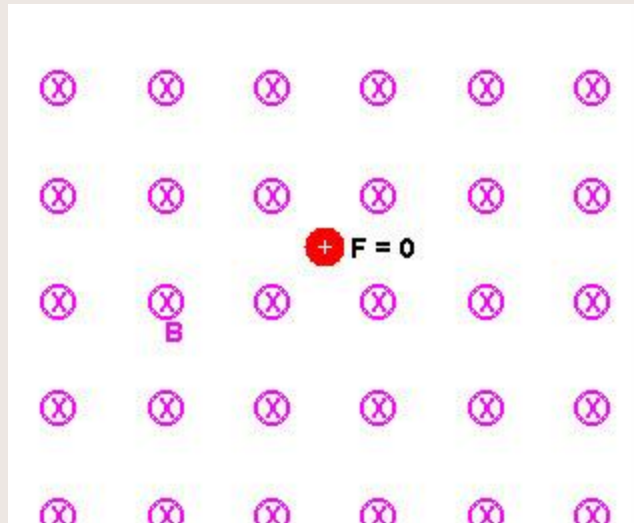
Right-Hand Rule Practice

- Find direction of Force on proton



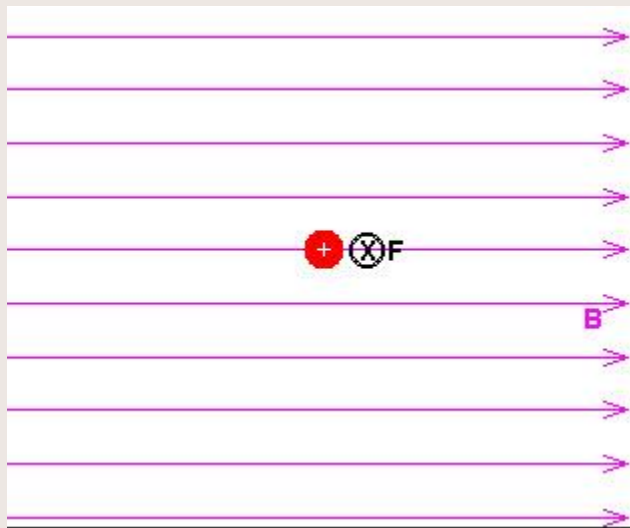
Right-Hand Rule Practice

- No Force because no velocity!



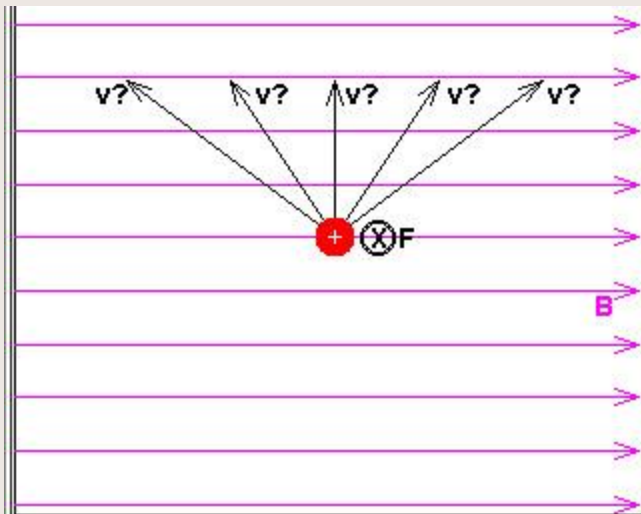
Right-Hand Rule Practice

- Find direction of velocity of proton



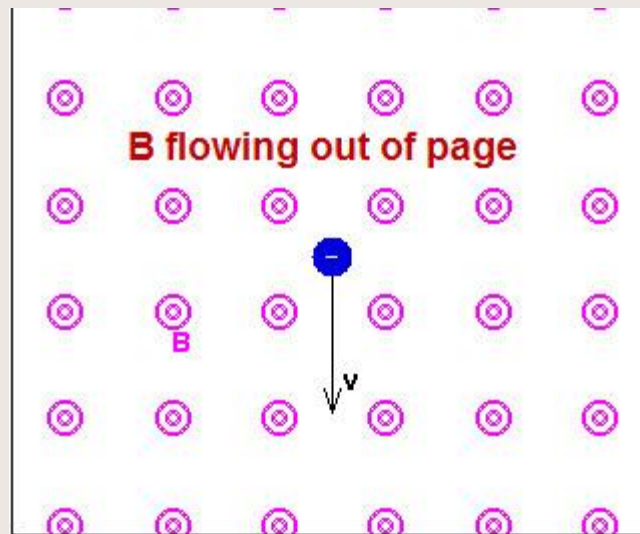
Right-Hand Rule Practice

- Find direction of velocity of proton



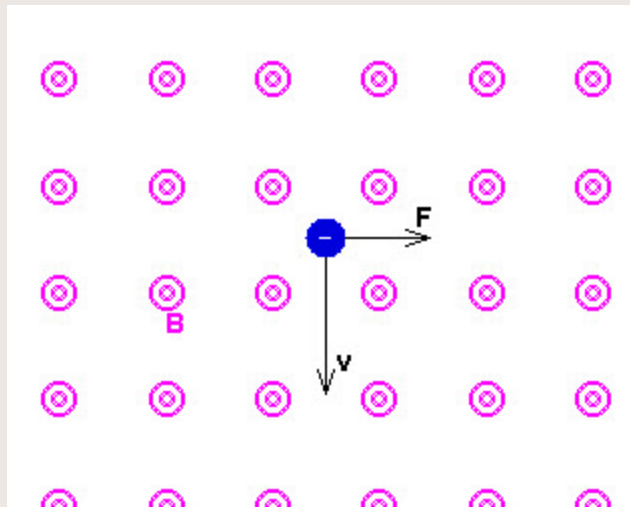
Right-Hand Rule Practice

- Find direction of Force on electron



Right-Hand Rule Practice

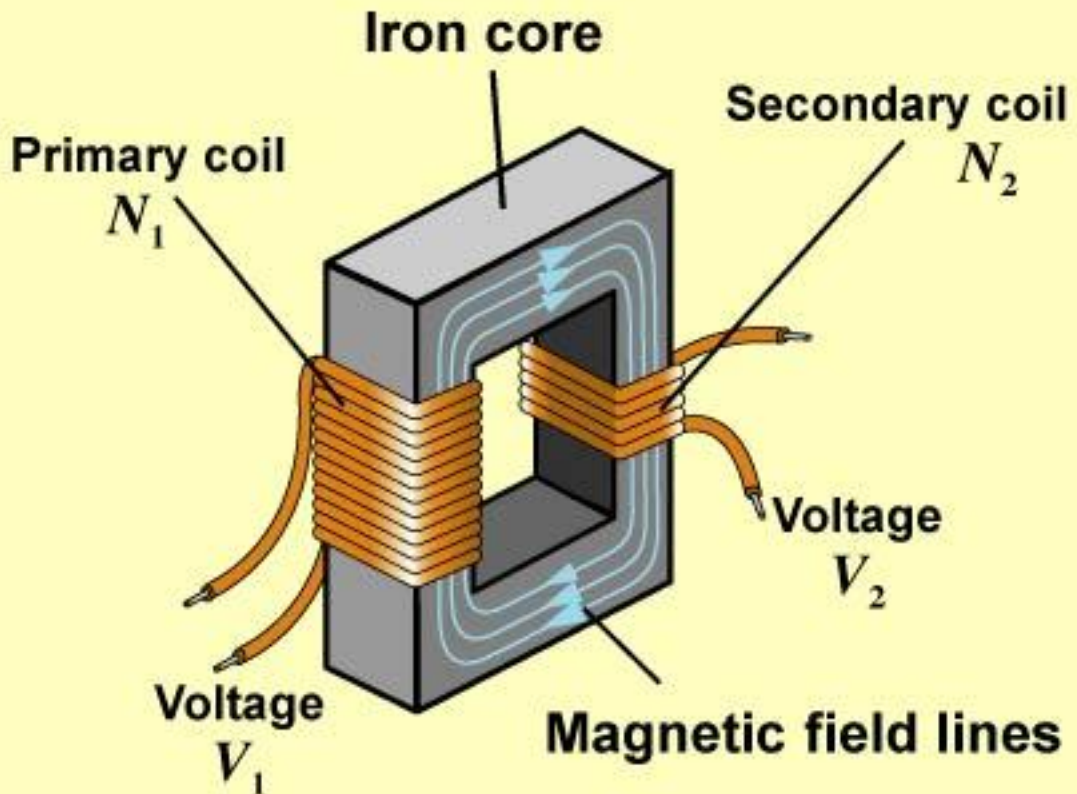
- Force is to the right since the charge is negative



Transformers: More than meets the eye!

Transformer

$$\begin{array}{l} \text{Primary} \\ \text{voltage (V)} \end{array} \frac{V_1}{\text{Secondary}} = \frac{N_1}{N_2} \begin{array}{l} \text{Turns in} \\ \text{primary coil} \end{array}$$
$$\begin{array}{l} \text{Secondary} \\ \text{voltage (V)} \end{array} \frac{V_2}{\text{primary coil}} = \frac{N_2}{N_1} \begin{array}{l} \text{Turns in} \\ \text{secondary coil} \end{array}$$



Magnetic Force on Moving Charges

$$\vec{F}_{\text{magnetic}} = q\vec{v} \times \vec{B}$$



$$\vec{F}_{\text{magnetic}} = \vec{I}l \times \vec{B}$$



- **Units:**

F = Force in Newtons (N)

q = charge in Coulombs (C)

B = magnetic field in Teslas (T)

I = current in Amperes (A)

l = length in meters (m)

- **Definition of Magnetic Field (B):**

1 Tesla = 1 N / Am = 1 N / (Cm/s)

1 Tesla = 10,000 Gauss

$$\vec{B} = \frac{\vec{F}_{\text{magnetic}}}{\vec{I}l} = \frac{\vec{F}_{\text{magnetic}}}{q\vec{v}}$$



Faraday's Law

$$emf = -N \frac{\Delta[AB(\cos \theta)]}{\Delta t}$$

- **Faraday's Law of Magnetic Induction:**

emf = Electro-Motive Force (Volts)

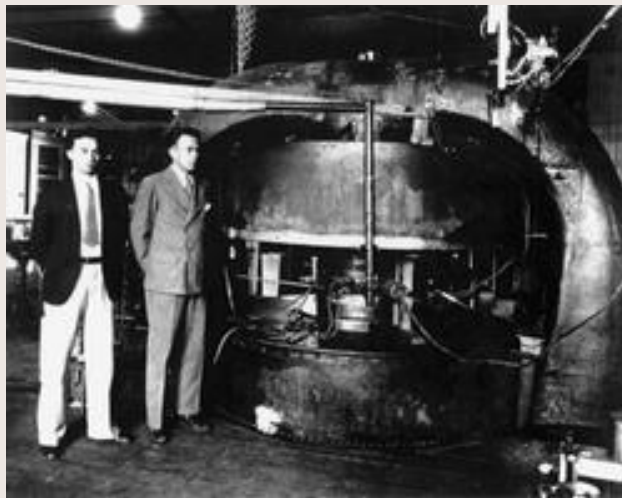
N = # of loops in circuit

A = Area of loop (m²)

B = **B** perpendicular to plane of loop (Teslas)

θ = angle between **B** and normal to plane of loop

t = time (seconds)



Example Problem



- **Helga's Super Vacuum**

$F = ?$ (magnitude & direction!)

$B = 200$ Teslas

$I = 20$ Amps

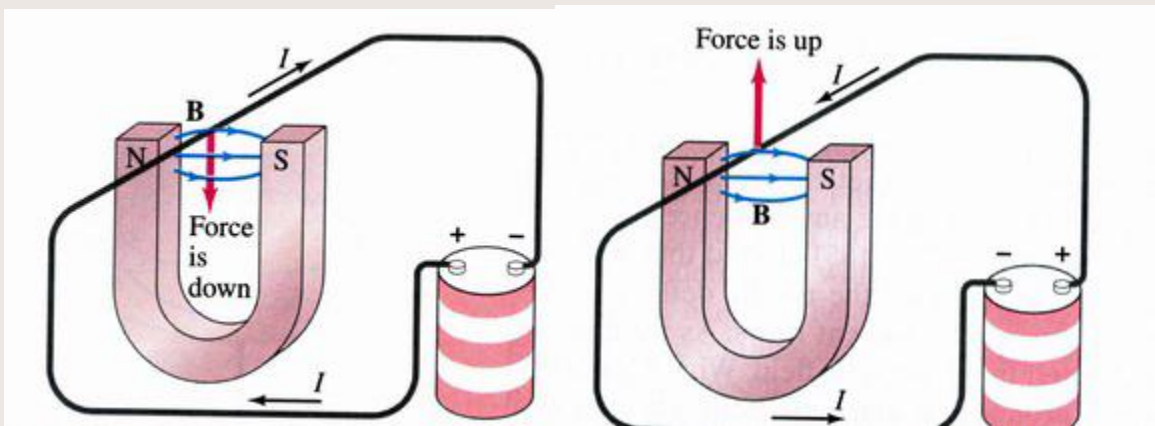
$l = 5.8$ m of copper wire in motorbrush



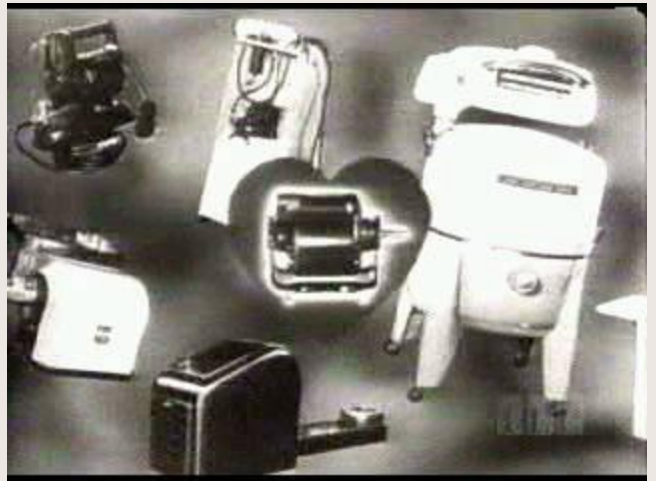
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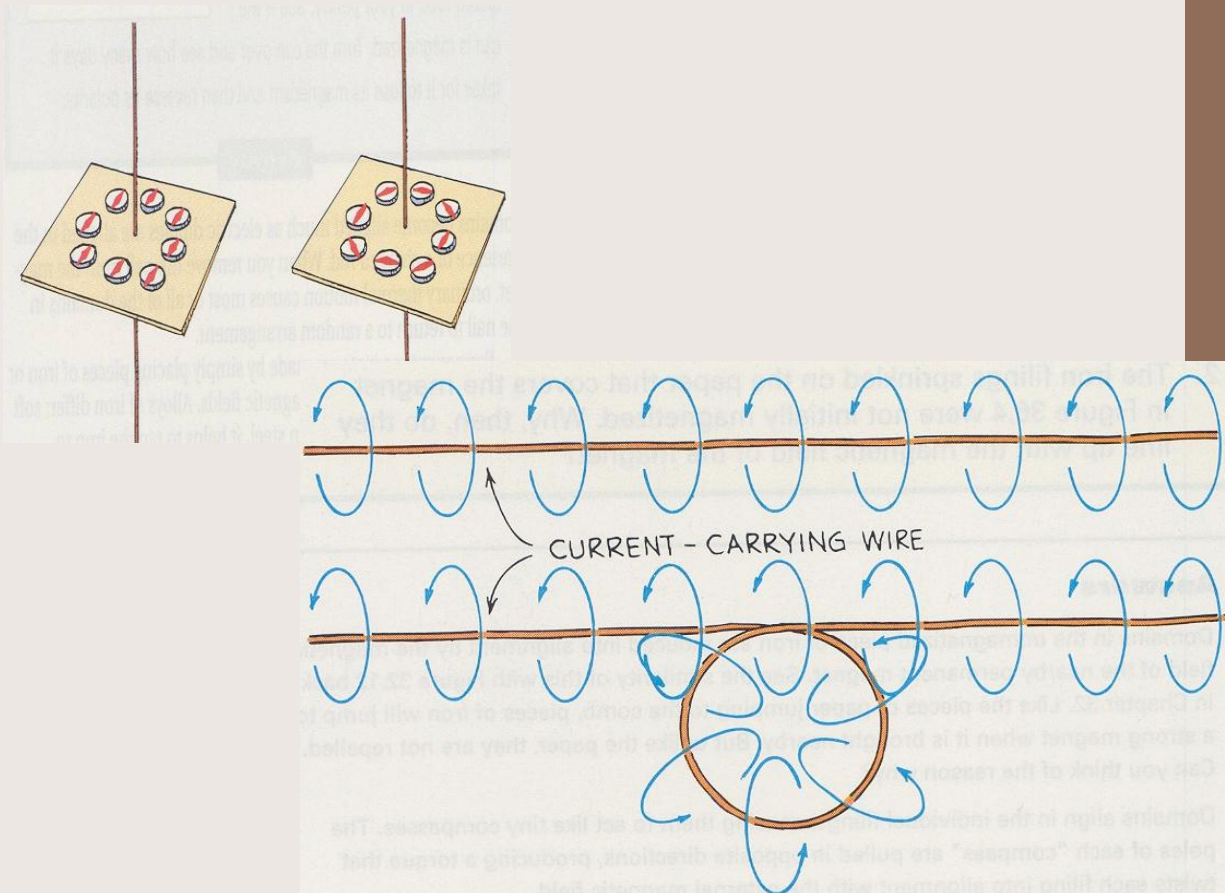


Generators & AC Current



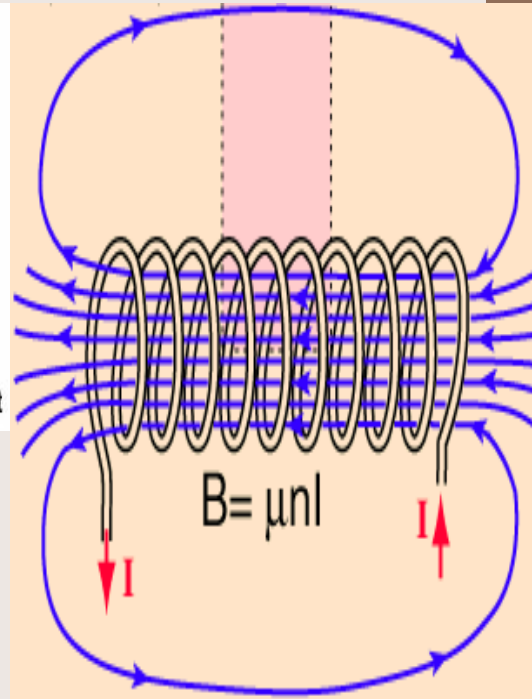
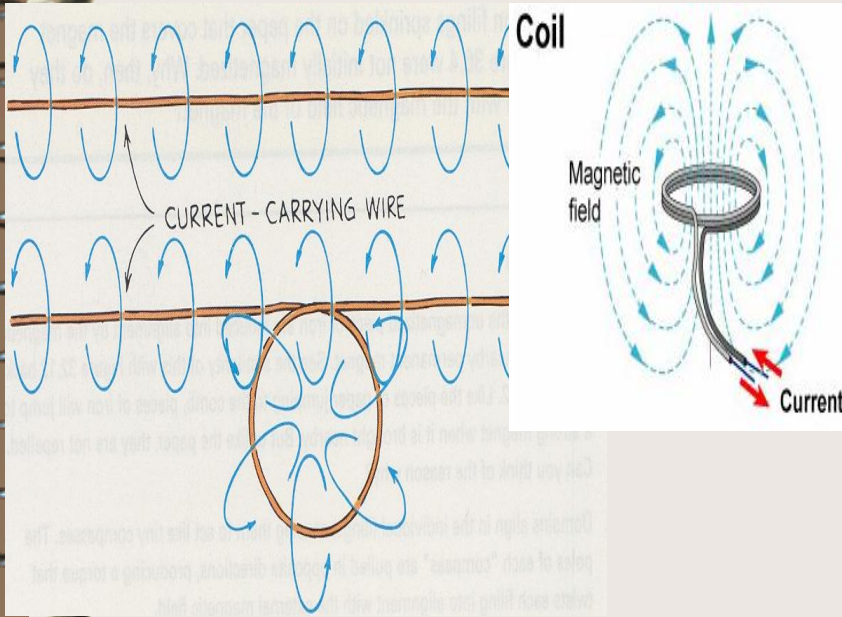
Making a magnetic field

- We can't make individual electrons spin, like ferromagnetic materials, but we can make current
- Current is charge in motion, so it makes a magnetic field



Add a loop, add more B

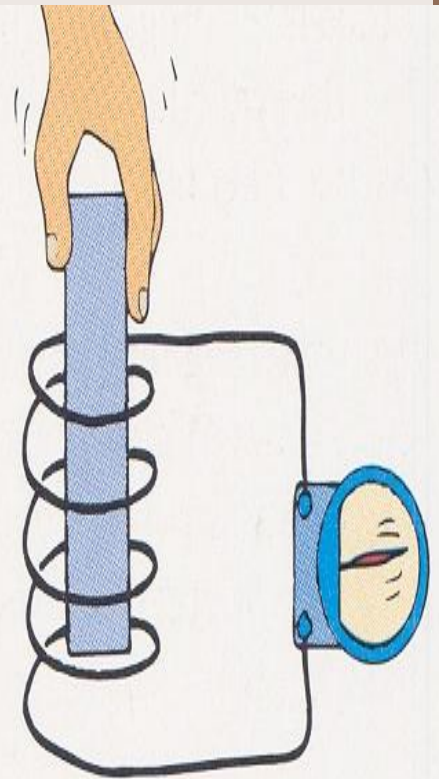
- Looping a current-carrying wire concentrates the magnetic field (B) in the loop's center
- Stacking loops adds more B
- More current is also more B
- Add a ferromagnetic nail in the core (center) and you got an electromagnet!



Induction: because it works

both ways

- Change the magnetic field in the coil and you get electrons to flow, this is an “induced” current
- Strongest magnetic field in the world won’t make any current unless it’s CHANGING
- Anything that “pushes” electrons is voltage, AKA electromotive force, or EMF



Electromagnetic Induction

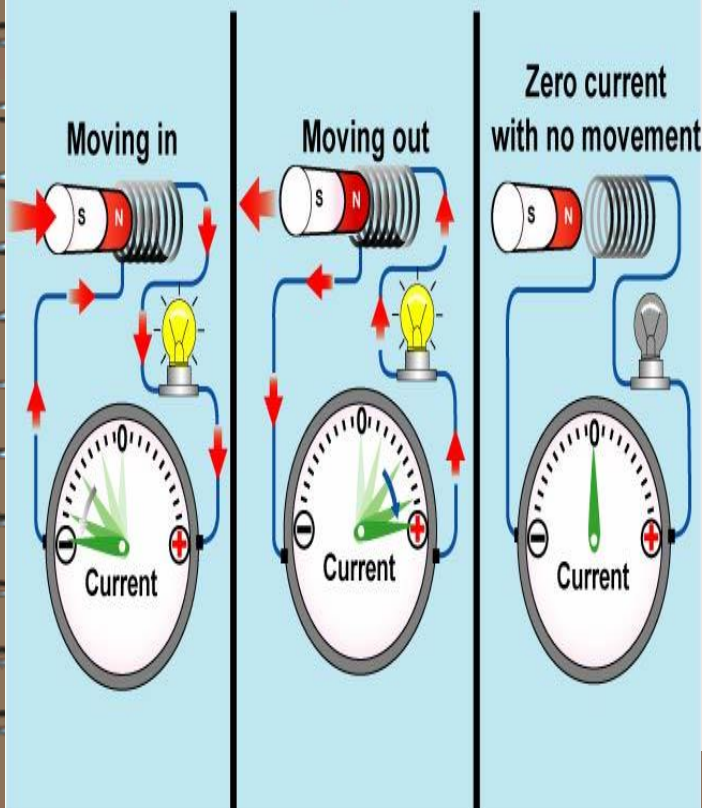


Figure 37.1 ▲

When the magnet is plunged into the coil, voltage is induced in the coil and charges in the coil are set in motion.

How to get more current

- Change the magnetic field in the coil = get electrons to flow
- Change it quickly/by a lot = get electrons to flow fast:
 - Move magnet fast
 - Use strong magnet
 - Add more coils

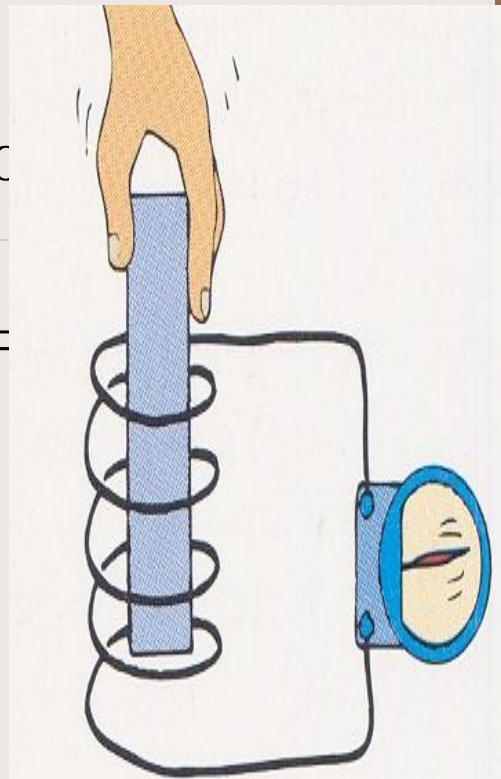
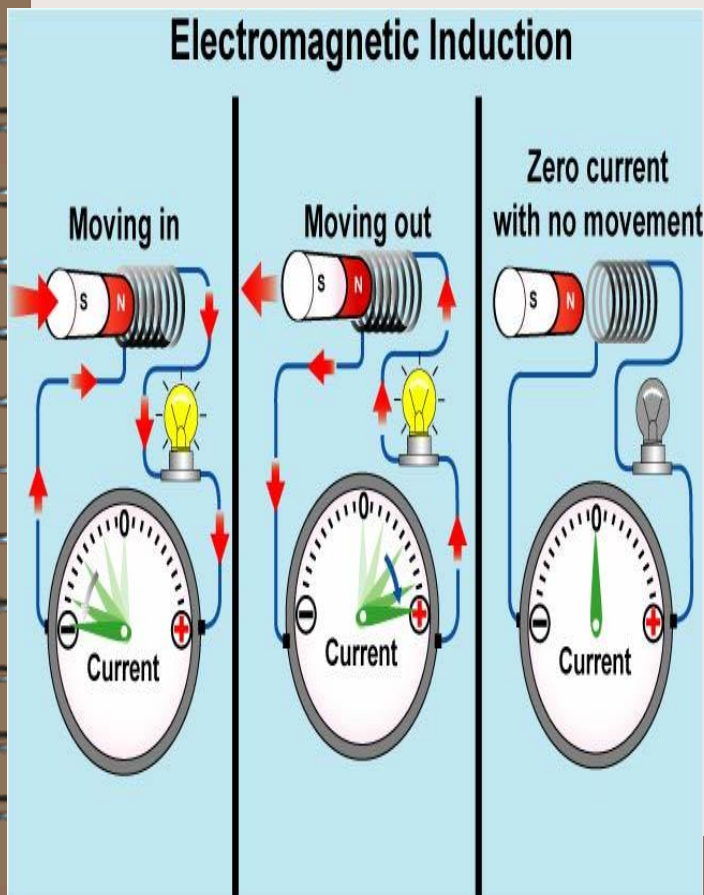


Figure 37.1 ▲

When the magnet is plunged into the coil, voltage is induced in the coil and charges in the coil are set in motion.



Transformers:

More than meets the eye!

- AC is alternating current
- Direction of current reverses 60x each second
- Iron core is a magnet
- Core magnetic polarity reverses 60x
- Changing magnetic field in 2nd coil makes current flow
- Different # of coils means different current (voltage)
- The only equation you need!

Transformer

$$\frac{\text{Primary voltage (V)} \quad V_1}{\text{Secondary voltage (V)} \quad V_2} = \frac{N_1 \text{ Turns in primary coil}}{N_2 \text{ Turns in secondary coil}}$$

