Physics (PHYS2500J)
Summary

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What we learned during the semester

Electromagnetics

- Electrostatics
  - Electric field, Gauss's law
  - Potential
  - Materials in electric field
  - Electric field energy
- Steady current field
  - Ohm's law
  - Current density field, continuity equation
- Magnetostatics
  - Lorentz force
  - Ampere's circuital law
  - Biot-Savart's law
  - Magnetic materials
- Electro-magnetic induction
  - Faraday's law
  - Maxwell's displacement current
- Circuits
- EM wave

(wave) optics

- Light
  - Coherence
  - Interference
  - Polarization

$$\vec{\nabla} \cdot \vec{E} = \rho/\epsilon_0$$

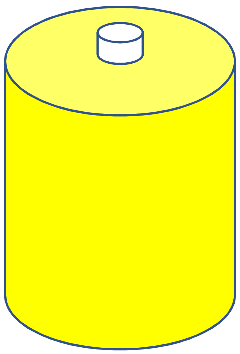
$$\vec{\nabla} \cdot \vec{B} = 0$$

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

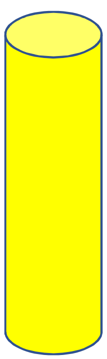
$$\vec{\nabla} \times \vec{B} = \mu_0 \left(J + \epsilon_0 \frac{\partial \vec{E}}{\partial t} \right)$$

Test

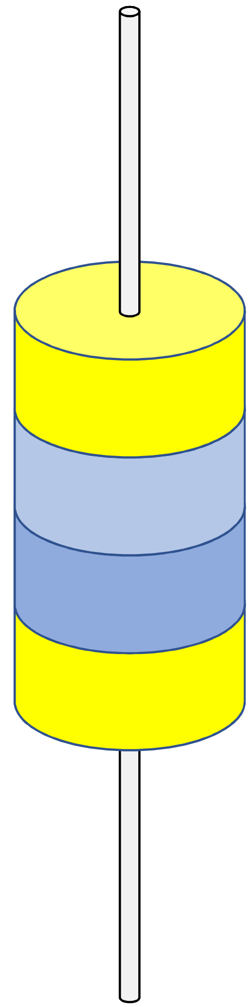
Try to draw the field and Poynting vectors for such devices



A battery



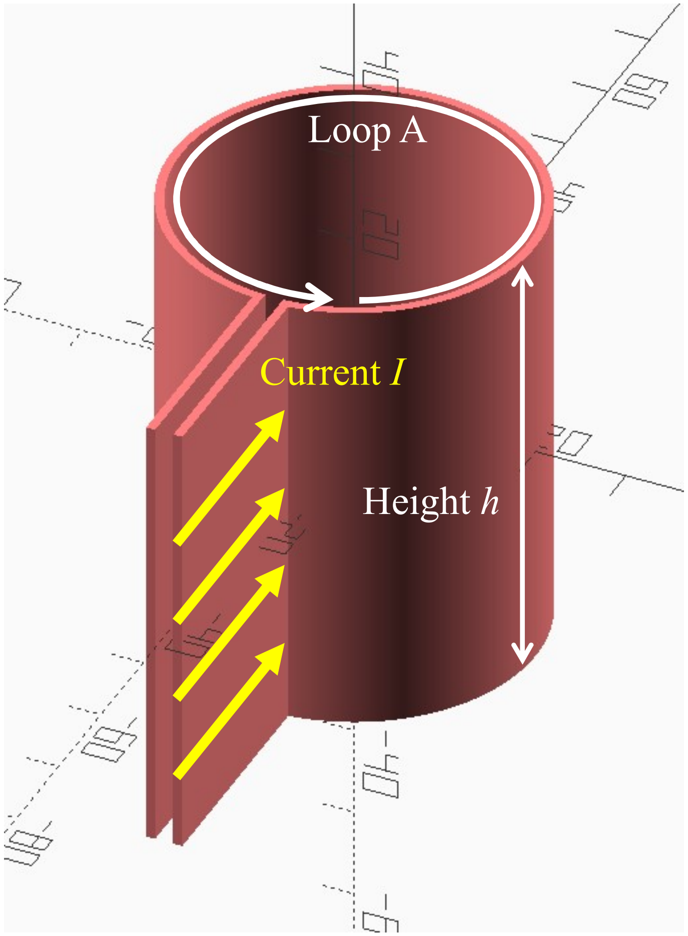
A section of wire



The load

Example problems: Charging of an ideal inductor

1. please explain the energy flow process of an ideal (no resistance) long one turn coil which is being charged.



a. Where is the magnetic induction B distributed, how much?

In the gap and the cylindrical area, vertically pointing up. using Ampere's circuital law

$$B = \frac{\mu_0 I}{h}$$

b. If the current is increasing with rate k (A/s). Where is the electric field distributed? How much? And how is energy transferred and stored?

At the bottle neck, for example. Electric field can be obtained from Faraday's law with the loop shown.

$$\oint_A \vec{E} \cdot \mathrm{d}\vec{l} = -\frac{dB}{dt}\pi R^2$$

Only in the neck, E is not 0 (otherwise inside perfect conductor)

$$Eg = -\frac{dB}{dt}\pi R^2 = -\frac{\mu_0}{h}k\pi R^2$$

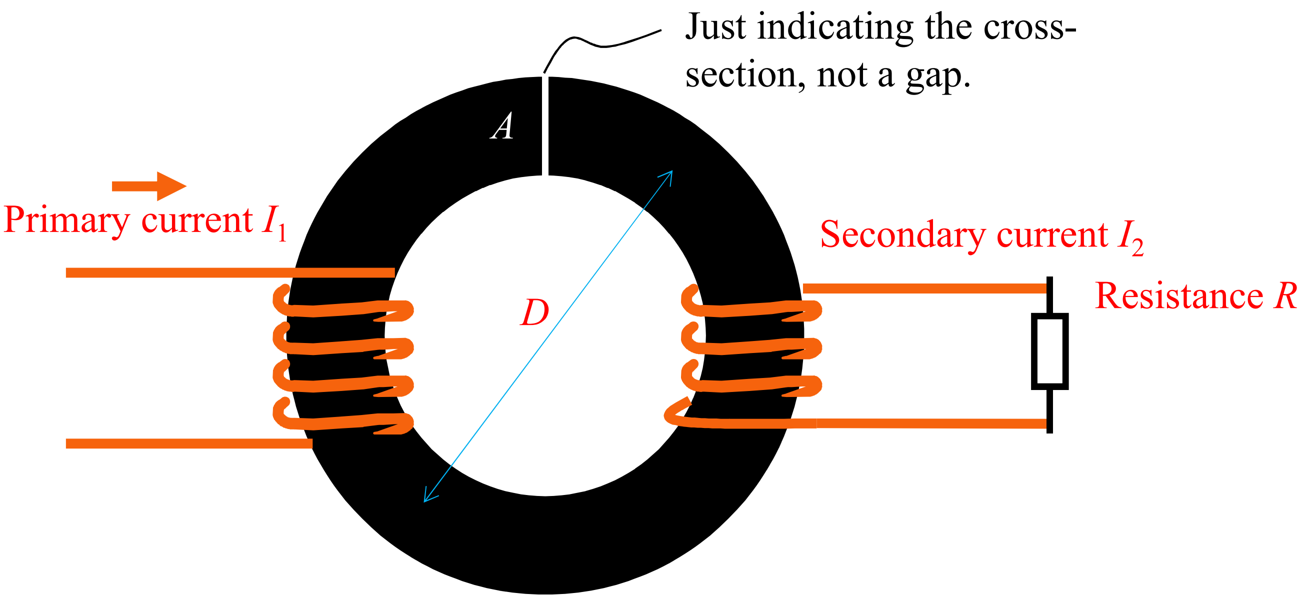
Poynting's vector:

$$E \times H = E\frac{B}{\mu_0} = \frac{B}{\mu_0}\frac{dB}{dt}\frac{\pi R^2}{g} = \frac{dB^2/2\mu_0}{dt}\frac{\pi R^2}{g}$$

The magnetic energy is transferred through Poynting vector and stored.

Example problems: ideal transformer

2. If voltage $V_1=V_0\cos\omega t$ is applied to the primary coil, what is the voltage V_2, current I_1 and I_2? In terms of permeability $\mu_r\mu_0$, average diameter D, cross section A, resistance R, numbers of turns n_1, and n_2.



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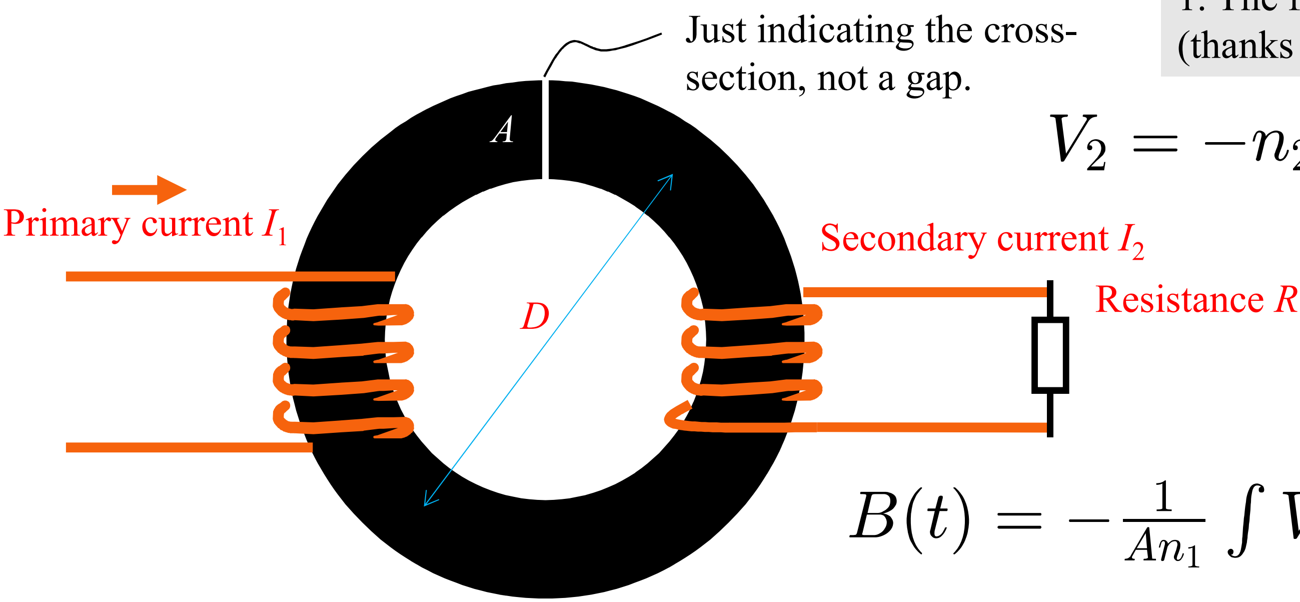

1. The flux Φ for both coils are the same (thanks to the iron core).

$$V_2 = -n_2 \frac{d\Phi}{dt} = \frac{n_2}{n_1} V_1 = \frac{n_2}{n_1} V_0 \cos\omega t$$

2. Relate V to B, then to I

$$\frac{dB}{dt} = -\frac{1}{A}\frac{V_1}{n_1}$$

$$B(t) = -\frac{1}{An_1}\int V_1 dt = -\frac{V_0}{\omega A n_1}\sin\omega t + B_0$$

$$n_1 I_1 + n_2 I_2 = \oint \vec{H} \cdot d\vec{l} = \frac{1}{\mu_r \mu_0}\oint \vec{B} \cdot d\vec{l} \approx 0$$

For ideal transformer, $\mu_r \rightarrow$ infinity, seems like there can not be any finite driving current (magneto-motive force, $n_1 I_1 + n_2 I_2$), otherwise B will be very large, which can not be the case because B is restricted by V, it is a finite number.

$$\left.\begin{aligned} V_1 &= \frac{n_1}{n_2} V_2 \\ I_1 &= -\frac{n_2}{n_1} I_2 \\ \frac{V_2}{I_2} &= R \end{aligned}\right\} \quad \frac{V_1}{I_1} = -\frac{n_1^2}{n_2^2}\frac{V_2}{I_2} = -\frac{n_1^2}{n_2^2} R$$

Example problems

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3. Is polarization a property of all electromagnetic waves, or is it unique to visible light? Can sound waves be polarized? What fundamental distinction in wave properties is involved? Explain.