Physics 1B
Electricity & Magnetism

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Outline of today

- Start Chapter 23

Magnetic Flux

- When we discussed Gauss' Law for electrostatics we used electric flux, Φ_E, through a closed Gaussian surface.

$$\Phi_E = EA\cos\theta$$

There is a corresponding magnetic flux, Φ_B, through a given area.

But with magnetic flux the area will not be a closed surface but rather an open surface.

The SI unit for magnetic flux is the Weber.

$$\boxed{1\ \text{Weber (Wb)} = 1\ \text{T}\cdot\text{m}^2}$$

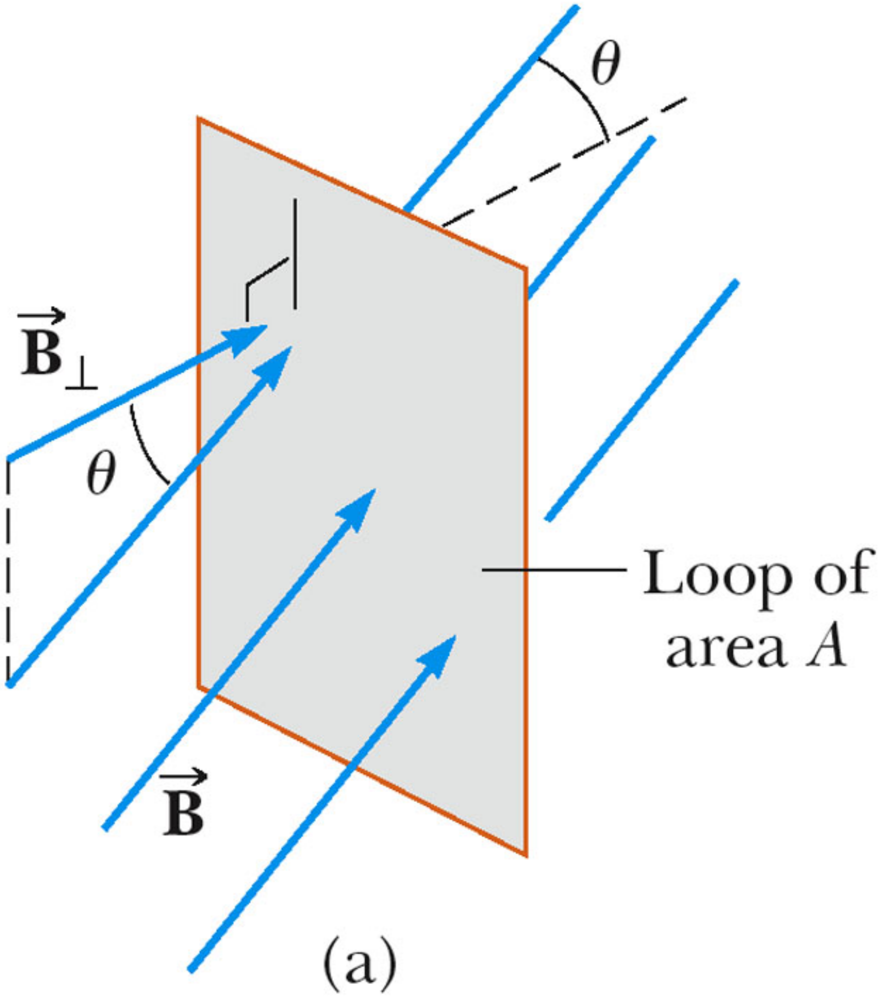
Magnetic Flux

- Let' s say you have a wire loop, of area A, that is immersed in a uniform magnetic field, B.
- The flux will be defined as:

$$\boxed{\Phi_B = B_{\perp} A = BA\cos\theta}$$

where θ is the angle between B and the normal to the plane of area.

In short, magnetic flux is how much magnetic field flows through a given area.



Faraday's Law

- <u>An interesting natural phenomenon:</u>
- A closed conductor will physically react to a changing magnetic flux and oppose the change.
- When the magnetic flux through a closed conductor changes, a current will become induced to oppose the change.
- This was discovered by Michael Faraday in 1820.
- He wrote a law (Faraday's Law) to summarize his findings:
- The induced emf, ε, in a closed wire is equal to the time rate of change of the magnetic flux, Φ_B.

Faraday's Law

- Mathematically, this becomes:

$$\boxed{\mathcal{E} = -\frac{\Delta\Phi_B}{\Delta t}}$$

The induced emf (in Volts) will induce a current to flow through the closed conductor.

If instead of one loop, there are N loops in the closed conductor, then Faraday's Law becomes:

$$\boxed{\mathcal{E} = -N\frac{\Delta\Phi_B}{\Delta t}}$$

What can produce a change in magnetic flux?

A change in area, A, of the conductor.

A change in the magnetic field, B.

A change in the angle, θ .

Lenz's Law

- The direction of the current flow will be given by Lenz's Law, which states:
- An induced emf, ε, always gives rise to a current whose magnetic field opposes the original change in magnetic flux.
- Lenz's Law explains the negative sign in Faraday's Law.
- It tells us which direction the emf will point (essentially the emf's polarity).
- Basically, Faraday's Law and Lenz's Law both state that a loop of wire will want its magnetic flux to remain constant.

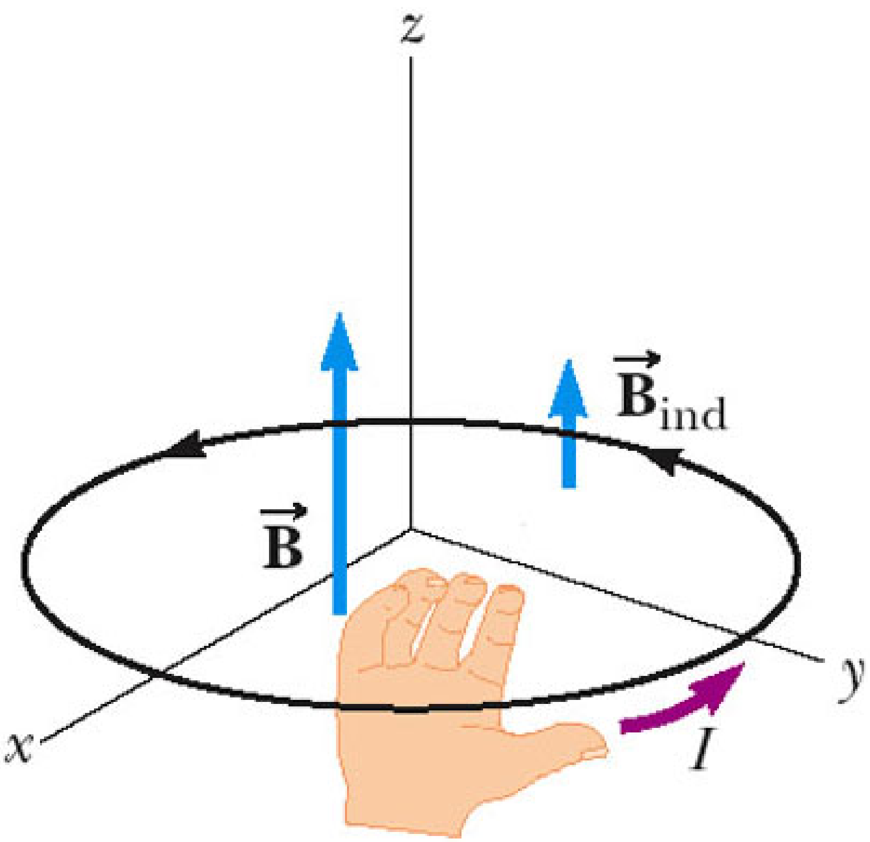
Lenz' s Law

- For example, let' s say we have a wire loop located in the xy plane that is immersed in an external magnetic field that points in the +z direction.

If the magnetic field were to suddenly decrease which direction will a current be induced?

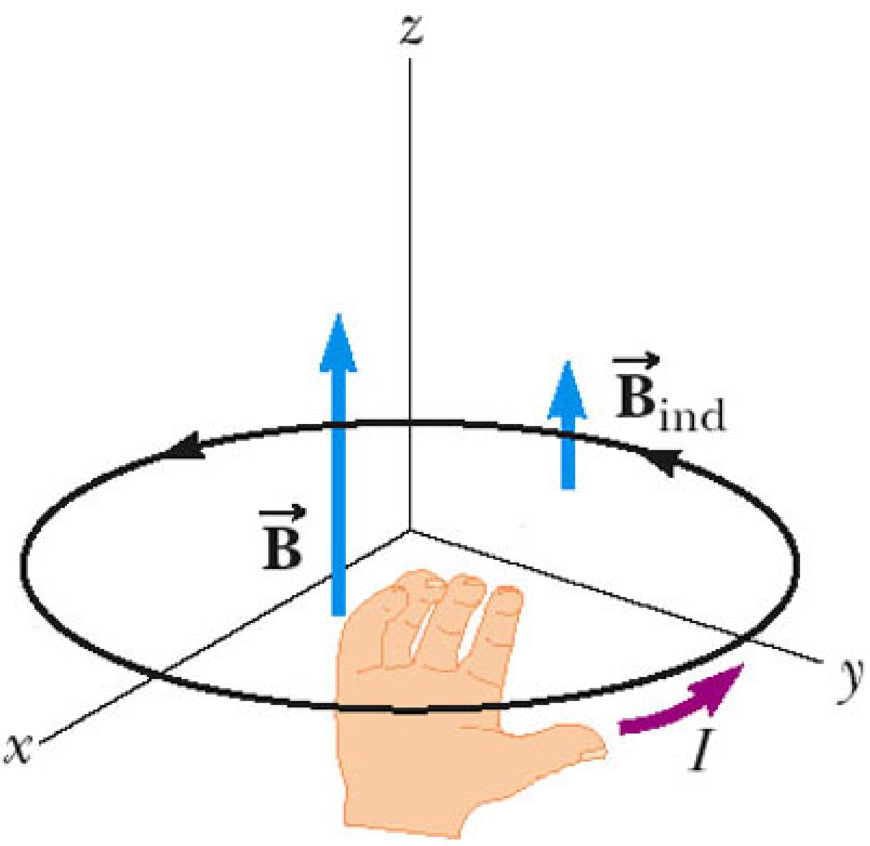
The wire loop wants the magnetic flux to remain constant.

As the external B field decreases, the wire loop will induce a current that creates a magnetic field which aids the original magnetic field.



Lenz’s Law

- To find the direction of the induced current, turn to RHR2.
- The direction of the induced magnetic field caused by this induced current must also point in the +z direction inside the loop.



This means that the induced current must move in the counterclockwise direction, when viewed from above.

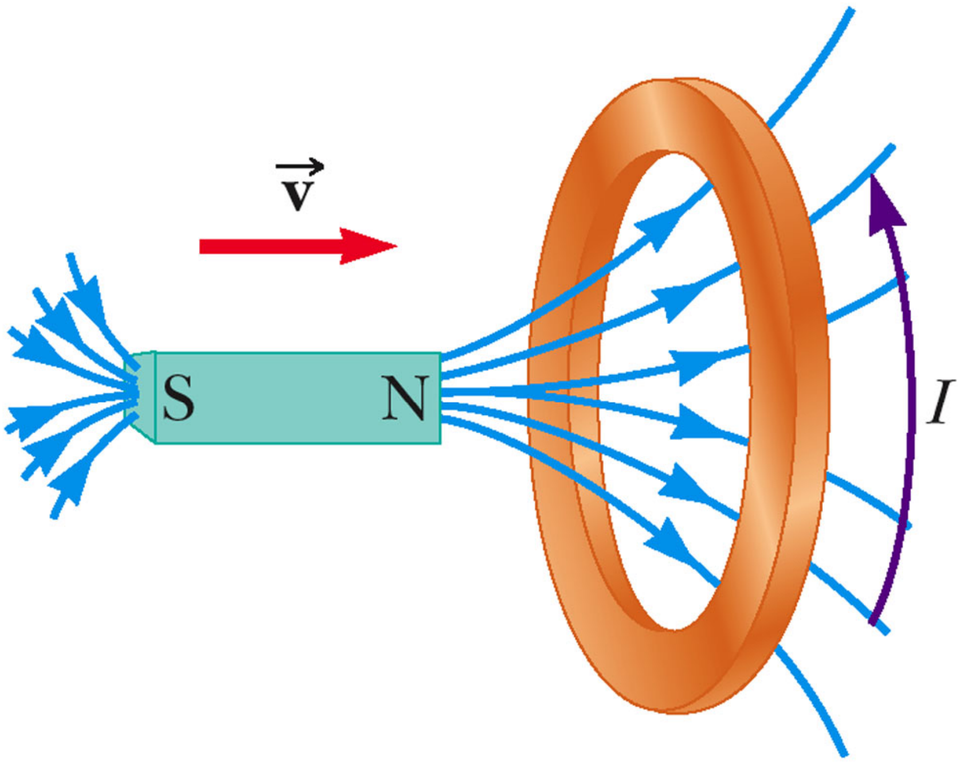
This is how you apply Lenz’s Law.

Lenz’s Law

- The tricky part of Lenz’s Law is that there are two magnetic fields to consider:
- The external magnetic field (which may or may not be changing) which is inducing the current in the conducting loop.

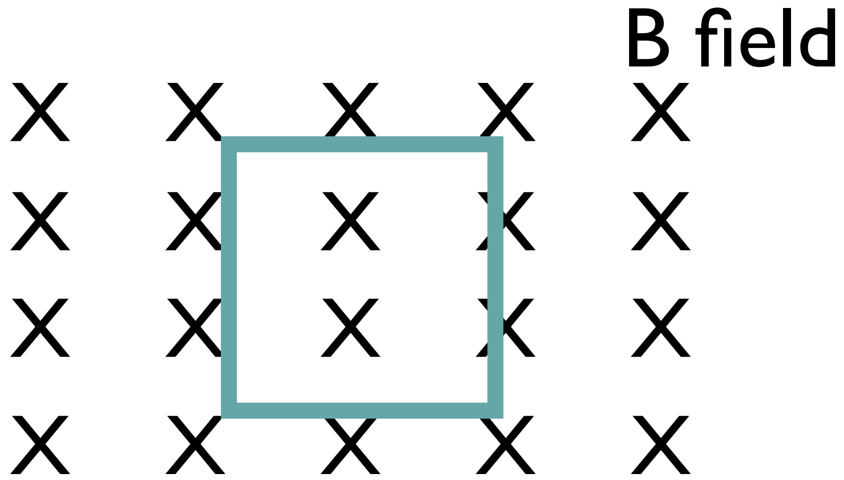
The induced magnetic field produced by the induced current in the loop.

These two magnetic fields may or may not point in the same direction (depending on the situation).



Faraday’ s Law

- Example
- A square coil (with each side 5.0cm) contains 100 loops of wire and is positioned perpendicular to a uniform 0.60T magnetic field. It is quickly removed from the magnetic field. It takes 0.10s for the whole coil to reach a field-free region. How much power is dissipated in the coil if its resistance is 100Ω?



Answer

First, you must define a coordinate system.

Here we must define the normal for the coil, we say that it is parallel to the magnetic field (into the board).

Answer

Faraday' s Law

This is a direct application of Faraday' s Law:

$$\boxed{\mathcal{E} = -N\frac{\Delta\Phi_B}{\Delta t}}$$

We already have been given N and Δ t, so we need to find Δ Φ B.

Initially, Φ B is:

$$\boxed{\Phi_B = BA\cos\theta = (0.60\mathrm{T})(0.05\mathrm{m})^2\cos 0^\circ}$$

$$\boxed{\Phi_B = 1.5\times 10^{-3}\,\mathrm{Wb}}$$

Finally, Φ B is zero, since the wire has no magnetic field lines moving through it.

$$\boxed{\Delta\Phi_B = \Phi_{B,final} - \Phi_{B,initial} = 0 - 1.5\times 10^{-3}\,\mathrm{Wb} = -1.5\times 10^{-3}\,\mathrm{Wb}}$$

Faraday's Law

Answer

The induced emf will be:

$$\mathcal{E} = -N\frac{\Delta\Phi_B}{\Delta t} = -(100)\frac{-1.5\times10^{-3}\,\mathrm{Wb}}{0.1\mathrm{s}}$$

$$\mathcal{E} = 1.5\ \mathrm{Volts}$$

By Ohm's Law we can find the induced current through the wire loop.

$$\mathcal{E} = \Delta V = IR$$

$$I = \frac{\mathcal{E}}{R} = \frac{1.5\mathrm{V}}{100\Omega} = 1.5\times10^{-2}\,\mathrm{A}$$

We can then find the power dissipated by:

$$P_{dis} = I^2R$$

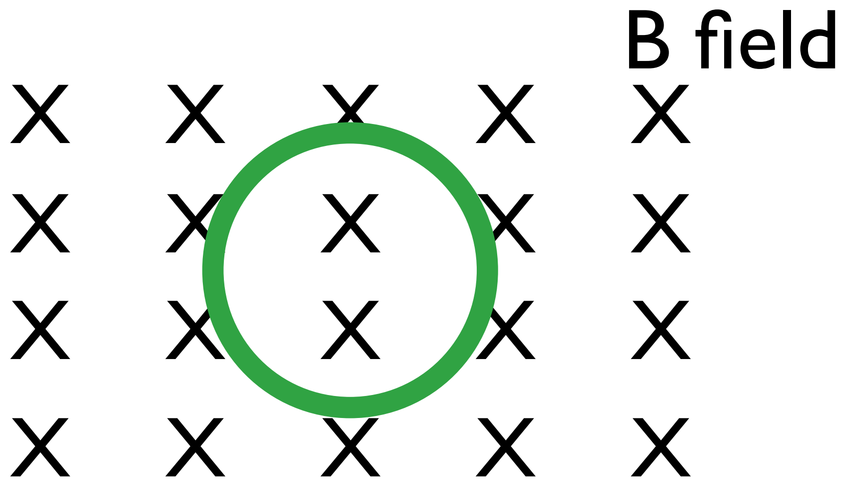
$$P_{dis} = \left(1.5\times10^{-2}\,\mathrm{A}\right)^2(100\Omega) = 2.3\times10^{-2}\,\mathrm{W}$$

Faraday's Law

- The wire loop dissipated power in the last example.
- This power goes into resistive heating.
- Does this violate conservation of energy? Where did this power come from?
- The power was supplied by whatever was pulling the loop out of the magnetic field.
- The loop does not want to have its magnetic flux change, so it will oppose whatever force tries to pull it out of the magnetic field.
- The force that pulls the loop out of the magnetic field performs work (ΔE).

Concept Question

- A circular coil of wire is positioned perpendicular to an external magnetic field that is directed into the board. The magnitude of the external magnetic field is then increased. What direction in the wire will the resulting induced current be?



A) Clockwise.

B) Counterclockwise.

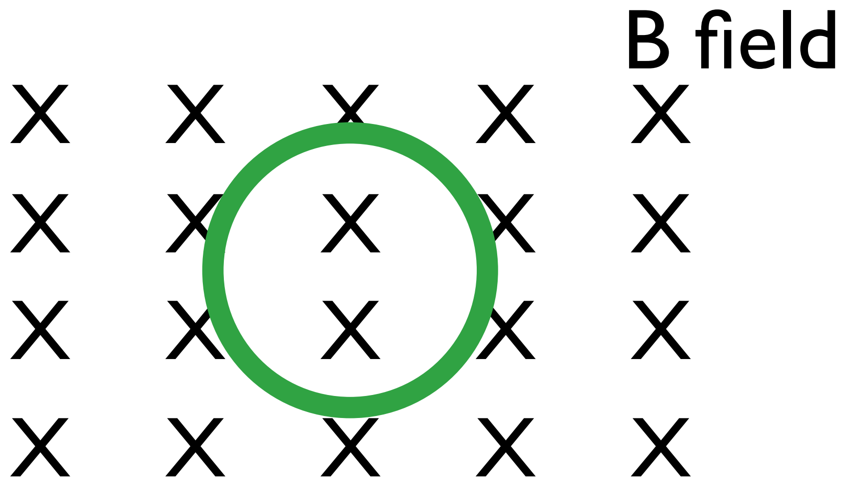
C) Out of the board.

D) Into the board.

E) There will be no current induced in the wire.

Concept Question

- A circular coil of wire is positioned perpendicular to an external magnetic field that is directed into the board. The area of the circular coil is then suddenly decreased. What direction in the wire will the resulting induced current be?



A) Clockwise.

B) Counterclockwise.

C) Out of the board.

D) Into the board.

E) There will be no current induced in the wire.

For Next Time (FNT)

Continue reading Chapter 23

Start working on the homework for Chapter 23