Chapter 34

34.1 Faraday's Discovery

A current in a coil is induced if the magnetic field through the coil is changing in time.

The current can be induced two different ways

1. By changing the size, orientation or location of the coil - This will change the amount of magnetic flux passing through the coil
2. By changing in time the strength of the magnetic field while holding the coil stationary

34.2 Motional EMF

We ~~kow~~ know that the force on a moving charge is

$$\vec{F} = q(\vec{E} + \vec{V} \times \vec{B})$$

this is

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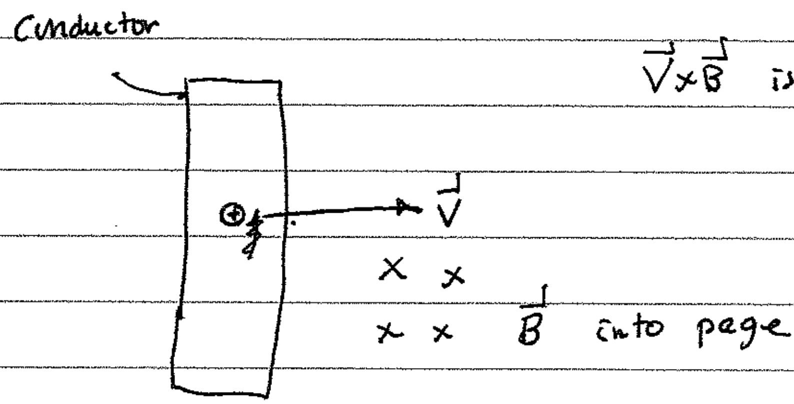
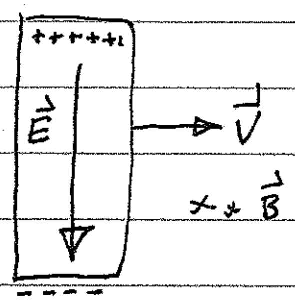


$\vec{V}\times\vec{B}$ is up

Force on electrons is down

~~electrons will migrate to~~

what will happen?



electrons will move down creating an electric field $\vec{E}$ pointing down

eventually electrons will stop flowing when

$$\vec{E}+\vec{V}\times\vec{B}=0$$

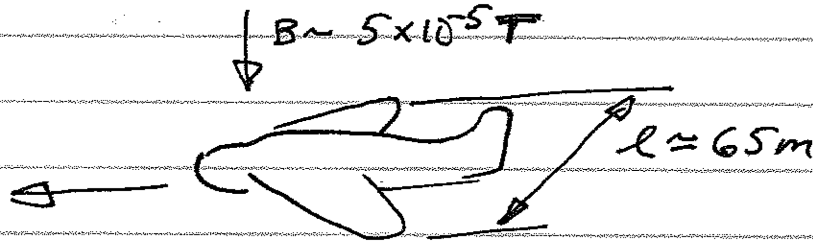
$\vec{V}\times\vec{B}$ is up $\quad \vec{E}$ is down

$$|\vec{E}| = |\vec{V}\times\vec{B}| = VB \text{ in this example}$$

Some numbers

$$\Delta V = V \ell B$$

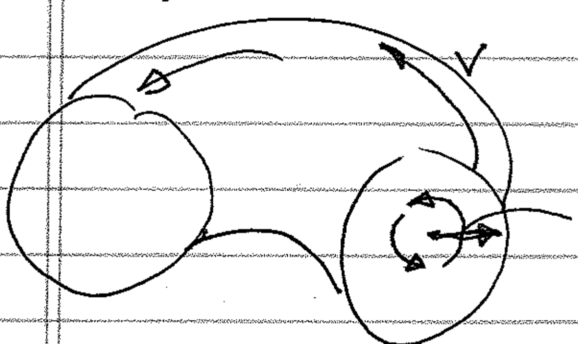
What is the potential drop across the wings of an airplane flying through the earth's magnetic field?



$V = 260$ m/s

$\Delta V = 0.85$ VOLTS

WHAT is the anticipated potential drop from the center of the ITER tokamak to the edge?



Plasma rotates with ~~vel~~ speed ~

$\ell \sim 3$m

$B \sim 1$T

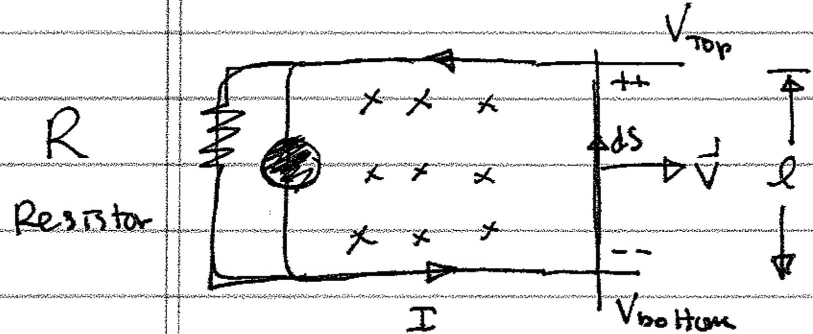
$V \sim 9.79 \times 10^{4}$ m/s $\left(62 \frac{\text{miles}}{\text{sec}}\right)$

$\Delta V = 2.9 \times 10^{5}$ Volts

~~Now consider an alternate example~~

Show Example from Text

Case #2 Allow current to flow



Current I flows through resistor

Potential diffenence

ΔV ~~V(up)~~ V(

$$\Delta V = V_{Top} - V_{bottom} = -\int_{bottom}^{top} \vec{E} \cdot d\vec{s} = V \ell B$$

(down, up)

$|\vec{E}| = VB$

$$\boxed{\text{Current that flows} \quad I = \frac{\Delta V}{R}}$$

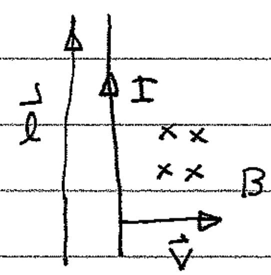
~~Picture assumes~~ We assume the magnetic field created by ~~Note direction of current~~ this current is negligible.

Power what is the power supplied to the resistor?

$$P_{Dissipated} = I^2 R = I\Delta V$$

Where does this power come from?

Something must be pushing on the wire to keep it moving at constant velocity.



Force on wire due to $\vec{B}$ $\quad \vec{F}_{mag} = I\vec{l} \times \vec{B}$

$|\vec{F}_{mag}| = IlB$

FORCE is to the left. To keep the wire moving to the right something must be pushing — me. to the right

$$|\vec{F}_{push}| = IlB$$

Rate at wich work is done $\quad \vec{V} \cdot \vec{F}_{push} = P_{push}$

$$P_{push} = IlBV = I(lBV) \qquad \Delta V = lBV$$

$$= I\Delta V$$

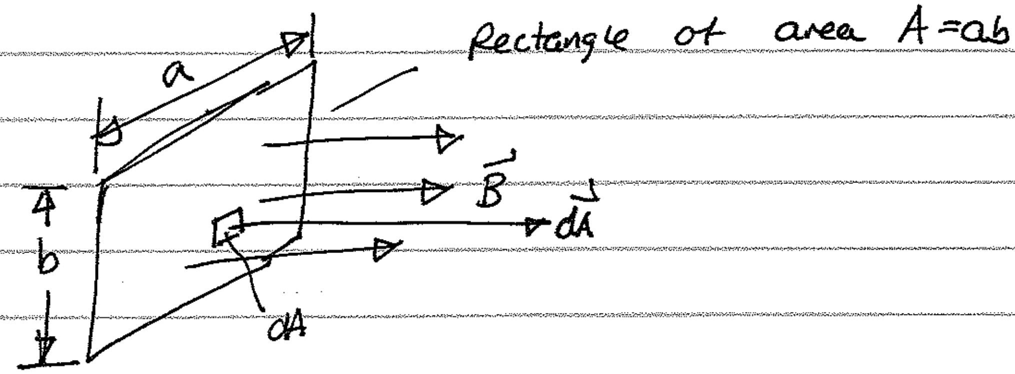
34.3 Magnetic Flux

We have already encountered the concept of flux through a surface

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

Remember for a closed surface $\Phi = 0$

Consider a non - closed surface

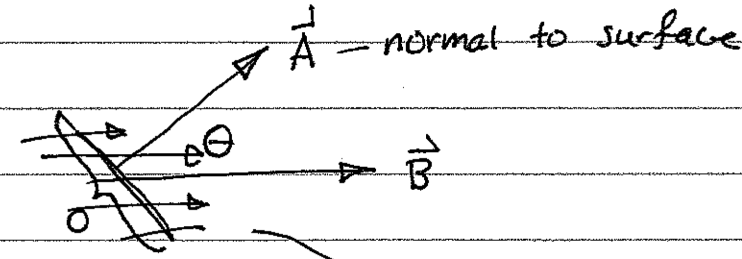


Suppose the rectangle is oriented such that $\vec{B}$ is normal to the surface

$d\vec{A}$ and $\vec{B}$ are parallel

$$\Phi = \int \vec{B} \cdot d\vec{A} = |\vec{B}| A = |\vec{B}| ab = |\vec{B}| A$$

Suppose I tilt the rectangle



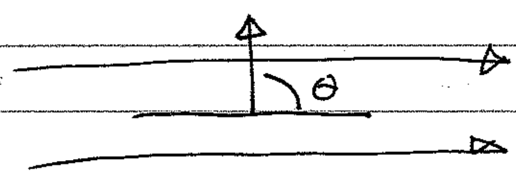
Fewer field lines pass through surface

$$\vec{B} \cdot d\vec{A} = |\vec{B}||d\vec{A}| \cos\theta$$

$$\phi = \int \vec{B} \cdot d\vec{A} = BA\cos\theta$$

less magnetic flux penetrates the surface

Suppose area is rotated 90°

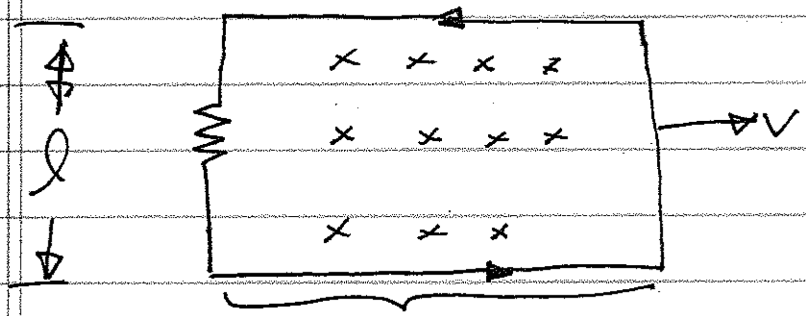


$\theta = 90°$

$$\phi = \int \vec{B} \cdot d\vec{A} = BA\cos 90° = 0$$

· A suggestive relation

Remember our example



this length is vt

What is the magnetic flux through this ~~to~~ AREA

$$|\Phi| = BA \qquad A = \ell v t$$

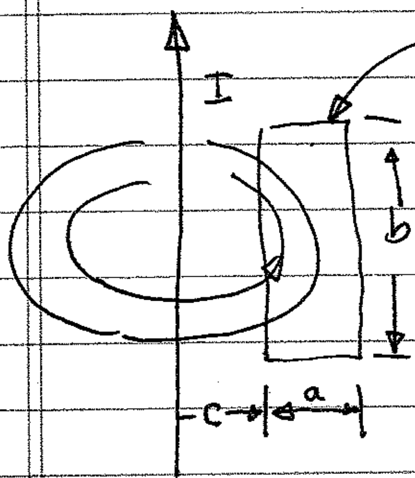
· DEFINE $\vec{A}$ direction to be out of page

$\vec{B}$ is in page,

$$\Phi = -B(\ell v t) \qquad \Delta V = B\ell v$$

$$\mathcal{E}_m \quad \boxed{\Delta V = -\frac{d\Phi}{dt}}$$

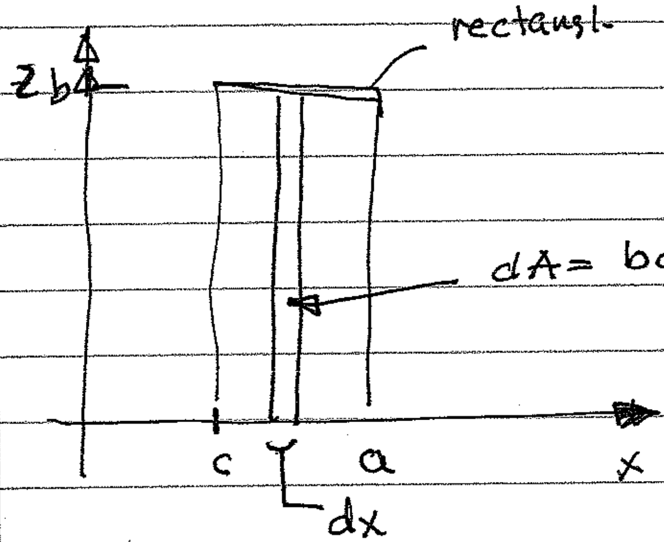
TWO EXAMPLES FLUX due to a line current throug a rectangle



what is the magnetic flux through this rectangle (taking into the page to be positive)

$$|\vec{B}| = \frac{\mu_0 I}{2\pi x}$$

x = distance from wire to some arbitrary point



$$dA = b\,dx$$

$$\Phi = \int_{x=c}^{x=c+a} B\,dA$$

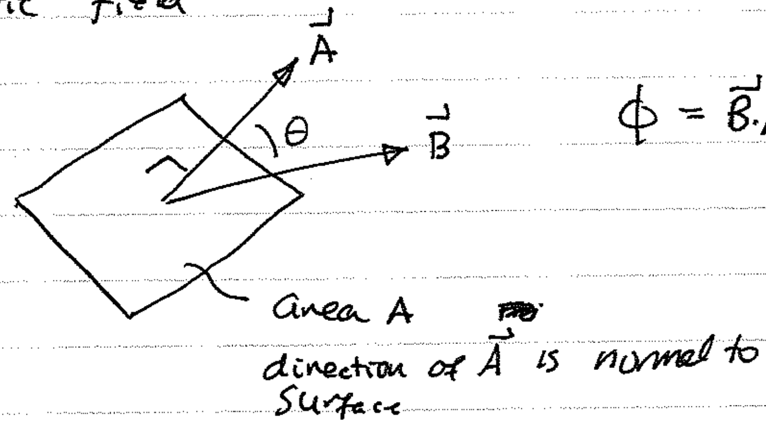
$$\Phi = \frac{\mu_0 I}{2\pi} \int_{x=c}^{x=c+a} \frac{b\,dx}{x}$$

$$\Phi = \frac{\mu_0 I}{2\pi} b \ln x \Big|_{x=c}^{x=c+a}$$

$$\Phi = \frac{\mu_0 I b}{2\pi} \ln\left(\frac{c+a}{c}\right)$$

Magnetic Flux in a nonuniform field

Previously we considered the flux through a rectangle in a uniform magnetic field



$$\phi = \vec{B}\cdot\vec{A} = |\vec{B}||\vec{A}|\cos\theta$$

What if $\vec{B}$ is nonuniform?

That is, $\vec{B} = \vec{B}(\vec{r})$

& $\vec{B}$ depends on position

ANS

$$\phi = \int_{\text{AREA}} \vec{B}\cdot d\vec{A}$$

Why is $\phi \neq 0$ AREA is not a closed surface

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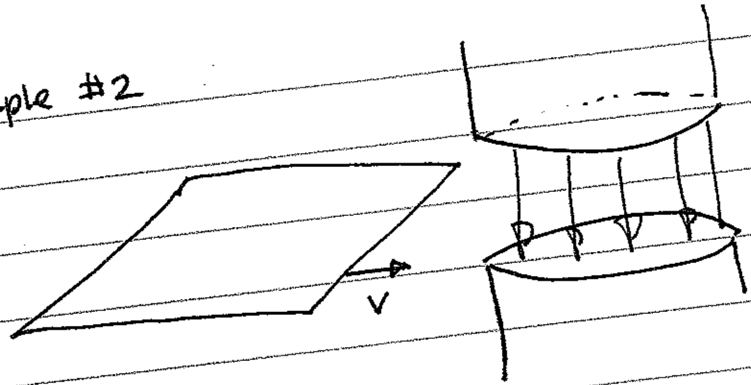
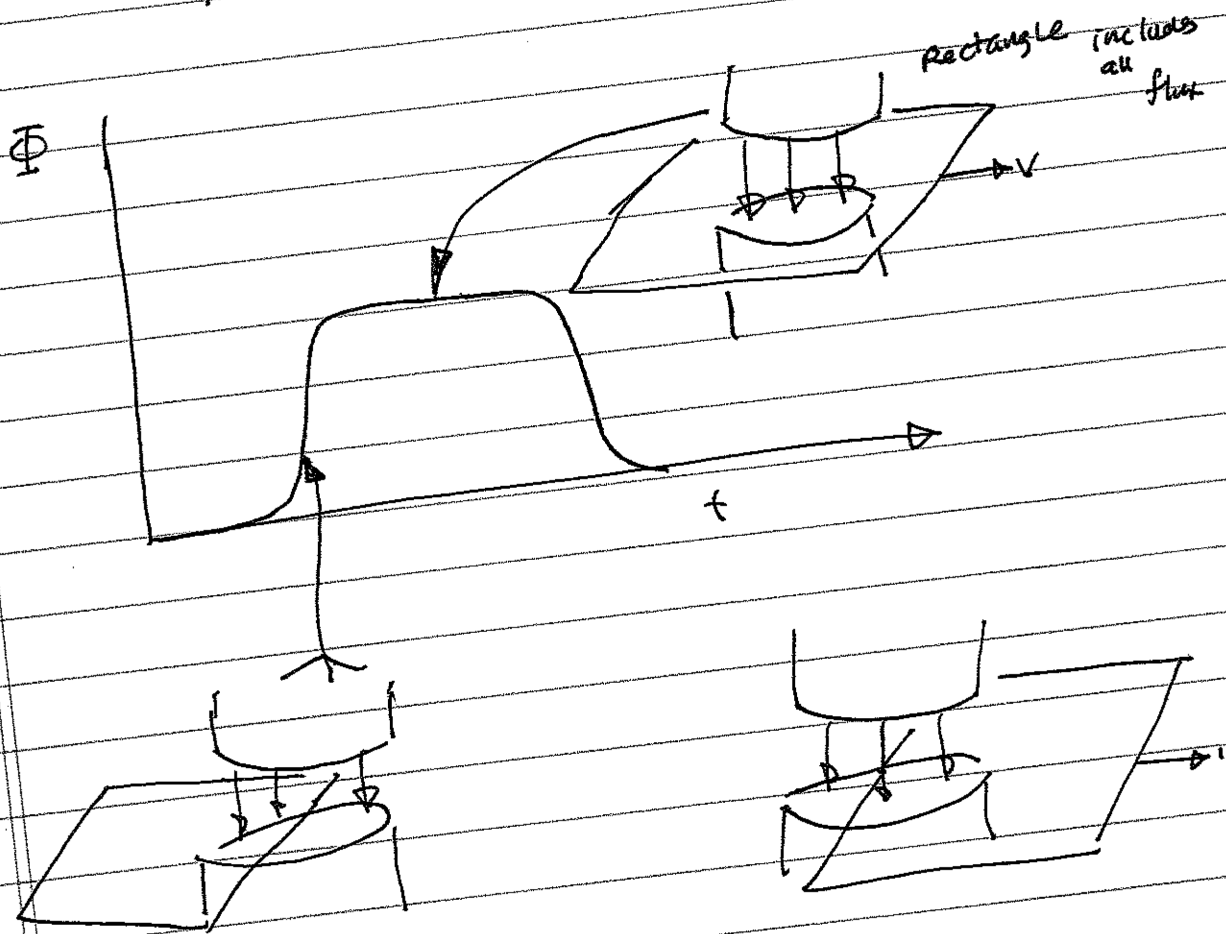
Example #2



Sketch $\Phi(t)$ as rectangle passes between pole pieces



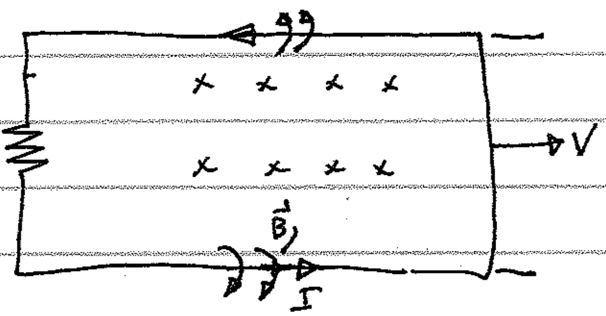
Rectangle enters B

Retangle leaves gap

Lenz's Law

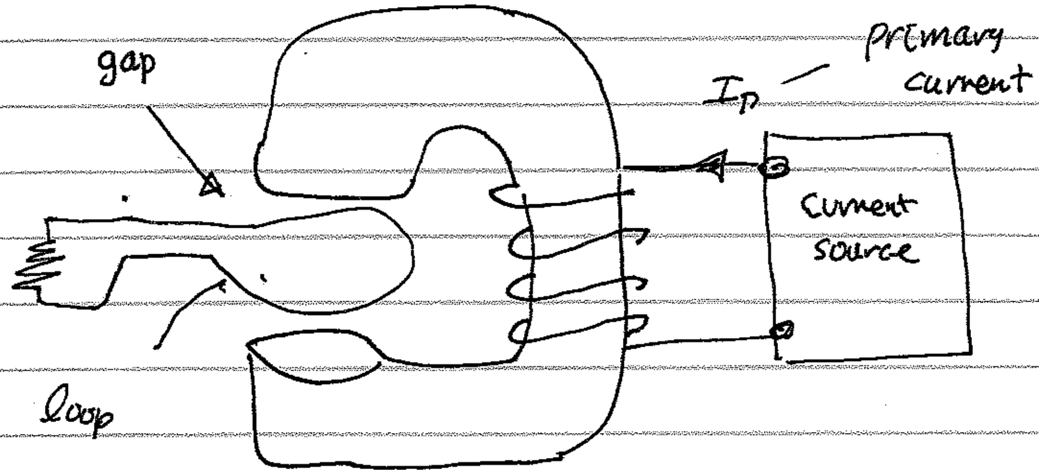
An induced current flows through a conducting loop in the direction that resists the change in magnetic field

Example: our PREVIOUS circuit



As the loop gets bigger the amount amount of flux passing through the area of the loop goes up.

current flows in a direction that makes a $\vec{B}$ that decreases the flux



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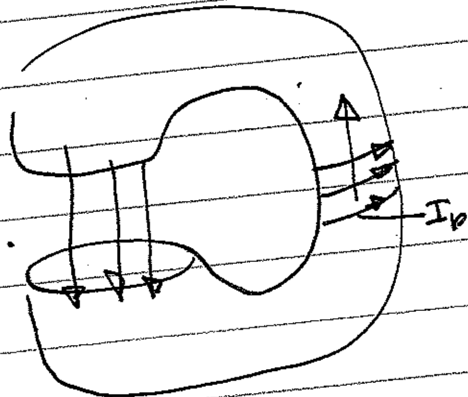
What will be direction of $\vec{B}$ in gap?



Ans: B is down in gap

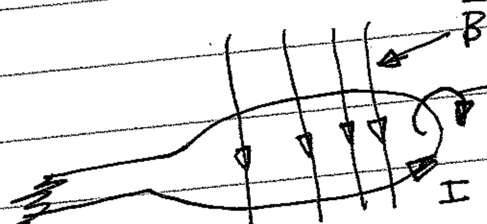
* If I hold I_p fixed what will be ~~the direction of~~ current in loop (secondary)

Ans: 0   no change in flux   no current

* If I increase I_p from one value to another what will be direction of I

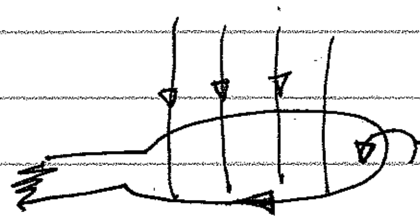
$\vec{B}$ increasing in time

$\vec{B}$ due to I



I flows as shown creating a magnetic field that resists the change in flux

What if I lower I_p but don't make it negative?

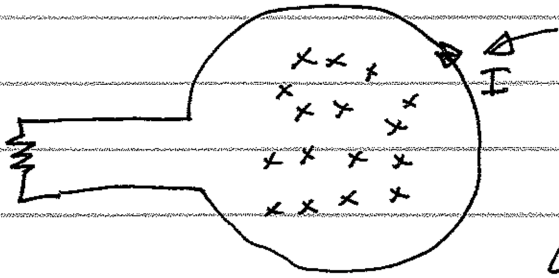


I flows as shown resisting decrease in flux

34.6 Induced electric field

This is the most important section of this chapter because it reveals that there must be electric fields induced by changing magnetic fields

Consider our loop in the changing magnetic field



Increasing $\vec{B}$ into page causes I to flow counter clockwise

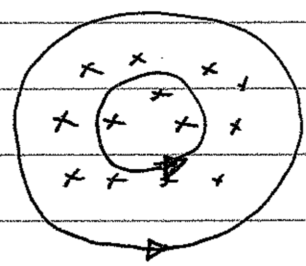
What could make electrons flow?

Force on electron

$$\vec{F} = -e(\vec{E} + \vec{v} \times \vec{B})$$

But wire is not moving ($\vec{v} = 0$)

So there must be an electric field



Induced electric field lines

(where is the charge)

Imagine that we evaluate $\oint \vec{E} \cdot d\vec{s} \neq 0$

It won't be zero!

This is not an electric field that can be described by Coulomb's Law!

Faraday's Law $\quad \Phi = \int_{loop} \vec{B} \cdot d\vec{A}$

$$\frac{d\Phi}{dt} = -\oint (\vec{E} + \vec{v} \times \vec{B}) \cdot d\vec{s}$$

What if we restrict ourselves to loops that are not moving?

THEN

$$\boxed{\frac{d\Phi}{dt} = \int \frac{\partial \vec{B}}{\partial t} \cdot d\vec{A} = -\oint \vec{E} \cdot d\vec{s}}$$