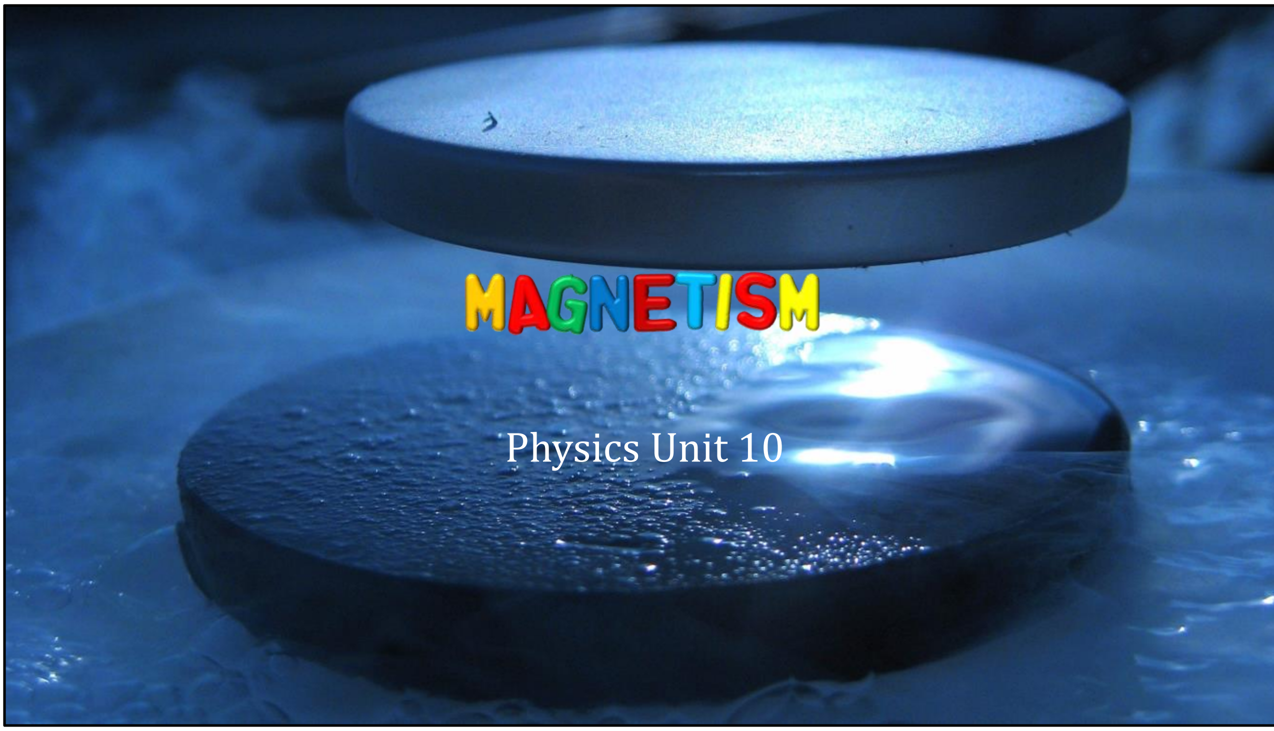
MAGNETISM
Physics Unit 10

- This Slideshow was developed to accompany the textbook
  - *OpenStax Physics*
    - *Available for free at https://openstaxcollege.org/textbooks/college-physics*
  - *By OpenStax College and Rice University*
  - *2013 edition*
- Some examples and diagrams are taken from the textbook.

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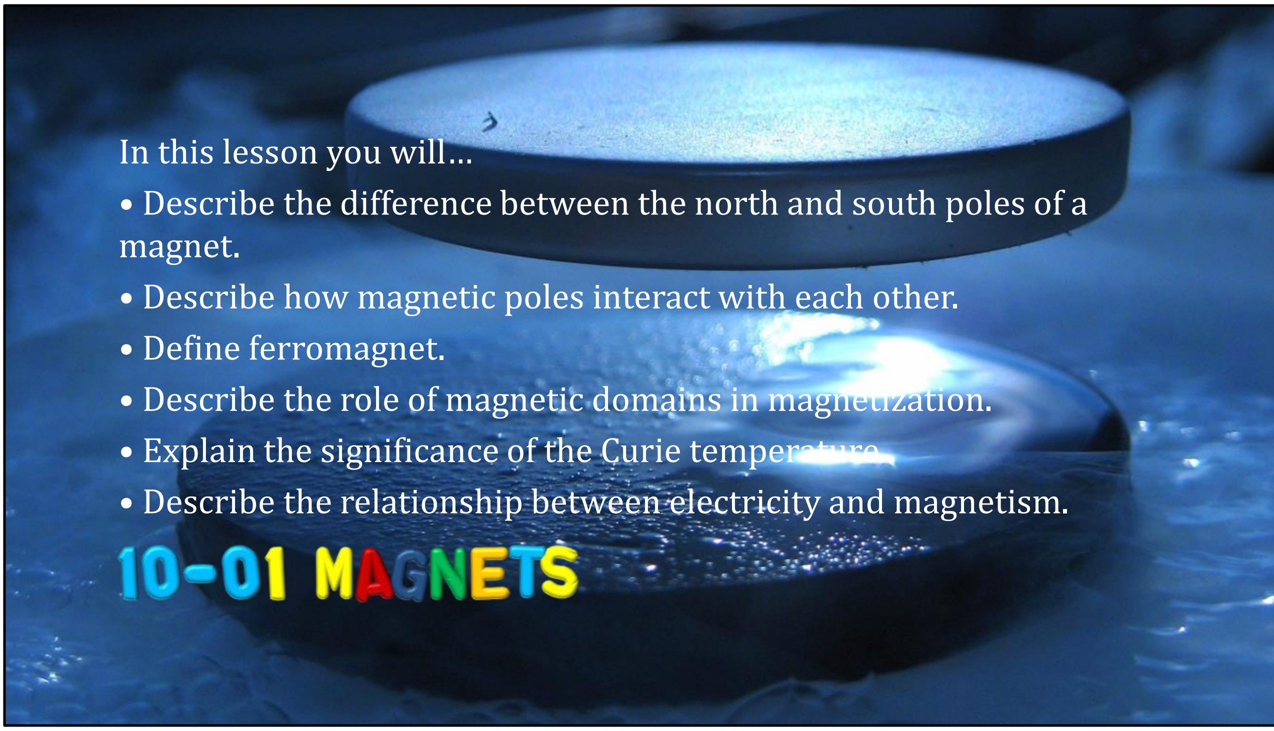
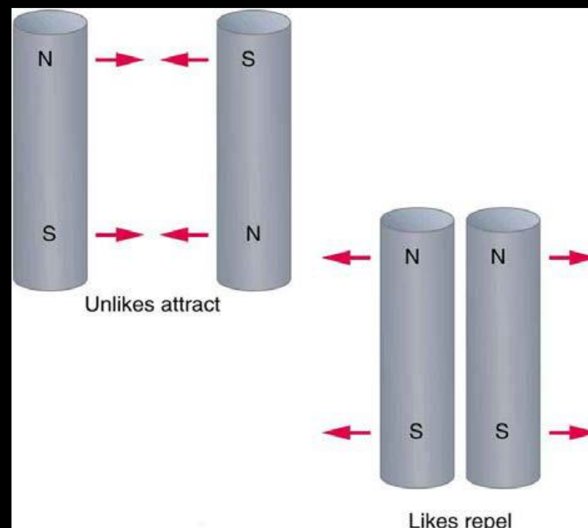

In this lesson you will…
• Describe the difference between the north and south poles of a magnet.
• Describe how magnetic poles interact with each other.
• Define ferromagnet.
• Describe the role of magnetic domains in magnetization.
• Explain the significance of the Curie temperature.
• Describe the relationship between electricity and magnetism.
10-01 MAGNETS

10-01 Magnets

- Magnets have two ends called poles
  - North and South poles
  - There are no single poles
- Like poles repel, Opposite poles attract



10-01 Magnets

- Electromagnetism
  - It was discovered that running current through a wire produced a magnet
  - The magnetism around permanent magnets and currents are very similar, so both must have common cause.
  - Current is the cause of all magnetism

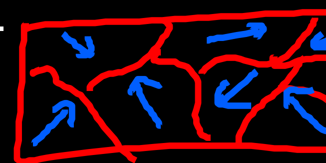
10-01 Magnets

- Ferromagnetism
  - Magnetic materials have an unpaired outer electron.
  - Atoms near each other line up so that the unpaired electrons spin the same direction.
  - This spinning creates magnetism

Metals beyond the first row of periodic table must loose their electrons too easily to be magnetized.

10-01 Magnets

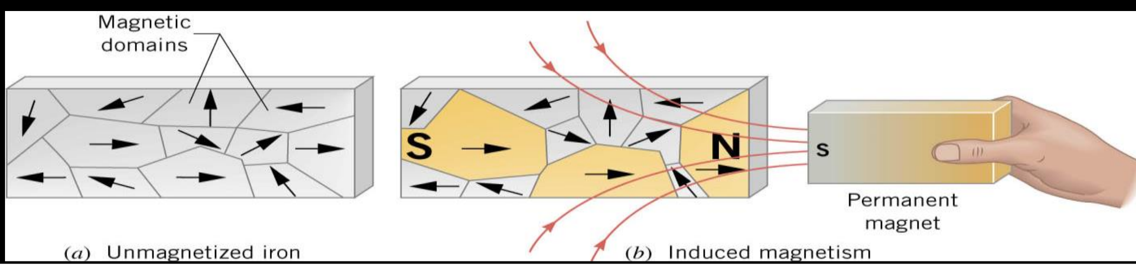
- Ferromagnetism
  - In permanent magnet the current is electrons in atoms.
    - Move around nucleus and spin
    - Most cancels out except in ferromagnetic materials



  - Ferromagnetic materials
    - Electron magnetic effects don't cancel over large groups of atoms.
    - This gives small magnetic regions size of 0.01 to 0.1 mm called **magnetic domains**.
    - In a permanent magnet, these domains are aligned.
  - Common magnetic materials are iron, nickel, cobalt, and chromium dioxide.

10-01 Magnets

- Induced Magnetism
  - Usually the magnetic domains are randomly arranged.
  - When it is placed in a B-field, the domains that are aligned with the B-field grow larger and the orientation of other domains may rotate until they are aligned.
  - This gives the material an overall magnetism.



Dropping or banging a permanent magnet can disalign the magnetic domains and thus have a weaker B-field.
The induced B-field can be 1000’s of time larger than the field that induced it, so electromagnets have iron cores wrapped with wire.

10-01 Homework

- This homework is attractive.
- Read 22.1-22.5
- There are no answers for me to post so here is an interesting picture caused by magnetism.

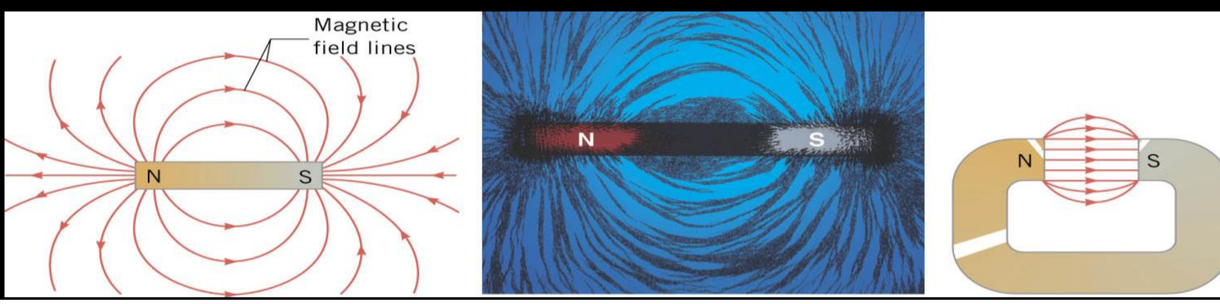
In this lesson you will…

- Define magnetic field and describe the magnetic field lines of various magnetic fields.
- Describe the effects of magnetic fields on moving charges.
- Use the right hand rule 1 to determine the velocity of a charge, the direction of the magnetic field, and the direction ofthe magnetic force on a moving charge.
- Calculate the magnetic force on a moving charge.
- Describe the effects of a magnetic field on a moving charge.
- Calculate the radius of curvature of the path of a charge that is moving in a magnetic field.

10-02 Magnetic Fields and Force on a Moving Charge

10-02 Magnetic Fields and Force on a Moving Charge

- Around a magnet is a magnetic field (**B**-field)
  - At every point in space there is a magnetic force
  - Can be seen with a compass
  - Unit is Tesla (T)
- Magnetic fields can be visualized with field lines.
  - Start at N pole and end at S pole
  - The more lines in one area means stronger field



Picture notes: a) Magnetic field lines; b) magnetic field lines made with iron filings; c) magnetic field lines – constant between poles.

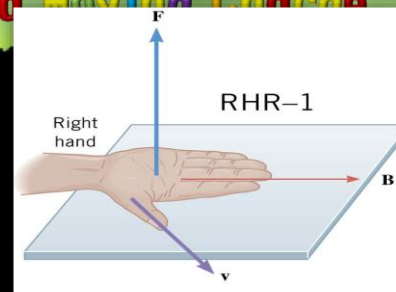
10-02 Magnetic Fields and Force on a Moving Charge

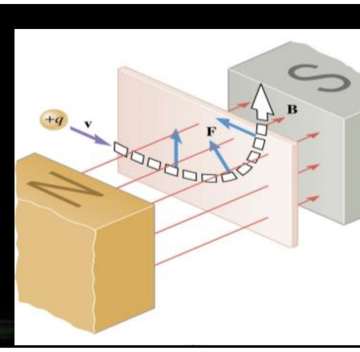
- Since currents (moving charges) make B-fields, then other B-fields apply a force to moving charges.
- For a moving charge to experience a force
  - Charge must be moving
  - The velocity vector of the charge must have a component perpendicular to the B-field
- $\vec{F} = q\vec{v} \times \vec{B}$
- $\vec{F} = qvB\sin\theta$
  - Where
  - F = force
  - q = charge
  - v = speed of charge
  - B = magnetic field
  - θ = angle between v and B

10-02 Magnetic Fields and Force on a Moving Charge

- Direction of force on positive moving charge
  - Right Hand Rule
    - Fingers point in direction of B-field
    - Thumb in direction of v
    - Palm faces direction of F on positive charge

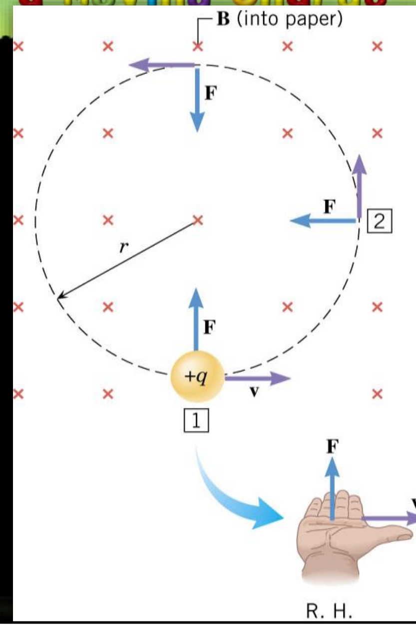
- Force will be zero if v and B are parallel, so a moving charge will be unaffected





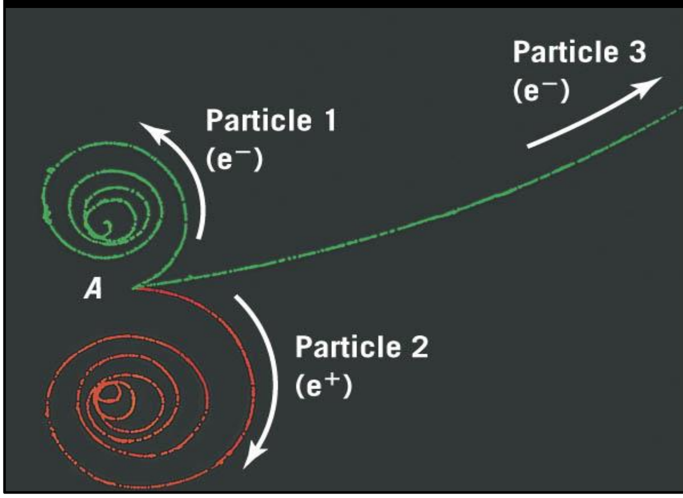
10-02 Magnetic Fields and Force on a Moving Charge

- Motion of moving charged particle in uniform B-field
  - Circular
  - $F = qvB\sin\theta$
  - $F_C = \frac{mv^2}{r}$
  - $qvB\sin\theta = \frac{mv^2}{r}$
  - $r = \frac{mv}{qB}$

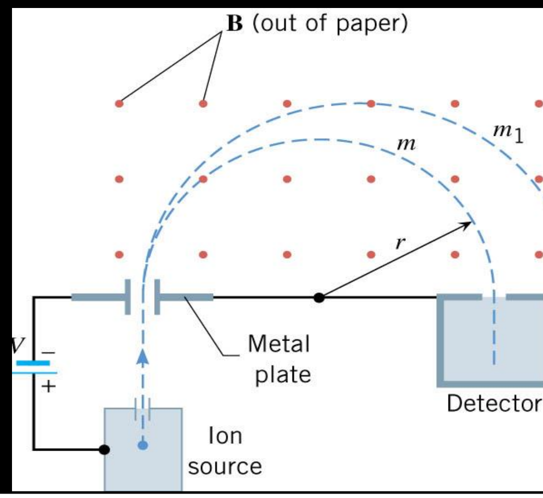


10-02 Magnetic Fields and Force on a Moving Charge

Bubble Chamber



Mass Spectrometer



Bubble chamber can be used to determine relative mass to speed and charge ratios of particles.

Mass spectrometer determines relative quantities of various masses in a substance by taking very small particles of the substance and charging them. The charged particles are sent through a uniform magnetic field. The radius of their path tells you their mass.

10-02 Magnetic Fields and Force on a Moving Charge

- A particle with a charge of -1.6×10^{-19} C and mass 9.11×10^{-31} kg moves along the positive x-axis from left to right. It enters a 3 T B-field is in the x-y plane and points at 45° above the positive x-axis.
  - What is the direction of the force on the particle?
    - Negative z direction
  - After it has been in the B-field, the particle moves in a circle. If the radius of its path is 2×10^{-10} m, what is the speed of the particle?
    - $v = 105.4$ m/s
  - What is the magnitude of the force on the particle?
    - 3.58×10^{-17} N

1) RHR is for positive charges. Since this is negative it will turn the other way.
2) $r = \frac{mv}{qB} \rightarrow 2 \times 10^{-10}\ m = \frac{(9.11\times10^{-31}\ kg)v}{(1.6\times10^{-19}\ C)(3\ T)} \rightarrow 9.6 \times 10^{-29}\ CTm = 9.11 \times 10^{-31}\ kg(v) \rightarrow v = 105.4\ m/s$
3) $F = qvB\sin\theta = (1.6 \times 10^{-19}\ C)\left(105.4\frac{m}{s}\right)(3\ T)(\sin 45°) = 3.58 \times 10^{-17}\ N$

10-02 Homework

- Force yourself to finish this work
- Read 22.7, 22.8

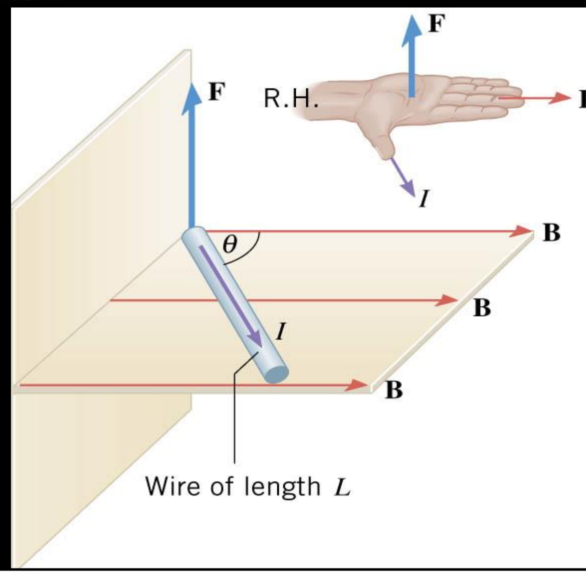
In this lesson you will…

- Describe the effects of a magnetic force on a current-carrying conductor.
- Calculate the magnetic force on a current-carrying conductor.
- Describe how motors and meters work in terms of torque on a current loop.
- Calculate the torque on a current-carrying loop in a magnetic field.

10-03 MAGNETIC FORCE ON CURRENT-CARRYING WIRE

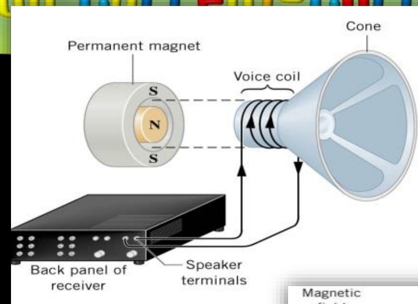
10-03 Magnetic Force on Current-Carrying Wire

- Force on a current-carrying wire in B-field
  - Direction Follows RHR
  - $F = qvB\sin\theta$
  - $F = \frac{q}{t} vtB\sin\theta$
  - $I = \frac{q}{t}$ $L = vt$
  - $F = ILB\sin\theta$



10-03 Magnetic Force on Current-Carrying Wire

- Speakers
  - Coil of wire attached to cone
  - That is enclose by a magnet
  - A varying current is run through the wire
  - The current in the B-field makes the speaker cone move back and forth



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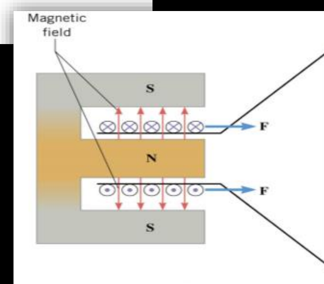
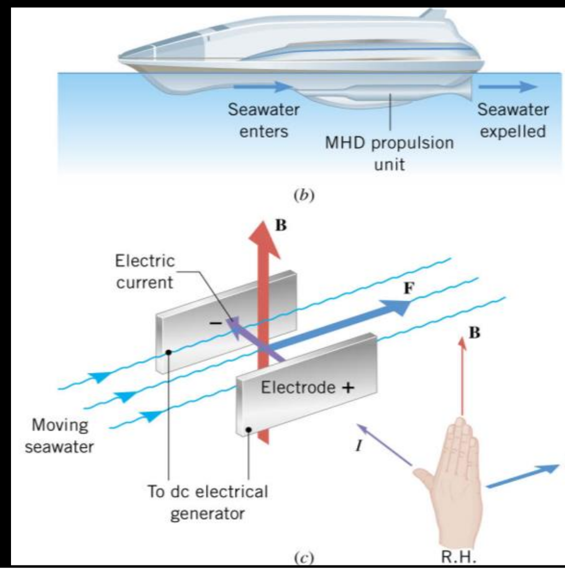


(b)

10-03 Magnetic Force on Current-Carrying Wire

- Magnetohydrodynamic Propulsion
  - Way to propel boats with no moving parts
  - Seawater enters tube under ship
  - In the tube are electrodes that run current through the water
  - Also in the tube is a strong magnetic field created by superconductors
  - The interaction with the electric current and B-field push the water out the back of the tube which pushes boat forward
    - $F = ILB \sin\theta$



This was the big secret in the movie “Hunt for Red October”

Can also be used to move dangerous chemicals without moving parts (like liquid sodium in large solar collectors)

10-03 Magnetic Force on Current-Carrying Wire

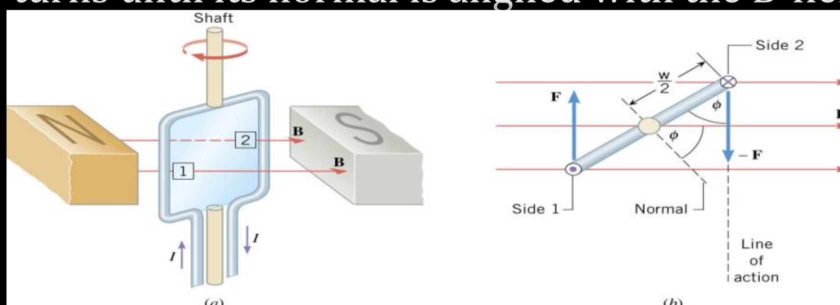
- A 2 m wire is in a 2×10^{-6} T magnetic field pointing into the page. It carries 2 A of current flowing up. What is the force on the wire?
- F = 8×10^{-6} T Left

RHR: F points to the left.

$$F = ILB\sin\theta = (2\,A)(2\,m)(2\times10^{-6}\,T)(\sin 90°) = 8\times10^{-6}\,N$$

10-03 Magnetic Force on Current-Carrying Wire

- What happens when you put a loop of wire in a magnetic field?
- Side 1 is forced up and side 2 is forced down (RHR)
- This produces a torque
- The loop turns until its normal is aligned with the B-field



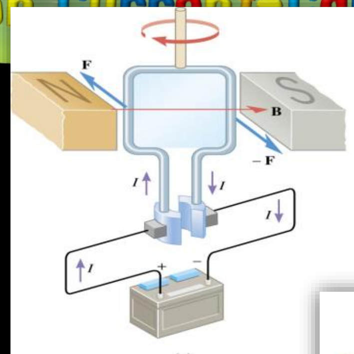
The normal is perpendicular to the plane of the loop

10-03 Magnetic Force on Current-Carrying Wire

- Torque on Loop of Wire
  - $\tau = NIAB \sin\phi$
- where
  - N = Number of loops
  - I = Current
  - A = Area of loop
  - B = Magnetic Field
  - ϕ = Angle between normal and B-field
- NIA = Magnetic Moment
  - Magnetic moment ↑, torque ↑

10-03 Magnetic Force on Current-Carrying Wire

- Electric Motor
  - Many loops of current-carrying wire placed between two magnets (B-field)
  - The loops are attached to half-rings
  - The torque turns the loops until the normal is aligned to B-field
  - At that point the half-rings don't connect to electric current
  - Momentum makes the loop turn more
  - The half-rings connect with the current to repeat the process



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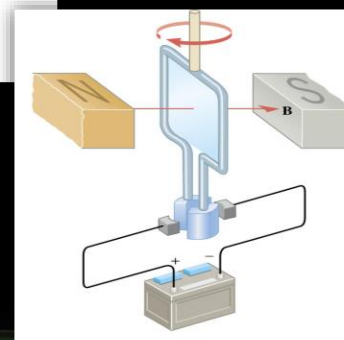


(b)

10-03 Magnetic Force on Current-Carrying Wire

- A simple electric motor needs to supply a maximum torque of 10 Nm. It uses 0.1 A of current. The magnetic field in the motor is 0.02 T. If the coil is a circle with radius of 2 cm, how many turns should be in the coil?

- N = 3.98 × 10^6 turns

$\tau = NIAB\sin\phi \rightarrow 10\ Nm = N(0.1\ A)(\pi(0.02\ m)^2)(0.02\ T)\sin 90° \rightarrow 10\ Nm = (2.513 \times 10^{-6}\ Nm)N \rightarrow N = 3.98 \times 10^6$

10-03 Homework

- Don’t get stuck on these magnet problems
- Read 22.9, 22.10, 22.11

In this lesson you will…

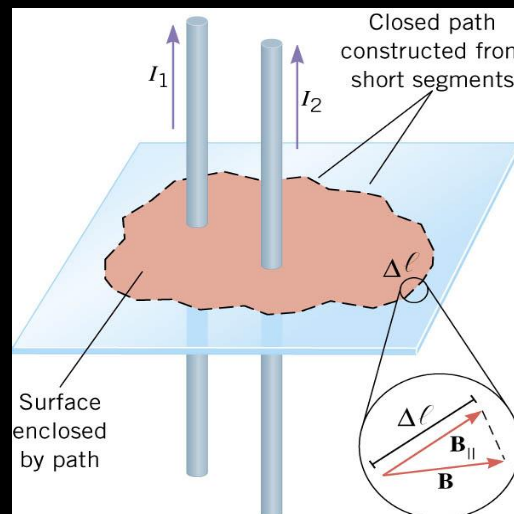
- Calculate current that produces a magnetic field.
- Use the right hand rule 2 to determine the direction of current or the direction of magnetic field loops.
- Describe the effects of the magnetic force between two conductors.
- Calculate the force between two parallel conductors.
- Describe some applications of magnetism.

10-04 MAGNETIC FIELDS PRODUCED BY CURRENTS

10-04 Magnetic Fields Produced by Currents

Ampere's Law

- $\sum \vec{B} \cdot \Delta\vec{\ell} = \mu_0 I$
- $\sum B_{\parallel} \Delta\ell = \mu_0 I$
- Where
  - B = the magnetic field ($B_{||}$ is the B-field parallel to ℓ)
  - $\Delta\ell$ = a portion of the path surround the current
  - μ_0 = permeability of free space = $4\pi \times 10^{-7}$ Tm/A
  - I = current enclosed by path

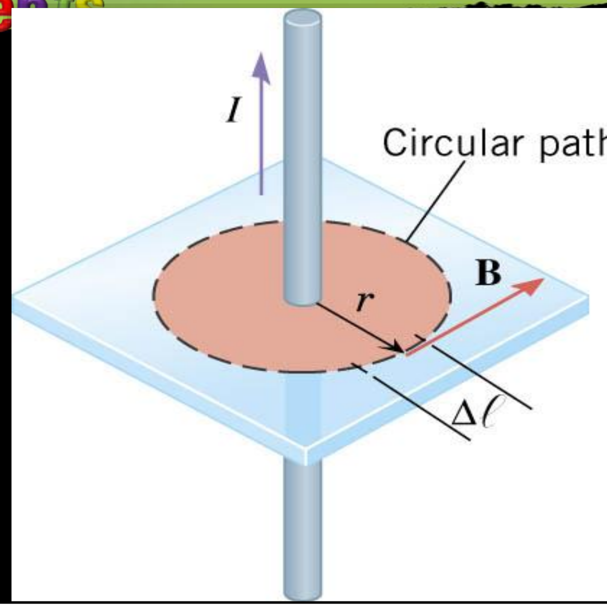


Note that Ampere's Law is valid for any wire configuration
If B is always parallel to the path, then the sum becomes Bℓ

10-04 Magnetic Fields Produced by Currents

- To make it simpler, let's use a circle for our path around one wire.
- $\sum \vec{B} \cdot \Delta\vec{\ell} = \mu_0 I$
- $B(2\pi r) = \mu_0 I$

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

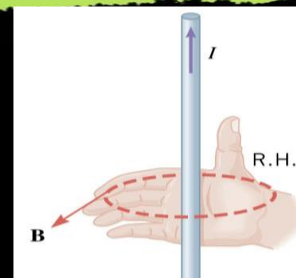


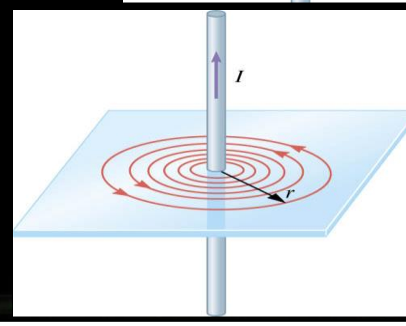
This agrees with the result from section 7.

10-04 Magnetic Fields Produced by Currents

- Electrical current through a wire
  - Straight wire
    - Right Hand Rule
      - Grab the wire with right hand
      - Thumb points in direction of current
      - Fingers curl in direction of magnetic field

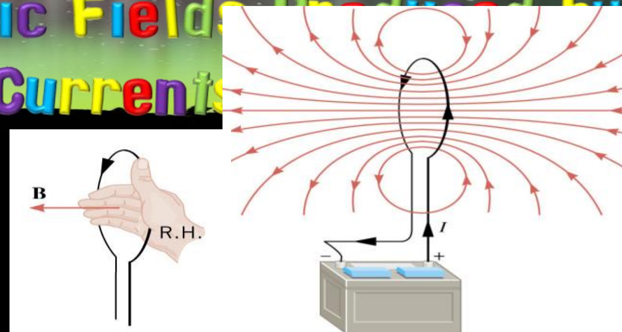
$$B = \frac{\mu_0 I}{2\pi r}$$

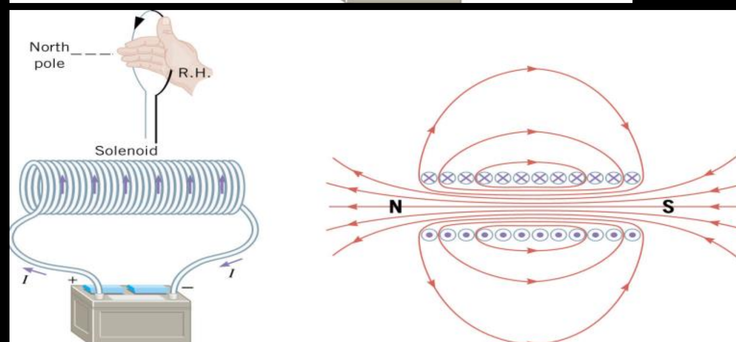




10-04 Magnetic Fields Produced by Currents

- Loop
  - Right Hand Rule
  - At center of loop
  - $B = N\frac{\mu_0 I}{2R}$
    - N=number of loops
- Solenoid
  - $B = \mu_0 n I$
    - n=loops/m





10-04 Magnetic Fields Produced by Currents

1. A long straight current-carrying wire runs from north to south.
   a. A compass needle is placed above the wire points with its N-pole toward the east. In what direction is the current flowing?
   b. If a compass is put underneath the wire, in which direction will the needle point?
2. A single straight wire produces a B-field. Another wire is parallel and carries an identical current. If the two currents are in the same direction, how would the magnetic field be affected? What if the currents are in the opposite direction?

1a. North (rhr)
1b. West (rhr)
2. The B-fields between wires cancel; outside of wires add. The B-fields between the wires add; outside of wires cancel.

10-04 Magnetic Fields Produced by Currents

- Suppose a piece of coaxial cable is made with a solid wire at the center. A metal cylinder has a common center with the wire and its radius is 1 mm. A 2 A current flows up the center wire and a 1.5 A current flows down the cylinder.
- Find the B-field at 4 mm from the center.
  - 2.5×10^{-5} T
- Find the B-field at 0.5 mm from the center.
  - 8×10^{-4} T
- What current should be in the cylinder to have no B-field outside of the cylinder?
  - -2 A

1) $B(2\pi r) = \mu_0 I \rightarrow\ B(2\pi 0.004\ m) = 4\pi \times 10^{-7}\frac{Tm}{A}(2\ A + -1.5\ A)$ → $B = 2 \times 10^{-7}\frac{Tm}{A}\frac{0.5\ A}{0.004\ m} = 2.5 \times 10^{-5}\ T$
2) $B(2\pi r) = \mu_0 I \rightarrow\ B(2\pi 0.0005\ m) = 4\pi \times 10^{-7}\frac{Tm}{A}\ (2\ A)$ → $B = 2 \times 10^{-7}\frac{Tm}{A}\frac{2\ A}{0.0005\ m} = 8 \times 10^{-4}\ T$
3) $-2A\ because\ 2A\ +\ -2A\ =\ 0A$

10-04 Magnetic Fields Produced by Currents

- Two wires are 0.2 m apart and 2 m long and both carry 2 A of current. What is the force on the wires?
  - F = 8×10^{-6} N towards each other
- Force of one wire on another parallel wire
  - $\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r}$
  - Attractive if same I's in same direction, repulsive if opposite

The wires point up.

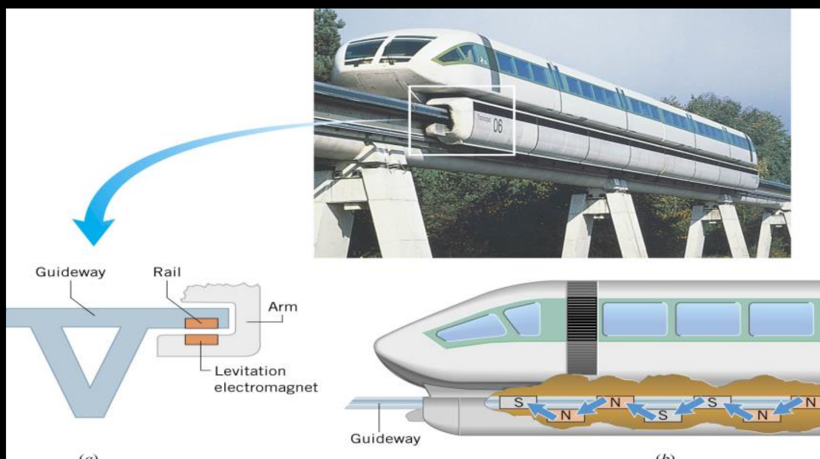
Find B-field due to the left wire first: B-field points into the page. $B = \frac{\mu_0 I}{2\pi r}$ → $B = \left(4\pi \times 10^{-7} \frac{Tm}{A}\right) \frac{2\ A}{2\pi 0.2\ m} = 2 \times 10^{-6}\ T$

Find the force experienced by the right wire due to this B-field: F points to the left.

$F = ILB \sin\theta = (2\ A)(2\ m)(2 \times 10^{-6}\ T)(\sin 90°) = 8 \times 10^{-6}\ N$

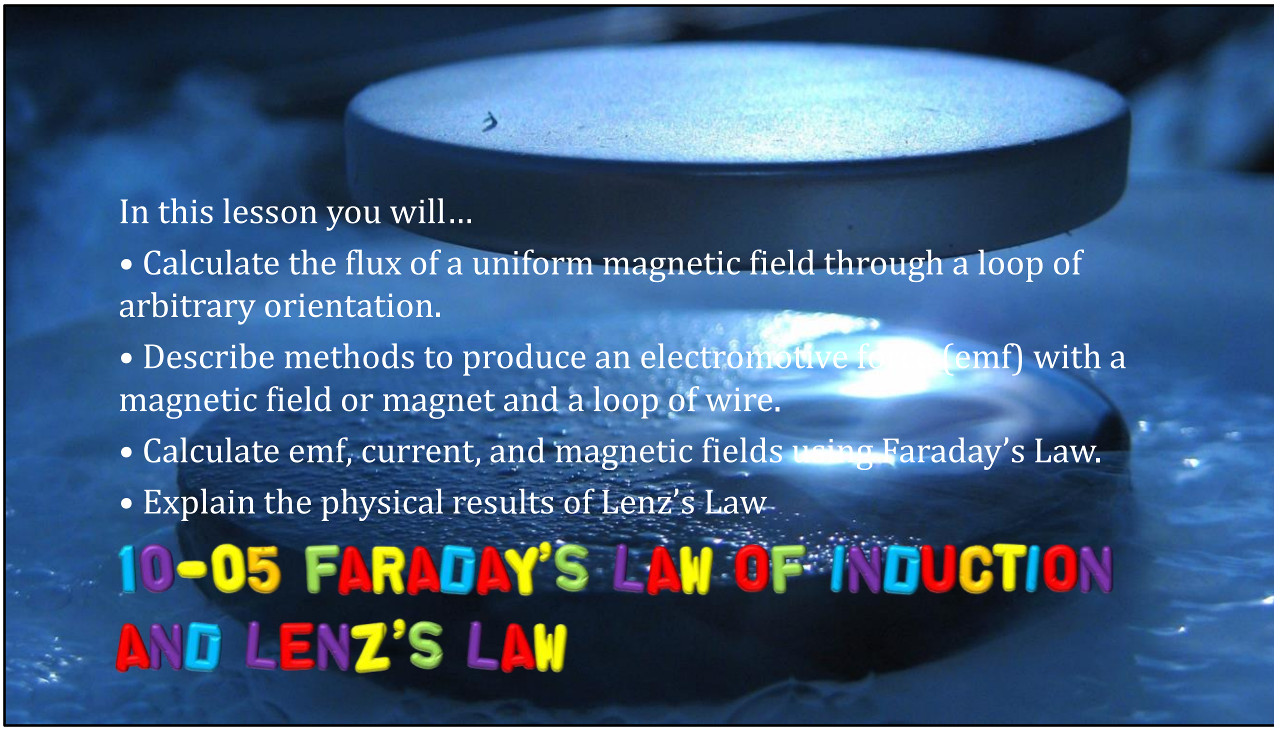
10-04 Magnetic Fields Produced by Currents

- Application – Maglev Trains



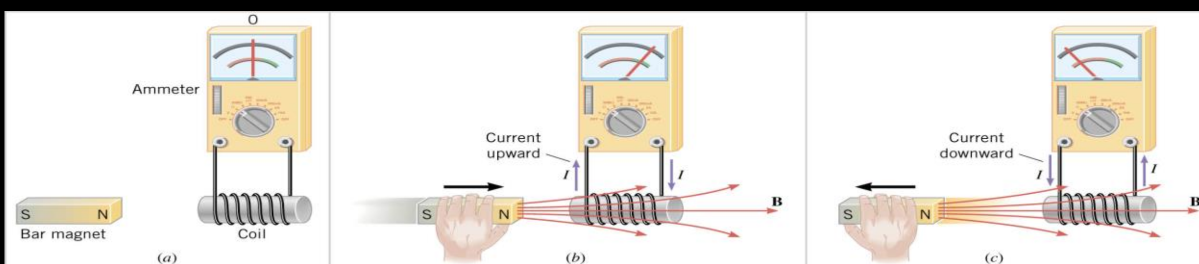
10-04 Homework

- You can field these questions easily.
- Read 23.1, 23.2


In this lesson you will…
• Calculate the flux of a uniform magnetic field through a loop of arbitrary orientation.
• Describe methods to produce an electromotive fo (emf) with a magnetic field or magnet and a loop of wire.
• Calculate emf, current, and magnetic fields using Faraday's Law.
• Explain the physical results of Lenz's Law
10-05 FARADAY'S LAW OF INDUCTION AND LENZ'S LAW

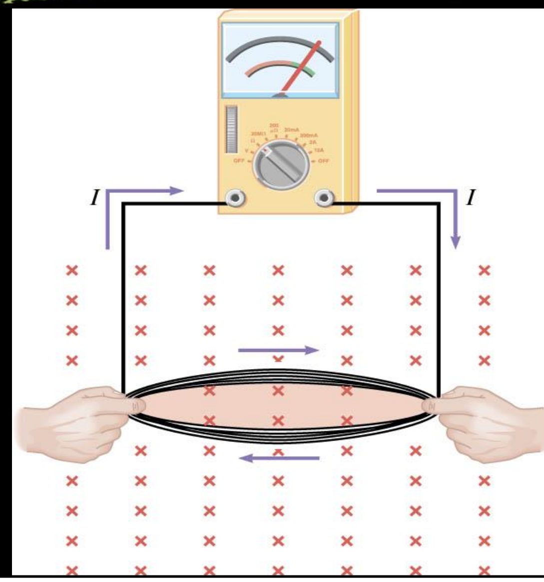
10-05 Faraday's Law of Induction and Lenz's Law

- Magnetic field can produce current.
- The magnetic field must be moving to create current.
- The current created is called **induced current**.
- The emf that causes the current is called **induced emf**.



10-05 Faraday's Law of Induction and Lenz's Law

- Another way to induce emf is by changing the area of a coil of wire in a magnetic field.

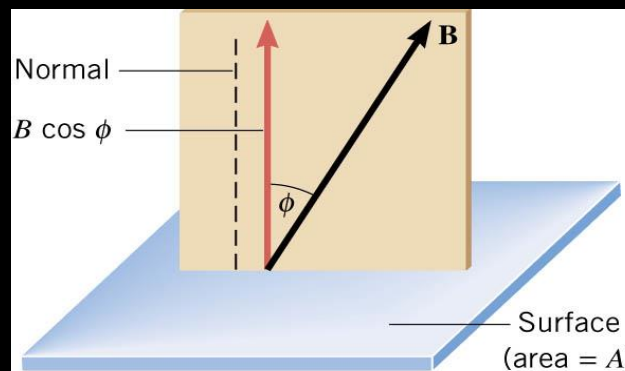


10-05 Faraday's Law of Induction and Lenz's Law

- Magnetic Flux through a surface
- $\Phi = \vec{B} \cdot \vec{A}$

$$\Phi = BA\cos\phi$$

- The angle is between the B-field and the normal to the surface.
- The magnetic flux is proportional to the number of field lines that pass through a surface.
- Any change in magnetic flux causes a current to flow



Dot product found by $BA\cos\theta$

10-05 Faraday's Law of Induction and Lenz's Law

- A rectangular coil of wire has a length of 2 cm and a width of 3 cm. It is in a 0.003 T magnetic field. What is the magnetic flux through the coil if the face of the coil is parallel to the B-field lines? What is the flux if the angle between the face of the coil and the magnetic field is 60°?
  - 0 Wb
  - 1.56×10^{-6} Wb

$\Phi = BA\cos\phi$

a) $\Phi = (0.003\ T)(0.02\ m \cdot 0.03\ m)(\cos 90°) = 0$ (no B-field lines pass through the coil)

b) $\Phi = (0.003\ T)(0.02\ m \cdot 0.03\ m)(\cos 30°) = 1.56 \times 10^{-6}\ Tm^2\ or\ (Tm^2 = Wb\ (weber))$

10-05 Faraday's Law of Induction and Lenz's Law

- emf is produced when there is a change in magnetic flux through a loop of wire.
- No change in flux; no emf.
- Experiments (and mathematics) show that $emf = -\frac{\Delta\Phi}{\Delta t}$ for a loop of wire
- If there are more than one loop, multiply by the number of loops.

10-05 Faraday's Law of Induction and Lenz's Law

- Faraday's Law of Electromagnetic Induction

$$emf = -N\left(\frac{\Phi - \Phi_0}{t - t_0}\right) = -N\frac{\Delta\Phi}{\Delta t}$$

- where
  - N = number of loops
  - Φ = magnetic flux
  - t = time
- Remember

$$\Phi = BA\cos\phi$$

- So changing B, A, or ϕ will produce a emf

Unit of emf is volt (V)

10-05 Faraday's Law of Induction and Lenz's Law

- A coil of wire (N = 40) carries a current of 2 A and has a radius of 6 cm. The current is decreased at 0.1 A/s. Inside this coil is another coil of wire (N = 10 and r = 3 cm) aligned so that the faces are parallel. What is the average emf induced in the smaller coil during 5 s?

  - 1.18×10^{-6} V

Find expression for B-field first

$$B = \frac{N\mu_0 I}{2R} \rightarrow at\ t = 0 \rightarrow B = \frac{40 \cdot 4\pi \times 10^{-7} \frac{Tm}{A} \cdot 2\ A}{2 \cdot 0.06\ m} = 8.3776 \times 10^{-4}\ T$$

$$at\ t = 5\ s \rightarrow B = \frac{40 \cdot 4\pi \times 10^{-7} \frac{Tm}{A} \cdot (2 - 0.5)\ A}{2 \cdot 0.06\ m} = 6.2832 \times 10^{-4}\ T$$

Find Φ_0 and Φ

$$\Phi_0 = (8.3776 \times 10^{-4}\ T)(\pi \cdot (0.03\ m)^2) \cos 0 = 2.369 \times 10^{-6}\ Wb$$

$$\Phi = (6.2832 \times 10^{-4}\ T)(\pi \cdot (0.03\ m)^2) \cos 0 = 1.777 \times 10^{-6}\ Wb$$

Find emf

$$emf = -N\left(\frac{\Delta\Phi}{\Delta t}\right) = -10\left(\frac{1.777 \times 10^{-6}\ Wb - 2.369 \times 10^{-6}\ Wb}{5\ s}\right)$$

$$= 1.18 \times 10^{-6}\ V$$

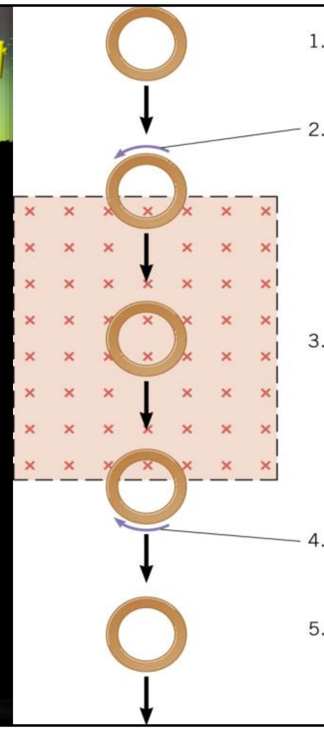
10-05 Faraday's Law of Induction and Lenz's Law

- Lenz's Law
  - The induced emf resulting from a changing magnetic flux has a polarity that leads to an induced current whose direction is such that the induced magnetic field opposes the original flux change.
- Reasoning Strategy
  - Determine whether the magnetic flux is increasing or decreasing.
  - Find what direction the induced magnetic field must be to oppose the change in flux by adding or subtracting from the original field.
  - Having found the direction of the magnetic field, use the right-hand rule to find the direction of the induced current.

Demonstration: copper tube with falling magnet – the B-field, and thus flux, changes as the magnet gets closer to a section of tube. As the magnet gets closer the flux increases. The induced current then produces a current that makes a B-field opposite the B-field of the magnet. The opposing fields supply an upwards force on the magnet and it falls slowly.

10-05 Faraday’s Law of Induct ’s Law

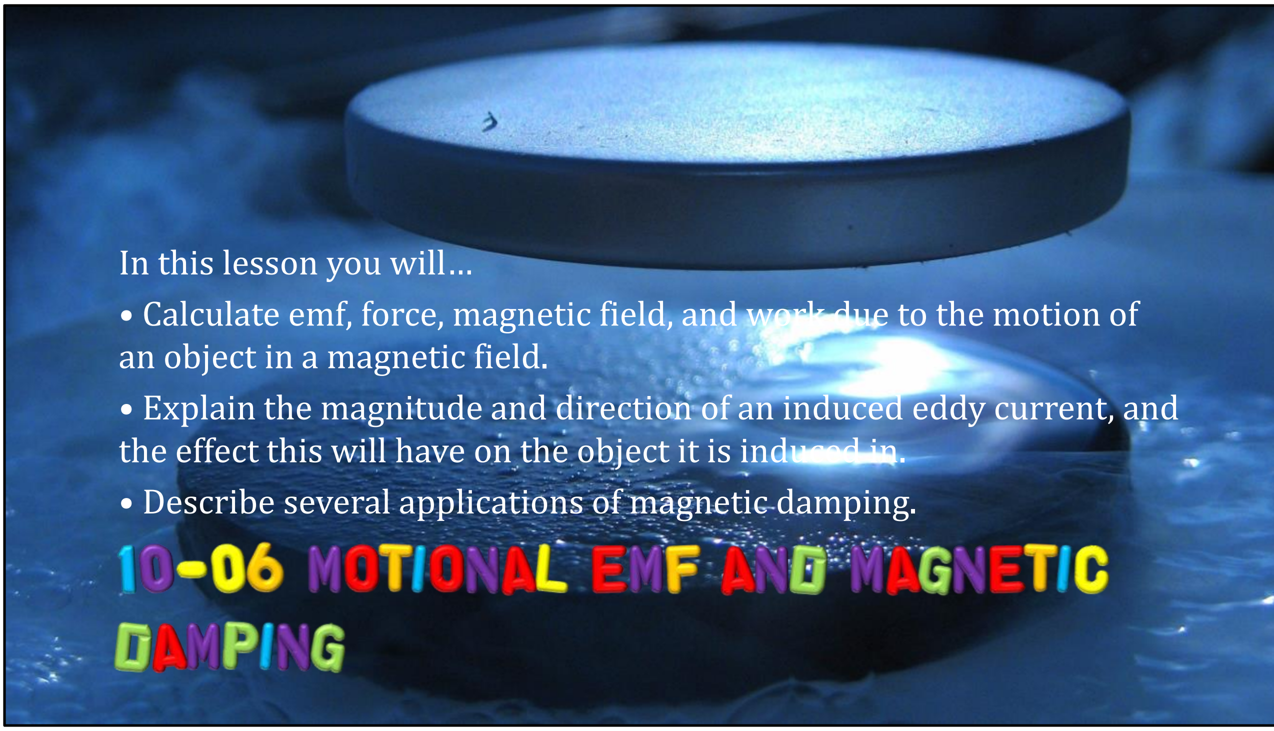
A copper ring falls through a rectangular region of a magnetic field as illustrated. What is the direction of the induced current at each of the five positions?



1) 0 A, No B-field so no current
2) Counterclockwise, flux is increasing since the area of the B-field in the loop is increasing. Induced B-field must oppose (out of paper), RHR says current is counterclockwise.
3) No current because no change in B-field, area, or angle
4) Clockwise; Flux is decreasing because the area of the B-field in loop is decreasing. Induced B-field must add to the field already there. RHR says current is clockwise.
5) No current because no B-field.

10-05 Homework

- Follow the Laws
- Read 23.3, 23.4


In this lesson you will…
• Calculate emf, force, magnetic field, and work due to the motion of an object in a magnetic field.
• Explain the magnitude and direction of an induced eddy current, and the effect this will have on the object it is induced in.
• Describe several applications of magnetic damping.
10-06 MOTIONAL EMF AND MAGNETIC DAMPING

10-06 Motional emf and Magnetic Damping

- Another way to produce a induced emf is by moving a conducting rod through a constant magnetic field.
- Each charge in rod is moving through the magnetic field with velocity, v.
- So, each charge experiences a magnetic force.

$$F = qvB \sin\theta$$

- Since the electrons can move they are forced to one end of the rod leaving positive charges at the other end.
- If there was a wire connecting the ends of the rod, the electrons would flow through the wire to get back to the positive charges.

This is called motional emf because it is from motion

10-06 Motional emf and Magnetic Damping

- This is called motional emf ($\mathcal{E}$)
- If the rod did not have the wire, the electrons would move until the attractive electrical force is balanced with the magnetic force.

$$Eq = qvB\sin\theta$$

$$Eq = qvB$$

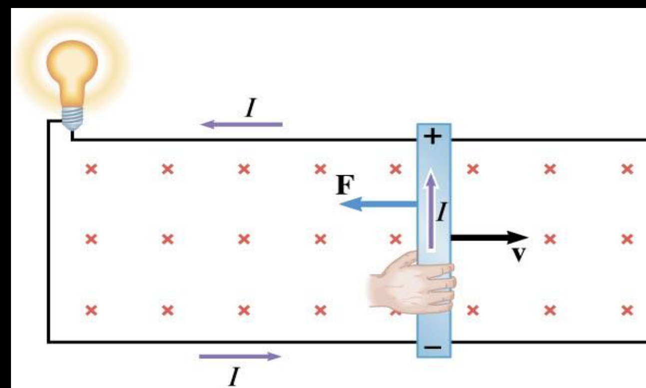
$$\frac{emf}{L}q = qvB$$

$$emf = vBL$$

v, B, and L must be all perpendicular to each other

10-06 Motional emf and Magnetic Damping

- It takes a force to move the rod.
- Once the electrons are moving in the rod, there is another force. The moving electrons in a B-field create a magnetic force on the rod itself.
- According to the RHR, the force is opposite the motion of the rod. If there were no force pushing the rod, it would stop.

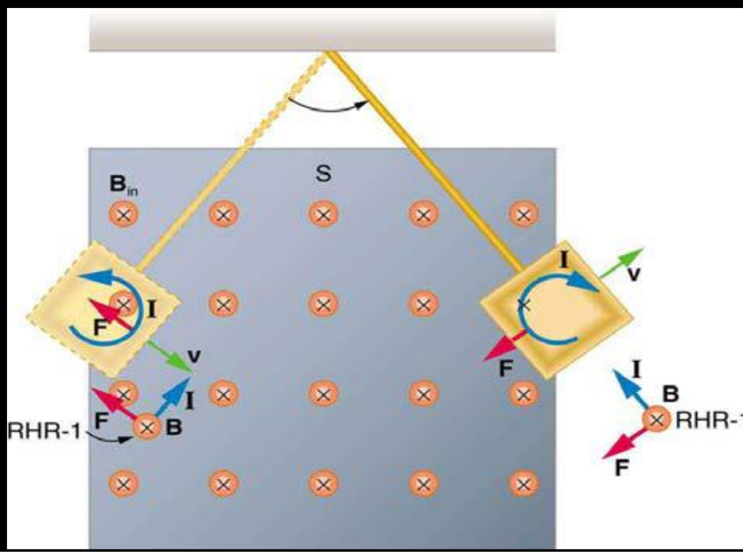


If the force went with the motion of the rod, then it would accelerate without bound.

10-06 Motional emf and Magnetic Damping

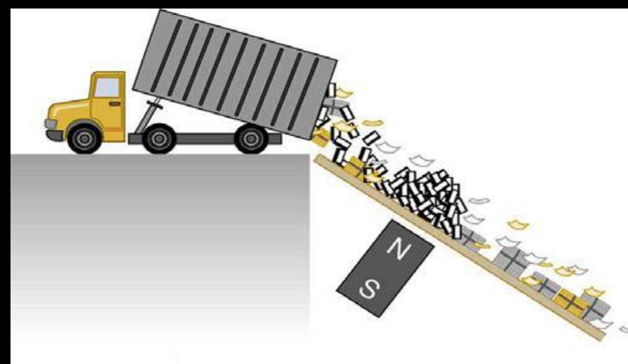
- Damping
  - When a conductor moves into (or out of) a magnetic field, an eddy current is created in the conductor
  - As the conductor moves into B-field, the flux increases
  - This produces a current by Faraday's Law and is directed in way that opposes change in flux.
  - This current's B-field causes a force on the conductor
  - The direction of the force will be opposite the motion of the conductor

10-06 Motional emf and Magnetic Damping



10-06 Motional emf and Magnetic Damping

- Applications of Magnetic Damping
  - Stopping a balance from moving
  - Brakes on trains/rollercoasters
    - No actual sliding parts, not effected by rain, smoother
    - Since based on speed, need conventional brakes to finish
  - Sorting recyclables
    - Metallic objects move slower down ramp



10-06 Motional emf and Magnetic Damping

- Metal Detectors
  - Primary coil has AC current
  - This induces current in metal
  - The induced current creates a B-field
  - This induced B-field creates current in secondary coil which sends signal to user

10-06 Homework

- Don’t let the homework dampen your spirits
- Read 23.5, 23.6

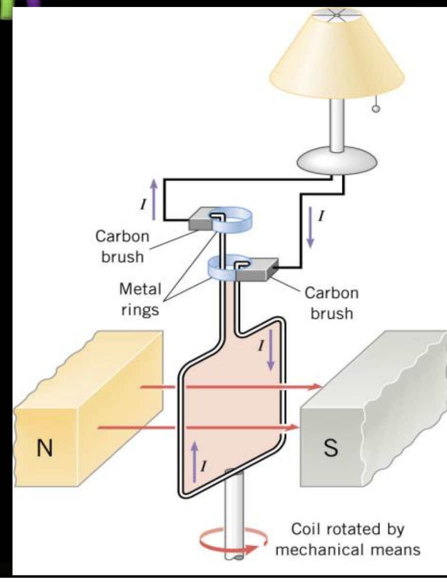
In this lesson you will…

- Calculate the emf induced in a generator.
- Calculate the peak emf which can be induced in a particular generator system.
- Explain what back emf is and how it is induced.

10-07 Electric Generators and Back EMF

10-07 Electric Generators and Back Emf

- A loop of wire is rotated in a magnetic field.
- Since the angle between the loop and the B-field is changing, the flux is changing.
- Since the magnetic flux is changing an emf is induced.



10-07 Electric Generators and Back Emf

- For a conducting rod moving in B-field

$$emf = vBL\sin\theta$$

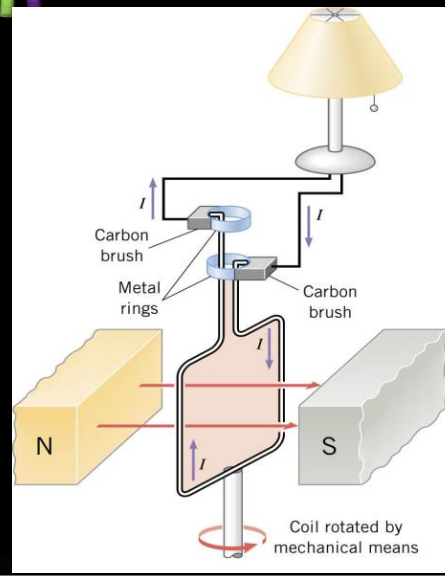
- Two rods for each loop so

$$emf = 2NvBL\sin\theta$$

- Often want in terms of angular velocity instead of tangential velocity

$$\theta = \omega t$$

$$emf = 2NvBL\sin\omega t$$



Angular velocity is how many radians (angles) it turns through in a given time.
Tangential velocity is how fast the rod is going in a straight line.

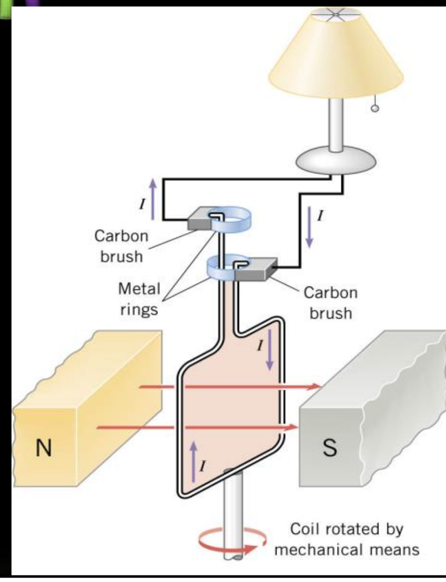
10-07 Electric Generators and Back Emf

- The vertical sides turn in circle with radius W/2.
- Tangential speed of each side

$$v = r\omega = \frac{W}{2}\omega$$

$$emf = 2N\frac{W}{2}\omega BL\sin\omega t$$

- Area is LW so



Angular velocity is how many radians (angles) it turns through in a given time. Tangential velocity is how fast the rod is going in a straight line.

10-07 Electric Generators and Back Emf

- emf produced in rotating planar coil

$$emf = NBA\omega \sin \omega t$$

- Where
  - N = number of loops
  - B = magnetic field
  - A = area of each loop
  - ω = angular velocity = 2π*f*
  - *t* = time in seconds

f is the frequency

10-07 Electric Generators and Back Emf

- According to Lenz's Law, the current will flow the one direction when the angle is increasing and it will flow the opposite direction when the angle is decreasing.

- These generators often called alternating current generators.

10-07 Electric Generators and Back Emf

- You have made a simple generator to power a TV. The armature is attached the rear axle of a stationary bike. For every time you peddle, the rear axel turns 10 times. Your TV needs a V_{rms} of 110V to operate. If the B-field is 0.2 T, each loop is a circle with r = 3 cm, and you can comfortably peddle 3 times a second; how many loops must you have in your generator so that you can watch TV while you exercise?
  - 1460 loops

Needed emf: $emf_{rms} = \frac{emf}{\sqrt{2}} \rightarrow 110\ V = \frac{emf}{\sqrt{2}} \rightarrow emf = 155.6\ V\ peak$

Peak emf occurs when $\sin \omega t = 1$

$emf_{peak} = NAB(2\pi f) \rightarrow 155.6\ V$
$= N(\pi(0.03\ m)^2)(0.2\ T)(2\pi 3 \cdot 10\ Hz) \rightarrow 155.6\ V = N(0.1066\ V) \rightarrow N$
$= 1460\ loops$

10-07 Electric Generators and Back Emf

- Back emf
  - When a coil is turned in a B-field an emf is produced
  - If an electric motor is running, its coil is turning in a B-field
  - By Lenz's Law, this emf will oppose the emf used to turn the motor (called back emf)
  - It will reduce the voltage across the motor and cause it to draw less current ($V = IR$)
  - The back emf is proportional to the speed, so when motor starts it draws max I, but as it speeds up the I decreases

10-07 Homework

- Please generate plenty of answers
- Read 23.7, 23.8

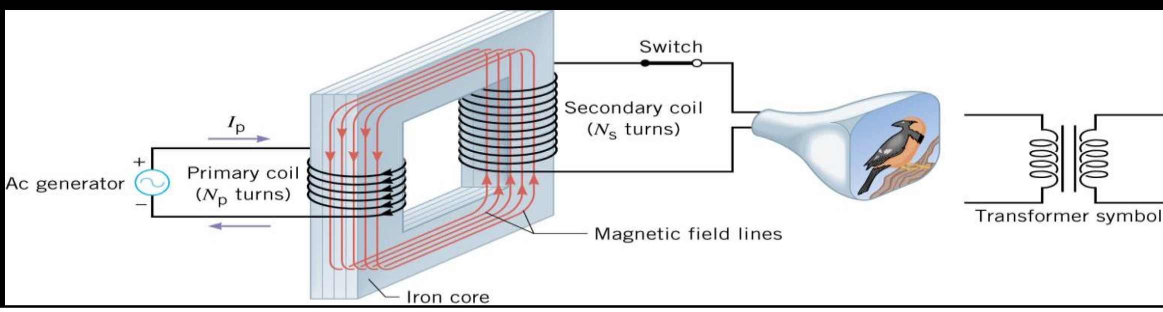

In this lesson you will…
• Explain how a transformer works.
• Calculate voltage, current, and/or number of turns given the other quantities.
• Explain how various modern safety features in electric circuits work, with an emphasis on how induction is employed.
10-08 TRANSFORMERS AND ELECTRICAL SAFETY

10-08 Transformers and Electrical Safety

- The voltage in a wall outlet is approximately 110V.
- Many electrical appliances can’t handle that many volts.
  - Computer speakers 9V
  - Projection TV 15000V
- A transformer changes the voltage for the appliance.

10-08 Transformers and Electrical Safety

- The primary coil creates a magnetic field in the iron core.
- Since the current in the coil is AC, the B-field is always changing.
- The iron makes the B-field go through the secondary coil.
- The changing B-field means the flux in the secondary coil is also changing and thus induces a emf.



10-08 Transformers and Electrical Safety

- Induced emf

$$emf_S = -N_S \frac{\Delta\Phi}{\Delta t}$$

- Primary emf

$$emf_P = -N_P \frac{\Delta\Phi}{\Delta t}$$

- Dividing

$$\frac{emf_S}{emf_P} = \frac{N_S}{N_P}$$

- Transformer equation

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

- But $P = IV$
  - Next slide please…

10-08 Transformers and Electrical Safety

$$\frac{I_P}{I_S} = \frac{V_S}{V_P} = \frac{N_S}{N_P}$$

- A transformer that steps up the voltage, steps down the current and vise versa.
- To keep electrical lines from getting hot, electrical companies use transformers to step up the voltage to up to 11000V. The box on electrical pole is a transformer that steps the voltage down to 220V.

Point out that a transformer that steps up the voltage, steps down the current.
A transformer that steps down the voltage, steps up the current.

10-08 Transformers and Electrical Safety

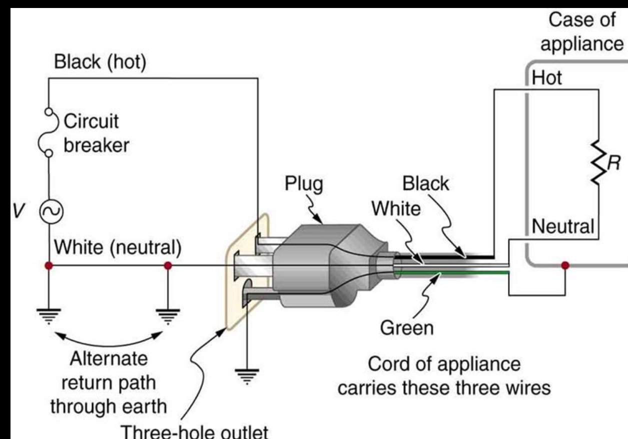
- A TV requires 15000V and 0.01 A to accelerate the electron beam. The outlet in the house supplies 120V. The primary coil of the transformer in the TV has 100 turns. How many turns should the secondary coil have?
  - 12500 turns
- How much current does the TV draw from the outlet?
  - 1.25 A

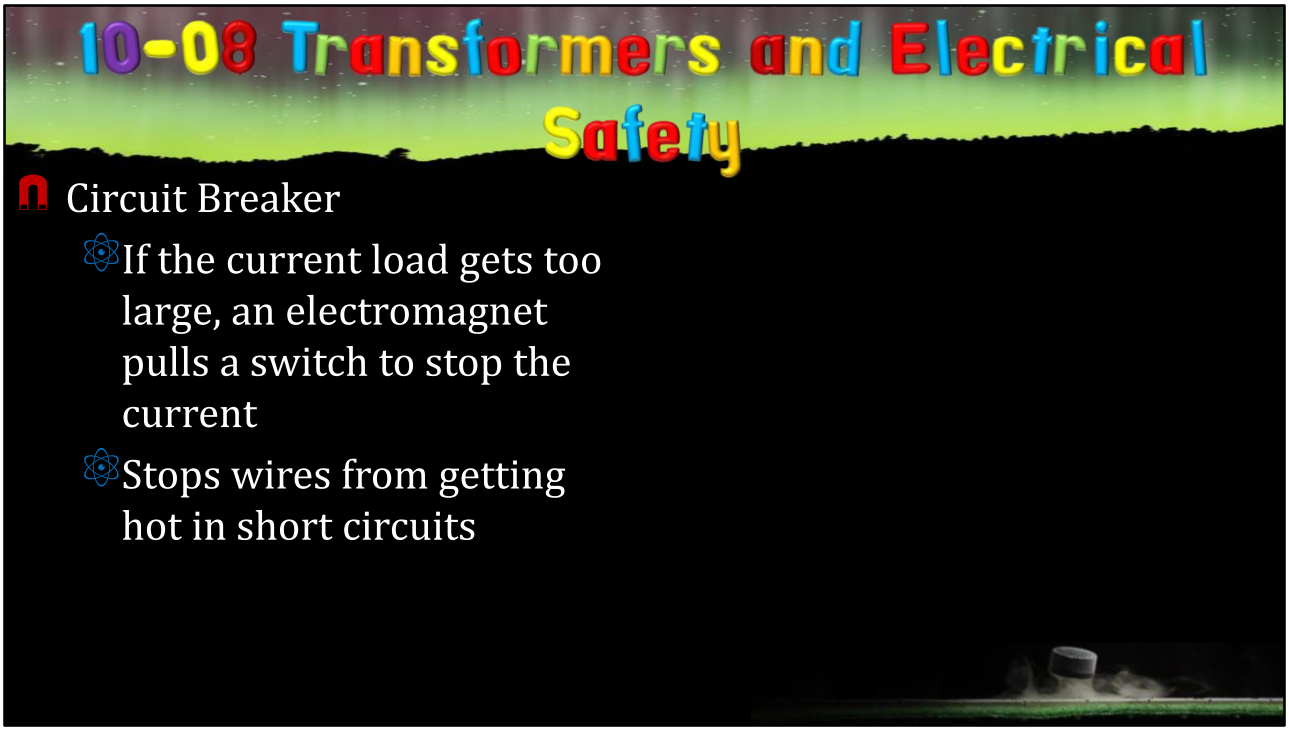
$$\frac{V_S}{V_P} = \frac{N_S}{N_P} \rightarrow \frac{15000\ V}{120\ V} = \frac{N_S}{100} \rightarrow 12500\ turns$$

$$\frac{I_P}{I_S} = \frac{V_S}{V_P} \rightarrow \frac{I}{0.01\ A} = \frac{15000\ V}{120\ V} \rightarrow 1.25\ A$$

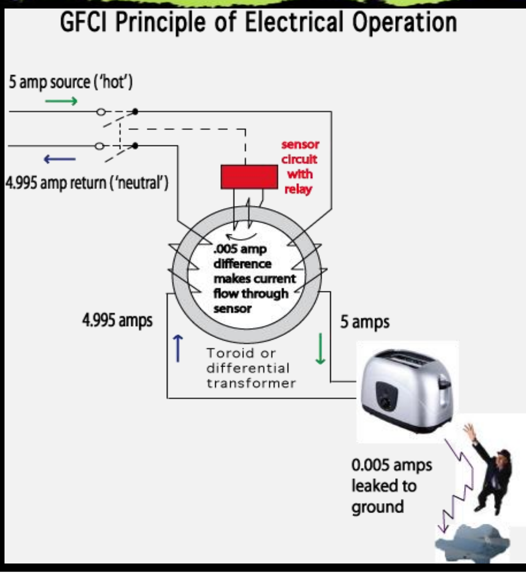
10-08 Transformers and Electrical Safety

- Safety
  - Two grounds
    - White wire
      - Wide prong
      - Return through ground
    - Green wire
      - 3rd prong
      - Grounds the case
  - Hot wire
    - Black/red
      - Carries the higher voltage




10-08 Transformers and Electrical Safety
Circuit Breaker
If the current load gets too large, an electromagnet pulls a switch to stop the current
Stops wires from getting hot in short circuits

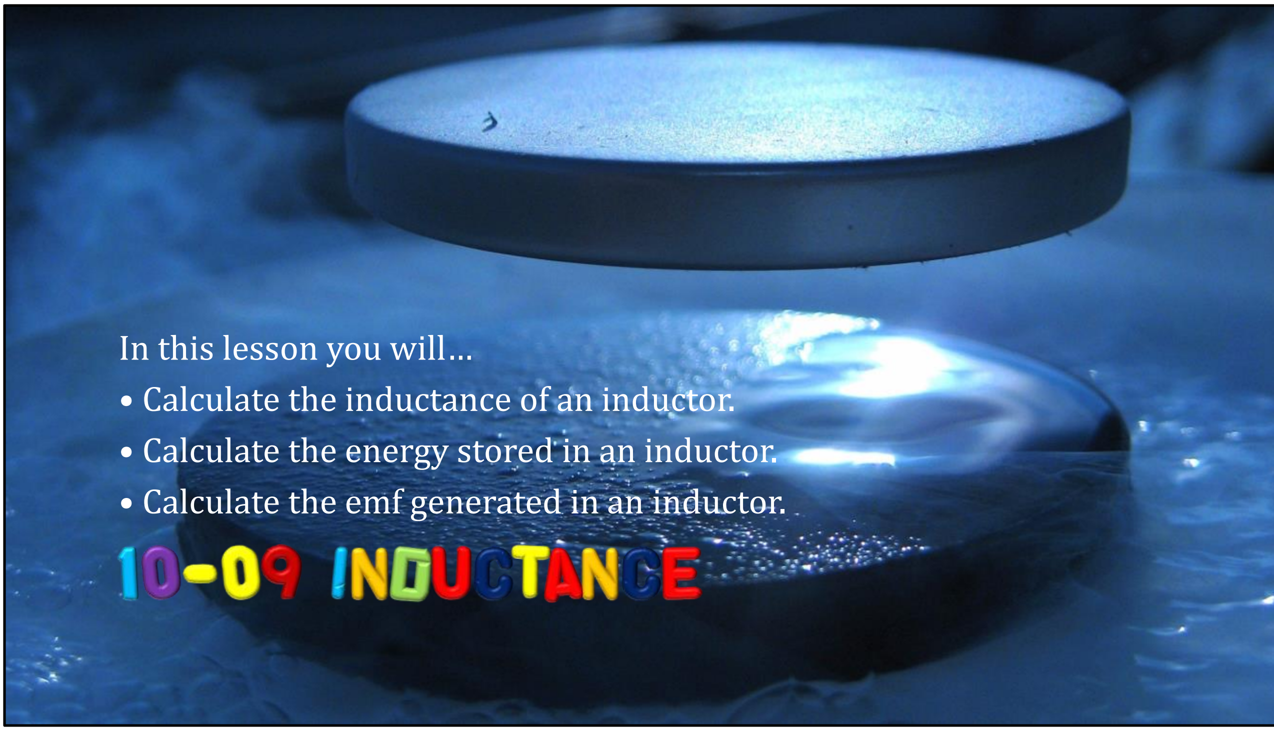
10-08 Transformers and Electrical Safety



- Ground Fault Interrupter
  - Both sides (hot and neutral) are wrapped around a metal toroid like a transformer, but the number of loops are equal
  - Normally the induced current is 0 since the two sides cancel
  - If an imbalance occurs (like current going through a person to the ground), an electromagnet pulls a switch

10-08 Homework

- Please transform the questions into answers
- Read 23.9


In this lesson you will…
• Calculate the inductance of an inductor.
• Calculate the energy stored in an inductor.
• Calculate the emf generated in an inductor.
10-09 INDUCTANCE

10-09 Inductance

- Induction is process where emf is induced by changing magnetic flux
- Mutual inductance is inductance of one device to another like a transformer
- Change in flux usually by changing current since they are solid pieces
- Can be reduced by counterwinding coils

$$emf_2 = -M\frac{\Delta I_1}{\Delta t}$$

- Where
- M = mutual inductance
  - Unit: H (henry)
- I = current
- t = time
- emf = induced emf

10-09 Inductance

- Self-inductance
  - A changing current in a coil causes a changing B-field in middle of coil
  - Changing B-field causes induced emf in the same coil
  - Resists change in current in the device

$$emf = -L\frac{\Delta I}{\Delta t}$$

- L = self-inductance
  - Unit: H (henry)

10-09 Inductance

- Self -Inductance

$$emf = -N\frac{\Delta\Phi}{\Delta t} = -L\frac{\Delta I}{\Delta t}$$

$$L = N\frac{\Delta\Phi}{\Delta I}$$

- For solenoid

$$L = \frac{\mu_0 N^2 A}{\ell}$$

- Where
  - L = inductance
  - $\mu_0 = 4\pi \times 10^{-7}\frac{Tm}{A}$
  - N = number of loops
  - A = cross-sectional area
  - ℓ = length of solenoid

10-09 Inductance

- The 4.00 A current through a 7.50 mH inductor is switched off in 8.33 ms. What is the emf induced opposing this?
- 3.60 V

$$emf = -L\frac{\Delta I}{\Delta t}$$

$$emf = -(7.50 \times 10^{-3}\ H)\frac{0\ A - 4.00\ A}{8.33 \times 10^{-3}\ s} = 3.60\ V$$

10-09 Inductance

- Energy stored in an inductor

$$E_{ind} = \frac{1}{2} L I^2$$

- Where
  - E_{ind} = energy
  - L = inductance
  - I = current

10-09 Homework

- Let me induce you to finish up this unit by solving these problems