MORE MAGNETISM

Physics mystery: Although the equations for electromagnetism allow for the existence of magnetic charges analogous to electric charges, no such charges have ever been observed.

In other words, *magnetic monopoles* do not exist.

All magnets are *dipoles*, i.e. they have 2 poles ("north" and "south").

Moving electric charges create magnetic fields.

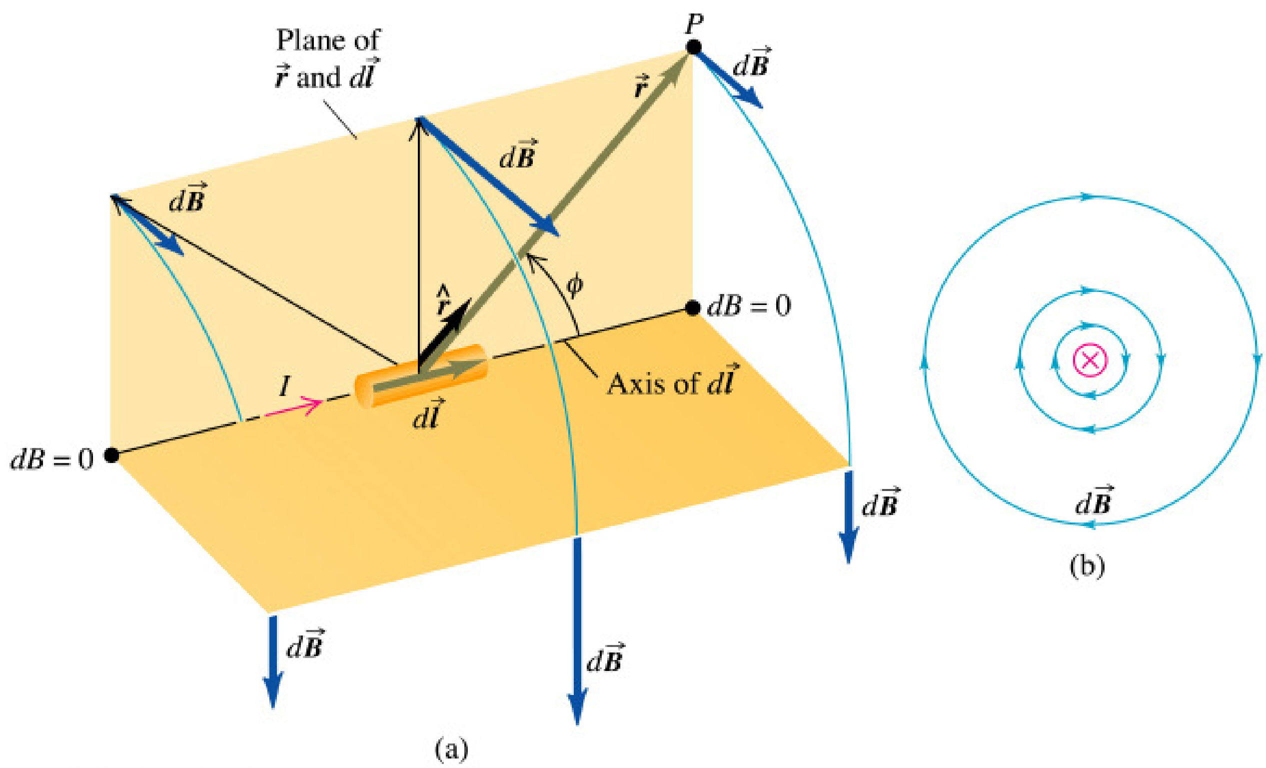
Moving magnets create electric fields.

Electromagnets are amplified by an iron core, because the iron atoms --which are themselves tiny magnets -- align themselves with the magnetic field produced by the electromagnet.

Energy density *u* of a magnetic field *B*: $u = \frac{1}{2\mu_0} B$ ($\mu_0 = 4\pi\times10^{-7}$ TeslaXmeter/Amp)

The magnetic field $d\vec{B}$ produced by a segment of wire of length $d\vec{l}$ carrying a current I at a position $\vec{r}$ from the segment: $d\vec{B} = \frac{\mu_0}{4\pi}\frac{I}{r^2} d\vec{l} \times \hat{e}_r$ where $\hat{e}_r = \frac{\vec{r}}{r} \equiv \hat{r}$ is the unit vector along $\vec{r}$.

The magnitude of $d\vec{B}$: $dB = \frac{\mu_0}{4\pi}\frac{Idl}{r^2}\sin(\phi)$, where ϕ is the angle between $\vec{r}$ and $d\vec{l}$.



THE 4 BASIC LAWS OF ELECTROMAGNETISM

Definitions

Electric flux -- Measure of the amount of electric field on a particular surface
[= (perpendicular component of electric field at surface) x (area of surface)]

Magnetic flux -- Measure of the amount of magnetic field on a particular surface
[= (perpendicular component of magnetic field at surface) x (area of surface)]

a loop – a closed path in that does not necessarily correspond to position of a wire.

AC -- Alternating current. Current that oscillates at a fixed frequency between positive and negative peak values.

1. **Gauss' Law**
   The electric flux through a closed surface is proportional to the charge contained within the surface.

2. **Gauss' Law for Magnetism**
   The magnetic flux through any closed surface is zero (i.e. magnetic monopoles do not exist.]

3. **Faraday's Law**
   The electric field on a loop is proportional to (the negative of) the *rate of change* in the magnetic flux through the loop.

4. **Ampere's Law**
   The magnetic field on a loop is proportional to the electric current through the loop.

- Faraday's Law can be used to convert mechanical energy into electrical energy.
  Method: Cause an incomplete loop of wire to rotate in a uniform magnetic field so that the magnetic flux through the loop is constantly changing. This will create an electric field on the wire which will produce an (AC) electric current.

  A converter of mechanical energy into electrical energy is called a **dynamo** or **generator.**

- Faraday's Law works backwards to convert electrical energy into mechanical energy.
  Method: Place an incomplete loop of wire in a uniform magnetic field. Apply a voltage across the ends of the loop. This will cause the loop to turn.

  A converter of electrical energy to mechanical energy is called a **motor**.

Example

The electric flux through a close surface is zero. How much charge is contained within the surface?

Answer: 0 Coulombs (by Gauss' Law)

Example

A constant magnetic flux passes through a loop of wire. How large is the electric field in the wire generated by the magnetic field?

Answer: 0 Volts/meter (by Faraday's Law. No change in magnetic flux ➔ no electric field in loop)

Example

An electromagnetic has 200 windings. If the number of windings is increased to 1000, how will this magnet's field be affected?

Answer: It will be 5 times stronger [by Ampere's Law. The loop of interest goes down through the center of the magnet's coil and returns along the outside to the top. The more windings, the more current that passes through this loop.]

Example

How many magnetic monopoles are in the moon?

Answer: zero (by Gauss' Law for magnetism)

MORE CIRCUIT ELEMENTS

Mutual Inductance

Consider two coils in close proximity. Send a changing current through coil #1. This produces a changing magnetic field, which goes through in coil #2. The changing magnetic field through coil #2 produces an electric field in coil #2 (by Faraday's Law). The electric field in coil #2 implies that there is a potential difference (voltage) between the start and end of the coil. In other words

$$V_2 = -M_{21} \frac{\Delta I_1}{\Delta t}$$

Translation: The voltage between the ends of coil #2 is proportional to the rate of change of the current I_1 through coil #1. M_{21} is the constant of proportionality and is called the "mutual inductance" between coils 1 and 2.

In short, a changing current in one coil *induces* a voltage in the other.

Example

The changing current in Coil #1 is inducing a potential difference V between the ends of Coil #2. In the current in Coil # 1 now changes twice as fast, what will be the new potential difference induce in Coil # 2?

V_2 is proportional to $\frac{\Delta I_1}{\Delta t}$, the rate of change of the current in Coil #1.

If the rate of change of current in Coil #1 is doubled, V_2 is doubled.

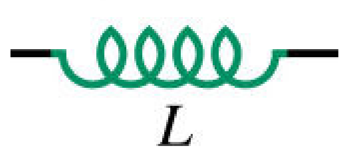
Answer: $2V$

Self Inductance

Suppose that coil #1 and coil #2 are the same coil, i.e. there is only one coil. Then we can apply the same argument above to conclude that a changing current in a coil produces an extra voltage in the coil. [Because of the negative sign (above), this extra voltage subtracts from the voltage producing the current.]

When a tiny coil is added to a circuit, it is called an "**inductor**".

The circuit symbol for an inductor is

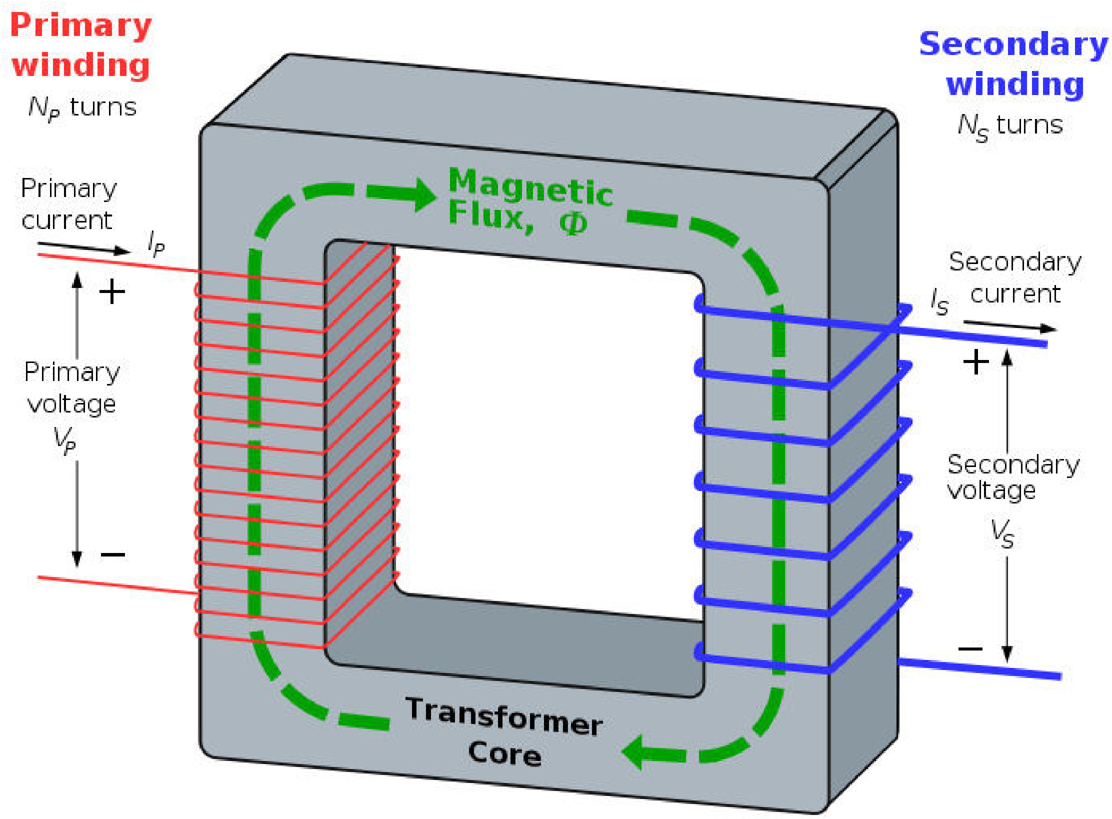


When coil #1 and coil #2 are the same coil, M_{21} in the equation above is replaced by L. L is called the "self inductance of the coil".

Inductors are used to reduce the rate at which the current changes in a circuit.

Energy U stored in an inductor: $U = \frac{1}{2} L I^2$. From this and the dimensions of the inductor it is possible to work out the energy density u of the magnetic field within the inductor: $u = \frac{1}{2\mu_0} B$

Transformer



- Uses inductance
- Used to increase or decrease an AC voltage by a desired amount

Faraday's Law for 1 loop:

voltage in 1 loop of wire = rate of change in magnetic flux through loop

Faraday's Law for a Coil of N loops (windings):

voltage in coil of N loops = N x (rate of change in magnetic flux through loops)

i.e.

rate of change in magnetic flux through loops $= \frac{V}{N}$

where

V = voltage in coil of N loops   (i.e. the voltage between the ends of the coil)
N = number of loops (windings) in the coil.

Suppose we have 2 coils, a so-called "primary" and "secondary". If the *same* magnetic flux is passing through both coils, we have

rate of change in magnetic flux through loops = $\frac{V_P}{N_P} = \frac{V_S}{N_S}$

Or

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

Example

The primary coil of transformer has 40 windings. The secondary coil has 10 windings. If the input voltage of the transformer is 110 Volts AC, what will be the output AC voltage?

Answer:

$N_p = 40$
$N_s = 10$
$V_P = 110$ V
$V_s = $?

$V_S = \frac{10}{40} 110$ Volts = 27.5 Volts ←