

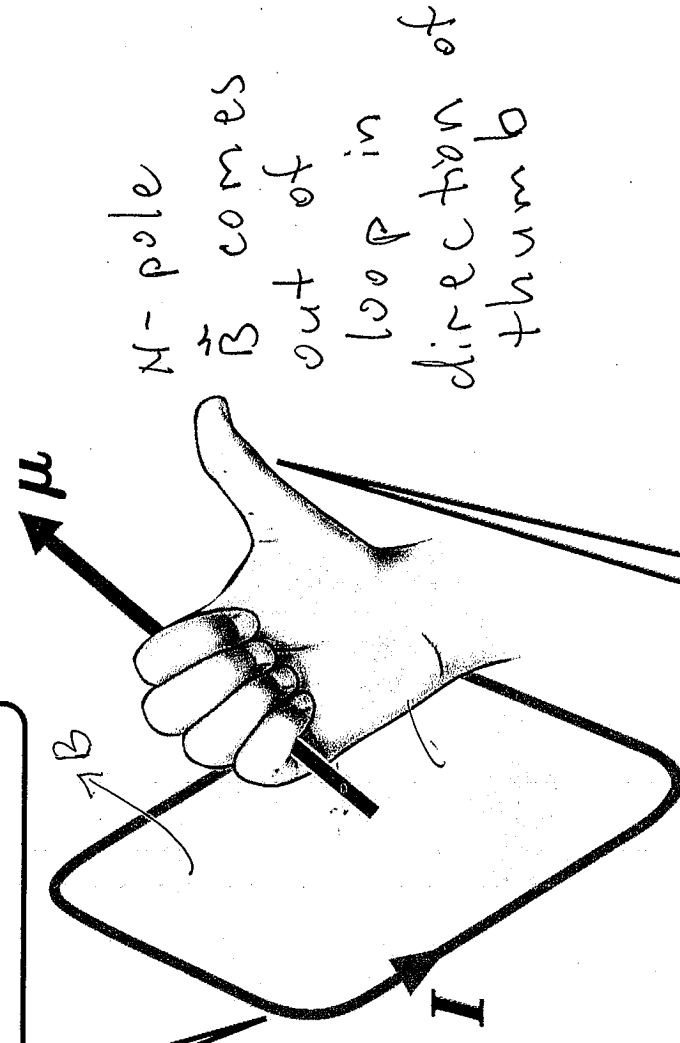
Lecture # 16

Faraday's Law

Direction of magnetic dipole

**If you curl fingers of your right hand around in direction of current...**

1.  $\vec{\mu} = I\vec{A}$  ; single loop
2.  $\vec{\mu} = N I\vec{A}$  ;  $N$ -identical loops (coil)
3.  $\vec{\mu} = N I\vec{A} (1 + \chi)$  (if loops surround permeable material with susceptibility  $\chi$ )



**...then your thumb points in direction of magnetic moment  $\mu$ .**

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In which direction is the south pole of loop?

- (a) into the page (b) up (c) down (d) out of the page

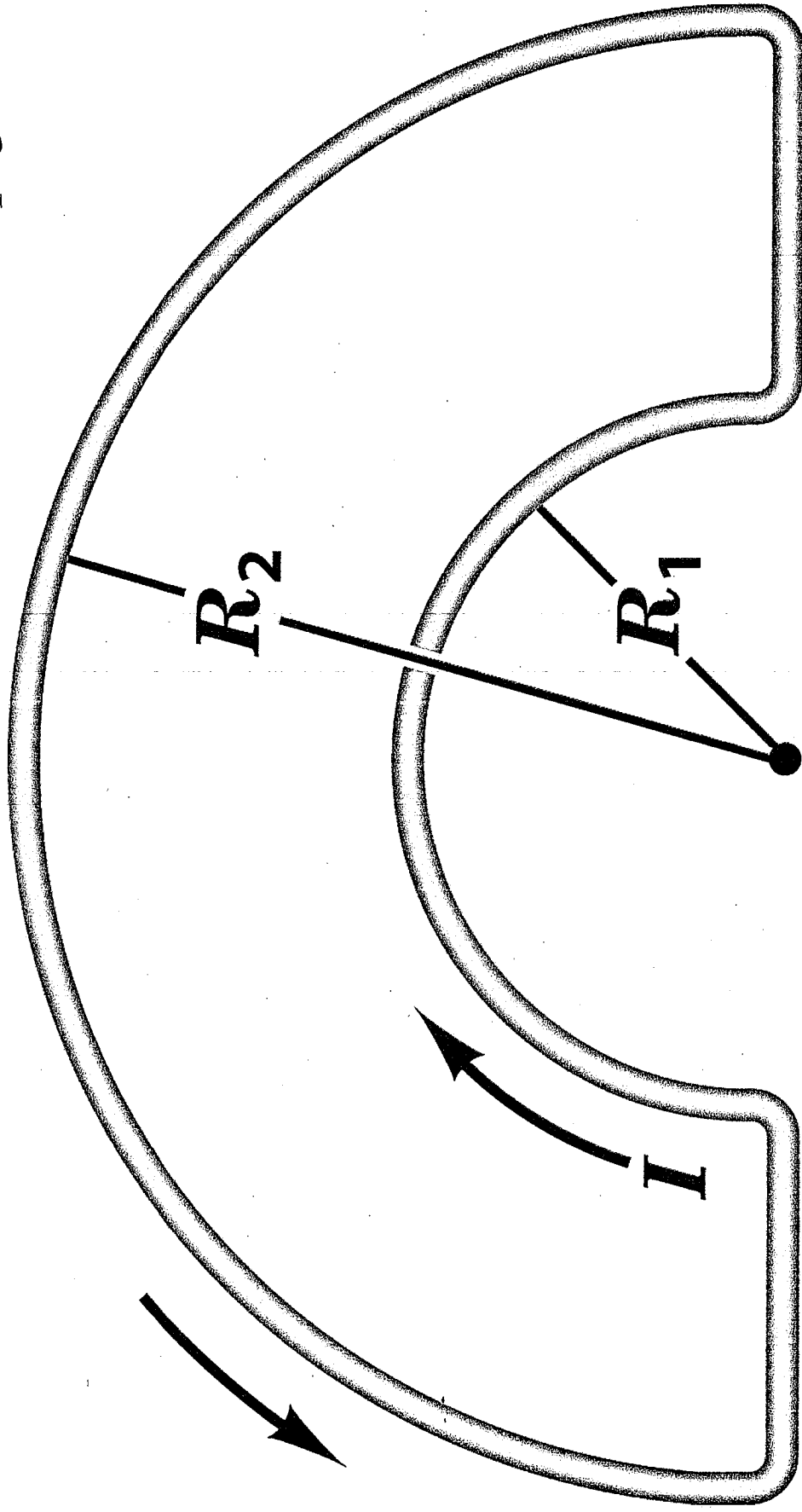


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The magnitude of the magnetic moment is:

- (a)  $I\pi(R_2^2 - R_1^2)$  (b)  $I\pi R_1 R_2$  (c)  $I2\pi R_2^2$  (d)  $I\pi(R_2^2 - R_1^2) / 2$

$$\mu = \frac{2N}{3} \frac{\mu}{\mu_0} \quad \text{---} \quad \mu = \frac{2N}{3} \mu_0$$

True or False

The north pole of this loop is above and the south pole is below this figure.

- (a) true      (b) false

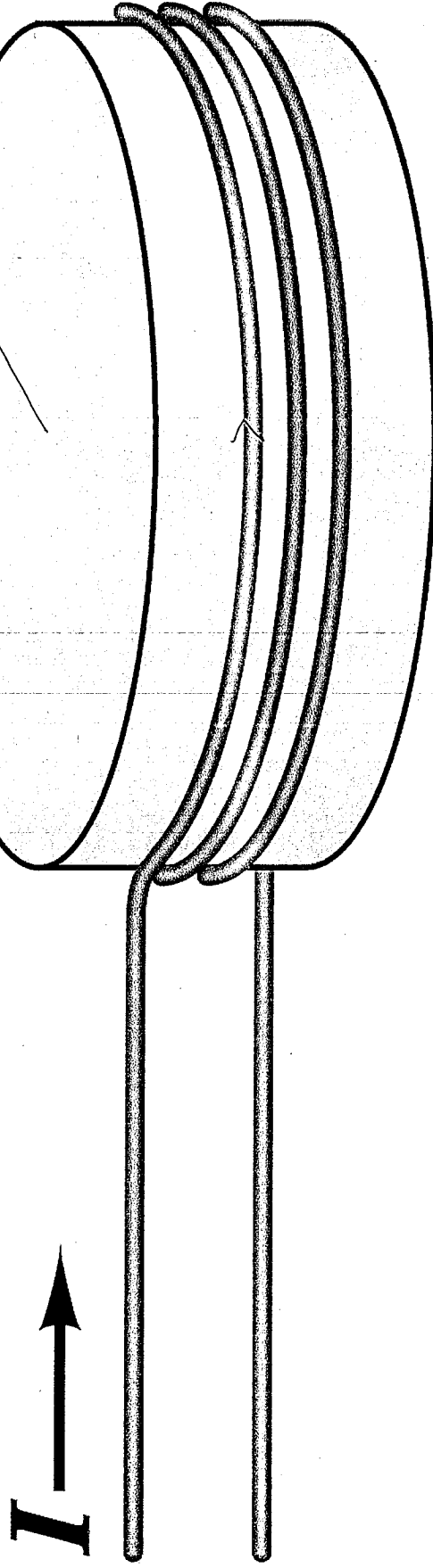


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If  $R$  is the radius of this solenoid with a magnetic permeability  $\mu$ , the magnitude of the magnetic moment is

- (a)  $I\pi R^2$       (b)  $3I\pi R^2$       (c)  $3I\pi R^2 \mu / \mu_0$       (d)  $I\pi R^2 \mu / \mu_0$

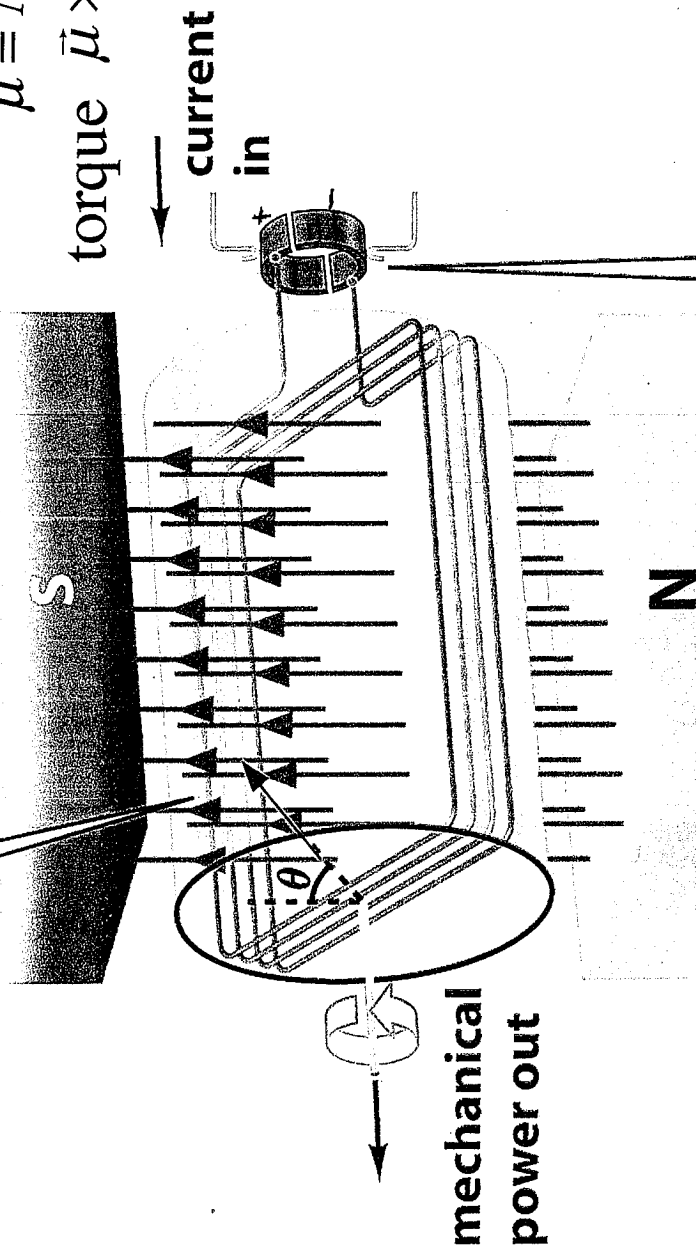
Magnetic forces on current segments produce torque on coil.

Electric engine converts electrical energy to mechanical energy

magnetic moment

$$\vec{\mu} = NIA$$

$$\text{torque } \vec{\mu} \times \vec{B}$$

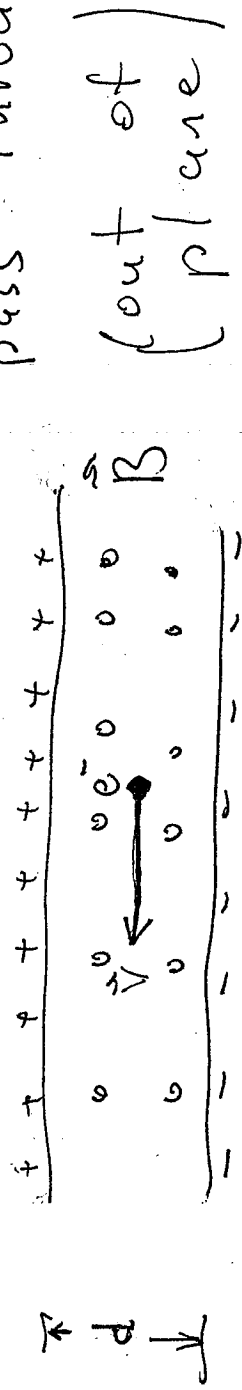


Dynamo: converts mechanical energy to electrical energy

Commutator reverses current direction in coil when plane of coil is perpendicular to magnetic field.

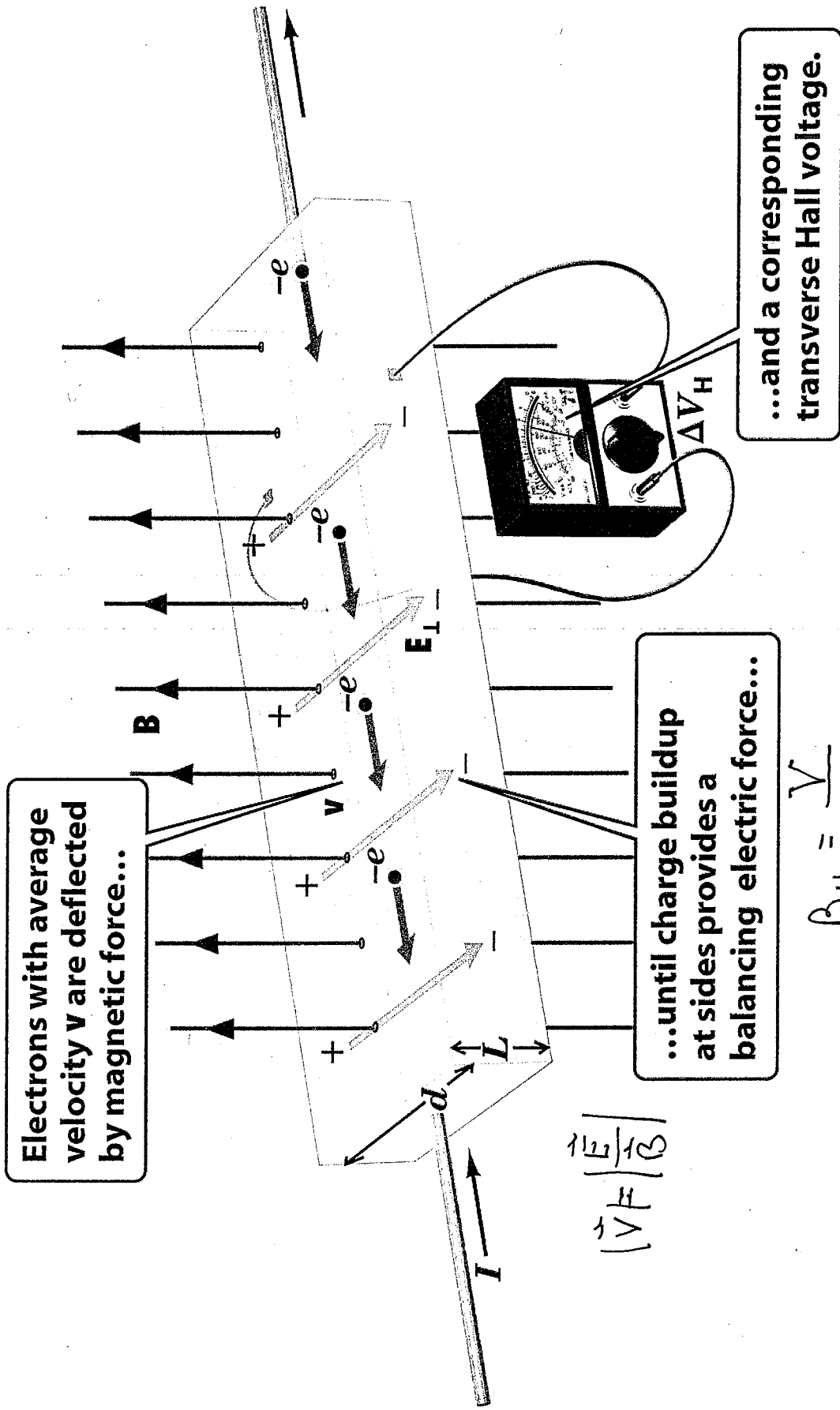
Figure 30-16 Physics for Engineers and Scientists 3/e © 2007 W. W. Norton & Company, Inc.

In terms of  $\vec{v}$ ,  $\vec{B}$  and  $d$ , what voltage is required for electron to pass through?



$$|\vec{V}| = \frac{E}{B}, \quad V = Ed = B|\vec{v}|d$$

Magnetic	Field	'Forces'	Electron	down
Electric	Field	'Forces'	electron	up



Electrons with average velocity  $\vec{v}$  are deflected by magnetic force...

...until charge buildup at sides provides a balancing electric force...

...and a corresponding transverse Hall voltage.

$$|\vec{v}_H| = \frac{v}{B}$$

$$R_H = \frac{V}{I}$$

$$= \frac{E_T d}{n e v A}$$

$$= \frac{E_T d}{n E_L d} = \frac{B}{n e L} = R_H \quad (5)$$

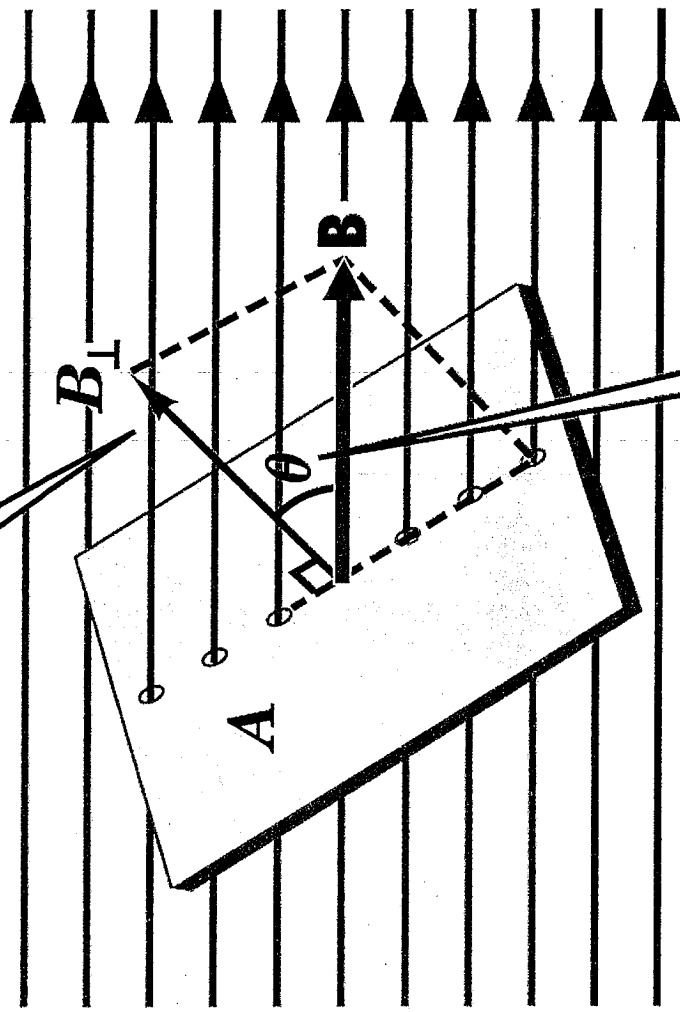
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Magnetic Flux

$$\Phi_m = \int \vec{B} \cdot d\vec{A}$$

$$= BA \cos \theta$$

Component of magnetic field perpendicular to surface is  $B_{\perp} = B \cos \theta$ .



$\theta$  is angle between magnetic field and perpendicular to surface.

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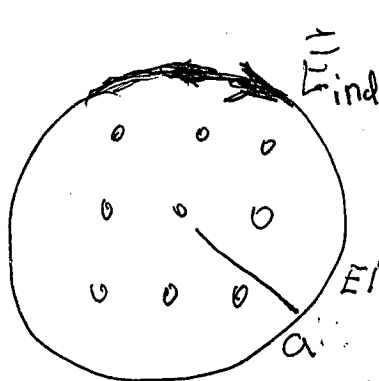
# Faraday's Law

Magnetic Fields Changing  
in time induce  
electric fields!

$$\text{magnetic flux} \equiv \Phi_m = \int \vec{B} \cdot d\vec{A}$$

$$\text{EMF} \equiv \oint_{\text{loop}} d\vec{s} \cdot \vec{E} = - \frac{\partial \Phi_m}{\partial t}$$

↑  
integral



$$B = B_0 + B_1 t/T$$

$$\text{EMF} = 2\pi a E_{\text{ind}} = \frac{\partial \Phi_m}{\partial t}$$

$$= \frac{\partial (B_0 + \frac{B_1 t}{T}) \pi a^2}{\partial t}$$

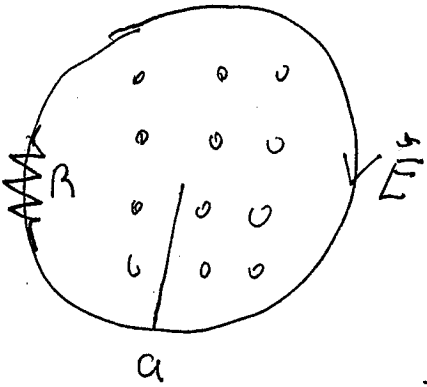
$$\frac{2\pi a E_{\text{ind}}}{T} = \pi B_1 a^2$$

$$E_{\text{ind}} = \frac{B_1 a}{2T}$$

$$2\pi a E_{\text{ind}} = \pi B_1 \frac{a^2}{T}$$

## Lenz's Law:

Induced Response  
resists change



Rising B-Field  $B = B_0 + B_1 t/T$

Induced Electric Field  
attempts to prevent  
B-field from rising

Let loop at radius  $a$   
have a resistance  $R$ .

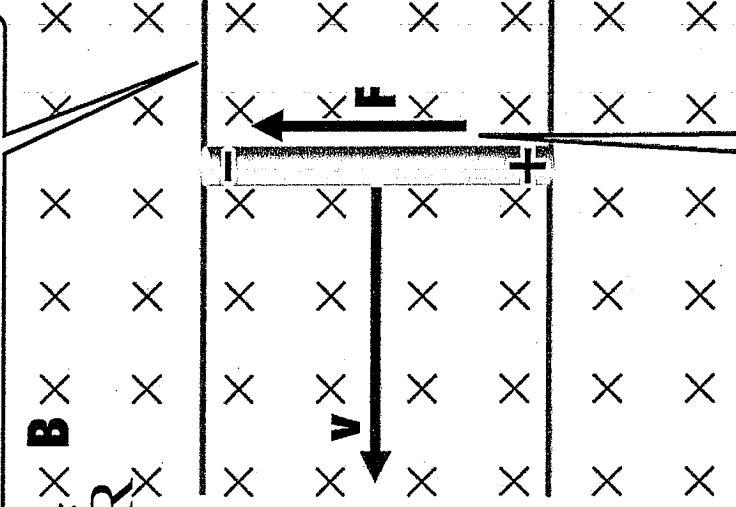
Current is induced in the  
loop to produce magnetic field  
to 'buck' (changing of) rising  
magnetic fields

$$\text{EMF} = 2\pi a E = \pi a^2 B_1 / T$$

$$I R = \pi a^2 B_1 / T$$

$$I = \frac{\pi a^2 B_1}{T R}$$

When rod moving to left is in contact with this conducting path...



Motional EMF produces currents that resist change in enclosed magnetic flux

current in resistor  $\times B$   
 Motional  $EMF = IR$   
 $EMF = vBL$   
 Thus  $I = vBL/R$

Faraday's View  
 Change of B-flux  
 In loop in time t  
 $\Delta\Phi_m = vBtL$   
 $EMF = d\Phi_m/dt = vBL$

...electrons flow clockwise around path...

...and conventional current flows counterclockwise.

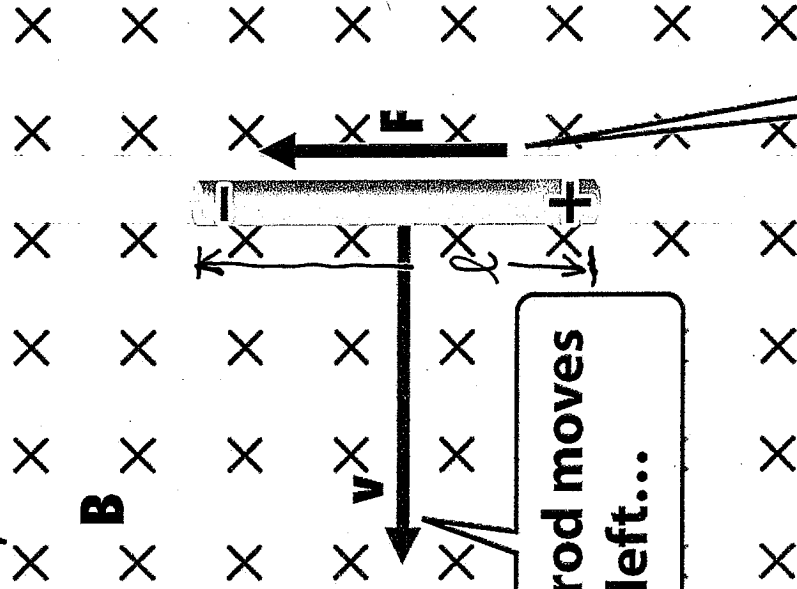
same EMF as motional EMF

Figure 31-2. Physics for Engineers and Scientists 3/e © 2007 W. W. Norton & Company, Inc.

Magnetic field  $\mathbf{B}$  is directed into plane of page.

## Motional EMF

Charges in a conductor feel a magnetic force when conductor moves in a magnetic field



$$\vec{F} = e\vec{v} \times \vec{B}$$

$$EMF = \frac{F}{e} l = vBl$$

When rod moves to the left...

...magnetic force pushes free electrons upward along rod.

Figure 31-1 Physics for Engineers and Scientists 3/e  
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