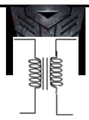
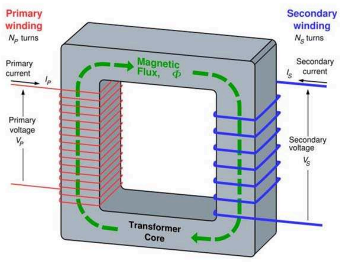
Transformers



- Now that we have power dissipated through an RLC series circuit, let's address an important issue.
- Not all devices require 120-V AC. Some devices require only 12-V AC.
  - How do we "transform" the amplitude of the voltage provided by the power company to another amplitude?
  - We go back to Faraday's Law of Induction.
- If we strategically place two *different* solenoids near each other in an AC circuit, then the EMF through the solenoids will have different values.
- A device which uses an arrangement of coils to vary the amplitude of the primary voltage source is called a transformer and one of its circuit symbol is shown above in the title.

Transformers - Picture

- The artist rendition below is that of a typical transformer.



- Iron core used to concentrate magnetic flux which ensures
  - the magnetic flux through primary and secondary coils is the same.

Transformers - Voltage

- Since the magnetic flux is the same through both coils, the rate of change of magnetic flux is the same through the two coils.

$$V_P = N_P \frac{d\Phi_B}{dt}$$

$$V_S = N_S \frac{d\Phi_B}{dt}$$

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

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

Transformers - Power

- It seems that the secondary voltage can be arbitrarily large.
- Does this violate conservation of energy?
  - No.
  - A transformer can not increase power.
- Ideal transformers transfer all the power supplied by the primary source to the secondary.

$$I_P\, V_P = I_S\, V_S \quad \text{(Statement of Conservation of Energy)}$$

Recap Electric Field

- We started talking about charges which led to forces which led to electric fields. This lead to Gauss's Law for charges:

$$\oint_S \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}} = \frac{Q_{\text{enclosed}}}{\varepsilon_0}$$

- We then discussed moving charges and defined electric potential, current, resistance, and capacitance. This lead to Kirchhoff's Rule for circuits:

$$\oint \vec{\mathbf{E}} \cdot d\vec{\mathbf{l}} = 0.$$

Recap Magnetic Field

- Our discussion of moving charges led us down a path toward Ampere's Law:

$$\oint_C \vec{\mathbf{B}} \cdot d\vec{\mathbf{l}} = \mu_0 \, I_{\text{enclosed}}.$$

and then there was Gauss's Law for magnetism.

$$\oint_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}} = 0.$$

- We then spent a lot of time looking at the effects of time-varying magnetic flux which is called Faraday's Law of induction (together with Lenz's Law):

$$\oint_C \vec{\mathbf{E}} \cdot d\vec{\mathbf{l}} = -\frac{d}{dt} \int \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}}.$$

Only Four Equations?

$$\oint_S \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}} = \frac{Q_{\text{enclosed}}}{\varepsilon_0}$$

$$\oint_C \vec{\mathbf{E}} \cdot d\vec{\mathbf{l}} = -\frac{d}{dt} \int \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}}.$$ (Changing B-flux creates E-field.)

$$\oint_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}} = 0.$$

$$\oint_C \vec{\mathbf{B}} \cdot d\vec{\mathbf{l}} = \mu_0 \, I_{\text{enclosed}}.$$ (Itching to be modified.)

A Symmetric Nature.

- It is natural to ask the question: "Does a *time-varying electric flux produce a magnetic field*?"
- Let's consider an RC - circuit (DC).
  - A current will exist in the circuit, but will decrease as the capacitor charges.
  - "Conduction" current is not continuous across the capacitor, yet a current exists in the circuit.
- Click here for current behavior.
- The changing electric flux within the capacitor is "like" a conduction current.James Clerk Maxwell (Scottish physicist) suggested that a changing electric flux should give rise to a magnetic field.

Changing Electric Flux

- We could quantify the rate of change of electric flux through the capacitor.
- Start with Gauss's LawTake a time derivative of the electric flux. I_d is called the "displacement" current.

$$\int \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}} = \frac{q}{\varepsilon_0}$$
$$I_d = \varepsilon_0 \frac{d}{dt} \int \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}}$$

Maxwell's Equations

$$\oint_S \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}} = \frac{Q_{\text{enclosed}}}{\varepsilon_0}$$
$$\oint_C \vec{\mathbf{E}} \cdot d\vec{\mathbf{l}} = -\frac{d}{dt} \int \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}}. \quad \text{(Changing } B\text{-flux creates } E\text{-field.)}$$
$$\oint_S \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}} = 0.$$
$$\oint_C \vec{\mathbf{B}} \cdot d\vec{\mathbf{l}} = \mu_0 I_{\text{enclosed}} + \mu_0 \varepsilon_0 \frac{d}{dt} \int \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}}.$$