Electricity and Magnetism
Review
Faraday's Law

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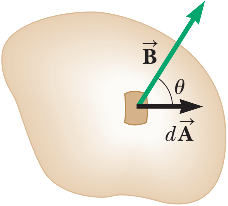
Overview

- Faraday's law
- Lenz's law
- magnetic field from a moving charge
- Gauss's law

Reminder: Magnetic Flux



Magnetic flux

The magnetic flux of a magnetic field through a surface **A** is

$$\Phi_B = \sum \mathbf{B} \cdot (\Delta \mathbf{A})$$

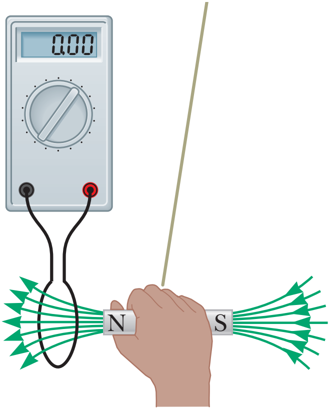
Units: Tm^2

If the surface is a flat plane and **B** is uniform, that just reduces to:

$$\Phi_B = \mathbf{B} \cdot \mathbf{A}$$

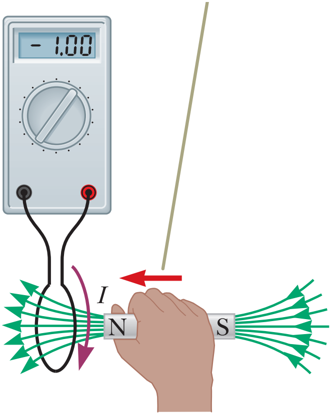
Changing flux and emf

When a magnet is at rest near a loop of wire there is no potential difference across the ends of the wire.



Changing flux and emf

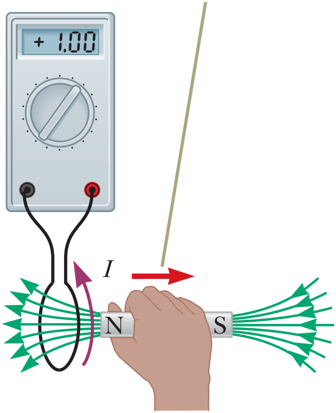
When the north pole of the magnet is moved towards the loop, the magnetic flux increases.



A current flows clockwise in the loop.

Changing flux and emf

When the north pole of the magnet is moved away from the loop, the magnetic flux decreases.



A current flows counterclockwise in the loop.

Faraday's Law

Faraday's Law

If a conducting loop experiences a changing magnetic flux through the area of the loop, an emf $\mathcal{E}_F$ is induced in the loop that is directly proportional to the rate of change of the flux, Φ_B with time.

Faraday's Law for a conducting loop:

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

Faraday's Law

Faraday's Law for a coil of N turns:

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

if Φ_B is the flux through a single loop.

Changing Magnetic Flux

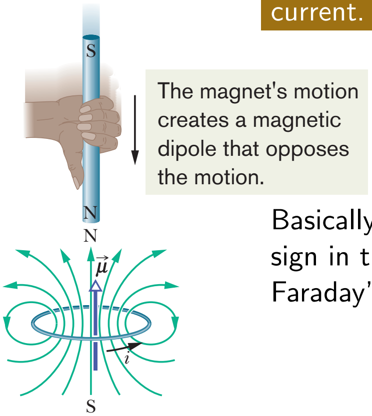
The magnetic flux might change for any of several reasons:

- the magnitude of **B** can change with time,
- the area A enclosed by the loop can change with time, or
- the angle θ between the field and the normal to the loop can change with time.

Lenz's Law

Lenz's Law

An induced current has a direction such that the magnetic field due to the current opposes the change in the magnetic flux that induces the current.

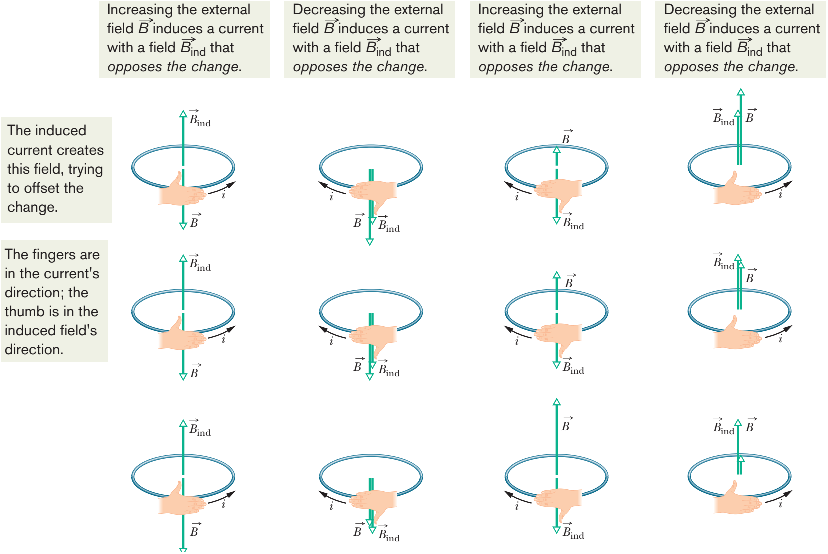


Basically, Lenz's law let's us interpret the minus sign in the equation we write to represent Faraday's Law.

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

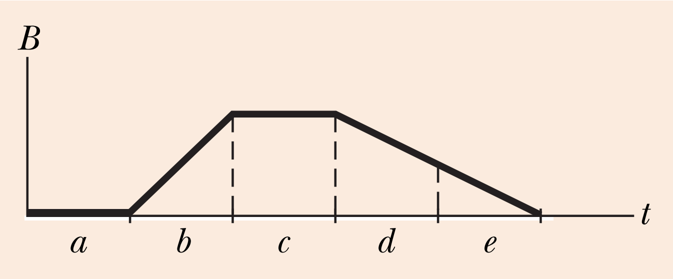
[1]Figure from Halliday, Resnick, Walker, 9th ed.

Lenz's Law: Page 795 in Textbook



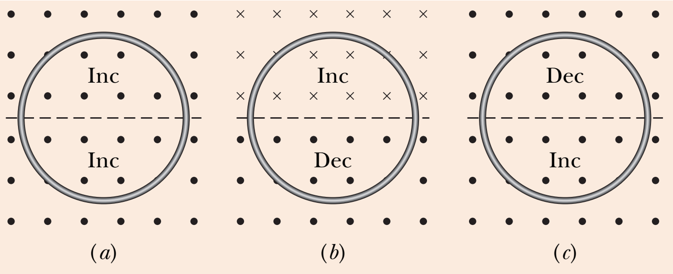
Faraday's Law Question

The graph gives the magnitude $B(t)$ of a uniform magnetic field that exists throughout a conducting loop, with the direction of the field perpendicular to the plane of the loop. Rank the five regions of the graph according to the magnitude of the emf induced in the loop, greatest first.



Faraday's Law

The figure shows three situations in which identical circular conducting loops are in uniform magnetic fields that are either increasing (Inc) or decreasing (Dec) in magnitude at identical rates. In each, the dashed line coincides with a diameter. Rank the situations according to the magnitude of the current induced in the loops, greatest first.



Magnetic fields from moving charges and currents

We are now moving into chapter 29.

Anything with a magnet moment creates a magnetic field.

This is a logical consequence of Newton's third law.

Magnetic fields from moving charges

A moving charge will interact with other magnetic poles.

This is because it has a magnetic field of its own.

The field for a moving charge is given by the Biot-Savart Law:

$$\mathbf{B} = \frac{\mu_0}{4\pi} \frac{q\,\mathbf{v} \times \hat{\mathbf{r}}}{r^2}$$

Magnetic fields from moving charges

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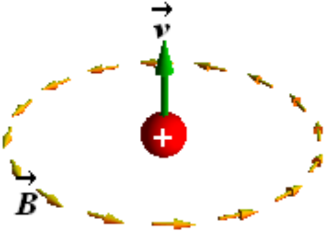


[1]Figure from rakeshkapoor.us.

Magnetic fields from currents

$$\mathbf{B} = \frac{\mu_0}{4\pi}\frac{q\,\mathbf{v} \times \hat{\mathbf{r}}}{r^2}$$

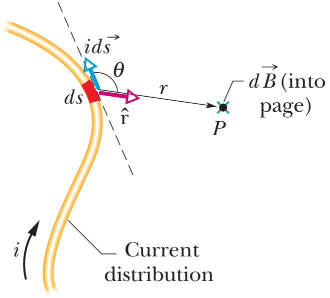
We can deduce from this what the magnetic field do to the current in a small piece of wire is.

Current is made up of moving charges!

$$q\,\mathbf{v} = q\frac{\Delta\mathbf{s}}{\Delta t} = \frac{q}{\Delta t}\Delta\mathbf{s} = I\Delta\mathbf{s}$$

We can replace $q\,\mathbf{v}$ in the equation above.

Magnetic fields from currents



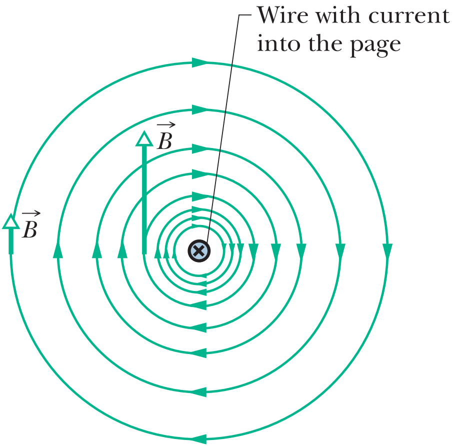
This is another version of the Biot-Savart Law:

$$\mathbf{B}_{\text{seg}} = \frac{\mu_0}{4\pi} \frac{I\, \Delta\mathbf{s} \times \hat{\mathbf{r}}}{r^2}$$

where $\mathbf{B}_{\text{seg}}$ is the magnetic field from a small segment of wire, of length Δs.

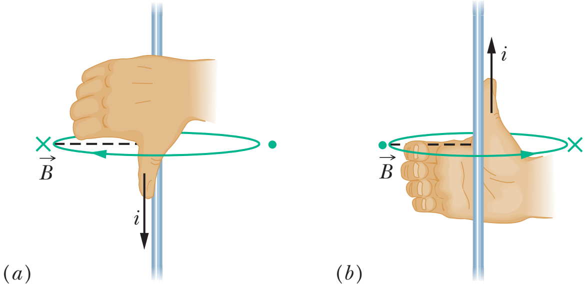
Magnetic fields from currents

Magnetic field around a wire segment, viewed end-on:



Magnetic fields from currents

How to determine the direction of the field lines (right-hand rule):



Magnetic field from a long straight wire

The Biot-Savart Law,

$$\mathbf{B}_{\text{seg}} = \frac{\mu_0}{4\pi} \frac{I \, \Delta \mathbf{s} \times \hat{\mathbf{r}}}{r^2}$$

implies what the magnetic field is at a perpendicular distance R from an **infinitely long straight wire**:

$$\mathbf{B} = \frac{\mu_0 I}{2\pi R}$$

(The proof requires some calculus.)

Gauss's Law for Magnetic Fields

Gauss's Law for magnetic fields.:

$$\oint \mathbf{B} \cdot \mathrm{d}\mathbf{A} = 0$$

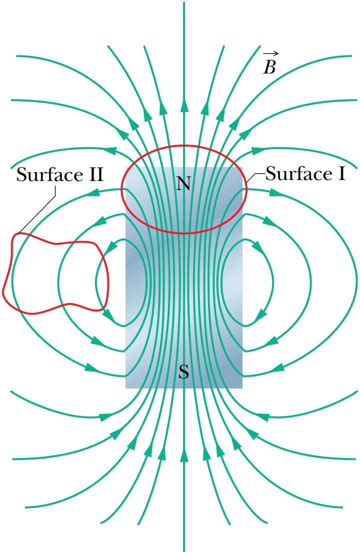
Where the integral is taken over a closed surface A. (This is like a sum over the flux through many small areas.)

We can interpret it as an assertion that magnetic monopoles do not exist.

The magnetic field has no sources or sinks.

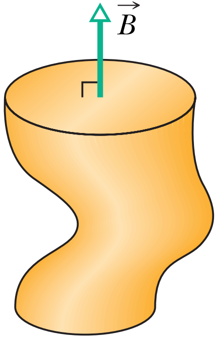
Gauss's Law for Magnetic Fields

$$\oint \mathbf{B} \cdot d\mathbf{A} = 0$$



Gauss's Law for Magnetism Question, Ch32 # 2

The figure shows a closed surface. Along the flat top face, which has a radius of 2.0 cm, a perpendicular magnetic field **B** of magnitude 0.30 T is directed outward. Along the flat bottom face, a magnetic flux of 0.70 mWb is directed outward. What are the
(a) magnitude and
(b) direction (inward or outward) of the magnetic flux through the curved part of the surface?



Summary

- Faraday's law
- Lenz's law
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Homework

Study!