Magnets

Magnets have two ____________ called ____________

- ____________ and ____________ poles
- There are no ____________ poles

Like poles ____________, Opposite poles ____________

Electromagnetism

- It was discovered that running ____________ through a ____________ produced a ____________
- The magnetism around ____________ magnets and ____________ are very similar, so both must have common __________.
- ____________ is the cause of all ____________

Ferromagnetism

- Magnetic materials have an ____________ outer ____________.
- ____________ near each other line up so that the unpaired ____________ spin the ____________ direction.
- This ____________ creates ____________

In permanent magnet the current is ____________ in atoms.

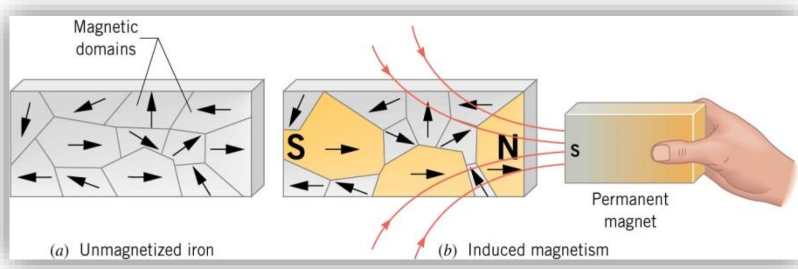
- Move around ____________ and ____________
- Most materials ____________ out except in ___________________ materials

Ferromagnetic materials

- Electron magnetic effects ____________ cancel over large ____________ of atoms.
- This gives ____________ magnetic ____________ size of ____________ to ____________ mm called magnetic ____________.
- In a permanent magnet, these ____________ are aligned.
- Common magnetic materials are ____________, ____________, ____________, and ___________________________.

Induced Magnetism

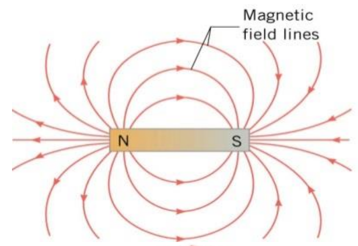
- Usually the magnetic ____________ are ____________ arranged.
- When it is placed in a ____________, the domains that are aligned with the B-field grow ____________ and the orientation of other domains may ____________ until they are aligned.
- This gives the material an ____________ magnetism.



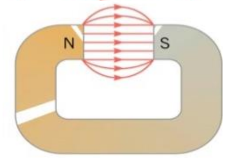
Homework

Read the current chapter in your textbook.

Magnetic Fields



- Around a magnet is a magnetic ____________ (B-field)
- At ____________ point in ____________ there is a magnetic ____________
- Can be seen with a ____________
- Unit is ____________ (T)



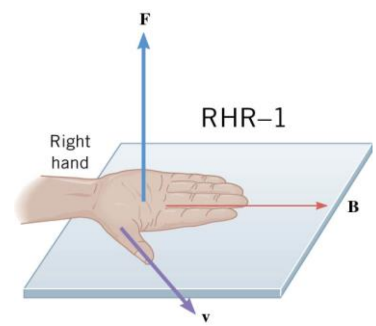
Magnetic Field Lines

- Magnetic fields can be ____________ with field ____________.
- Start at ____________ pole and end at ____________ pole
- The more lines in one area means ____________ field

Force on a Moving Charge

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

Direction of force on positive moving charge

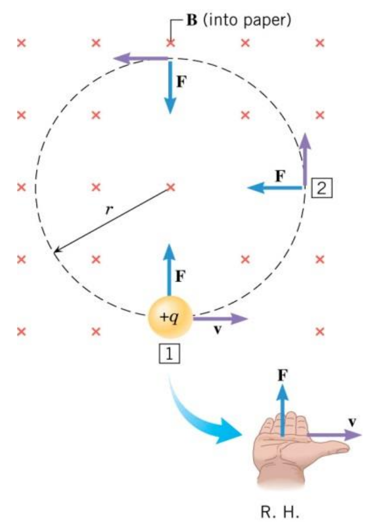


Right Hand Rule

- Fingers point in direction of ____________
- Thumb in direction of ____________
- Palm faces direction of ____________ on ____________ charge
- Force will be ________ if v and B are parallel, so a moving charge will be unaffected

Motion of moving charged particle in uniform B-field

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



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?

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?

What is the magnitude of the force on the particle?

Homework

1. Is the Earth's magnetic field parallel to the ground at all locations? If not, where is it parallel to the surface? Is its strength the same at all locations? If not, where is it greatest?
2. If a charged particle moves in a straight line through some region of space, can you say that the magnetic field in that region is necessarily zero?
3. How can the motion of a charged particle be used to distinguish between a magnetic and an electric field?
4. What are the signs of the charges on the particles in Figure 1?
5. Which of the particles in Figure 2 has the greatest velocity, assuming they have identical charges and masses?
6. Which of the particles in Figure 2 has the greatest mass, assuming all have identical charges and velocities?

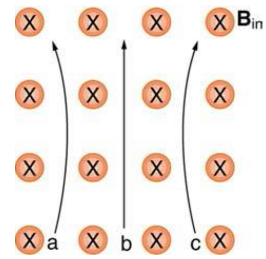


Figure 1

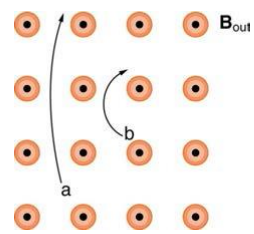


Figure 2

7. What is the direction of the magnetic force on a positive charge that moves as shown in each of the six cases shown in Figure 3? (OpenStax 22.1) **left, into, up, no, right, down**
8. Repeat Exercise 7 for a negative charge. (OpenStax 22.2) **right, out, down, no, left, up**
9. What is the direction of the velocity of a negative charge that experiences the magnetic force shown in each of the three cases in Figure 4, assuming it moves perpendicular to *B*? (OpenStax 22.3) **right, into, down**
10. Repeat Exercise 9 for a positive charge. (OpenStax 22.4) **left, out, up**
11. What is the direction of the magnetic field that produces the magnetic force on a positive charge as shown in each of the three cases in the Figure 5, assuming *B* is perpendicular to *v*? (OpenStax 22.5) **into, left, out**
12. Repeat Exercise 11 for a negative charge. (OpenStax 22.6) **out, right, into**
13. What is the maximum force on an aluminum rod with a 0.100-μC charge that you pass between the poles of a 1.50-T permanent magnet at a speed of 5.00 m/s? In what direction is the force? (OpenStax 22.7) $\mathbf{7.50 \times 10^{-7}}$**N, ⊥**
14. (a) Aircraft sometimes acquire small static charges. Suppose a supersonic jet has a 0.500-μC charge and flies due west at a speed of 660 m/s over the Earth's south magnetic pole, where the 8.00×10^{-5}-T magnetic field points straight down. What are the direction and the magnitude of the magnetic force on the plane? (b) Discuss whether the value obtained in part (a) implies this is a significant or negligible effect. (OpenStax 22.8) $\mathbf{2.64 \times 10^{-8}}$ **N, south, negligible**
15. (a) A cosmic ray proton moving toward the Earth at 5.00×10^{7} m/s experiences a magnetic force of 1.70×10^{-16} N. What is the strength of the magnetic field if there is a 45° angle between it and the proton's velocity? (b) Is the value obtained in part (a) consistent with the known strength of the Earth's magnetic field on its surface? Discuss. (OpenStax 22.9) $\mathbf{3.01 \times 10^{-5}}$ **T, yes**

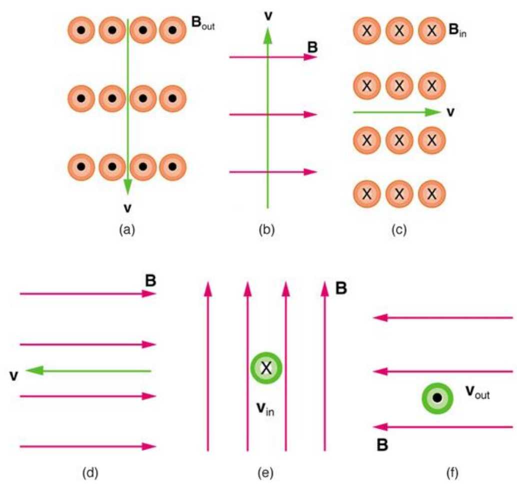


Figure 3

16. A cosmic ray electron moves at 7.50×10^{6} m/s perpendicular to the Earth's magnetic field at an altitude where field strength is 1.00×10^{-5} T. What is the radius of the circular path the electron follows? (OpenStax 22.12) **4.27 m**
17. A proton moves at 7.50×10^{7} m/s perpendicular to a magnetic field. The field causes the proton to travel in a circular path of radius 0.800 m. What is the field strength? (OpenStax 22.13) **0.979 T**

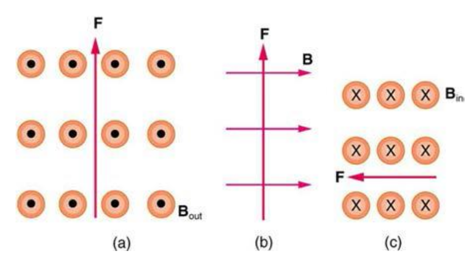


Figure 4

18. (a) Viewers of Star Trek hear of an antimatter drive on the Starship Enterprise. One possibility for such a futuristic energy source is to store antimatter charged particles in a vacuum chamber, circulating in a magnetic field, and then extract them as needed. Antimatter annihilates with normal matter, producing pure energy. What strength magnetic field is needed to hold antiprotons, moving at 5.00×10^{7} m/s in a circular path 2.00 m in radius? Antiprotons have the same mass as protons but the opposite (negative) charge. (b) Is this field strength obtainable with today's technology or is it a futuristic possibility? (OpenStax 22.14) **0.261 T, yes**

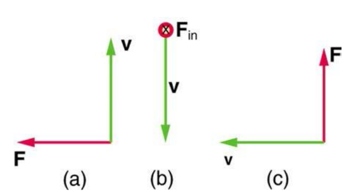
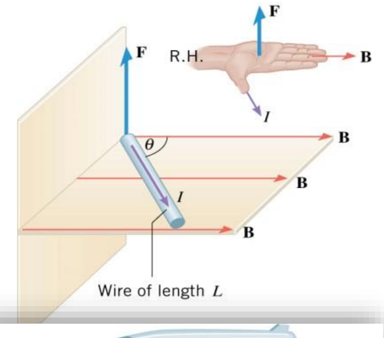


Figure 5

19. (a) An oxygen-16 ion with a mass of 2.66×10^{-26} kg travels at 5.00×10^{6} m/s perpendicular to a 1.20-T magnetic field, which makes it move in a circular arc with a 0.231-m radius. What positive charge is on the ion? (b) What is the ratio of this charge to the charge of an electron? (c) Discuss why the ratio found in (b) should be an integer. (OpenStax 22.15) $\mathbf{4.80 \times 10^{-19}}$ **C, 3**

 Name: ________________________

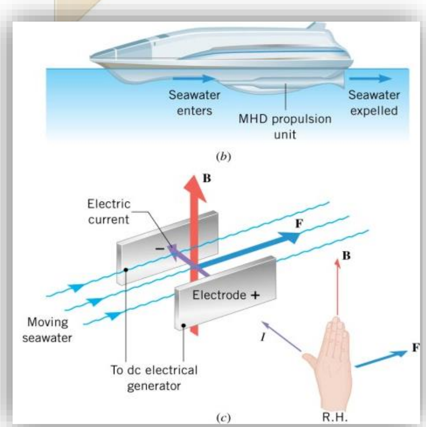
Force on a Current-Carrying Wire in B-field



- Direction Follows ________________
- $F = ILB\sin\theta$

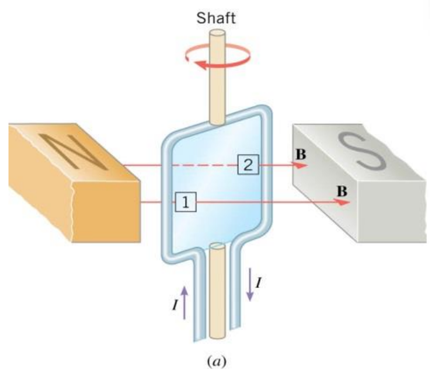
A 2 m wire is in a 2×10^{-6} T magnetic field pointing into the page. It carries 2 A of current flowing up. What is the force on the wire?

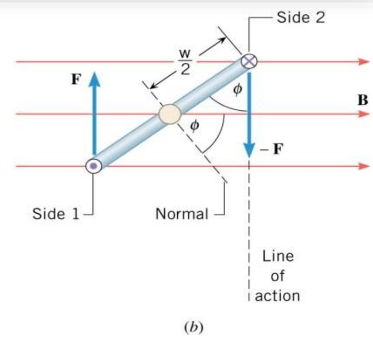
Magnetohydrodynamic Propulsion



- Way to ________________ boats with ________________ moving parts
- ________________ enters tube under ship
- In the tube are electrodes that run ________________ through the water
- Also in the tube is a strong ________________ field created by ________________
- The interaction with the electric ________________ and ________________ push the ________________ out the back of the tube which pushes boat forward
- $F = ILB\,sin\,\theta$

Torque on a Current Loop in B-field



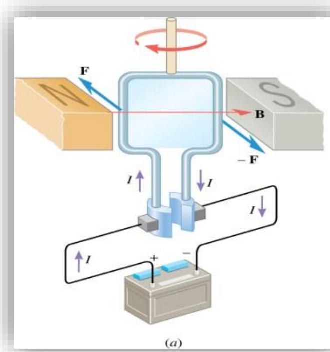


What happens when you put a loop of wire in a magnetic field?

- Side 1 is forced ________________ and side 2 is forced ________________ (RHR)
- This produces a ________________
- The loop turns until its normal is ________________ with the B-field
- 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 ________________
    - Magnetic ________________ ↑, torque ↑

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?

Electric Motor



- Many loops of ______________-carrying wire placed between two ______________ (B-field)
- The loops are attached to ________________
- The ______________ turns the ______________ until the normal is ______________ to B-field
- At that point the half-rings ________________ connect to electric ________________
- ________________ makes the loop turn more
- The half-rings ________________ with the current to ________________ the process

Homework

1. Why would a magnetohydrodynamic drive work better in ocean water than in fresh water? Also, why would superconducting magnets be desirable?
2. Which is more likely to interfere with compass readings, AC current in your refrigerator or DC current when you start your car? Explain.
3. What is the direction of the magnetic force on the current in each of the six cases in Figure 1? (OpenStax 22.31) **left, into, up, no, right, down**
4. What is the direction of a current that experiences the magnetic force shown in each of the three cases in Figure 2, assuming the current runs perpendicular to B? (OpenStax 22.32) **left, out, up**
5. (a) What is the force per meter on a lightning bolt at the equator that carries 20,000 A perpendicular to the Earth's 3.00×10^{-5}-T field? (b) What is the direction of the force if the current is straight up and the Earth's field direction is due north, parallel to the ground? (OpenStax 22.34) **0.600 N/m, West**

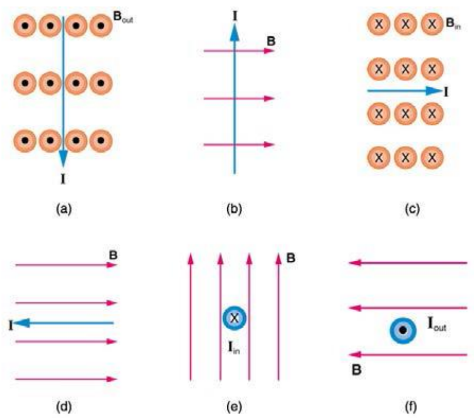


Figure 1

6. (a) A DC power line for a light-rail system carries 1000 A at an angle of 30.0° to the Earth's 5.00×10^{-5}-T field. What is the force on a 100-m section of this line? (b) Discuss practical concerns this presents, if any. (OpenStax 22.35) **2.50 N, must attach them**
7. What force is exerted on the water in an MHD drive utilizing a 25.0-cm-diameter tube, if 100-A current is passed across the tube that is perpendicular to a 2.00-T magnetic field? (The relatively small size of this force indicates the need for very large currents and magnetic fields to make practical MHD drives.) (OpenStax 22.36) **50.0 N**

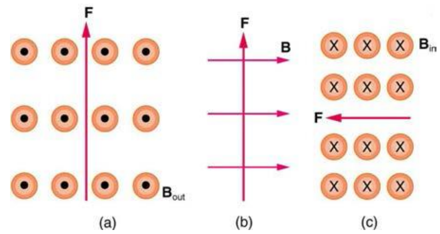
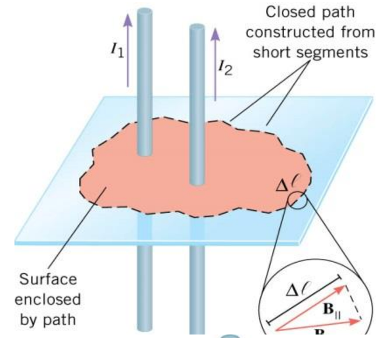


Figure 2

8. A wire carrying a 30.0-A current passes between the poles of a strong magnet that is perpendicular to its field and experiences a 2.16-N force on the 4.00 cm of wire in the field. What is the average field strength? (OpenStax 22.37) **1.80 T**
9. (a) What is the maximum torque on a 150-turn square loop of wire 18.0 cm on a side that carries a 50.0-A current in a 1.60-T field? (b) What is the torque when ϕ is 10.9°? (OpenStax 22.42) **389 Nm, 73.5 Nm**
10. Find the current through a loop needed to create a maximum torque of 9.00 N·m. The loop has 50 square turns that are 15.0 cm on a side and is in a uniform 0.800-T magnetic field. (OpenStax 22.43) **10.0 A**
11. Calculate the magnetic field strength needed on a 200-turn square loop 20.0 cm on a side to create a maximum torque of 300 N·m if the loop is carrying 25.0 A. (OpenStax 22.44) **1.50 T**
12. A proton has a magnetic field due to its spin on its axis. The field is similar to that created by a circular current loop 0.650×10^{-15} m in radius with a current of 1.05×10^{4} A (no kidding). Find the maximum torque on a proton in a 2.50-T field. (This is a significant torque on a small particle.) (OpenStax 22.47) $\mathbf{3.48 \times 10^{-26}}$ **Nm**

 Name: ________________________

Ampere's Law



$$\sum\vec{B}\cdot\Delta\vec{\ell} = \mu_0 I$$
$$\sum B_{\parallel}\Delta\ell = \mu_0 I$$

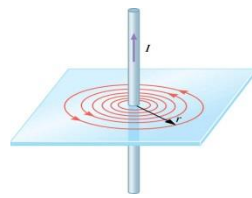
- Where B = the magnetic field ($B_{||}$ is the B-field _______________ to ℓ), $\Delta\ell$ = a portion of the _______________ surround the current, μ_0 = ____________________ of free space = $4\pi \times 10^{-7}$ Tm/A, I = current _______________ by path

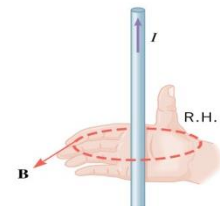
Long Straight Wire

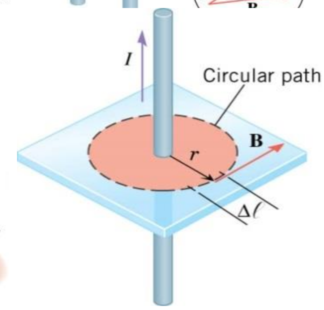
- To make it simpler, let's use a _______________ for our path around _______________ wire.

$$\sum\vec{B}\cdot\Delta\vec{\ell} = \mu_0 I$$
$$B(2\pi r) = \mu_0 I$$
$$B = \frac{\mu_0 I}{2\pi r}$$

- Right Hand Rule
  - Grab the wire with _______________ hand
  - Thumb points in direction of _______________
  - Fingers curl in direction of _______________ field

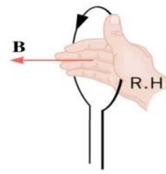


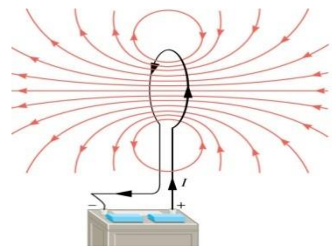




Loop

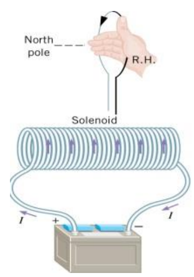
- Right Hand Rule
- At _______________ of loop
- $B = N\frac{\mu_0 I}{2R}$
  - N=number of loops

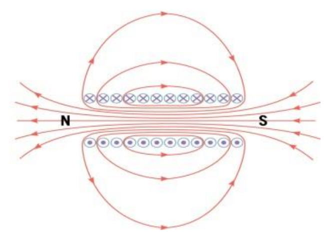




Solenoid

- $B = \mu_0 nI$
  - n=loops/m





A long straight current-carrying wire runs from north to south.
A compass needle is placed above the wire points with its N-pole toward the east. In what direction is the current flowing?

If a compass is put underneath the wire, in which direction will the needle point?

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?

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.

Find the B-field at 0.5 mm from the center.

What current should be in the cylinder to have no B-field outside of the cylinder?

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?

- Force of one wire on another ______________ wire
  - $\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r}$
  - Attractive if same I's in ______________ direction, repulsive if ______________

Homework

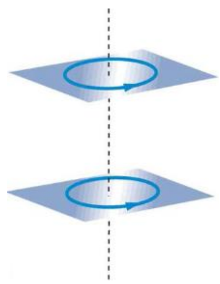


Figure 1

1. Suppose two long straight wires run perpendicular to one another without touching. Does one exert a net force on the other? If so, what is its direction? Does one exert a net torque on the other? If so, what is its direction? Justify your responses by using the right hand rules.
2. Use the right hand rules to show that the force between the two loops in Figure 1 is attractive if the currents are in the same direction and repulsive if they are in opposite directions. Is this consistent with like poles of the loops repelling and unlike poles of the loops attracting? Draw sketches to justify your answers.
3. (a) The hot and neutral wires supplying DC power to a light-rail commuter train carry 800 A and are separated by 75.0 cm. What is the magnitude and direction of the force between 50.0 m of these wires? (b) Discuss the practical consequences of this force, if any. (OpenStax 22.50) **8.53 N, repulsive**

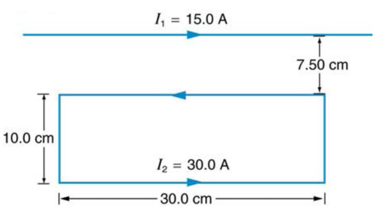


Figure 2

4. The force per meter between the two wires of a jumper cable being used to start a stalled car is 0.225 N/m. (a) What is the current in the wires, given they are separated by 2.00 cm? (b) Is the force attractive or repulsive? (OpenStax 22.51) **150 A, repulsive**
5. A 2.50-m segment of wire supplying current to the motor of a submerged submarine carries 1000 A and feels a 4.00-N repulsive force from a parallel wire 5.00 cm away. What is the direction and magnitude of the current in the other wire? (OpenStax 22.52) **400 A, opposite**
6. The wire carrying 400 A to the motor of a commuter train feels an attractive force of 4.00×10^{-3} N/m due to a parallel wire carrying 5.00 A to a headlight. (a) How far apart are the wires? (b) Are the currents in the same direction? (OpenStax 22.53) **0.100 m, Yes**

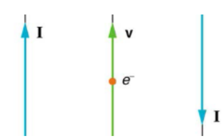


Figure 3

7. Figure 2 shows a long straight wire near a rectangular current loop. What is the direction and magnitude of the total force on the loop? (OpenStax 22.55) $\mathbf{2.06 \times 10^{-4}}$ **N, repulsive**
8. Indicate whether the magnetic field created in each of the three situations shown in Figure 3 is into or out of the page on the left and right of the current. (OpenStax 22.58) **out, into; into, out; into, out**

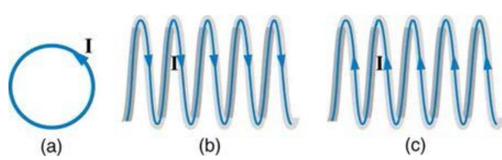


Figure 4

9. What are the directions of the fields in the center of the loop and coils shown in Figure 4? (OpenStax 22.59) **out, right, left**
10. What are the directions of the currents in the loop and coils shown in Figure 5? (OpenStax 22.60) **CW, CW as seen from left, CW as seen from right**
11. Inside a motor, 30.0 A passes through a 250-turn circular loop that is 10.0 cm in radius. What is the magnetic field strength created at its center? (OpenStax 22.62) $\mathbf{4.71 \times 10^{-2}}$ **T**

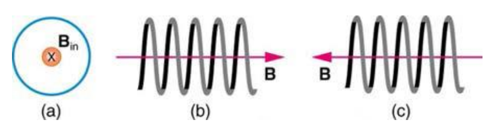
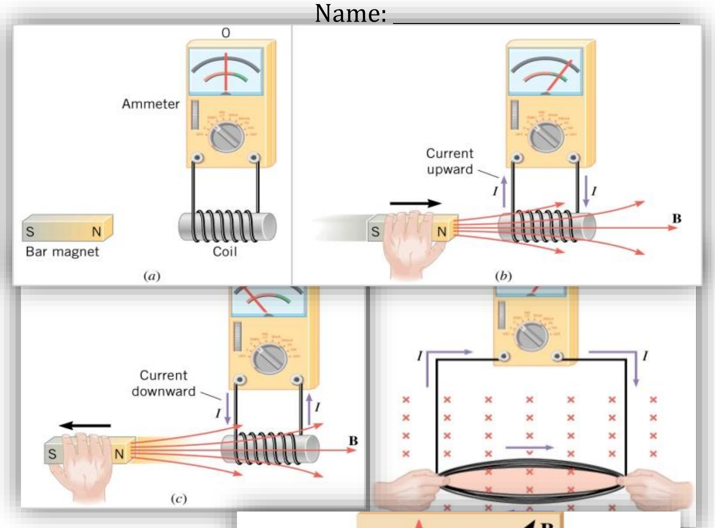


Figure 5

12. How strong is the magnetic field inside a solenoid with 10,000 turns per meter that carries 20.0 A? (OpenStax 22.64) **0.251 T**
13. How far from the starter cable of a car, carrying 150 A, must you be to experience a field less than the Earth's (5.00×10^{-5} T)? Assume a long straight wire carries the current. (OpenStax 22.66) **0.600 m**
14. Calculate the size of the magnetic field 20 m below a high voltage power line. The line carries 450 MW at a voltage of 300,000 V. (OpenStax 22.72) $\mathbf{1.5 \times 10^{-5}}$ **T**

Physics 10-05 Faraday's Law of Induction and Lenz's Law Name: ______________________

Faraday's Law of Induction



Magnetic ____________ can produce ____________.

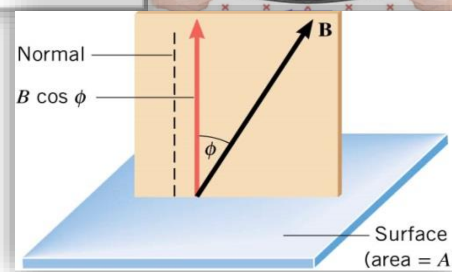
- The magnetic field must be ____________ to create current.
- The current created is called ____________ current.
- The emf that ________ the current is called _________ emf.
- Another way to induce emf is by changing the ____________ of a ____________ of wire in a magnetic field.

Magnetic Flux through a surface

$$\Phi = \vec{B} \cdot \vec{A}$$

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

- The angle is between the ____________ and the ____________ to the surface.
- The magnetic flux is proportional to the ____________ of field ____________ that pass through a ____________.
- Any ____________ in magnetic flux causes a ____________ to flow



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°?

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

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 ____________, ____________, or ____________ will produce a ____________

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?

Lenz's Law

- The induced emf resulting from a changing magnetic flux has a ____________ that leads to an ____________ current whose direction is such that the induced magnetic ____________ ____________ the original flux ____________.

Reasoning Strategy

- Determine whether the magnetic flux is ____________ or ____________.

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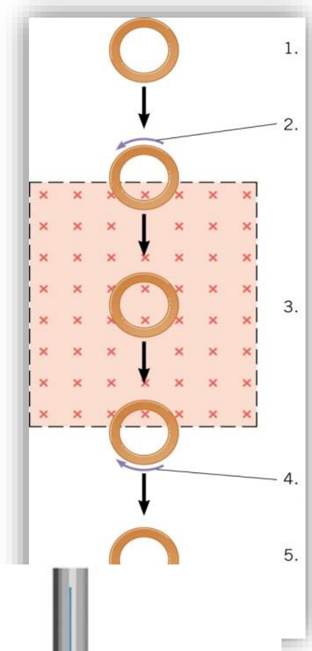
- Find what direction the induced magnetic field must be to __________ the change in flux by __________ or __________ from the original field.
- Having found the __________ of the magnetic field, use the ________________ to find the direction of the __________ current.

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?



Homework

1. Explain how magnetic flux can be zero when the magnetic field is not zero.
2. A particle accelerator sends high-velocity charged particles down an evacuated pipe. Explain how a coil of wire wrapped around the pipe could detect the passage of individual particles. Sketch a graph of the voltage output of the coil as a single particle passes through it.
3. What is the value of the magnetic flux at coil 2 in Figure 1(a) due to coil 1? (OpenStax 23.1) **0**
4. What is the value of the magnetic flux through the coil in Figure 1(b) due to the wire? (OpenStax 23.2) **0**
5. Referring to Figure 2(a), what is the direction of the current induced in coil 2: (a) If the current in coil 1 increases? (b) If the current in coil 1 decreases? (c) If the current in coil 1 is constant? (OpenStax 23.3) **CCW, CW, no**
6. Referring to Figure 2(b), what is the direction of the current induced in the coil: (a) If the current in the wire increases? (b) If the current in the wire decreases? (c) If the current in the wire suddenly changes direction? (OpenStax 23.4) **CCW, CW, CW**
7. Referring to Figure 3, what are the directions of the currents in coils 1, 2, and 3 (assume that the coils are lying in the plane of the circuit): (a) When the switch is first closed? (b) When the switch has been closed for a long time? (c) Just after the switch is opened? (OpenStax 23.5) **CCW, CCW, CW; no, no, no; CW, CW, CCW**
8. Repeat the previous problem with the battery reversed. (OpenStax 23.6) **CW, CW, CCW; no, no, no; CCW, CCW, CW**
9. Suppose a 50-turn coil lies in the plane of the page in a uniform magnetic field that is directed into the page. The coil originally has an area of 0.250 m^2. It is stretched to have no area in 0.100 s. What is the direction and magnitude of the induced emf if the uniform magnetic field has a strength of 1.50 T? (OpenStax 23.8) **188 V CW**
10. (a) An MRI technician moves his hand from a region of very low magnetic field strength into an MRI scanner's 2.00 T field with his fingers pointing in the direction of the field. Find the average emf induced in his wedding ring, given its diameter is 2.20 cm and assuming it takes 0.250 s to move it into the field. (b) Discuss whether this current would significantly change the temperature of the ring. (OpenStax 23.9) **3.04 mV, no**
11. Referring to the situation in the previous problem: (a) What current is induced in the ring if its resistance is 0.0100 Ω? (b) What average power is dissipated? (c) What magnetic field is induced at the center of the ring? (d) What is the direction of the induced magnetic field relative to the MRI's field? (OpenStax 23.10) **0.304 A, 0.924 mW, $\mathbf{1.74 \times 10^{-5}}$ T, CCW**
12. A 0.250 m radius, 500-turn coil is rotated one-fourth of a revolution in 4.17 ms, originally having its plane perpendicular to a uniform magnetic field. (This is 60 rev/s.) Find the magnetic field strength needed to induce an average emf of 10,000 V. (OpenStax 23.12) **0.425 T**
13. (a) A lightning bolt produces a rapidly varying magnetic field. If the bolt strikes the earth vertically and acts like a current in a long straight wire, it will induce a voltage in a loop aligned like that in Figure 2(b). What voltage is induced in a 1.00 m diameter loop 50.0 m from a 2.00×10^6 A lightning strike, if the current falls to zero in 25.0 μs? (b) Discuss circumstances under which such a voltage would produce noticeable consequences. (OpenStax 23.14) **251 V**

Figure 1

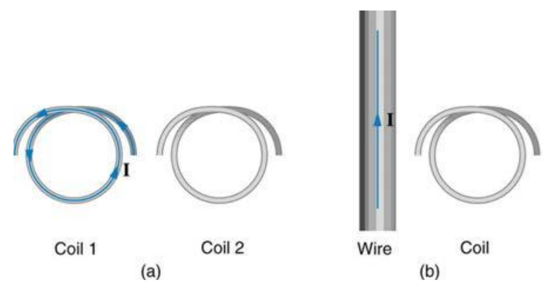


Figure 2

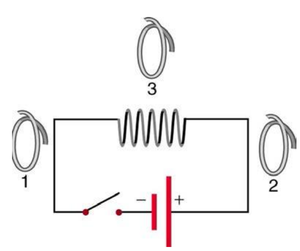


Figure 3

Motional emf

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

$$F = qvB \sin\theta$$

- Since the ____________ can move they are _________ to one end of the rod leaving ___________ charges at the other end.
- If there was a ____________ connecting the ____________ of the rod, the electrons would flow through the ____________ to get back to the ____________ charges.
  - This is called ____________ ____________ ($\mathcal{E}$)
- If the rod did ____________ have the wire, the electrons would move until the ____________ electrical force is balanced with the ____________ force.

$$emf = vBL$$

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

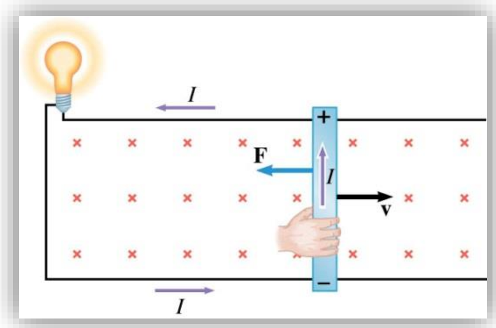


Figure 1

Damping

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

Applications of Magnetic Damping

- Stopping a ____________ from moving
- ____________ on trains/rollercoasters
  - No actual ____________ parts, not effected by rain, smoother
  - Since based on speed, need ________________ brakes to finish
- Sorting ____________
  - Metallic objects move ____________ down ramp with ____________ under it
- ____________ Detectors

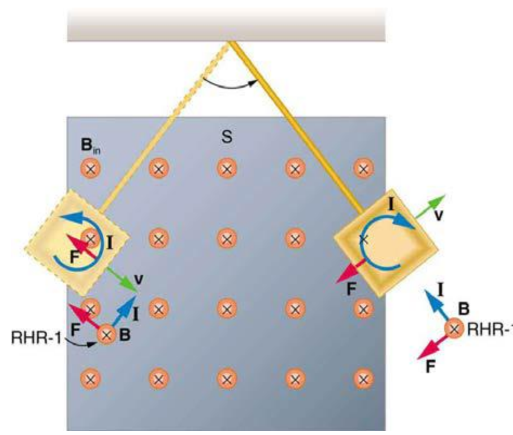


Figure 2

Homework

1. Why must part of the circuit be moving relative to other parts, to have usable motional emf? Consider, for example, that the rails in Figure 1 above are stationary relative to the magnetic field, while the rod moves.
2. A powerful induction cannon can be made by placing a metal cylinder inside a solenoid coil. The cylinder is forcefully expelled when solenoid current is turned on rapidly. Use Faraday's and Lenz's laws to explain how this works. Why might the cylinder get live/hot when the cannon is fired?

3. An induction stove heats a pot with a coil carrying an alternating current located beneath the pot (and without a hot surface). Can the stove surface be a conductor? Why won't a coil carrying a direct current work?
4. (a) A jet airplane with a 75.0 m wingspan is flying at 280 m/s. What emf is induced between wing tips if the vertical component of the Earth's field is 3.00×10^{-5} T? (b) Is an emf of this magnitude likely to have any consequences? Explain. (OpenStax 23.17) **0.630 V, no**
5. (a) A nonferrous screwdriver is being used in a 2.00 T magnetic field. What maximum emf can be induced along its 12.0 cm length when it moves at 6.00 m/s? (b) Is it likely that this emf will have any consequences or even be noticed? (OpenStax 23.18) **1.44 V, no**
6. At what speed must the sliding rod in Figure 1 move to produce an emf of 1.00 V in a 1.50 T field, given the rod's length is 30.0 cm? (OpenStax 23.19) **2.22 m/s**
7. The 12.0 cm long rod in Figure 1 moves at 4.00 m/s. What is the strength of the magnetic field if a 95.0 V emf is induced? (OpenStax 23.20) **198 T**
8. A coil is moved through a magnetic field as shown in Figure 3. The field is uniform inside the rectangle and zero outside. What is the direction of the induced current and what is the direction of the magnetic force on the coil at each position shown? (OpenStax 23.27) **none; CW I, left F; none; CCW I, left F; none**

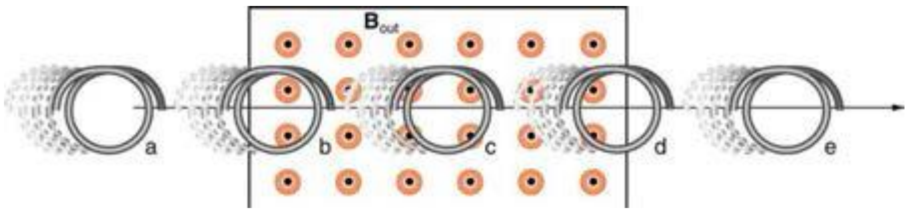
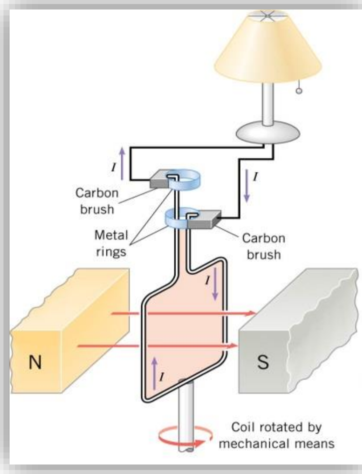


Figure 3

Name: ________________________

Electric Generators



- A ____________ of wire is ____________ in a ____________ field.
- Since the ____________ between the loop and the B-field is ____________, the ____________ is changing.
- Since the magnetic ____________ is changing an *emf* is ____________.
- *emf* produced in ____________ ____________ coil

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

- Where N = number of loops, B = magnetic field, A = area of each loop, ω = angular velocity = $2\pi f$, t = time in seconds
- According to ____________ Law, the current will flow the one direction when the angle is ____________ and it will flow the ____________ direction when the angle is ____________.
- These generators often called ____________ current ____________.

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?

Back emf

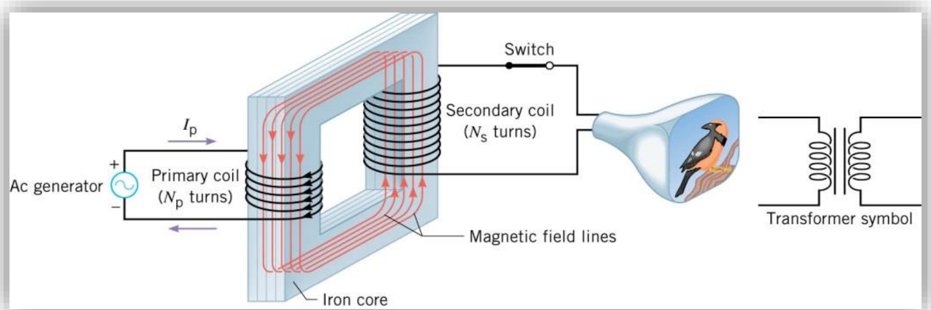
- When a coil is ____________ in a B-field an *emf* is ____________
- If an electric motor is ____________, its coil is ____________ in a B-field
- By ____________ Law, this *emf* will ____________ the *emf* used to ____________ the motor (called back *emf*)
- It will ____________ the ____________ across the motor and cause it to draw ____________ current ($V = IR$)
- The back *emf* is ________________ to the ____________, so when motor starts it draws ____________ I, but as it speeds up the I ____________

Homework

1. Suppose you find that the belt drive connecting a powerful motor to an air conditioning unit is broken and the motor is running freely. Should you be worried that the motor is consuming a great deal of energy for no useful purpose? Explain why or why not.
2. Calculate the peak voltage of a generator that rotates its 200-turn, 0.100 m diameter coil at 3600 rpm in a 0.800 T field. (OpenStax 23.28) **474 V**
3. At what angular velocity in rpm will the peak voltage of a generator be 480 V, if its 500-turn, 8.00 cm diameter coil rotates in a 0.250 T field? (OpenStax 23.29) $\mathbf{7.30 \times 10^3}$ **rpm**
4. (a) A bicycle generator rotates at 1875 rad/s, producing an 18.0 V peak *emf*. It has a 1.00 by 3.00 cm rectangular coil in a 0.640 T field. How many turns are in the coil? (b) Is this number of turns of wire practical for a 1.00 by 3.00 cm coil? (OpenStax 23.32) **50.0, Yes**
5. This problem refers to the bicycle generator considered in the previous problem. It is driven by a 1.60 cm diameter wheel that rolls on the outside rim of the bicycle tire. (a) What is the velocity of the bicycle if the generator's angular velocity is 1875 rad/s? (b) What is the maximum *emf* of the generator when the bicycle moves at 10.0 m/s, noting that it was 18.0 V under the original conditions? (c) If the sophisticated generator can vary its own magnetic field, what field strength will it need at 5.00 m/s to produce a 9.00 V maximum emf? (OpenStax 23.33) **15m/s, 12.0 V, 0.960 T**
6. (a) A car generator turns at 400 rpm when the engine is idling. Its 300-turn, 5.00 by 8.00 cm rectangular coil rotates in an adjustable magnetic field so that it can produce sufficient voltage even at low rpms. What is the field strength needed to produce a 24.0 V peak *emf*? (b) Discuss how this required field strength compares to those available in permanent and electromagnets. (OpenStax 23.34) **0.477 T, can use normal magnet**
7. Suppose a motor connected to a 120 V source draws 10.0 A when it first starts. (a) What is its resistance? (b) What current does it draw at its normal operating speed when it develops a 100 V back *emf*? (OpenStax 23.39) **12.0 Ω, 1.67 A**
8. A motor operating on 240 V electricity has a 180 V back *emf* at operating speed and draws a 12.0 A current. (a) What is its resistance? (b) What current does it draw when it is first started? (OpenStax 23.40) **5.00 Ω, 48.0 A**
9. What is the back *emf* of a 120 V motor that draws 8.00 A at its normal speed and 20.0 A when first starting? (OpenStax 23.41) **72.0 V**
10. The motor in a toy car operates on 6.00 V, developing a 4.50 V back *emf* at normal speed. If it draws 3.00 A at normal speed, what current does it draw when starting? (OpenStax 23.42) **12.0 A**

Transformers

- The ____________ in a wall outlet is approximately ____________.
- Many electrical appliances ____________ handle that many ____________.
  - Computer speakers ____________
  - Projection TV ____________
- A ______________ changes the voltage for the ____________.
- The ____________ coil creates a ____________ field in the ____________ core.
- Since the ____________ in the coil is ____________, the *B*-field is always ____________.
- The ____________ makes the *B*-field go through the ____________ coil.
- The ____________ *B*-field means the ____________ in the ____________ coil is also ____________ and thus ____________ a *emf*.



Transformer equation

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

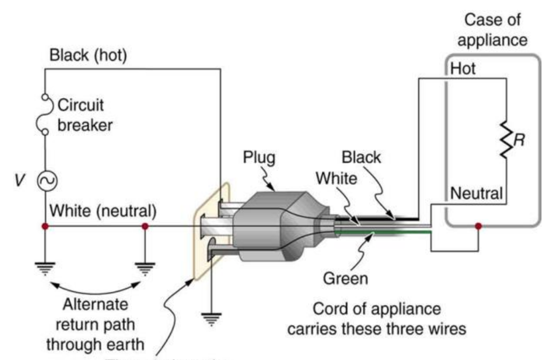
- A transformer that steps ____________ the ____________, steps ____________ the ____________ and vise versa.
- To keep electrical lines from getting ____________, electrical companies use transformers to step ____________ the voltage to up to ____________. The box on electrical pole is a ______________ that steps the voltage down to _______.

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?

How much current does the TV draw from the outlet?

Safety

- Two ____________
  - ____________ wire
    - ____________ prong
    - ____________ through ground
  - ____________ wire
    - ____________prong
    - Grounds the ____________
- ____________ wire
  - ____________________________
  - Carries the ____________ voltage

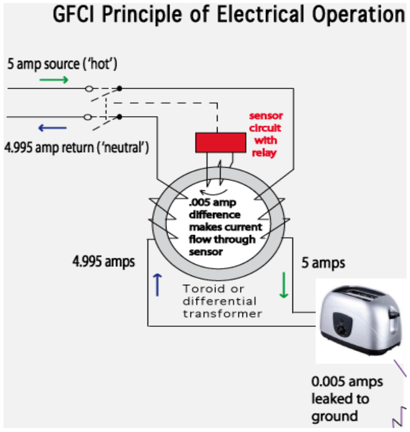


Physics 10-08 Transformers and Electrical Safety Name: ___________________________

Circuit Breaker

- If the current load gets too ______________, an __________________ pulls a ______________ to stop the current
- Stops wires from getting ______________ in ______________ circuits

Ground Fault Interrupter



- Both sides (hot and neutral) are wrapped around a metal ______________ like a __________________, but the number of loops are ______________
- Normally the induced current is _________ since the two sides ______________
- If an ______________ occurs (like current going through a person to the ground), an ______________________ pulls a ______________

Homework

1. Explain what causes physical vibrations in transformers at twice the frequency of the AC power involved.
2. Does plastic insulation on live/hot wires prevent shock hazards, thermal hazards, or both?
3. Why are ordinary circuit breakers and fuses ineffective in preventing shocks?
4. A plug-in transformer supplies 9.00 V to a video game system. (a) How many turns are in its secondary coil, if its input voltage is 120 V and the primary coil has 400 turns? (b) What is its input current when its output is 1.30 A? (OpenStax 23.44) $\mathbf{30.0, 9.75 \times 10^{-2}\ A}$
5. An American traveler in New Zealand carries a transformer to convert New Zealand's standard 240 V to 120 V so that she can use some small appliances on her trip. (a) What is the ratio of turns in the primary and secondary coils of her transformer? (b) What is the ratio of input to output current? (c) How could a New Zealander traveling in the United States use this same transformer to power her 240 V appliances from 120 V? (OpenStax 23.45) **2.00, 0.500**
6. A cassette recorder uses a plug-in transformer to convert 120 V to 12.0 V, with a maximum current output of 200 mA. (a) What is the current input? (b) What is the power input? (c) Is this amount of power reasonable for a small appliance? (OpenStax 23.46) **20.0 mA, 2.40 W, yes**
7. (a) What is the voltage output of a transformer used for rechargeable flashlight batteries, if its primary has 500 turns, its secondary 4 turns, and the input voltage is 120 V? (b) What input current is required to produce a 4.00 A output? (c) What is the power input? (OpenStax 23.47) **0.96 V, 32.0 mA, 3.84 W**
8. (a) The plug-in transformer for a laptop computer puts out 7.50 V and can supply a maximum current of 2.00 A. What is the maximum input current if the input voltage is 240 V? Assume 100% efficiency. (b) If the actual efficiency is less than 100%, would the input current need to be greater or smaller? Explain. (OpenStax 23.48) **0.063 A, greater**

Inductance

- _______________ is process where _______________ is induced by changing magnetic _______________

Mutual Inductance

- Mutual inductance is _______________ of one _______________ to _______________ like a transformer
  - Change in _______________ usually by changing _______________ since they are solid pieces
  - Can be reduced by ______________________________ coils

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

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

Self-inductance

- A changing _______________ in a coil causes a changing _______________ in _______________ of coil
- Changing B-field causes _______________ emf in the _______________ coil
- Resists _______________ in _______________ in the device

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

  - Where L = self-inductance, (Unit: H (henry))
- Self-Inductance

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

- For _______________

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

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

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?

Energy stored in an inductor

$$E_{ind} = \frac{1}{2}LI^2$$

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

Homework

1. How would you place two identical flat coils in contact so that they had the greatest mutual inductance? The least?
2. How would you shape a given length of wire to give it the greatest self-inductance? The least?
3. Two coils are placed close together in a physics lab to demonstrate Faraday's law of induction. A current of 5.00 A in one is switched off in 1.00 ms, inducing a 9.00 V emf in the other. What is their mutual inductance? (OpenStax 23.55) **1.80 mH**
4. If two coils placed next to one another have a mutual inductance of 5.00 mH, what voltage is induced in one when the 2.00 A current in the other is switched off in 30.0 ms? (OpenStax 23.56) **0.333 V**
5. A device is turned on and 3.00 A flows through it 0.100 ms later. What is the self-inductance of the device if an induced 150 V emf opposes this? (OpenStax 23.58) **5.00 mH**
6. Camera flashes charge a capacitor to high voltage by switching the current through an inductor on and off rapidly. In what time must the 0.100 A current through a 2.00 mH inductor be switched on or off to induce a 500 V emf? (OpenStax 23.60) $\mathbf{4.00 \times 10^{-7}}$ **s**
7. A large research solenoid has a self-inductance of 25.0 H. (a) What induced emf opposes shutting it off when 100 A of current through it is switched off in 80.0 ms? (b) How much energy is stored in the inductor at full current? (c) At what rate in watts must energy be dissipated to switch the current off in 80.0 ms? (d) In view of the answer to the last part, is it surprising that shutting it down this quickly is difficult? (OpenStax 23.61) **31.3 kV,** $\mathbf{1.25 \times 10^{5}}$ **J, 1.56 MW, no**
8. (a) Calculate the self-inductance of a 50.0 cm long, 10.0 cm diameter solenoid having 1000 loops. (b) How much energy is stored in this inductor when 20.0 A of current flows through it? (c) How fast can it be turned off if the induced emf cannot exceed 3.00 V? (OpenStax 23.62) **19.7 mH, 3.95 J, 0.132 s**
9. A precision laboratory resistor is made of a coil of wire 1.50 cm in diameter and 4.00 cm long, and it has 500 turns. (a) What is its self-inductance? (b) What average emf is induced if the 12.0 A current through it is turned on in 5.00 ms (one-fourth of a cycle for 50 Hz AC)? (c) What is its inductance if it is shortened to half its length and counterwound (two layers of 250 turns in opposite directions)? (OpenStax 23.63) **1.39 mH, -3.33 V, 0**
10. The heating coils in a hair dryer are 0.800 cm in diameter, have a combined length of 1.00 m, and a total of 400 turns. (a) What is their total self-inductance assuming they act like a single solenoid? (b) How much energy is stored in them when 6.00 A flows? (c) What average emf opposes shutting them off if this is done in 5.00 ms (one-fourth of a cycle for 50 Hz AC)? (OpenStax 23.64) $\mathbf{1.01 \times 10^{-5}}$ **H,** $\mathbf{1.82 \times 10^{-4}}$ **J, 12.12 mV**

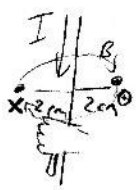
Physics

Unit 10: Magnetism

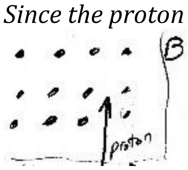
1. *Know the fundamental properties of permanent magnets.*
2. *Know how to induce emf.*
3. *Know the RHR's, and Lenz's Law.*
4. *A solenoid that is 2 m long and has a diameter of 0.5 m has 150 turns. Find the magnitude and direction of the magnetic field at the center of the solenoid if the current is 5 A clockwise.*
5. *A straight wire carries 5 A of current. If the wire is vertical and the current runs down, find the magnitude and direction of the magnetic field 2 cm from the wire.*
6. *A loose proton enters a magnetic field whose direction is coming out of the page. What does its path look like? If the path is bent, what way does it bend?*
7. *The path of a charged particle is bent clockwise in a magnetic field that is pointed out of the page. What is sign of the charge of the particle?*
8. *The force on a 3 cm wire that carries 10 A is 0.051 N. The wire is in a 0.5 T magnetic field. What is the angle between the wire and the magnetic field?*
9. *A current goes down and the magnetic field points to the right. What is the direction of the force on the wire carrying the current?*
10. *A single circular loop of wire is in a 0.5 T B-field. The normal makes an angle of 30° with the B-field. If there is a 5 A current in the loop (r = 5 cm), what is the torque on the loop?*
11. *Two wires are side by side and very close to each other. One wire carries 2 A and the other 3A in the same direction. What is magnetic field 5 cm from the wires?*
12. *A circular loop of wire (r = 5 cm) is in a magnetic field (B = 0.5 T) with the normal of the loop parallel to the B-field. The B-field increases at a rate of 0.1 T/s. What is the induced emf in the loop? What direction would a current flow through the loop?*
13. *A transformer's primary coil has 160 turns and 240 V. How many turns are needed in the secondary coil to get 80 V? Is this a step-up or step-down transformer?*
14. *A solenoid with 10 turns has a cross-sectional area of 2.0 cm^2 and length of 5 cm. How much energy is stored in the magnetic field of the solenoid when it carries a current of 5.0 A?*
15. *Two coils share a common axis. The mutual inductance of this pair of coils is 10.0 mH. If the current in coil **1** is changing at the rate of 10 A/s, what is the magnitude of the emf generated in coil **2**?*

4. $L = 2\ m, d = 0.5\ m, N = 150, I = 5\ A$
$B = \mu_0 n I;\ n = \frac{N}{L} = \frac{150}{2\ m} = 75\ m^{-1}$
$B = \left(4\pi \times 10^{-7} \frac{Tm}{A}\right)(75\ m^{-1})(5\ A) =$
$\mathbf{4.71 \times 10^{-4}\ T}$
*RHR says points **into paper***

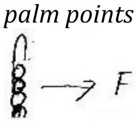
5. $I = 5\ A, r = 0.02\ m$
$B = \frac{\mu_0 I}{2\pi r}$
$B = \frac{\left(4\pi \times 10^{-7} \frac{Tm}{A}\right)(5\ A)}{2\pi (0.02\ m)} = \mathbf{5 \times 10^{-5}\ T}$
Goes in on left, out on right



6. *Since the proton is charged, the path is bent.*

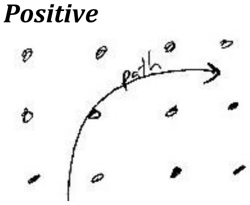


RHR – fingers
- thumb in direction of v
- palm points in direction of F



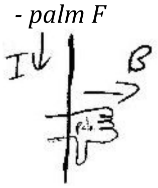
***Bends to clockwise** (electron would bend counterclockwise)*

7. ***Positive***



8. $L = 0.03\ m,\ I = 10\ A, F = 0.051\ N, B = 0.5\ T$
$F = ILB \sin\theta$
$0.051\ N = (10\ A)(0.03\ m)(0.5\ T) \sin\theta$
$0.34 = \sin\theta$
$\boldsymbol{\theta = 19.9°}$

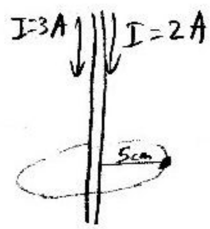
9. *RHR – fingers B*
- thumb I
- palm F



F is out of page

10. $N = 1, B = 0.5\ T,\ \theta = 30°,\ I = 5\ A, r = 0.05\ m$
$\tau = NIAB \sin\theta$
$\tau = 1(5\ A)(\pi(0.05\ m)^2)(0.5\ T) \sin 30° =$
$\mathbf{0.00982\ Nm}$

11. *Ampere's Law*



$\Sigma B \cdot \Delta\ell = \mu_0 I$
$B(2\pi r) = \mu_0 I$
$B(2\pi 0.05\ m) = \left(4\pi \times 10^{-7} \frac{Tm}{A}\right)(3\ A + 2\ A)$
$B(0.31416\ m) = 6.2832 \times 10^{-6}\ Tm$
$\mathbf{B = 2 \times 10^{-5}\ T}$

12. $N = 1, r = 0.05\ m, B = 0.5\ T, \frac{\Delta B}{\Delta t} = 0.1 \frac{T}{s}$
$emf = -N \frac{\Delta\Phi}{\Delta t}, \Phi = BA \cos\theta$
$emf = -1 \cdot \frac{B_f A \cos 0 - B_0 A \cos 0}{\Delta t}$
$emf = -\left(\frac{A(B_f - B_0)}{\Delta t}\right)$
$emf = -\left(A \frac{\Delta B}{\Delta t}\right)$
$emf = -(\pi(0.05\ m)^2)\left(0.1 \frac{T}{s}\right) = \mathbf{-7.85 \times 10^{-4}\ V}$
Flux is getting stronger so induced B-field should cancel the original B-field.
RHR – curl your fingers through the loop in the direction of the induced B-field. Your thumb will point the direction of the current.

13. $N_p = 160, V_p = 240\ V, V_s = 80\ V$
$\frac{V_s}{V_p} = \frac{N_s}{N_p}$
$\frac{80\ V}{240\ V} = \frac{N_s}{160}$
$N_s = 53.3$
***54 turns; Step-down** since V decreases.*

14. $L = \frac{u_0 N^2 A}{\ell}$
$$L = \frac{\left(4\pi \times 10^{-7} \frac{Tm}{A}\right)(10)^2(0.0002\ m^2)}{0.05\ m}$$
$$= 5.0265 \times 10^{-7}\ H$$
$$E_{ind} = \frac{1}{2} L I^2$$
$$E_{ind} = \frac{1}{2}(5.0265 \times 10^{-7}\ H)(5\ A)^2$$
$$= \mathbf{6.28 \times 10^{-6}\ J}$$

15. $emf_1 = -M \frac{\Delta I_2}{\Delta t}$
$emf_1 = -(0.010\ H)\left(10 \frac{A}{s}\right) = \mathbf{-0.100\ V}$