

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

### 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.

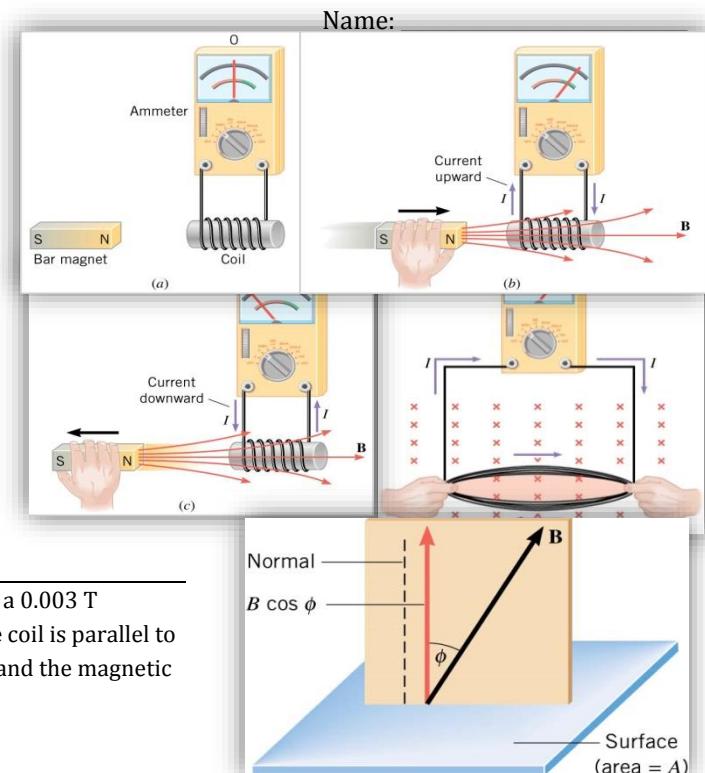
Magnetic Flux through a surface

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

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

- 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,  $\Phi$  = 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

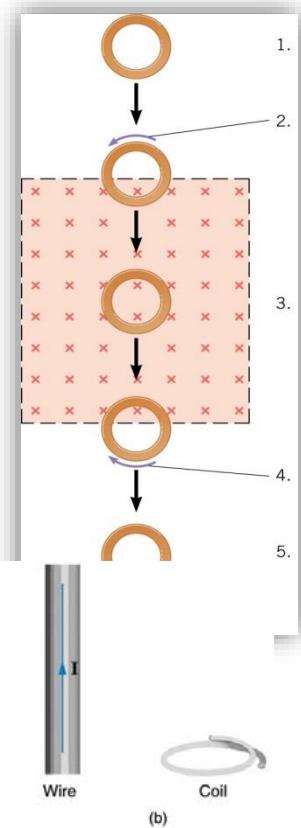
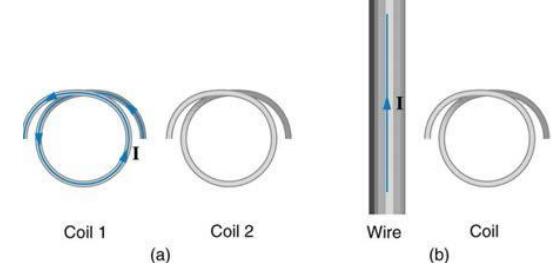
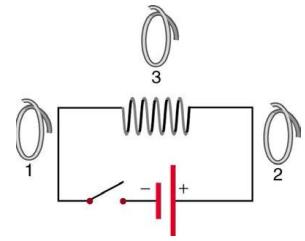
- Determine whether the magnetic flux is \_\_\_\_\_ or \_\_\_\_\_.

- 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

- Explain how magnetic flux can be zero when the magnetic field is not zero.
- 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.
- What is the value of the magnetic flux at coil 2 in Figure 1(a) due to coil 1? (OpenStax 23.1) **0**
- What is the value of the magnetic flux through the coil in Figure 1(b) due to the wire? (OpenStax 23.2) **0**
- 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**
- 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**
- 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**
- Repeat the previous problem with the battery reversed. (OpenStax 23.6) **CW, CW, CCW; no, no, no; CCW, CCW, CW**
- 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  $0.250 \text{ m}^2$ . It is stretched to have no area in  $0.100 \text{ s}$ . What is the direction and magnitude of the induced emf if the uniform magnetic field has a strength of  $1.50 \text{ T}$ ? (OpenStax 23.8) **188 V CW**
- (a) An MRI technician moves his hand from a region of very low magnetic field strength into an MRI scanner's  $2.00 \text{ T}$  field with his fingers pointing in the direction of the field. Find the average emf induced in his wedding ring, given its diameter is  $2.20 \text{ cm}$  and assuming it takes  $0.250 \text{ s}$  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**
- Referring to the situation in the previous problem: (a) What current is induced in the ring if its resistance is  $0.0100 \Omega$ ? (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,  $1.74 \times 10^{-5} \text{ T}$ , CCW**
- A  $0.250 \text{ m}$  radius, 500-turn coil is rotated one-fourth of a revolution in  $4.17 \text{ ms}$ , originally having its plane perpendicular to a uniform magnetic field. (This is  $60 \text{ rev/s}$ .) Find the magnetic field strength needed to induce an average emf of  $10,000 \text{ V}$ . (OpenStax 23.12) **0.425 T**
- (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  $1.00 \text{ m}$  diameter loop  $50.0 \text{ m}$  from a  $2.00 \times 10^6 \text{ A}$  lightning strike, if the current falls to zero in  $25.0 \mu\text{s}$ ? (b) Discuss circumstances under which such a voltage would produce noticeable consequences. (OpenStax 23.14) **251 V**

**Figure 1****Figure 2****Figure 3**