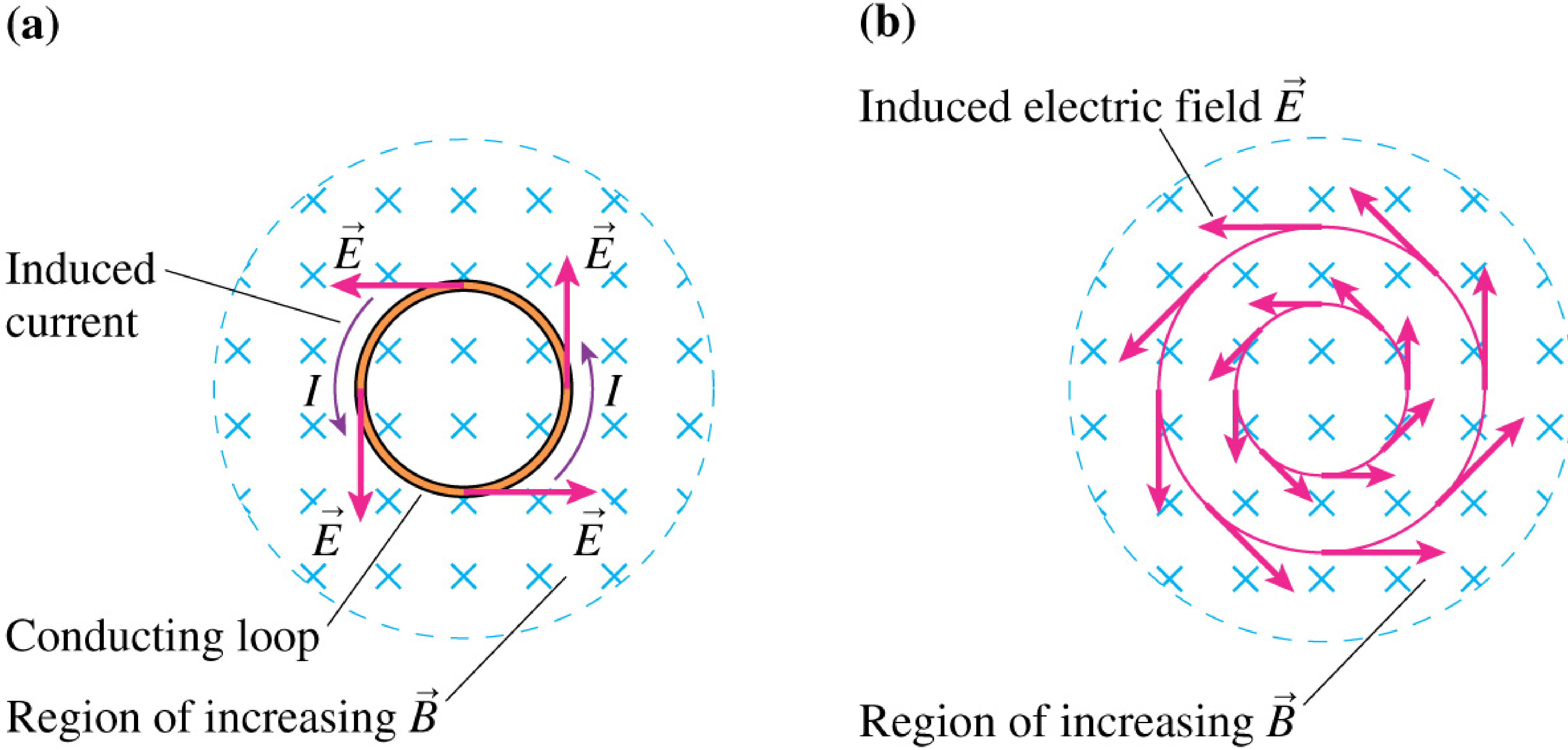
Lecture 18: Chapter 33, November 3 2005

A non-Coulomb (Induced) electric field

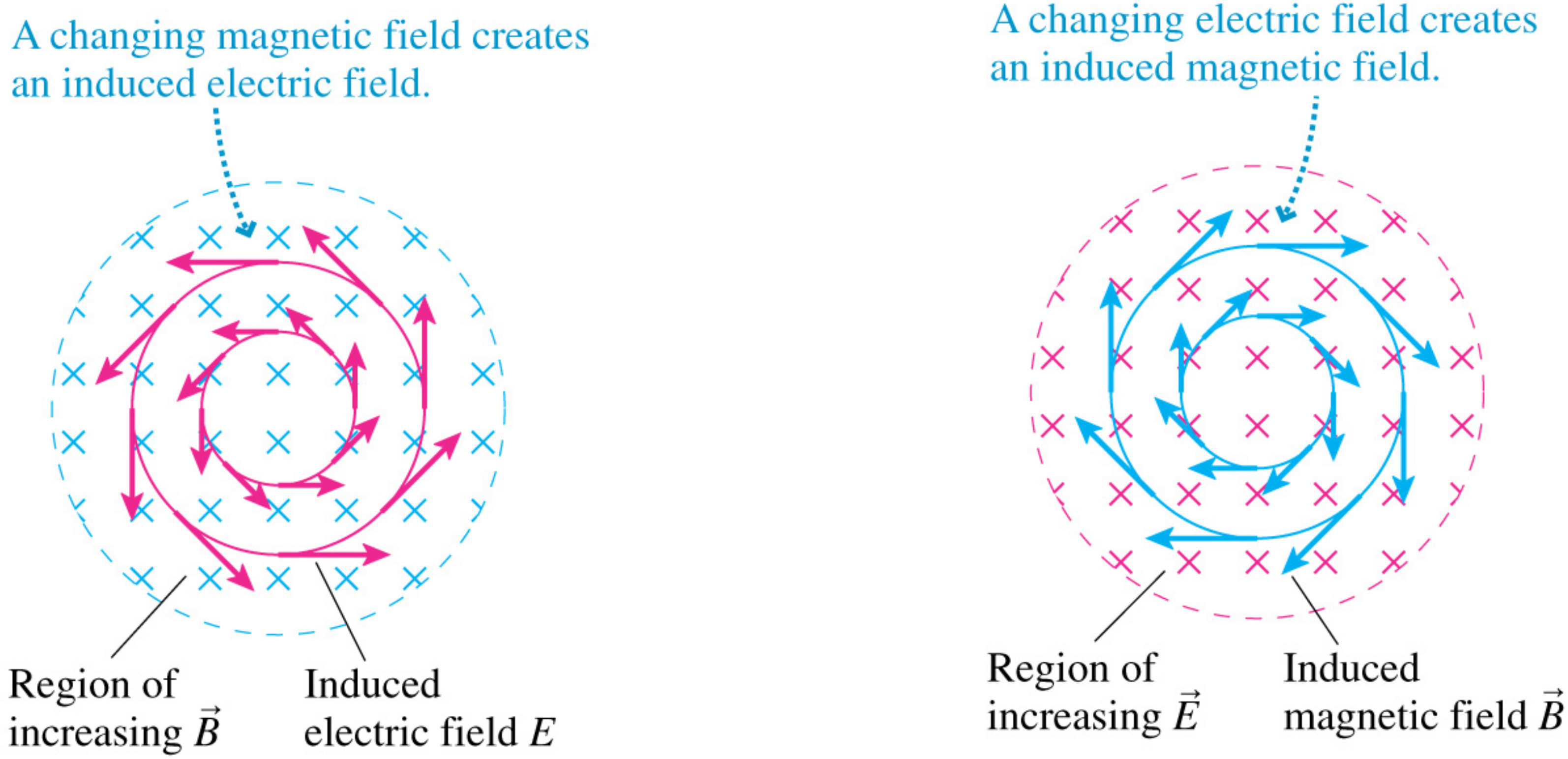


Two different ways of creating an electric field:

- A Coulomb field is created by positive and negative charges
- A non-Coulomb (Induced) electric field is created *by a changing magnetic field*

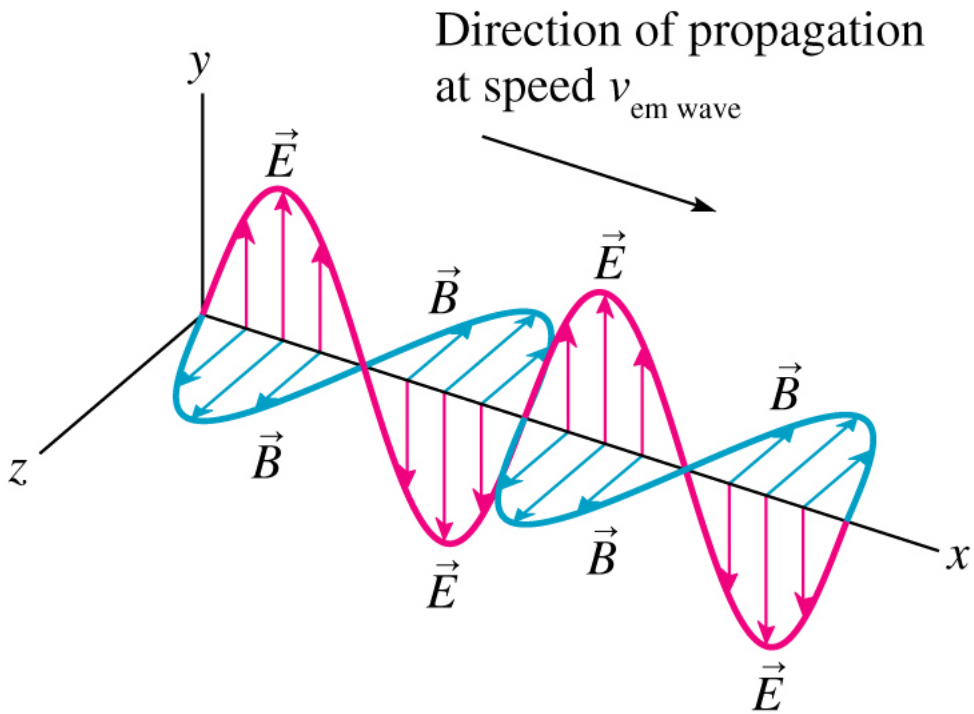
Maxwell's Theory

- Changing ***B*** creates non-Coulomb (induced) ***E***. The magnitude of emf induced in the loop is $\mathcal{E} = E 2\pi R \Rightarrow E = |\, d\Phi_m/dt \,|/\, 2\pi R$.
- Can changing ***E*** create ***B***? To complete the symmetry, Maxwell proposed (1855) a new kind of ***B*** created by varying ***E***.



The induced ***B*** looks like ***E*** in previous transparency, but it has the opposite direction

EM Wave



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- Self-sustaining ***E*** and ***B*** that are completely independent of any charges or currents
- Continually recreated via through EM induction
- Has a form of EM wave
- ***E*** and ***B*** are perpendicular to each other and to the direction of travel

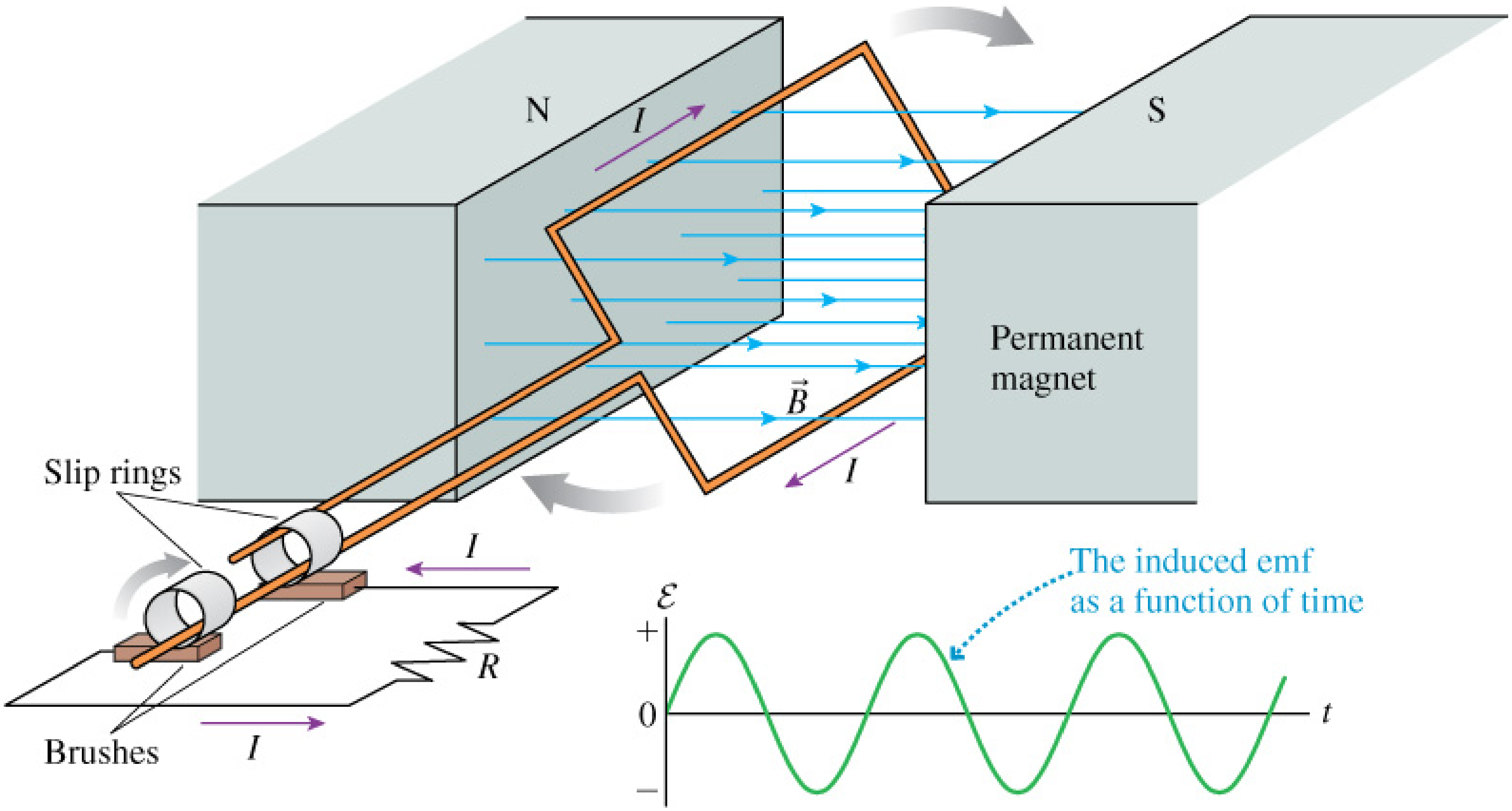
- Maxwell's theory predicted:

$$v_{EM\_wave} = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} = 3.00 \times 10^8 \, m/s$$

- Light is EM wave!

Applications of Induced Currents

How can we generate ac currents?

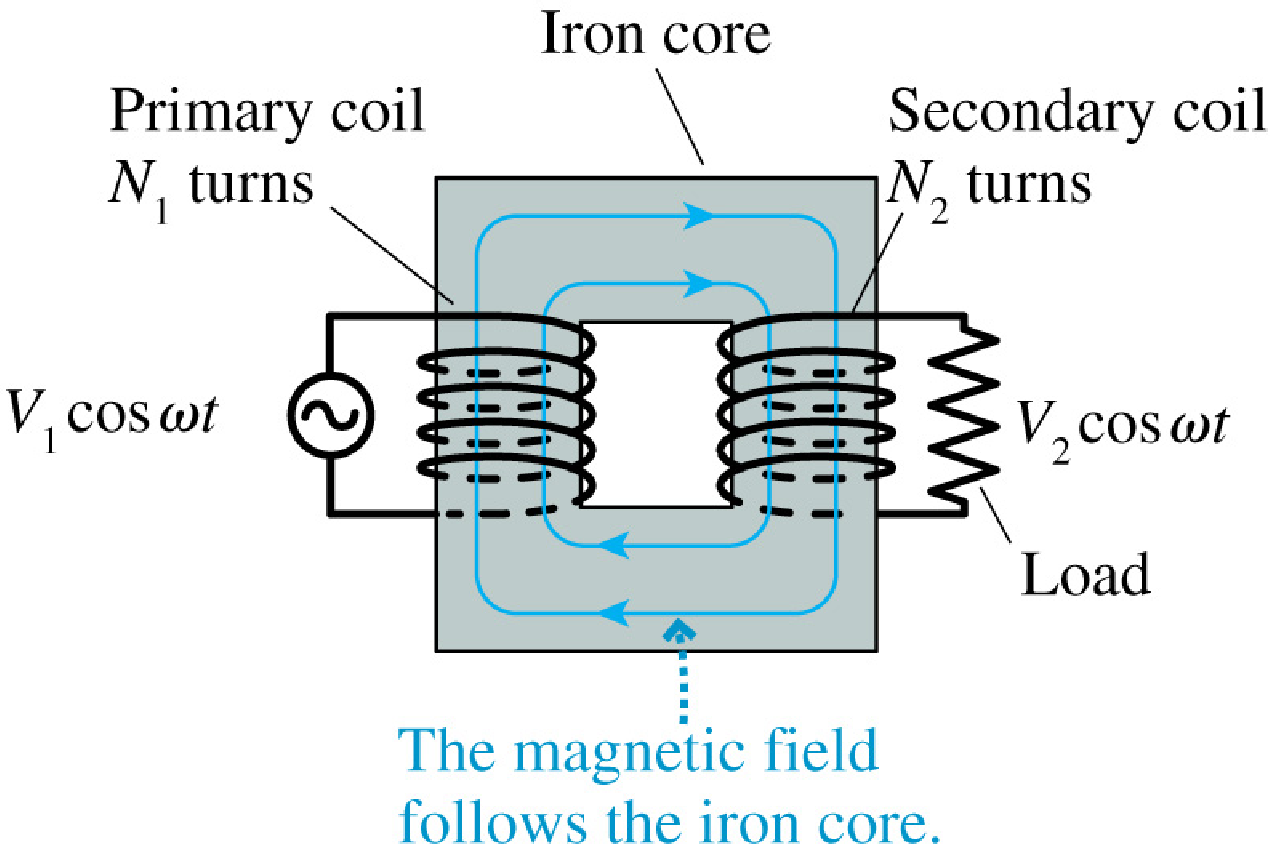


Φ_m = ***AB*** = $AB \cos\theta = AB \cos \omega t$

$\mathcal{E}_{coil} = N(d\Phi_m/dt) = ABN(d(\cos \omega t) = -\,\omega ABN \sin \omega t$

Applications of Induced Currents

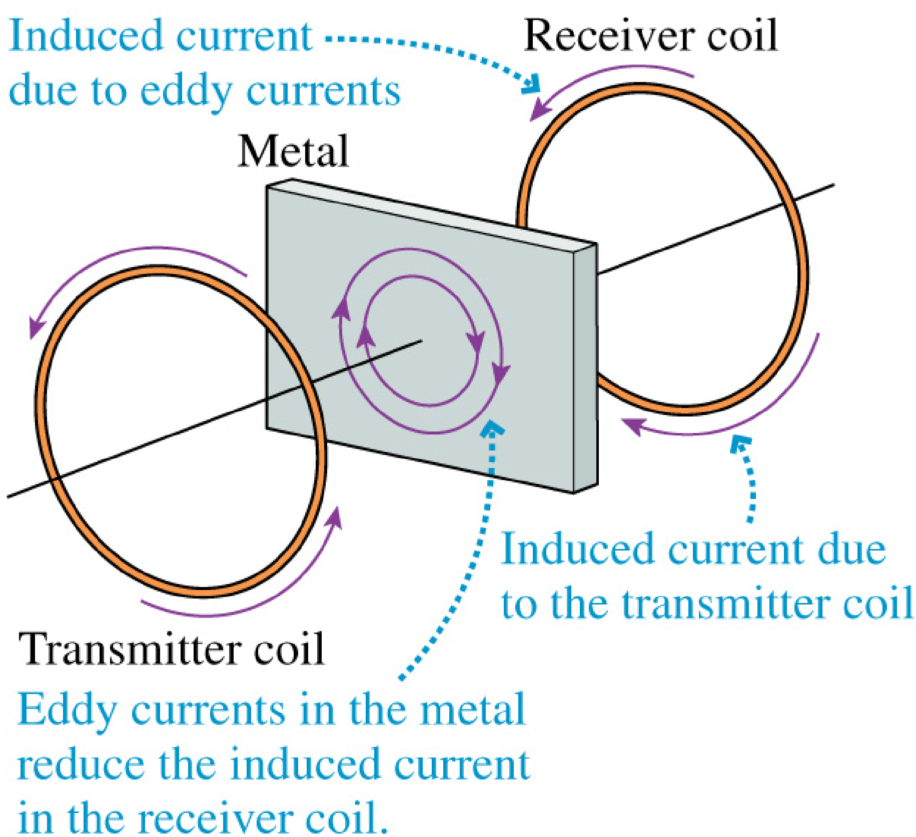
Transformers



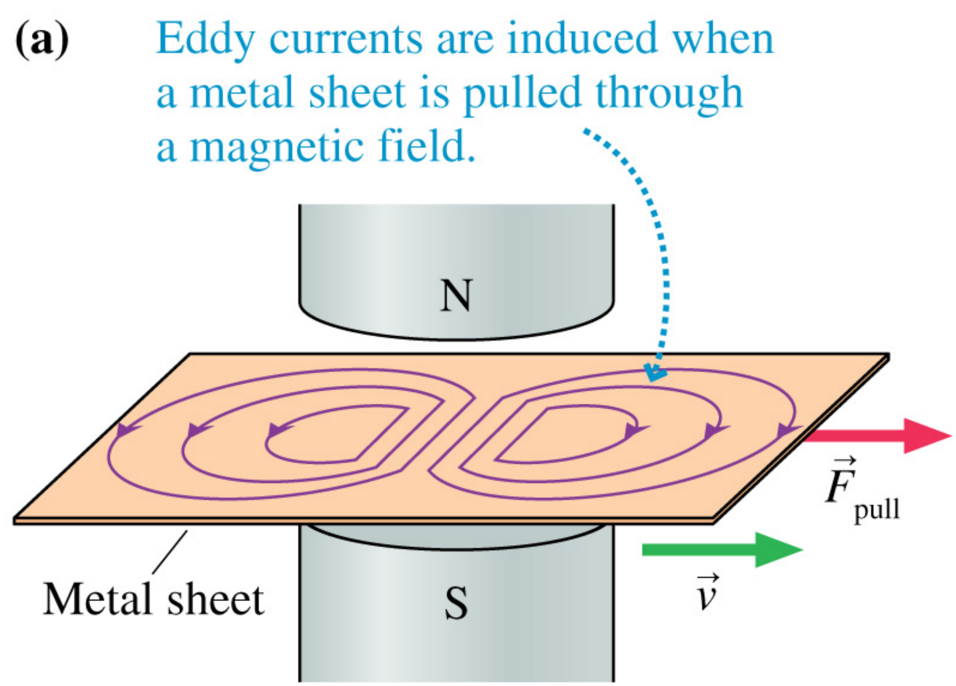
$$V_2 = (N_2/N_1)V_1$$

Applications of Induced Currents

Metal Detectors

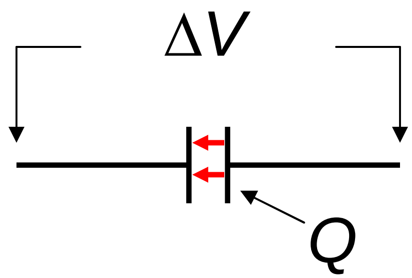


Eddy Currents

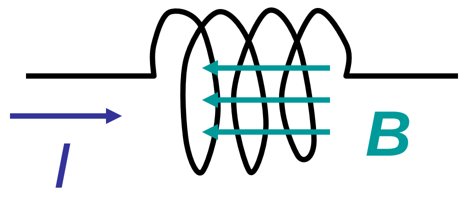


• Eddy currents attempt to prevent the flux from changing $\Rightarrow$ the net field at the receiver decreases

Capacitors and Inductors



An inductor is a coil of wire producing a uniform ***B***



- In capacitors we apply ΔV and create charges Q on the plates

- Capacitor – device creating electric field with energy $U_C = \frac{1}{2}C(\Delta V)^2$

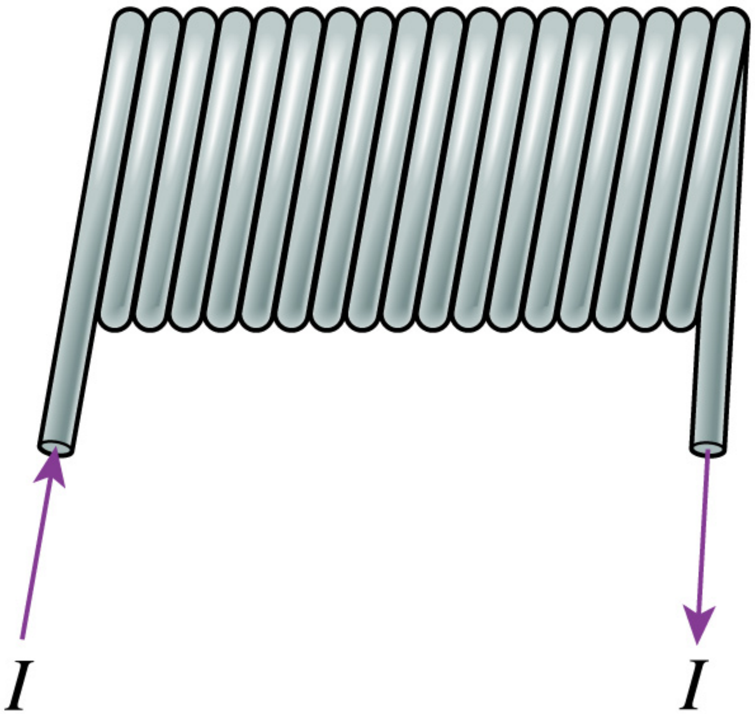
- Capacitance $C = Q/\Delta V$

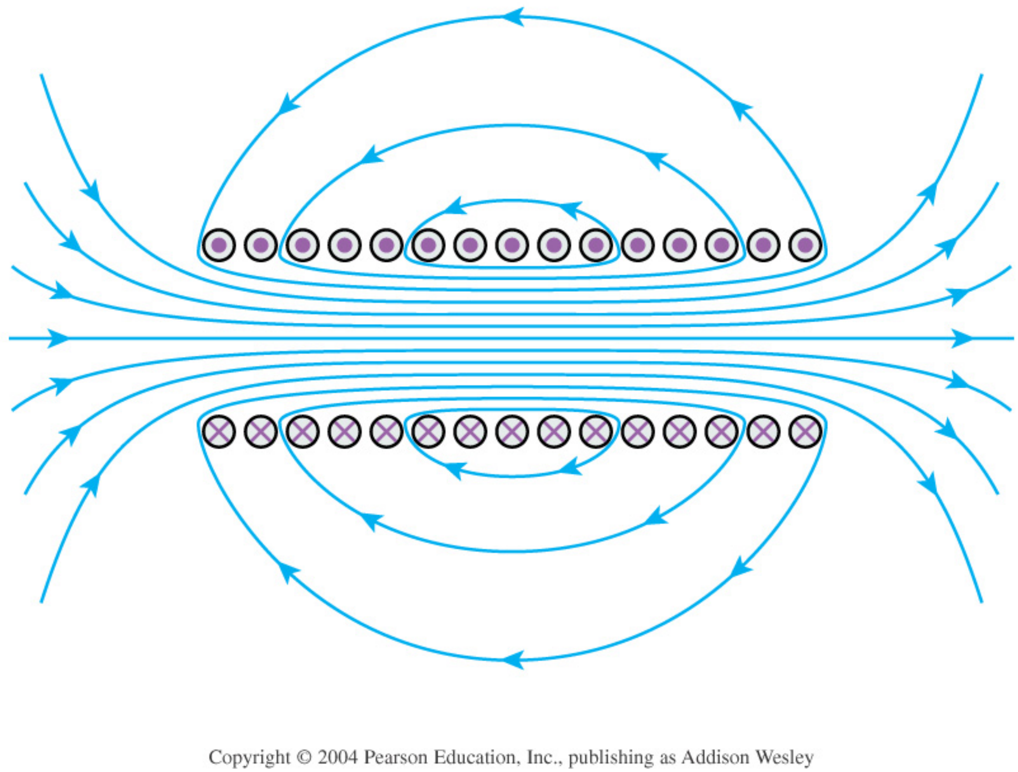
- In inductors we provide I and create $\Phi_m = NAB$, N-number of turns

- Inductor – device creating magnetic field with certain energy

- Inductance $L = \Phi_m/I$

The magnetic Field of a Solenoid

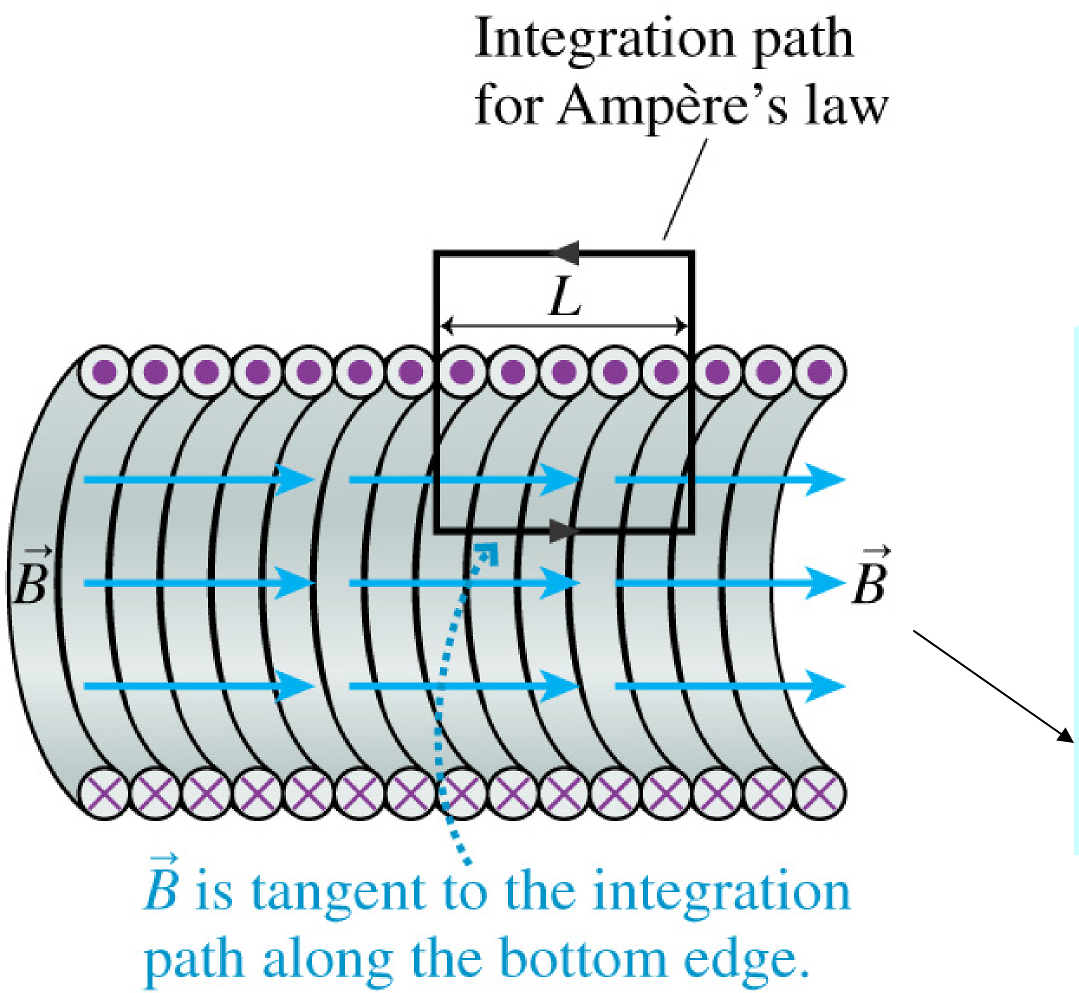




•The field in the center is strong and parallel to the axis, whereas the field outside is very weak

• In the center of solenoid the field ***B*** is uniform

Calculating the Field of Solenoid



Ampere's Law:

$$\oint \vec{B} d\vec{s} = \mu_0 I_{through} = \mu_0 NI$$

$$\oint \vec{B} d\vec{s} = BL = \mu_0 NI$$

$$B_{solenoid} = \frac{\mu_0 NI}{L} = \mu_0 nI$$

$n = N / L$ – number of turns per unit length

Inductance

• The charge on a capacitor is analogous to Φ_m: larger diameter capacitor plate holds more charge just as a larger diameter solenoid contains more flux $L = \Phi_m/I$.

• Strictly speaking, this is called self-inductance since it is created by the device itself.

Calculating Inductance of a Solenoid

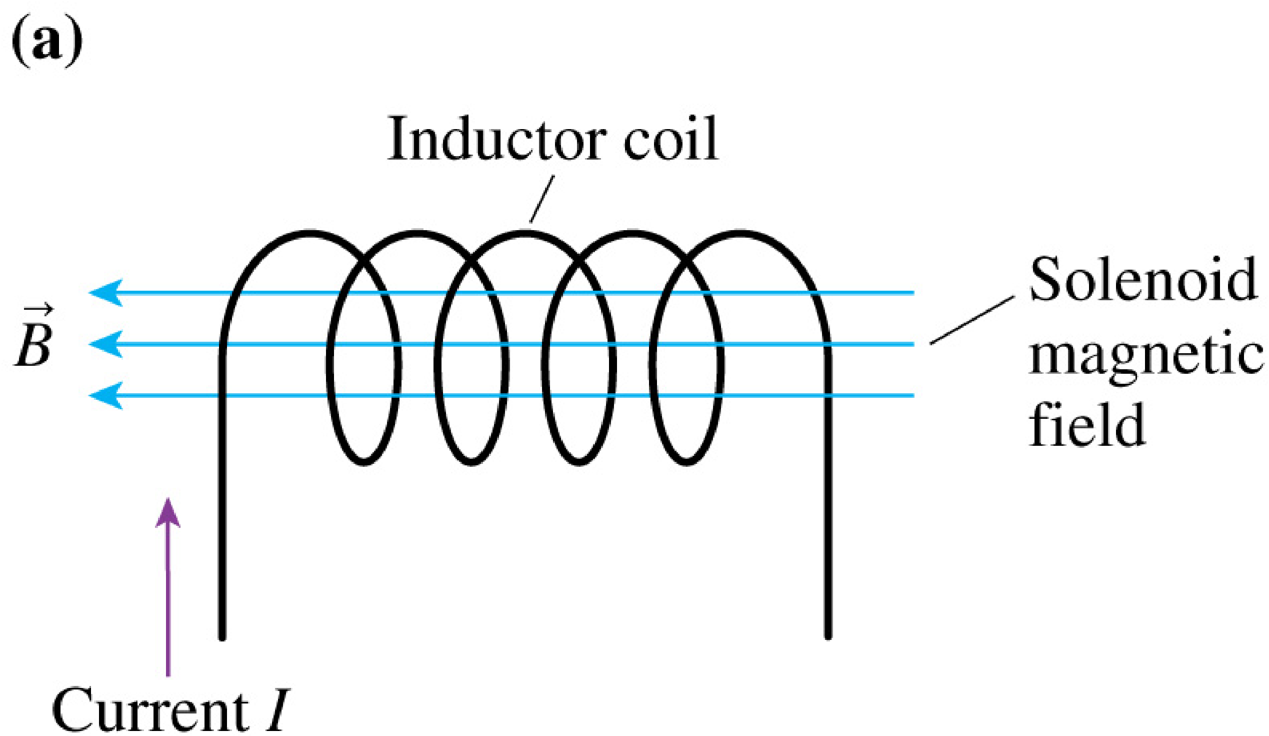
$$B = \frac{\mu_0 NI}{l}$$

$$\Phi_{per\_coil} = AB, where\_A = \pi R^2$$

$$Total: \Phi_m = N\Phi_{per\_coil} = \frac{\mu_0 N^2 A}{l} I$$

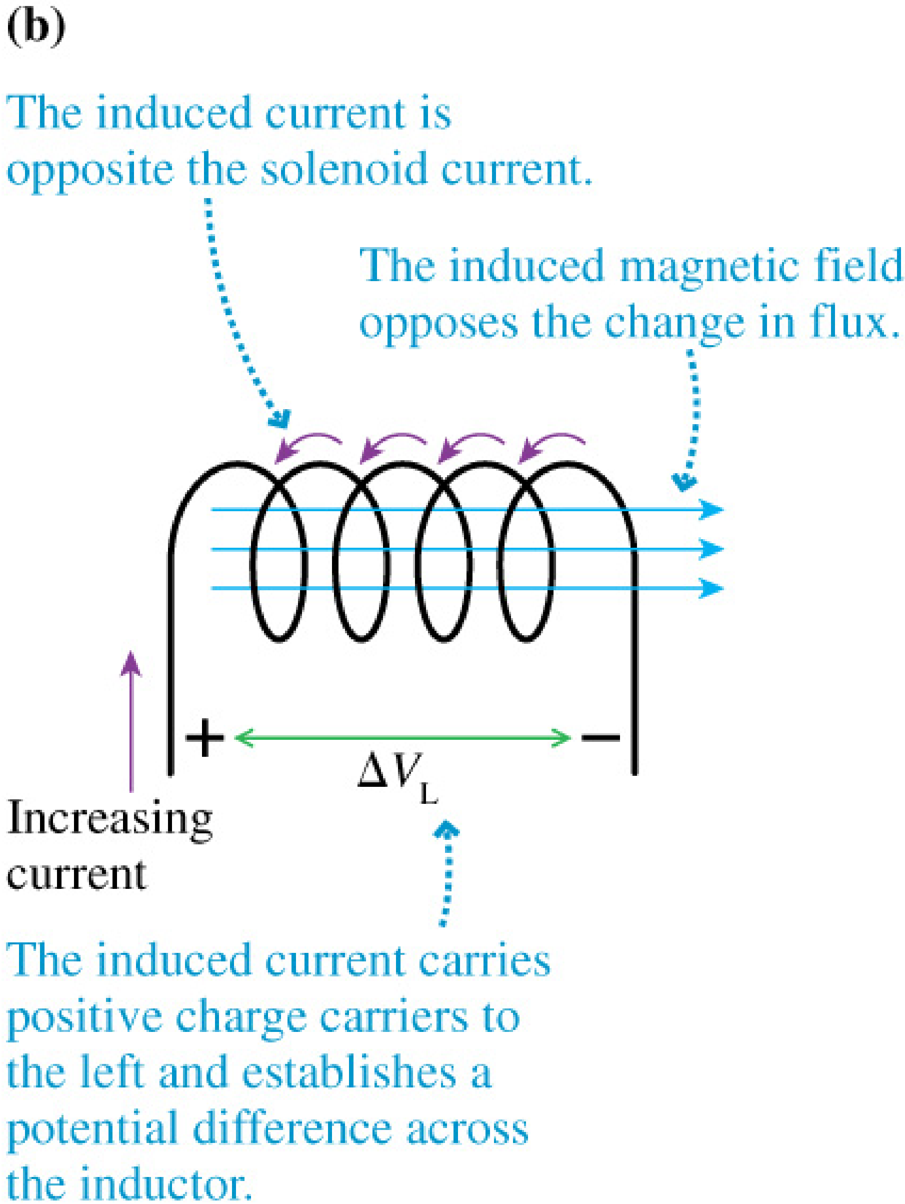
$$Thus: L_{solenoid} = \frac{\Phi_m}{I} = \frac{\mu_0 N^2 A}{l}$$

Steady State Inductor



• In steady state the inductor can be modeled as a zero-resistance wire if R ~ 0.

Inductor in a Transient Regime



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- Due to Lenz's law an induced current will oppose the changes in flux. This will cause a potential difference ΔV_L across the solenoid.

The Potential Difference Across an Inductor

Calculate ΔV or $\mathcal{E}$ using Faraday's Law:

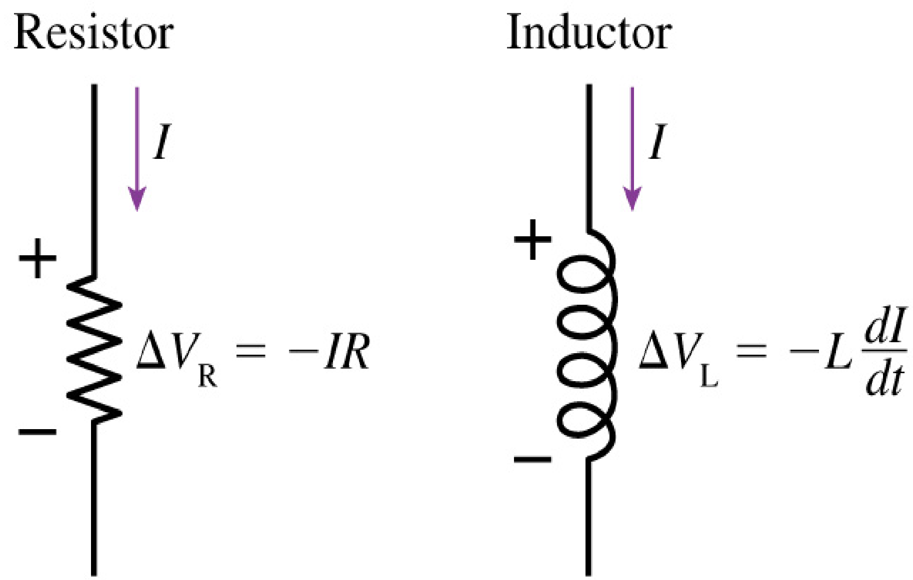
$\mathcal{E}_{coil} = N\, |d\Phi_{\text{per coil}}/dt\,| = |\,\Phi_m\, /dt\,|$

Since $\Phi_m = LI$ – definition L

$\mathcal{E}_{\text{coil}} = L|dI/dt|$

Taking into account sign of the induced voltage:

$$\Delta V_L = -\,L\,|\,dI/dt\,|$$



The potential always decreases.

The potential decreases if the current is increasing.

The potential increases if the current is decreasing.

End of Lecture 18
Reading: Entire Chapter 33
HW8 and HW9