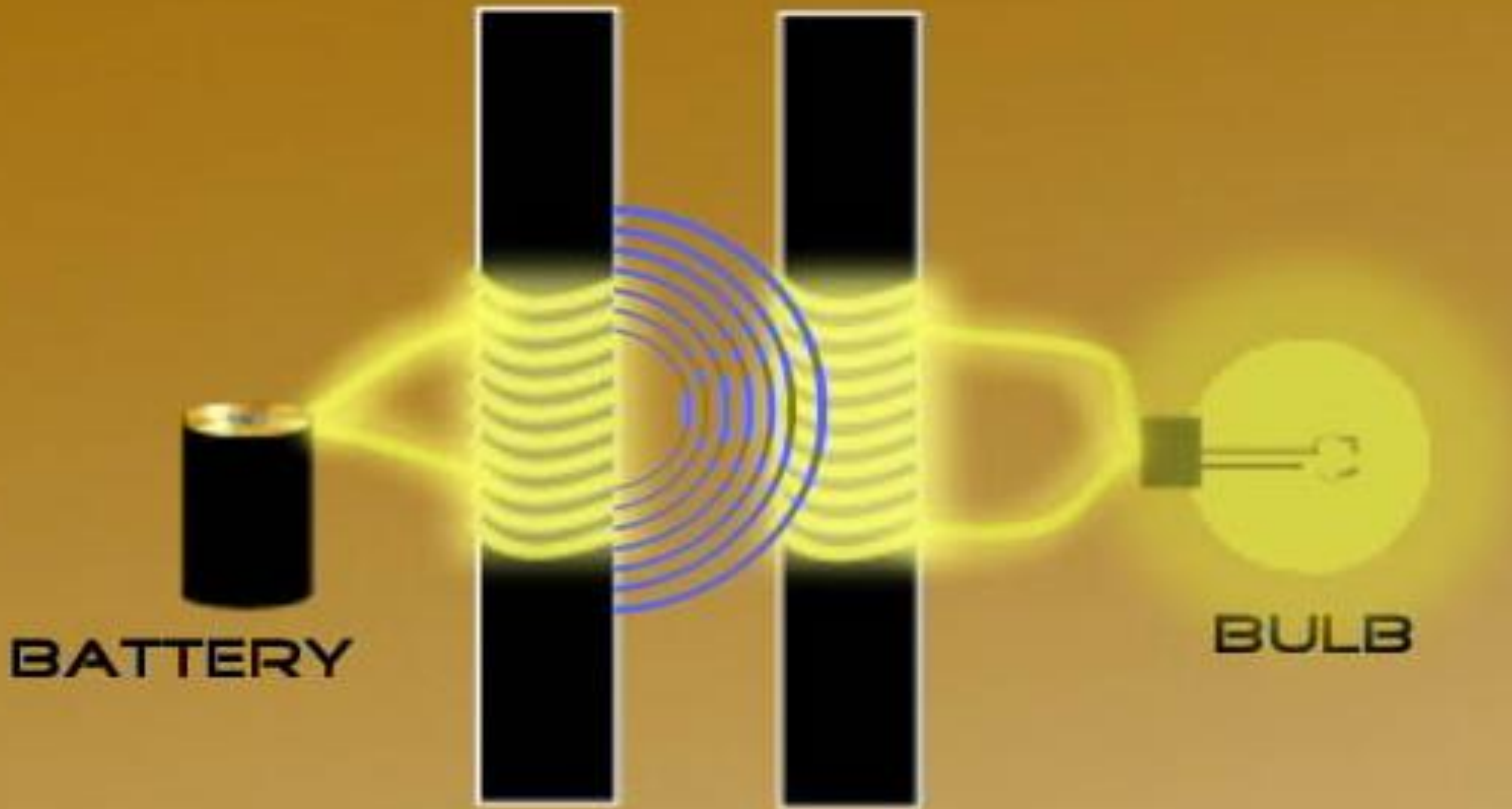
ELECTROMAGNETIC INDUCTION

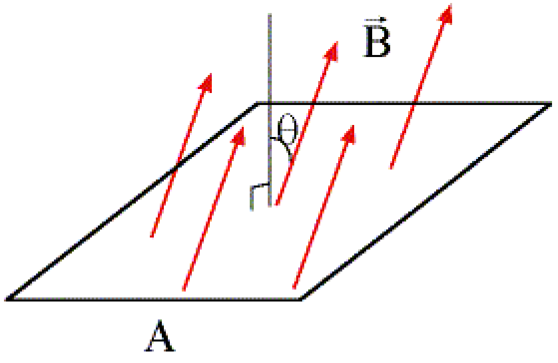


Magnetic Flux

- Recall: when you put a loop of wire in a magnetic field it will rotate until the magnetic moment (the vector normal to area) is aligned with the field.
- The degree of alignment with the field is measured using magnetic flux Φ_B:

$$\Phi_B \equiv \left|\vec{B}\right| A \cos\theta$$

- Magnetic flux tells us how much field is passing through the loop given the angle between field and normal
- Magnetic flux is measured in Tm^2



Faraday’s Law

- Principle of EM induction: A change in the magnetic flux through a loop produces an a induced ‘EMF’ or **electromotive force** (voltage) $\mathcal{E}$ and therefore an induced current in the loop is given by **Faraday’s Law**:

$$\mathcal{E} = -N\left|\frac{\Delta\Phi_B}{\Delta t}\right|$$

- The minus sign tells us that the induced emf would be created so that its own field points in a direction opposite to the change in the field causing it in the first place. (Lenz’s Law; coming up shortly)
- Simulation: http://phet.colorado.edu/en/simulation/faraday

Example

- For a coil with $N = 2, A = 0.0050\ \mathrm{m}^2,\ |B|_i = 0.010\ \mathrm{T}, \theta = 0°$, the field changes to $|B|_f = 0.030\ \mathrm{T}$ still in the same direction. What's the resulting emf $\mathcal{E}$ if the change took one second? $\mathcal{E} = -N\left|\frac{\Delta\Phi_B}{\Delta t}\right|$

$$\Delta\Phi_B = \Phi_f - \Phi_i$$

$$\Phi_i = |B|_i A_i \cos\theta_i = (0.010\ \mathrm{T})(0.0050\ \mathrm{m}^2)\cos 0 = 5.0 \times 10^{-5} Tm^2$$

$$\Phi_f = |B|_f A_f \cos\theta_f = (0.030\ \mathrm{T})(0.0050\ \mathrm{m}^2)\cos 0$$
$$= 15.0 \times 10^{-5}\mathrm{Tm}^2$$

$$\Delta\Phi_B = 1.0 \times 10^{-4}\mathrm{Tm}^2$$

$$\mathcal{E} = -N\left|\frac{\Delta\Phi_B}{\Delta t}\right| = -2 \times \left(\frac{1.0 \times 10^{-4} Tm^2}{1\ s}\right) = -2.0 \times 10^{-4}\mathrm{V}$$

Quickuiz

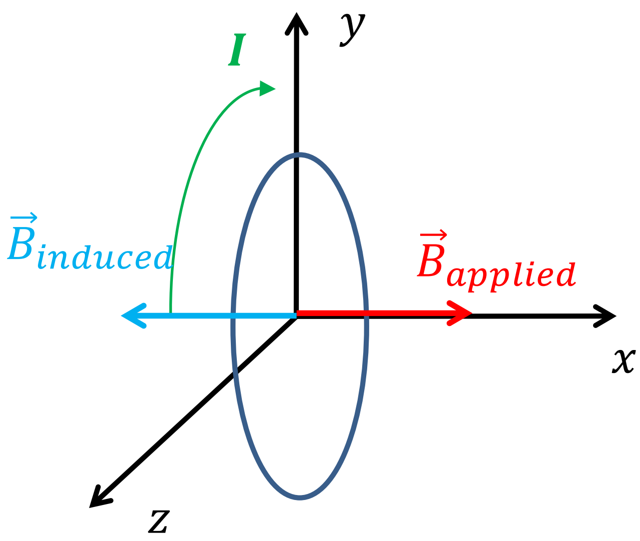
A uniform magnetic field points in the $+x$ direction. A circular coil of wire lies in the yz-plane. The uniform magnetic field increases in magnitude by 10%, still pointing in the $+x$ direction. The magnetic flux through the coil changes, and Faraday's Law of induction states that there will be an induced emf (voltage) and induced current in the coil. The induced current flows clockwise as viewed from $+x$, what direction will the magnetic field produced by the current point, according to RH Rule #2?

A. $+x$ direction

B. $+y$ direction

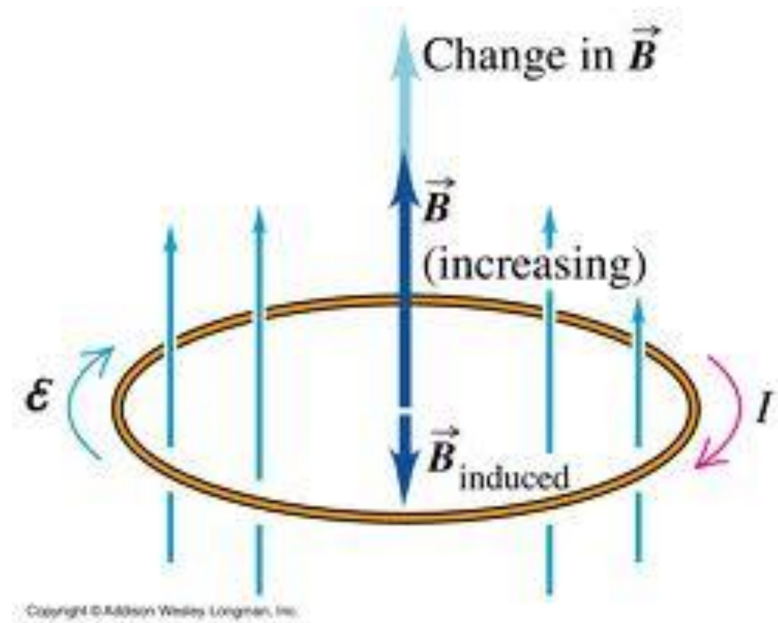
C. $-x$ direction

D. $-y$ direction



Lenz's Law

- <u>Lenz's Law</u>: The direction of the induced emf and induced current will be such as to produce a magnetic field which opposes the original change in magnetic flux
- This is needed to prevent a violation of the conservation of energy!



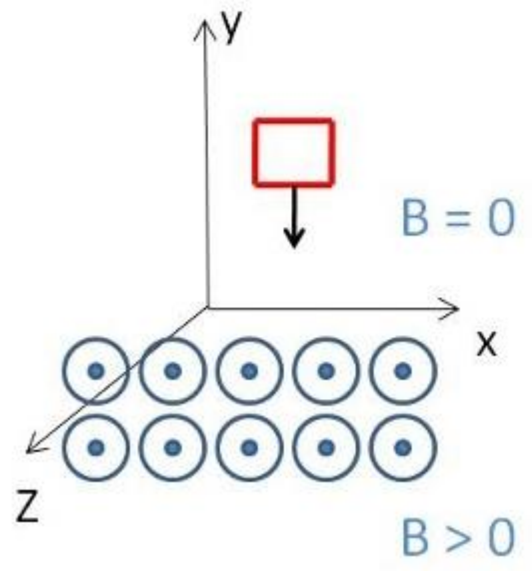
Quickuiz

Consider a rectangular loop of wire falling in the negative-y direction. The magnetic field is $B = 0$ for all points $y > 0$, and is uniform and points in the positive-z direction for all points $y < 0$, as shown in the diagram. If the falling rectangular loop is entirely within the region $y > 0$ as shown, describe the current flowing in the loop as viewed from the vantage point at positive-z (i.e. your vantage point looking at the diagram).

A. Clockwise current flow

B. Counterclockwise current flow

C. No current flows in the loop



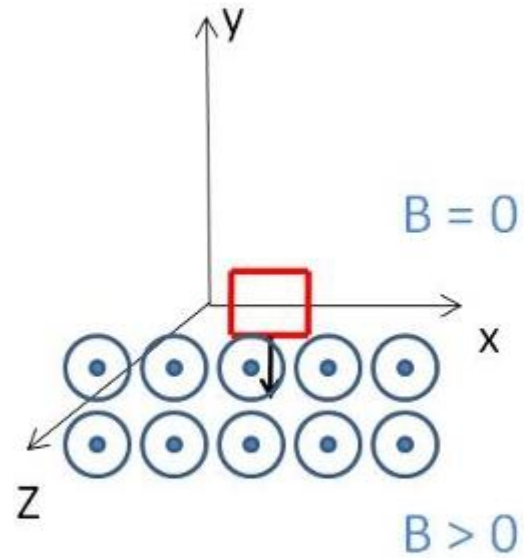
Quickuiz

The rectangular loop of wire is still falling in the negative-y direction, but is now partway in the region $y > 0$ and partway in the region $y < 0$. The magnetic field is the same as in the previous question, as shown in the diagram. Describe the current flowing in the loop as viewed from the vantage point at positive-z (i.e. your vantage point looking at the diagram).

A. Clockwise current flow

B. Counterclockwise current flow

C. No current flows in the loop



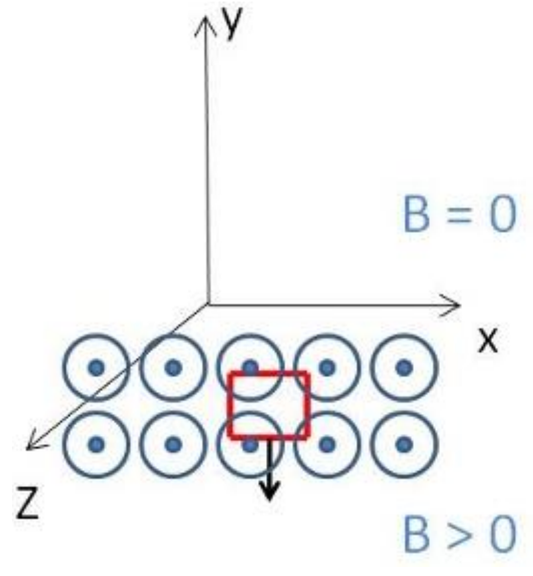
Quickuiz

The loop of wire is now entirely within the region $y < 0$, and is still falling in the $-y$ direction. The magnetic field is the same as in the previous two questions. Describe the current flowing in the loop as viewed from the vantage point at positive-z (i.e. your vantage point looking at the diagram.)

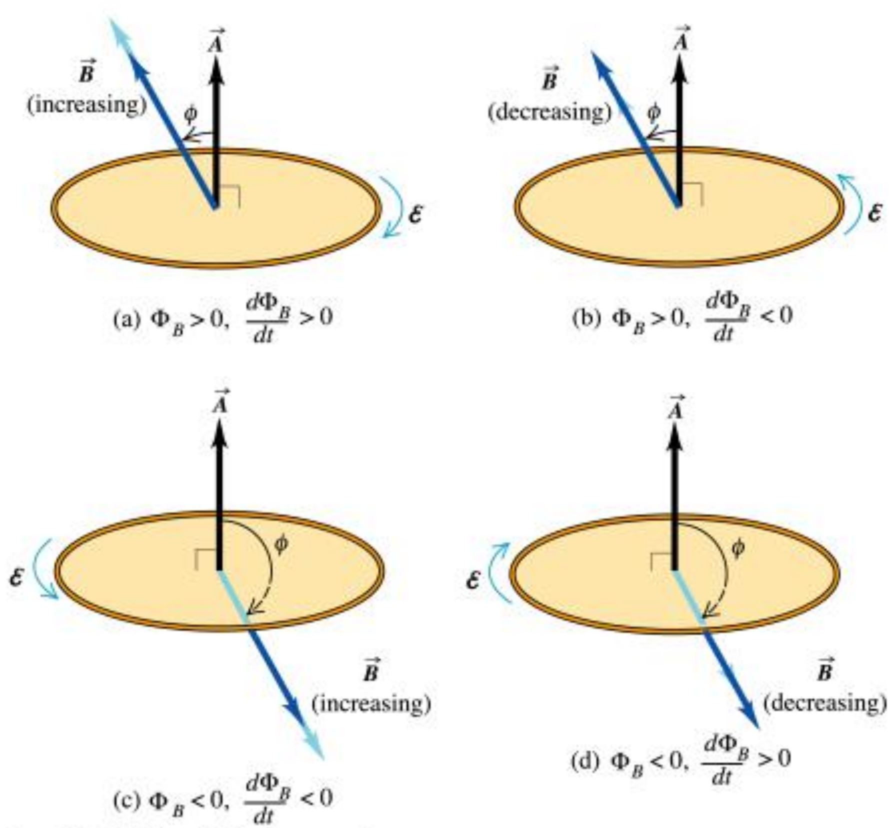
A. Clockwise current flow

B. Counterclockwise current flow

C. No current flows in the loop



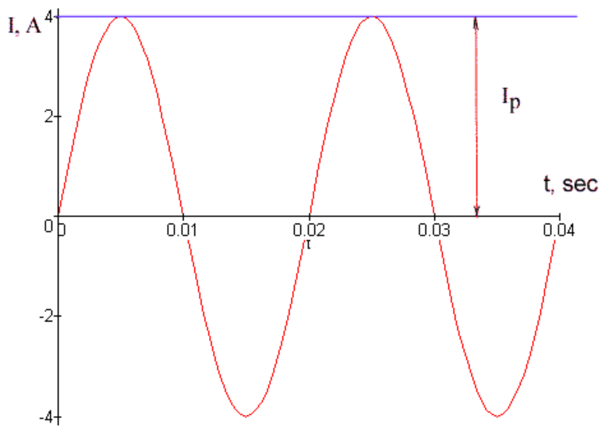
Examples

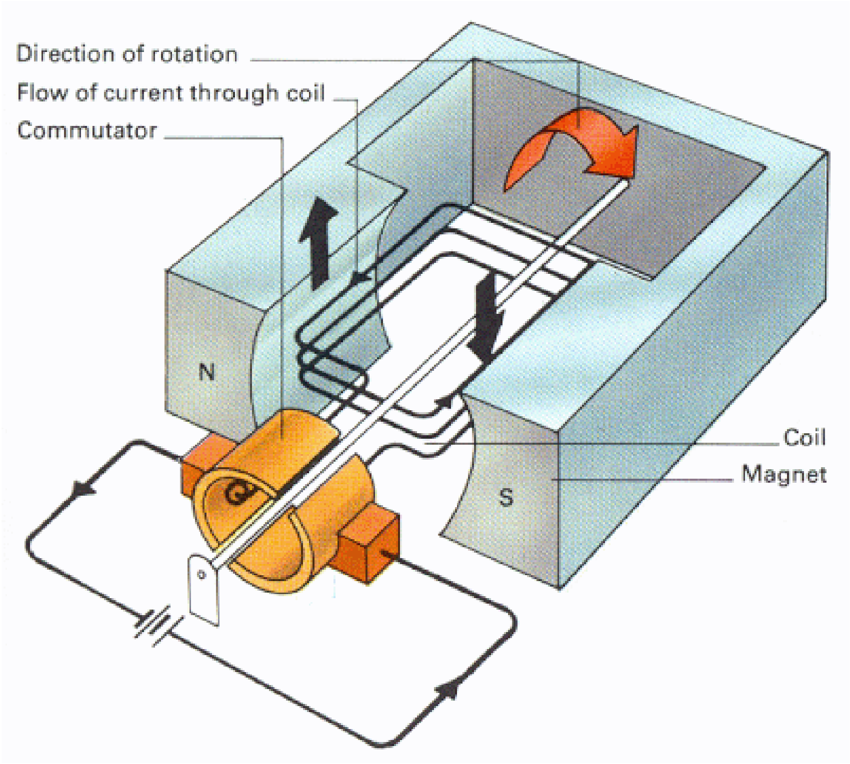


$\vec{A}$
$\vec{B}$ (increasing)
ϕ
$\mathcal{E}$
(a) $\Phi_B > 0, \ \frac{d\Phi_B}{dt} > 0$
$\vec{A}$
$\vec{B}$ (decreasing)
ϕ
$\mathcal{E}$
(b) $\Phi_B > 0, \ \frac{d\Phi_B}{dt} < 0$
$\vec{A}$
ϕ
$\mathcal{E}$
$\vec{B}$ (increasing)
(c) $\Phi_B < 0, \ \frac{d\Phi_B}{dt} < 0$
$\vec{A}$
ϕ
$\mathcal{E}$
$\vec{B}$ (decreasing)
(d) $\Phi_B < 0, \ \frac{d\Phi_B}{dt} > 0$

Applications: 1. Induction Motor

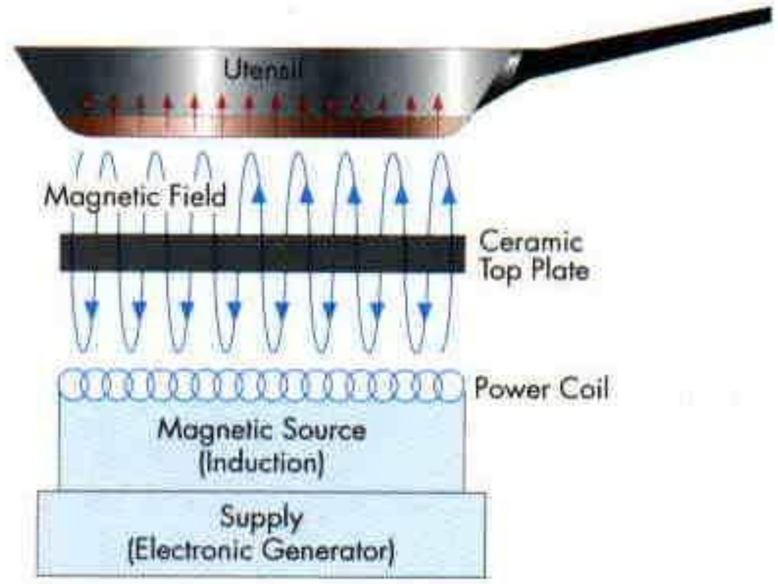
- As the coil is rotated in the magnetic field flux changes and induces current to flow in the coil
- What is the direction of the current in the coil?
- It keeps changing! This is why the power we get at home gives alternating current AC





Applications: 2. Magnetic Induction Stoves

- Magnetic induction cooking.
- The magnetic field induces an electric field in the metal of the pan.
- never use aluminum foil on it!



Electrical Resistance

- We have already seen in lab that current and potential difference (voltage) are related through Ohm's Law:

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

- where R is the resistance measured in ohms $\Omega = \mathrm{V/A}$
- Since emf ($\mathcal{E}$) is a potential difference, for a coil where flux is changing we have:

$$I_{induced} = \frac{\mathcal{E}}{R} = -\frac{N}{R}\left|\frac{\Delta\Phi_B}{\Delta t}\right|$$