Ch 29 - Electromagnetic Induction & Faraday's Law

1820-1821 electric current produces mag field?

1830 ?

Faraday (1791-1867) first thought magnetic field produces current: but - think back to Weld...

Concept of flux:

Magnetic flux

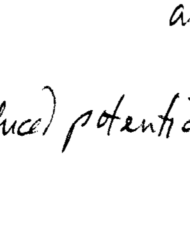
$\Phi_B = \vec{B} \cdot \vec{A} = BA\cos\theta$ (Compare w/ $\Phi_E = \vec{E} \cdot \vec{A}$

if not uniform, $\boxed{\Phi_B = \int \vec{B} \cdot d\vec{A}}$ unit Weber $1Wb = 1T \cdot m^2$

actually : changing flux creates a potential difference and that pot'l diff causes current to flow ($V = IR$

induced potential diff $= \boxed{\mathcal{E} = -\frac{d\Phi_B}{dt}}$ Faraday's Law of Induction

Example: Loop of wire in B field (ex 29-2)



$l = 5cm$

$B = 0.16T$

$R = 0.612\Omega$

a) Φ_B when $\vec{B} \perp$ to face of loop

b) Φ_B when angle btw $\vec{B}$ and $\vec{A}$ is $30°$

c) avg current when rotated a→b) in 0.14s

29-2

Soluh $\theta = 0!$

a) $\Phi_B = \vec{B}\cdot\vec{A} = BA\cos\theta$

$= (0.16T)(2.5\times10^{-3}m^2)(1)$

$= 4\times10^{-4}$ Wb

b) $\theta = 30$ $\Phi_B = (4\times10^{-4})\cos 30 = 3.5\times10^{-4}$ Wb ← less, as expected

c) $\mathcal{E} = -\frac{d\Phi_B}{dt}$ $|\mathcal{E}| = \frac{\Delta\Phi_B}{\Delta t} = \frac{BA\cos 0 - BA\cos 30}{\Delta t}$

$= \frac{4\times10^{-4}\text{ Wb} - 3.5\times10^{-4}\text{ Wb}}{0.14\text{ s}}$

$= 3.6\times10^{-4}$ V

$V = IR$

$I = \frac{V}{R} = \frac{\mathcal{E}}{R} = \frac{3.6\times10^{-4}\text{ V}}{0.012\ \Omega} = \boxed{0.030\text{ A}}$

Direction of Current

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

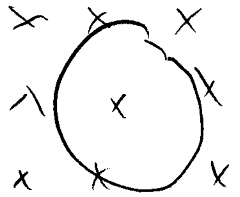
" The induced emf is always in a direction that opposes the original change in flux that caused it "

Stated another way

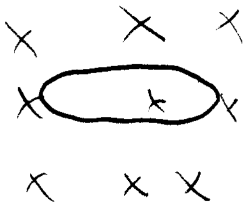
" A current produced by an induced emf moves in a direction so that the mag field created by that current opposes the original change in flux "

↑ Lenz's law

example



→ rotate loop



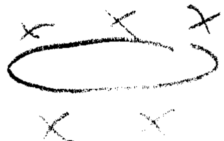
is flux increasing or decreasing?

original field: into the board

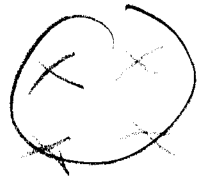
induced field: also into the board - why? opposes change in flux

direct of current? clockwise

rotate back:



→

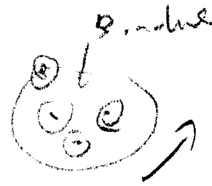


flux increasing

field into board

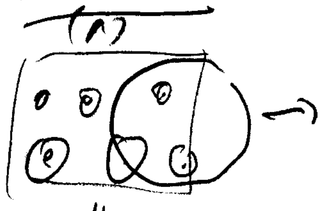
induced field; out of board

direct of current:  ccw



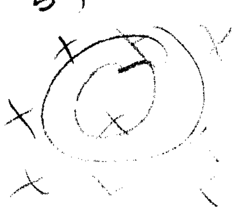
Practice:

(a)



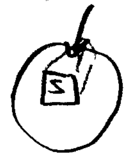
pulling loop out of mag field

(b)



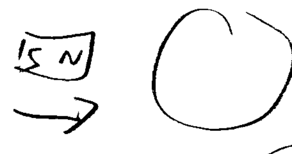
shrinking mag field

(c)



S mag pole moving up from below loop

(d)

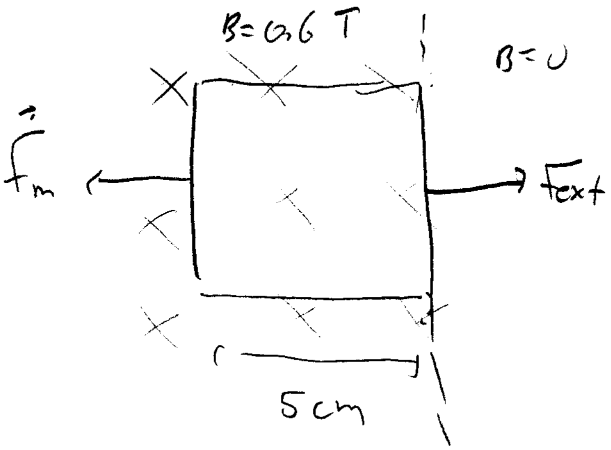


a) ccw
b) cw
c) ccw
d) ○

discuss solutions

29-4

Example (28-5)



and R = 100 Ω

A coil with 100 loops is pulled at a constant speed to the right.

At t = 0 shown

Δt = 0.1 s whole loop is in field-free region

find

a) the rate of change in flux through the coil

b) the emf and current induced.

c) How much energy is dissipated in the coil?

d) what was the avg. force required?

Solution

a) rate is constant

$$\frac{d\Phi_b}{dt} = \frac{\Delta \Phi_b}{\Delta t} = \frac{0 - BA\cos 0}{\Delta t}$$

$$= -\frac{(0.6\,T)(0.05\,m)^2}{0.1\,s} = -1.5\times10^{-2}\,\frac{Wb}{s}$$

flux is decreasing ✓ (final smaller than initial)

b) $\mathcal{E} = -\frac{d\Phi_b}{dt}$ for one coil

$\mathcal{E} = -N\frac{\Delta\Phi_b}{\Delta t}$ for N coils

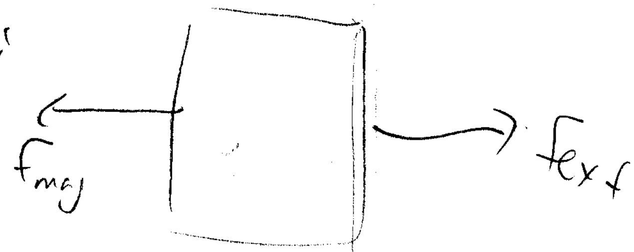
$\mathcal{E} = -(100)(-1.5\times10^{-2}\,Wb/s) = 1.5\,V$

$I = \frac{\mathcal{E}}{R} = \frac{1.5\,V}{100\,\Omega} = 150\,mA$ cw

c) $E = Pt = I^2Rt = (15\times10^{-3}A)^2(100\,\Omega)(0.1\,s)$
$= 2.25\times10^{-3}\,J$

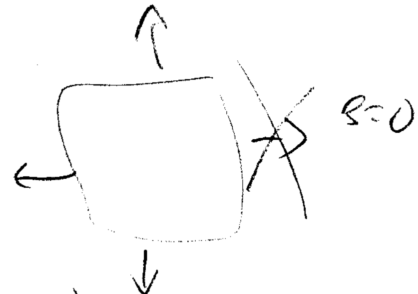
d) $W = Fd \Rightarrow F = \frac{W}{d} = \frac{2.25\times10^{-3}\,J}{0.05\,m} = 0.045\,N$

Alternatelly ;



just!

$f_{mag} < f_{ext} \rightarrow f_{mag} \approx f_{ext}$



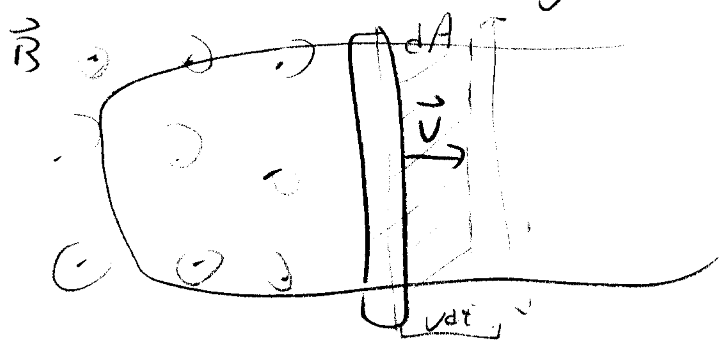
$f_{mag} = N I \vec{l} \times \vec{B}$

$l = 5\,cm$

$F = (100)(0.015A)(0.05m)(0.06T)$
$= 0.045N$

July 27

Consider the following



$dA = lv\,dt$

$$\varepsilon = \frac{d\Phi_B}{dt} = \frac{B\,dA}{dt} = \frac{B\,lv\,\cancel{dt}}{\cancel{dt}} = Blv.$$

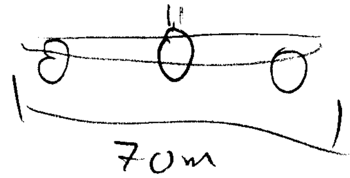
"motional emf"

Do Demo

29-6

ex 29-~~8~~ What about airplanes?

$V = 1000 \frac{km}{h}$

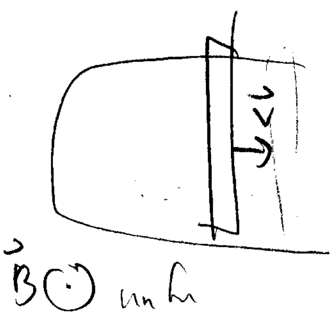


earth's mag field $\sim 5\times10^{-5}$T vertical

$$\mathcal{E} = B\ell v = (5\times10^{-5})(70m)\left(\frac{1000\,km}{hr}\right)\left(\frac{1h}{3600s}\right)\left(\frac{1000\,m}{1km}\right) \approx 1V$$

okay !!

Ex 29-8 what is the force required to steadily move rod?



$$\vec{F} = I\vec{\ell}\times\vec{B}$$
$$|F| = I\ell B$$

$$I = \frac{\mathcal{E}}{R} = \frac{B\ell v}{R}$$

$$F = \frac{B\ell v}{R}\ell B = \frac{B^2\ell^2 v}{R}$$

is this a constant force? (yes if B ℓ R const)

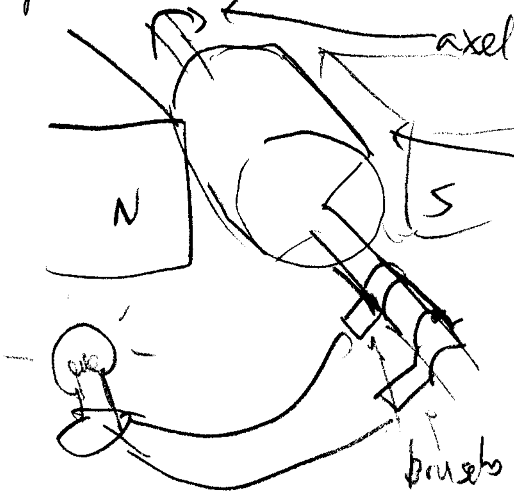
what if R not constant?

R increases, so force decreases

Electric Generators

motor: electrical → mechanical energy

generator: mechanical → electric energy



uniform field:

area of loop

$$\mathcal{E} = -\frac{d\Phi_B}{dt} = -\frac{d}{dt}\int \vec{B}\cdot d\vec{A} = -\frac{d}{dt}\,B\cdot A = -\frac{d}{dt}(BA\cos\theta)$$

$$= -BA\frac{d}{dt}(\cos\theta)$$

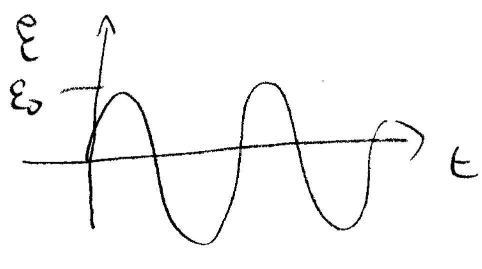
$$= +BA\sin\theta\,\frac{d\theta}{dt} \qquad \frac{d\theta}{dt} = \omega \quad \text{let } \theta_0 = 0 \quad \theta = \cancel{\theta_0} + \omega t$$

$$= +BA\sin\omega t\,(\omega)$$

for N loops of wire

$$\mathcal{E} = NAB\omega\sin\omega t$$

$$= \mathcal{E}_0\sin\omega t$$

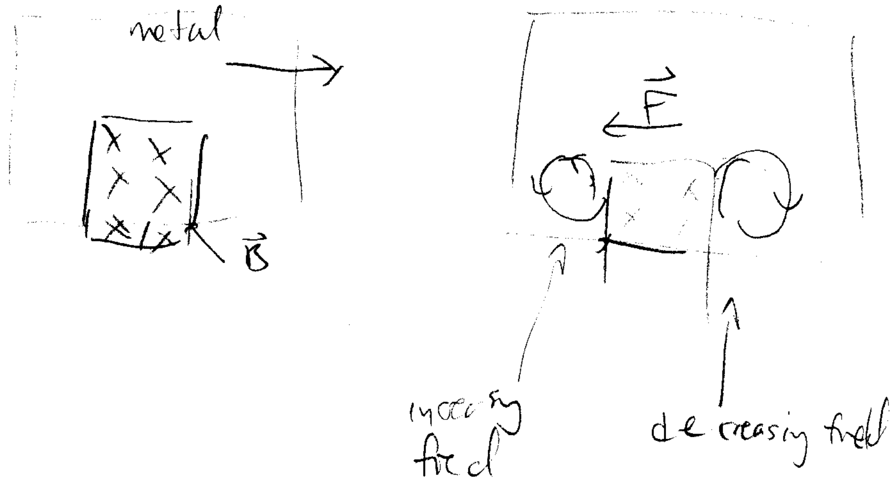


AC current $\left(I = \frac{V}{R}\right)$

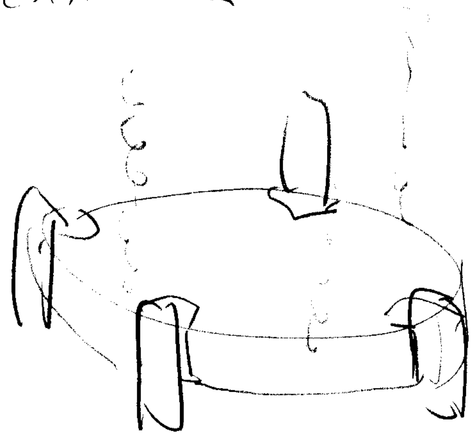
DO DEMO

29-8

Eddy Currents

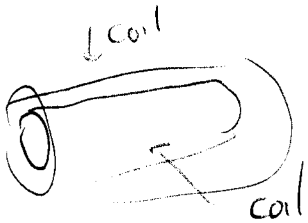


resists motion

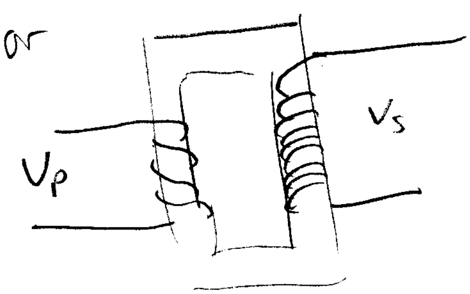


damps vibrations!

Transformers



or



current from primary source creates magnetic field ~~[illegible]~~ voltage induced in secondary coils is $V_s = -N_s \frac{d\Phi_B}{dt}$

while $V_p = N_p \frac{d\Phi_B}{dt}$

The rate of change of flux is equal

$$\frac{V_s}{N_s} = \frac{V_p}{N_p}$$

$$\Rightarrow \boxed{\frac{V_s}{V_p} = \frac{N_s}{N_p}}$$

Can transform one voltage to another.

note V_s will have the same frequency as V_p.

$N_s > N_p$ "step-up transformer"

$N_s < N_p$ "step-down transformer"

commonly >99% efficient

example cell phone charger

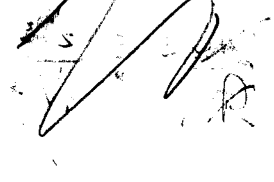
$120\ V_{ac} \rightarrow 5\ V_{ac}$

suppose $N_s = 30$ charger supplies 700 mA

a) find N_p

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \rightarrow N_p = \frac{N_s V_p}{V_s} = \frac{(30)(120V)}{(5V)} = 720 \text{ turns}$$

b) find the current in the primary coil



$P = IV$ ~100% efficient so

$$I_p V_p = I_s V_s$$

$$\frac{I_s}{I_p} = \frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$I_p = \frac{I_s N_s}{N_p} = (0.70A)\left(\frac{30}{720}\right) = 29 mA$$

c) what is the power?

$$P = I_s V_s = (0.70A)(5.0V) = 3.5W$$

29-7 Changing Mag field Produces an Electric field

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

potential diffrnce

$$\mathcal{E} = \oint \vec{E} \cdot d\vec{l}$$

$$\oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$$

path encloses area through which mag field is changing

notice: forces due to changing $\vec{B}$ are nonconservative

$$\oint \vec{E} \cdot d\vec{l} \neq 0 \; !$$