PHY 114 A General Physics II
11 AM-12:15 PM TR Olin 101

Plan for Lecture 13 (Chapter 31):

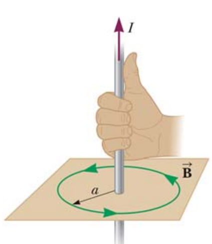
Faraday's Law

1. **Time varying magnetic flux ➔ induced EMF**
2. **Electric generators and motors**
3. **Eddy currents**

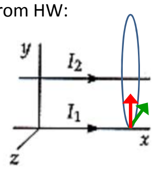
Remember to send in your chapter reading questions…

5	02/02/2012	Electric potential	25.5-25.8	(Review for exam)	
	02/07/2012	Exam			
6	02/09/2012	Capacitance and dielectrics	26.1-26.7	26.4,26.13,26.30	02/14/2012
7	02/14/2012	Current and resistance	27.1-27.6	27.3,27.12,27.29	02/16/2012
8	02/16/2012	Direct current circuits	28.1-28.2	28.3,28.7,28.19	02/21/2012
9	02/21/2012	Direct current circuits	28.3-28.5	28.23,28.25,28.34	02/23/2012
10	02/23/2012	Review	26.1-28.5	(Review for exam)	
	02/28/2012	Exam			
11	03/01/2012	Magnetic fields	29.1-29.6	29.5,29.12,29.47	03/06/2012
12	03/06/2012	Magnetic field sources	30.1-30.6	30.5,30.21,30.29	03/08/2012
➔ 13	03/08/2012	Faraday's law	31.1-31.5	31.12,31.23,31.40	03/20/2012
	03/13/2012	*No class (Spring Break)*			
	03/15/2012	*No class (Spring Break)*			
14	03/20/2012	Induction and AC circuits	32.1-32.6		
15	03/22/2012	AC circuits	33.1-33.9		
16	03/27/2012	Electromagnetic waves	34.1-34.3		
17	03/29/2012	Electromagnetic waves	34.4-34.7		

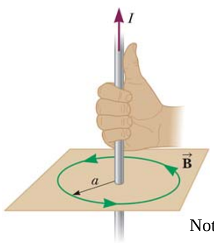
Comment on magnetic field directions:
Right-hand "thumb" rule for current-carrying wires



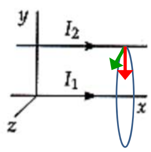
From HW:



Comment on magnetic field directions:
Right-hand "thumb" rule for current-carrying wires



From HW:

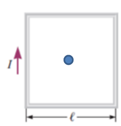


Note : Forces from currents are very small :
For example, if $I_1 = I_2 = 20\text{ A}, \ell = 1\text{m}, a = 0.01\text{m}$

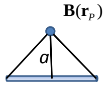
$$F = \frac{\mu_0 I_1 I_2 \ell}{2\pi a} = 0.008N$$

More webassign hints:

Consider the following figure.



$$\mathbf{B}(\mathbf{r}_P) = \hat{\mathbf{z}} \frac{\mu_0 I}{4\pi a}(\sin\theta_1 - \sin\theta_2)$$



(a) A conducting loop in the shape of a square of edge length ℓ = 0.420 m carries a current I = 8.00 A a
figure above. Calculate the magnitude and direction of the magnetic field at the center of the square.
magnitude μT
direction ---Select---

(b) If this conductor is reshaped to form a circular loop and carries the same current, what is the value o
magnetic field at the center?
magnitude μT
direction ---Select---

Summary:

Ampere's law :
Integral form : $\oint \mathbf{B} \cdot d\mathbf{s} = \mu_0 I_{in}$
Differential form : $\nabla \times \mathbf{B} = \mu_0 \mathbf{J}$

Faraday's law :
$$\int E(\mathbf{r}) \cdot d\mathbf{s} = -\frac{d}{dt} \int \mathbf{B}(r) \cdot dA$$
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

Gauss's law :
Integral form : $\oint \mathbf{E}(\mathbf{r}) \cdot d\mathbf{A} = \frac{Q_{in}}{\varepsilon_0}$
Differential form : $\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$

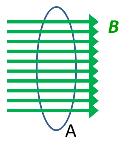
Note :
$$\oint \mathbf{B}(\mathbf{r}) \cdot d\mathbf{A} = 0$$
$$\nabla \cdot \mathbf{B} = 0$$

Faraday's law

Effects of time-changing currents and fields

Magnetic flux:

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

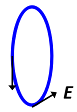


In this case:

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

Induced EMF:

$$\mathcal{E} = \int \mathbf{E}\cdot d\mathbf{s}$$



Faraday's law $\mathcal{E} = -\frac{d\Phi_B}{dt}$

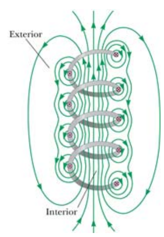
Examples of $\frac{d\Phi_B}{dt}$:

Field inside solenoid:

$$B = \frac{\mu_0 N I}{\ell}$$

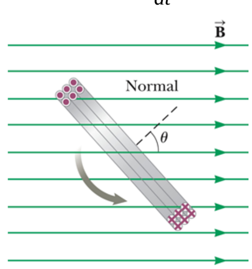
If I is changing with time:

$$\frac{dB}{dt} = \frac{\mu_0 N}{\ell}\frac{dI}{dt}$$



Faraday's law $\mathcal{E} = -\frac{d\Phi_B}{dt}$

Examples of $\frac{d\Phi_B}{dt}$:

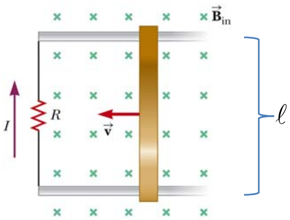


$$\frac{d\Phi_B}{dt} = \frac{d(\mathbf{B}\cdot\mathbf{A})}{dt} = BA\frac{d\cos\theta}{dt}$$

Faraday's law

$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

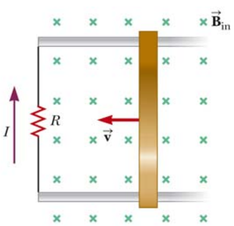
Example



$$\frac{d\Phi_B}{dt} = -B_{in}\ell v$$

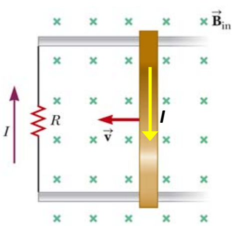
$$\mathcal{E} = IR = -\frac{d\Phi_B}{dt} = B_{in}\ell v$$

$$I = \frac{B_{in}\ell v}{R}$$



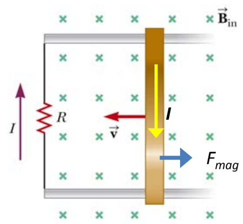
Consider the setup shown in the figure. What can cause the bar to move with velocity v:

A. Evil physics professor
B. Applied force on bar pulling to right
C. Applied force on bar pulling to left
D. Magnetic forces



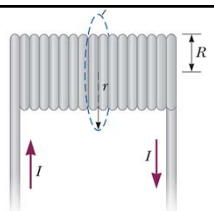
Consider the setup shown in the figure where current ***I*** is flowing through the mobile bar. What is the effect of the magnetic force acting on the bar?

A. It is too small to have an effect.
B. It has an effect in the same direction as the applied force.
C. It has an effect in the opposite direction as the applied force.



$$I = \frac{B_{in} \ell v}{R}$$

$$F_{mag} = \ell I B_{in} = \frac{B_{in}^2 \ell^2 v}{R}$$



Field inside solenoid:

$$B = \frac{\mu_0 N I}{\ell}$$

If I is changing with time:

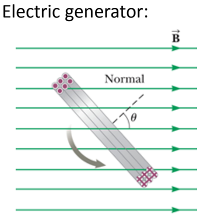
$$\frac{dB}{dt} = \frac{\mu_0 N}{\ell}\frac{dI}{dt}$$

Electric field induced at radius r:

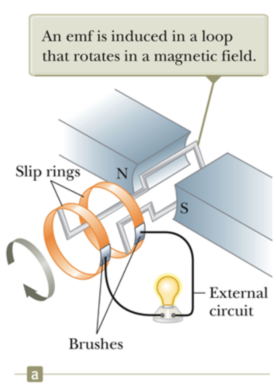
$$\mathcal{E} = \int \mathbf{E} \cdot d\mathbf{s} = E(2\pi r) = -\frac{d\Phi_B}{dt} = -\pi R^2 \frac{dB}{dt}$$

$$E = -\frac{R^2}{2r}\frac{dB}{dt} = -\frac{R^2}{2r}\frac{\mu_0 N}{\ell}\frac{dI}{dt}$$

Electric generator:



$\theta = \omega t$



$$\mathcal{E} = -N \frac{d\left(BA\cos(\omega t)\right)}{dt}$$

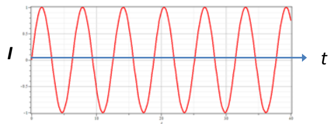
$$= NBA\,\omega \sin(\omega t)$$

Electric generator:

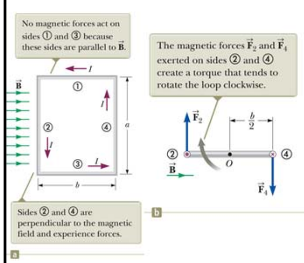
$$\mathcal{E} = -N\frac{d\left(BA\cos(\omega t)\right)}{dt}$$
$$= NBA\,\omega\sin(\omega t)$$

If the resistance in the generator coil is R, current in the coil is given by:

$$I = \frac{\mathcal{E}}{R} = \frac{NBA\,\omega}{R}\sin(\omega t) \equiv I_{\max}\sin(\omega t)$$



Torque on a current-carrying wire in a magnetic field



Recall that a generator has a current-carrying coil in a magnetic field.

A. No problem – that was in Chap. 29 and no longer relevant.
B. Generator coil will experience a torque which makes the coil spin faster.
C. Generator coil will experience a torque which makes the coil spin slower.

Electric generators and motors

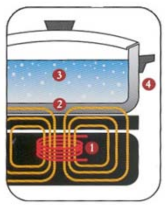
Hybrid vehicles are designed so that their electric motors are equipped with circuits to take advantage of "regenerative" braking, effectively converting the motor to a generator to recharge the batteries when the breaks are activated.

Other uses for inductors

- Rechargeable electric toothbrush
- Induction heating cooking

Uses of Faraday's law continued:

http://theinductionsite.com/how-induction-works.shtml



How Induction Cooking Works:

1. The element's electronics power a coil (the red lines) that produces a high-frequency electromagnetic field (represented by the orange lines).
2. That field penetrates the metal of the ferrous (magnetic-material) cooking vessel and sets up a circulating electric current, which generates heat. (But see the note below.)
3. The heat generated *in the cooking vessel* is transferred to the vessel's contents.
4. Nothing outside the vessel is affected by the field--as soon as the vessel is removed from the element, or the element turned off, heat generation stops.

(Image courtesy of Induction Cooking World)