PHY294H

- Professor: Joey Huston
- email:huston@msu.edu
- office: BPS3230
- Homework will be with Mastering Physics (and an average of 1 hand-written problem per week)
  - **Help-room hours: <u>12:40-2:40 Monday (note change)</u>; 3:00-4:00 PM Friday**
  - **hand-in problem for next Wed: 32.80**
- Quizzes by iclicker (sometimes hand-written)
- **Final exam Thursday May 5 10:00 AM – 12:00 PM 1420 BPS**
- Course website: www.pa.msu.edu/~huston/phy294h/index.html
  - lectures will be posted frequently, mostly every day if I can remember to do so

Intro to a physics text

Ludwig Boltzmann, who spent much of his life studying statistical mechanics, died in 1906, by his own hand. Paul Ehrenfest, carrying on the work, died similarly in 1933. Now it is our turn to study statistical mechanics. Perhaps it will be wise to approach the subject cautiously. We will begin

Review

Electricity and Magnetism

Electricity

Charge **generates** E Field

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$

Charge **affects** E Field

$$F = qE$$

Magnetism

Moving Charge **generates** B Field

$$B = \frac{\mu_0}{4\pi}\frac{qv\sin\theta}{r^2}$$

Moving Charge **affects** B Field

$$F = qvB\sin\theta$$

OR since current is moving charges:

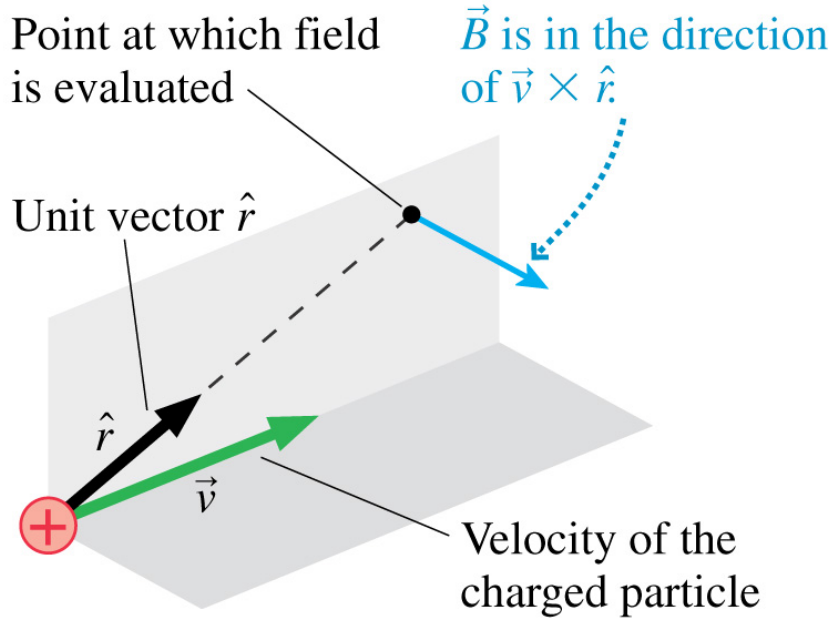
$$\vec{B} = \frac{\mu_0}{4\pi}\frac{I\Delta\vec{s}\times\hat{r}}{r^2}$$

$$\vec{F} = I\vec{l}\times\vec{B}$$

Problemo

- Remember that a charged particle moving with a velocity v creates a magnetic field at every point in space

$$\vec{B} = \frac{\mu_o}{4\pi}\frac{q\vec{v}x\hat{r}}{r^2}$$



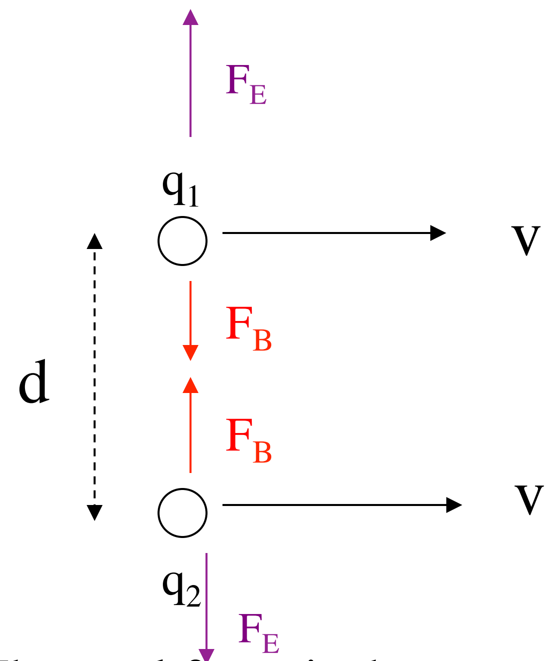
Problemo, continued

- Suppose I have two charged particles q_1 and q_2 each moving with the same speed v parallel to each other, separated by a distance d
- q_1 produces a magnetic field at the position of q_2 and vice versa
  - B_2 is out of the plane of the page and B_1 is into the plane of the page
- There's a magnetic force F_B acting on on q_1 and q_2

$$F_B = \frac{\mu_o}{4\pi}\frac{q_1 q_2 v^2}{d^2}$$

- There's also an electric force acting on q_1 and q_2

$$F_E = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{d^2}$$

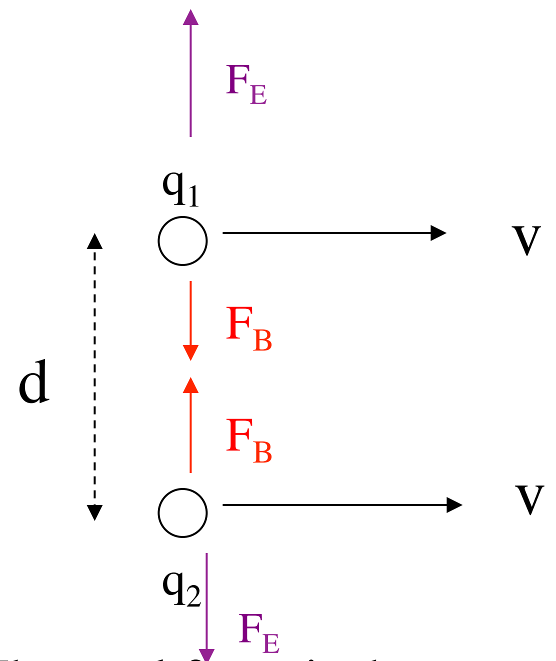


The total force is the vector sum of the electric force and the magnetic force.

$$\frac{F_B}{F_E} = \frac{\frac{\mu_o}{4\pi}\frac{q_1 q_2 v^2}{d^2}}{\frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{d^2}} = \mu_o \varepsilon_o v^2 = \frac{v^2}{c^2}$$

Problemo, continued

- **What is the force for an observer moving along with the charges at the same velocity v?**



There's a magnetic force F_B acting on on q_1 and q_2

$$F_B = \frac{\mu_o}{4\pi}\frac{q_1 q_2 v^2}{d^2}$$

- There's also an electric force acting on q_1 and q_2

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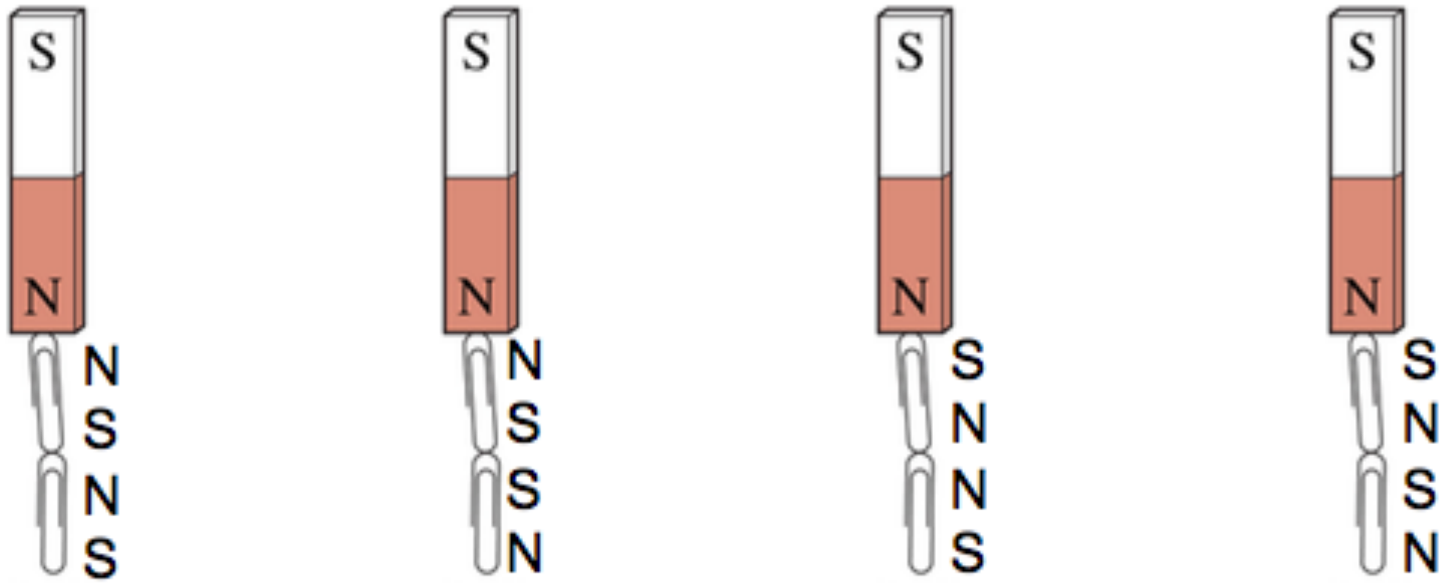
The total force is the vector sum of the electric force and the magnetic force.

$$\frac{F_B}{F_E} = \frac{\frac{\mu_o}{4\pi}\frac{q_1 q_2 v^2}{d^2}}{\frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{d^2}} = \mu_o \varepsilon_o v^2 = \frac{v^2}{c^2}$$

iclicker question

A chain of paper clips is hung from a permanent magnet. Which diagram shows the correct induced pole structure of the paper clips?



A. B. C. D.

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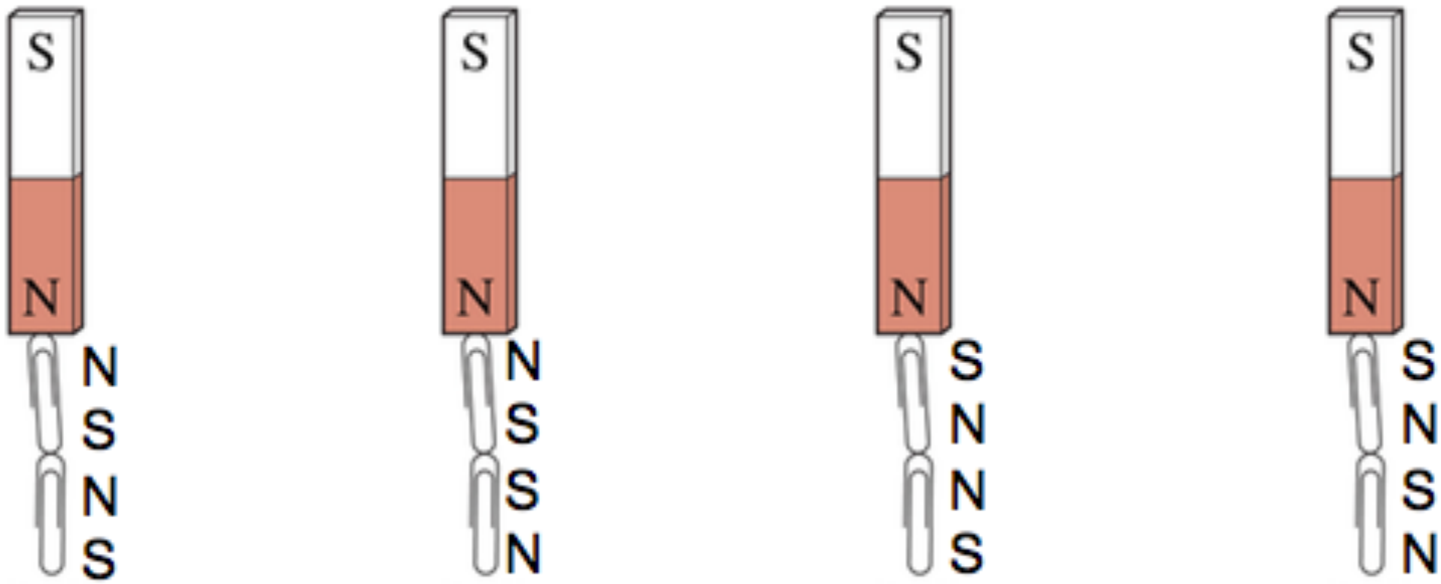


A. B. C. D.

Magnetic induction

- This next chapter is mostly about Michael Faraday
  - 1791-1867
- Little formal education; almost entire self-taught
  - he was apprenticed as a book-binder and ended up reading most of the books he was supposed to bind

Royal Lectures

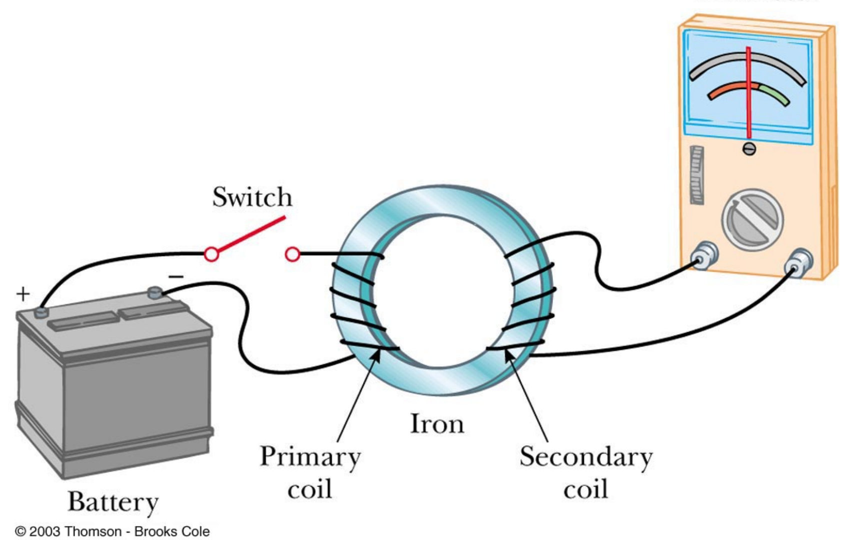
- He attended all of the public lectures given by the Royal Academy of Sciencies
- Kept a notebook from the lectures of Sir Humprey Davies, bound it an presented it to him
  - Davies made him a lab assistant
- We' ve already encountered a unit named after him (the Farad) and some of his most useful ideas
  - electric and magnetic field lines

because of his lack of formal mathematical training, most of Faraday' s thinking was intuitive

An important experiment

- This is his most famous experiment
  - and he thought of it while…
- In the early 1800's he was where we are now in this course
  - strong electric fields create magnetic fields (by creating currents)
  - from symmetry it seemed that strong magnetic fields should be able to create electric fields (and currents)

this is the experiment that he set up



what did he find?
let's try our version.

An important experiment

- This is his most famous experiment
  - and he thought of it while…

  sitting in his laboratory
- In the early 1800's he was where we are now in this course
  - strong electric fields create magnetic fields (by creating currents)
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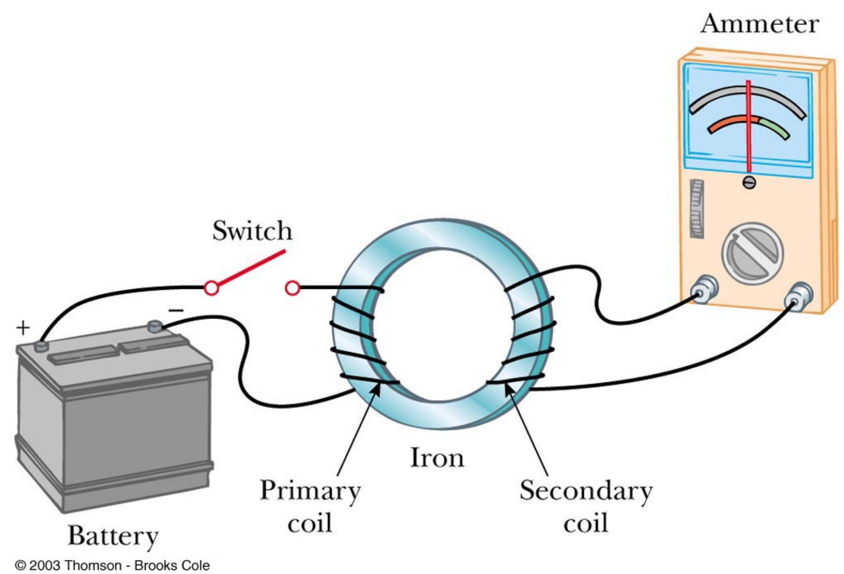
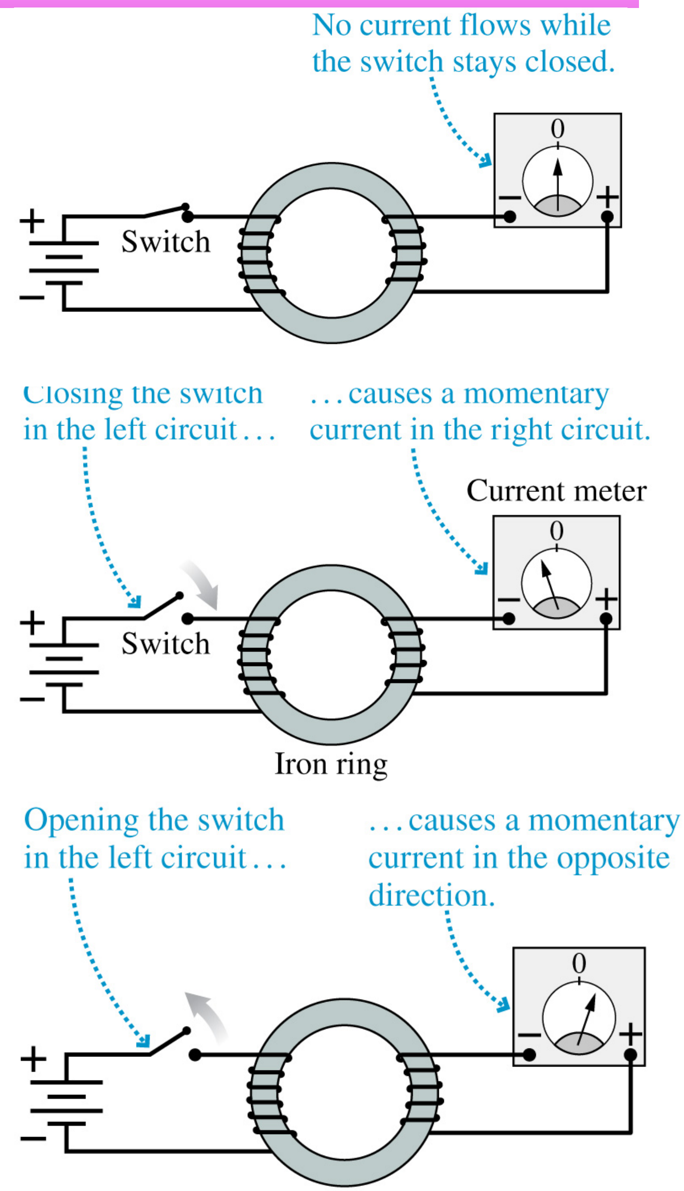
this is the experiment that he set up



what did he find?

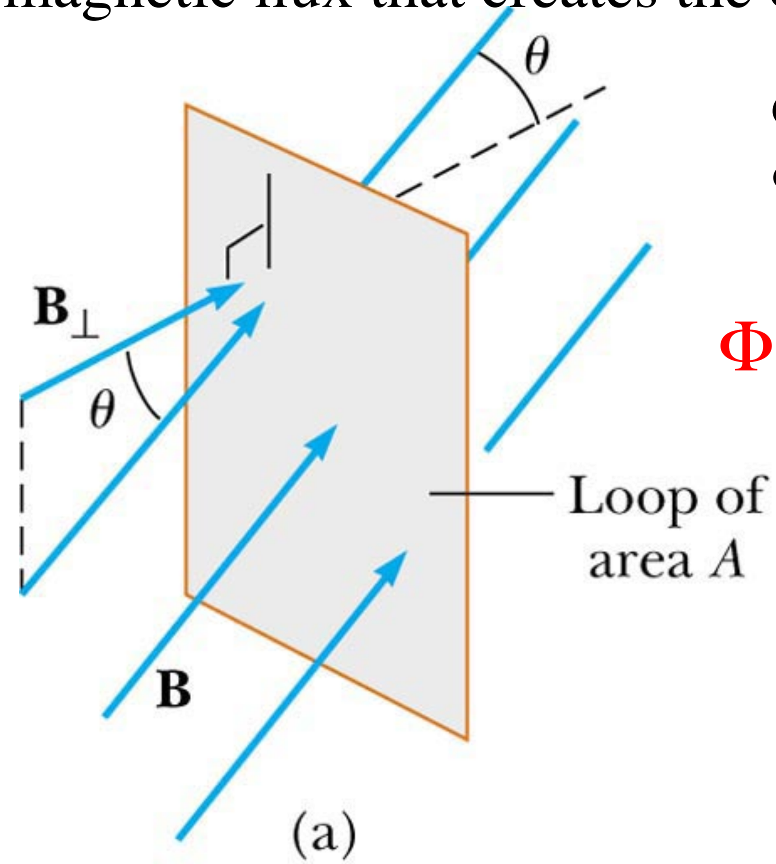
What he found

- A strong magnetic field does not create an electric current
- But we did notice a current in the meter when we first closed the switch and just after we opened it again
- So it's not a magnetic field that creates an electric current; it's a changing magnetic field



Magnetic flux

…and it's not the changing magnetic field per se but the changing magnetic flux that creates the current

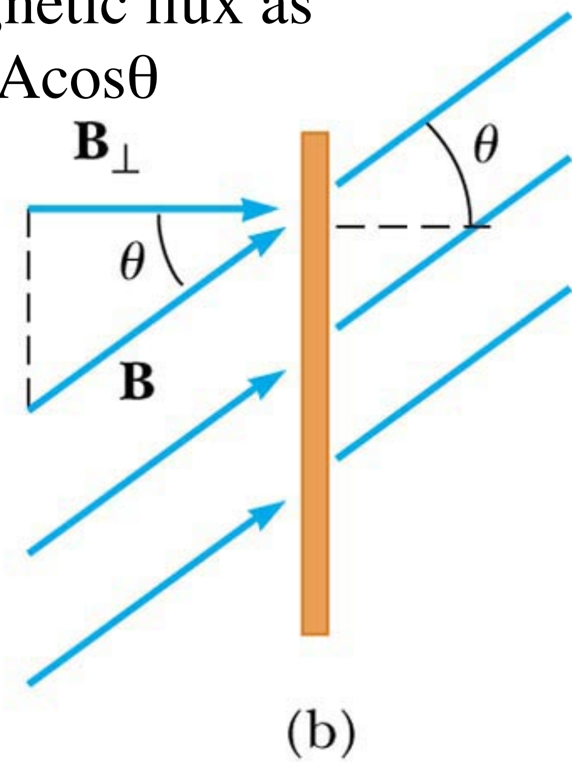


define the magnetic flux as

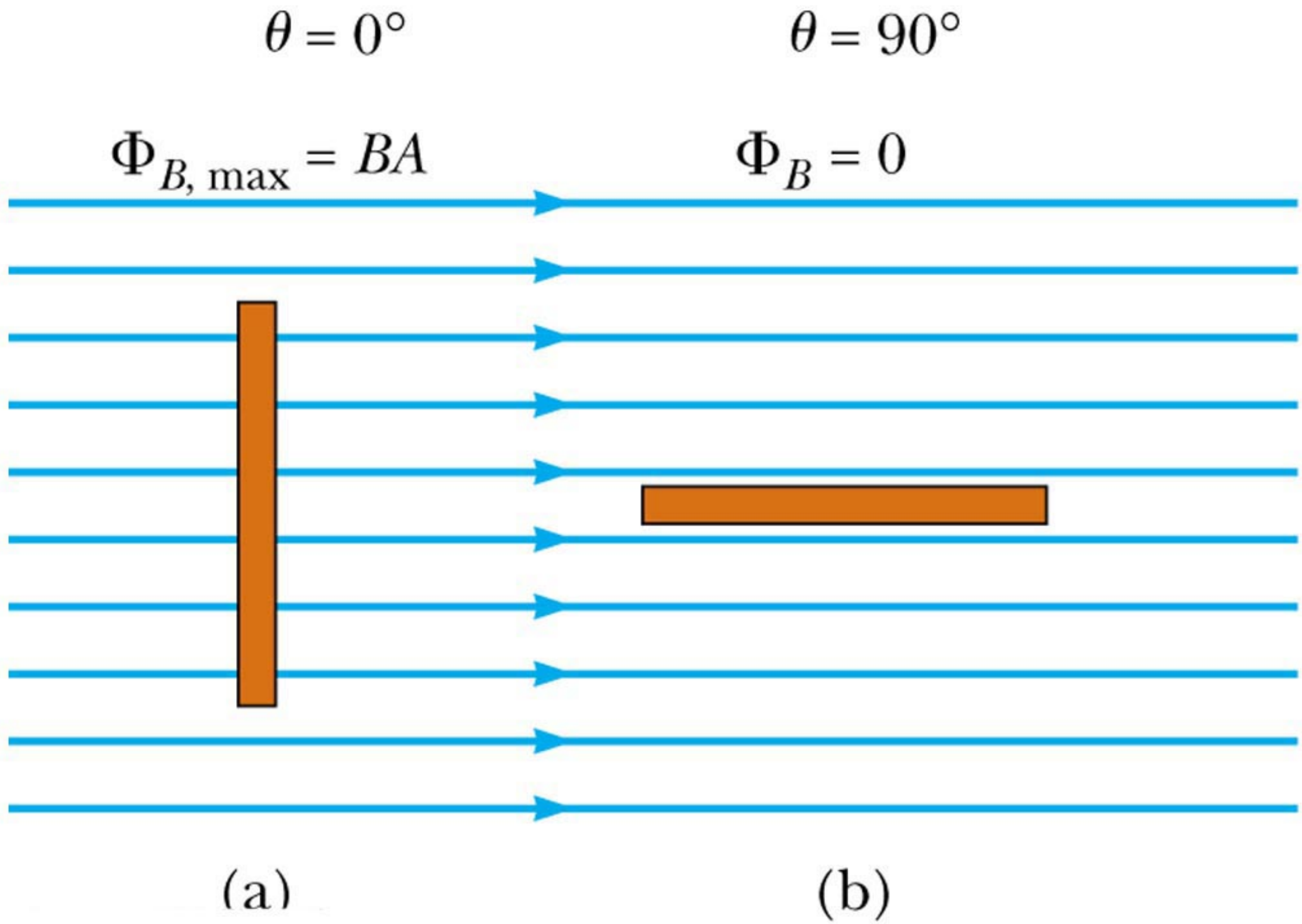
$\Phi_B = B_T A = BA\cos\theta$

$$\Phi_B = \int \vec{B} \bullet d\vec{A}$$

think of it as counting the # of field lines passing thru a surface



Magnetic flux



iclicker question

Which loop has the larger magnetic flux through it?

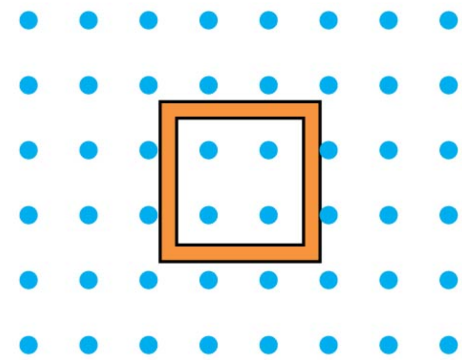
A. Loop A.

B. Loop B.

C. The fluxes are the same.

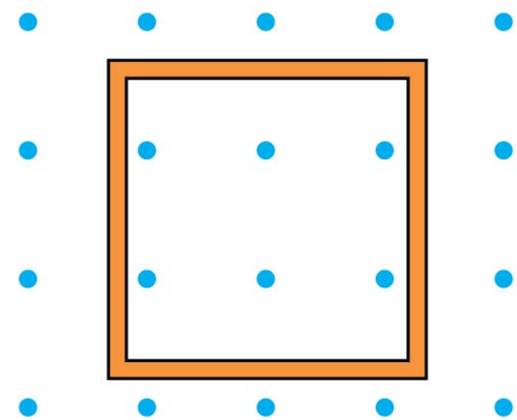
D. Not enough information to tell.

A.



This field is twice as strong.

B.



This square is twice as wide.

iclicker question

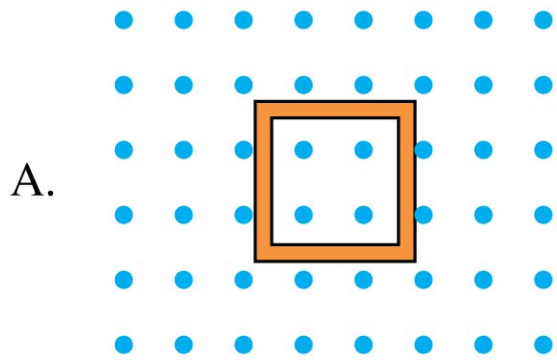
Which loop has the larger magnetic flux through it?

A. Loop A.

B. Loop B. $\Phi_m = L^2 B$

C. The fluxes are the same.

D. Not enough information to tell.



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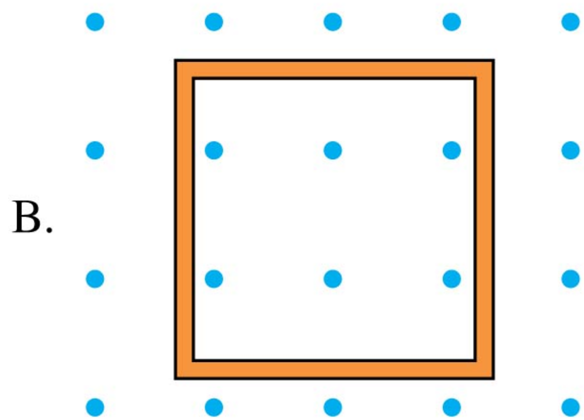


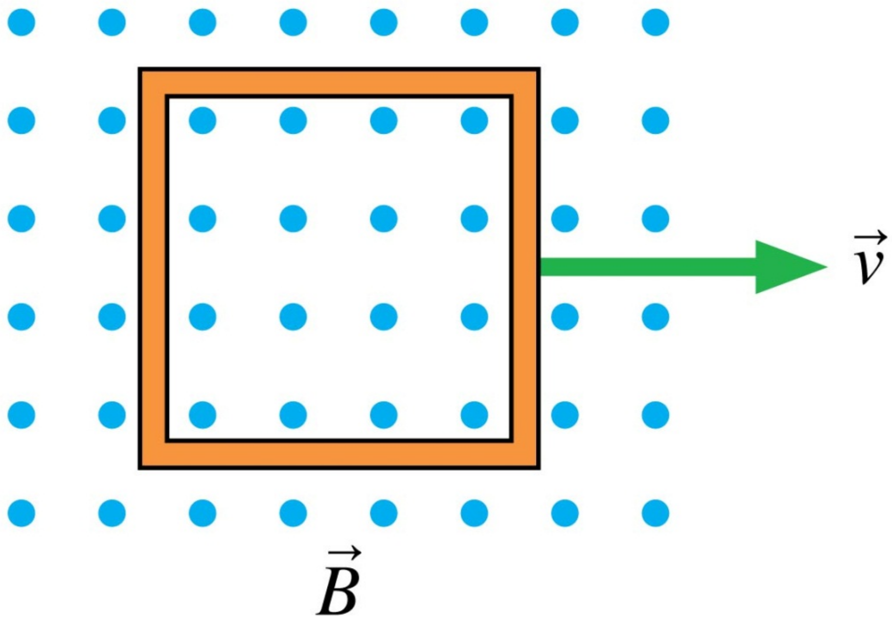
This square is twice as wide.

iclicker question

The metal loop is being pulled through a uniform magnetic field. Is the magnetic flux through the loop changing?

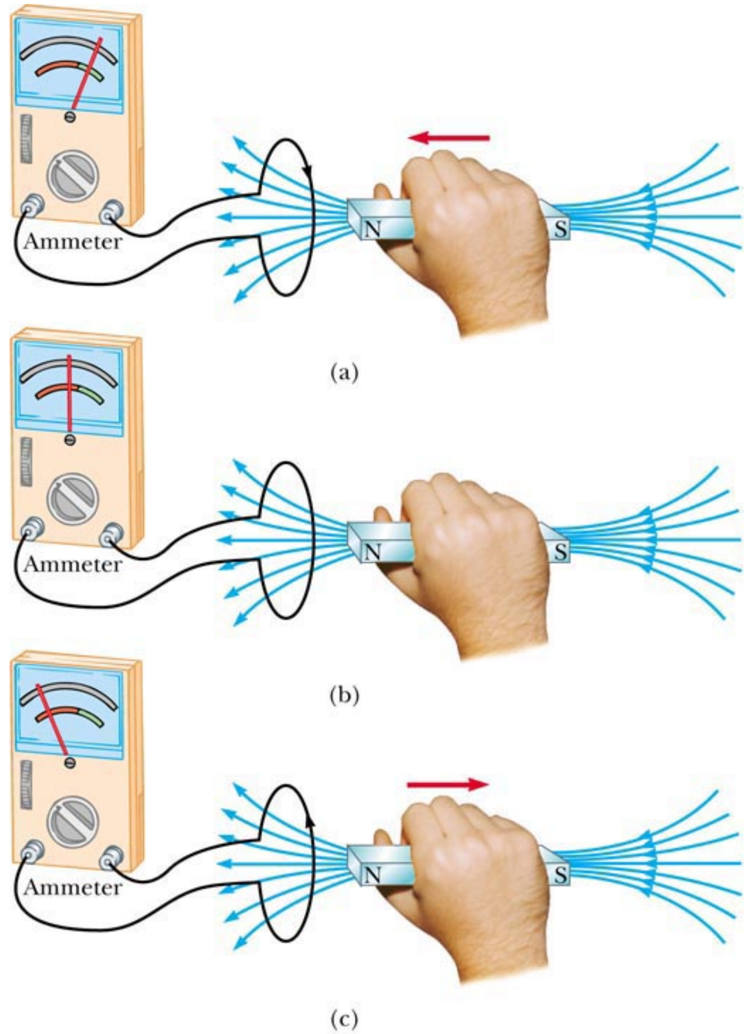
A. Yes.

B. **No.**



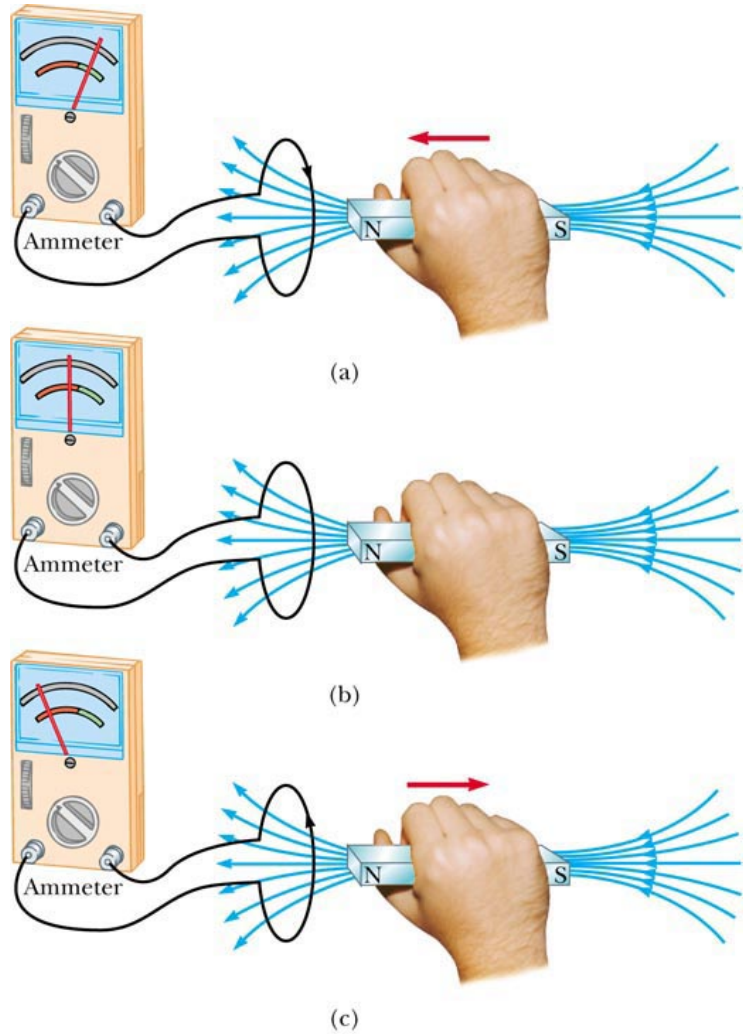
Faraday's law of induction

- Let's take a closer look



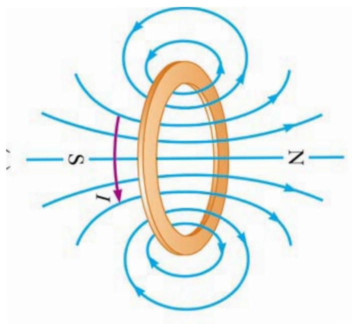
Notice the direction of the current flow

- The direction of the induced emf is such that it tries to produce a current whose magnetic field opposes the change in flux thru the loop
- Lenz's law
  - any change is resisted no matter what the direction

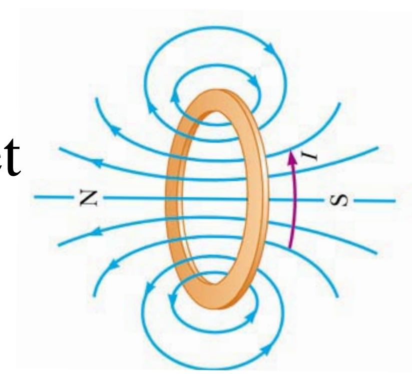


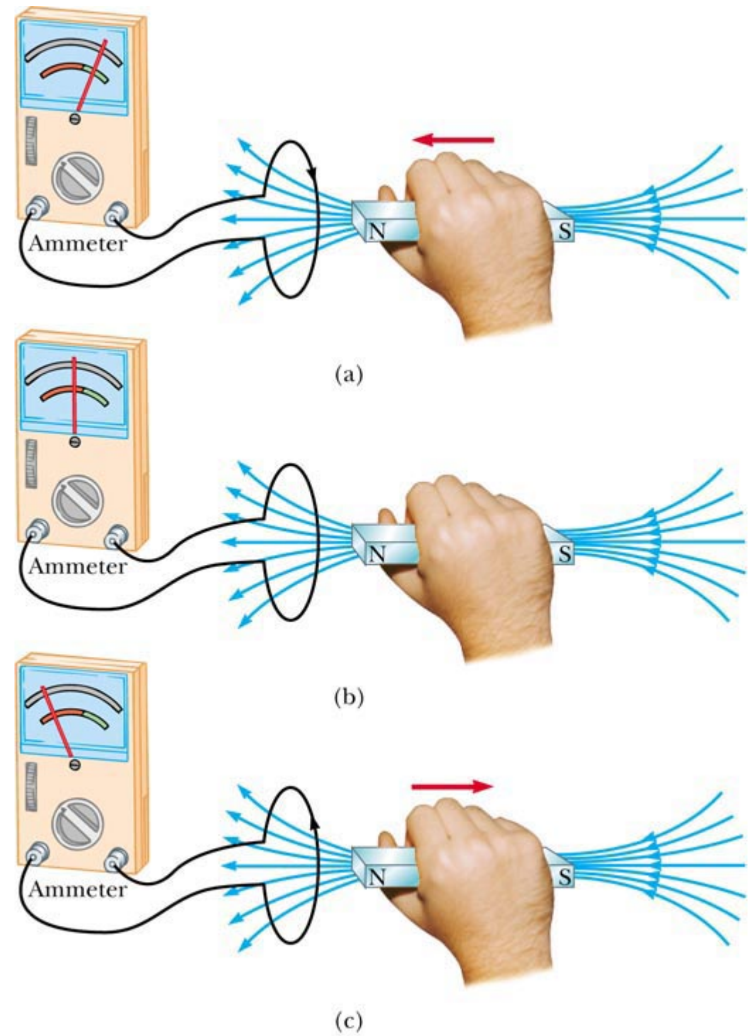
Notice the direction of the current flow

I push the magnet in; the coil is pushing back



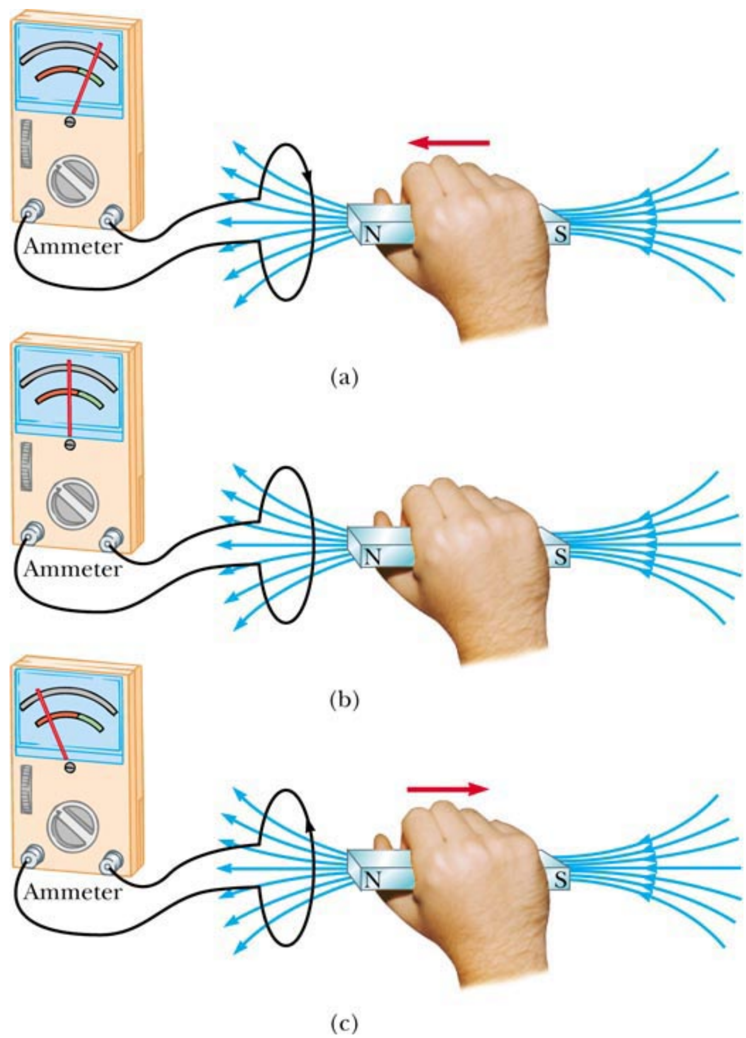
I pull the magnet out; the coil is pulling back





Change of flux

- From careful experimentation I find that I can create a larger current by moving the magnet more quickly into and out of the coil
- It's not the change in magnetic flux per se that's important, but the change of flux per time

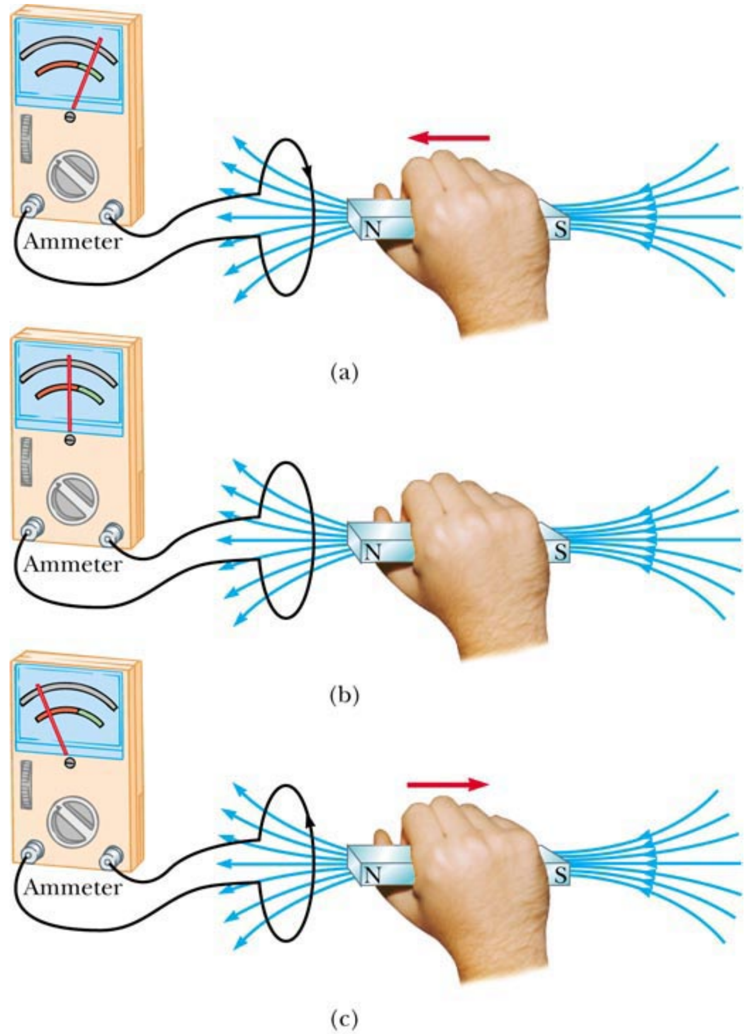


Faraday's law of induction

- The emf ε equals the time rate of change of the magnetic flux

$$\varepsilon = -N\frac{d\phi_B}{dt}$$

this - sign is so important we're going to give it a name all to itself: Lenz's law

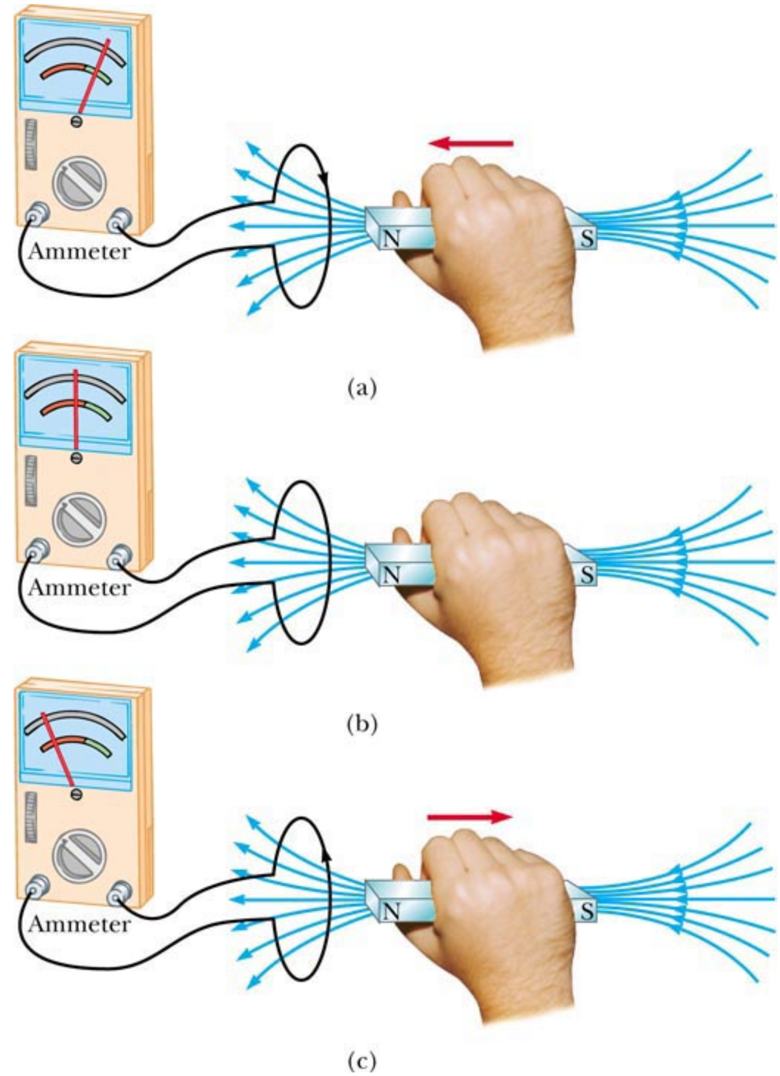


Faraday’ s law

- The voltage induced by a changing magnetic flux is equal to the rate of change of the flux

$$|\varepsilon| = \frac{d\phi}{dt} = \frac{d}{dt}\left[BA\cos\theta\right]$$

- Note that for the flux to change
  - B can change
  - A can change
  - the angle between B and A can change



Lenz's law

- This resistance to change is given a name all to itself and results in a minus sign being inserted in Faraday's law

$$\varepsilon = -\frac{d\phi}{dt}$$

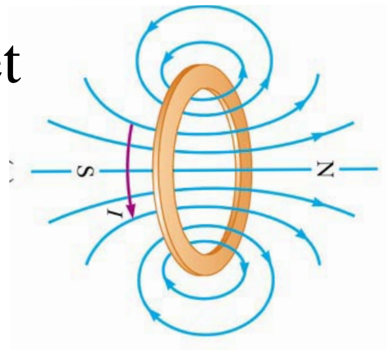
- Sometimes it's written as

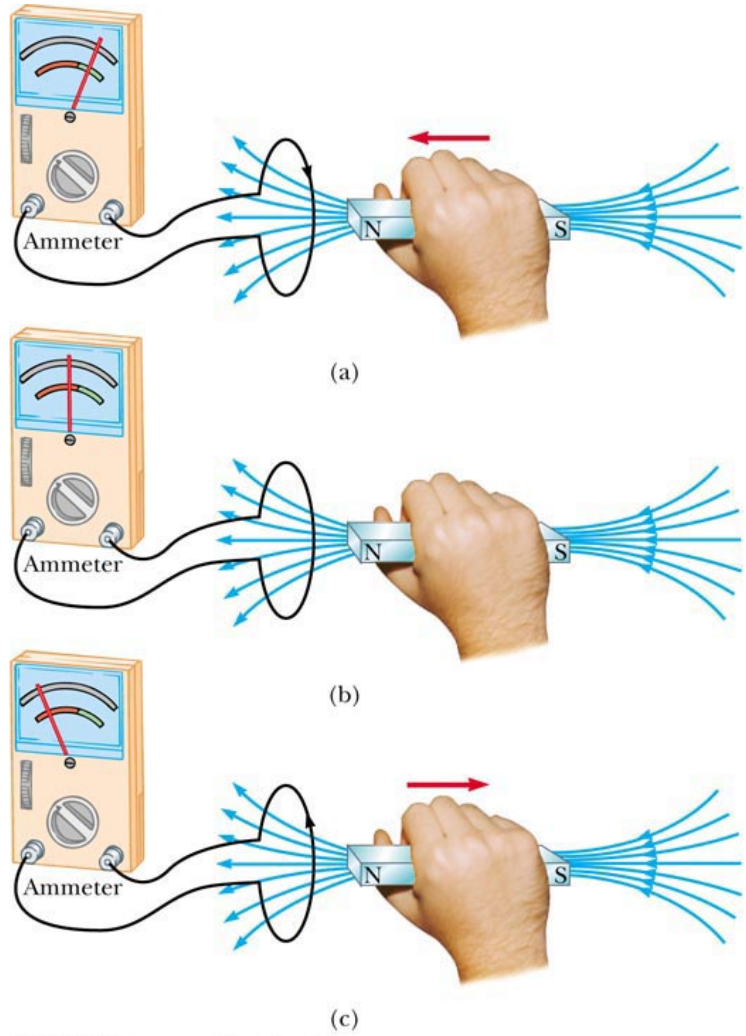
$$\varepsilon = -N\frac{d\phi}{dt}$$ if there are N coils

Heinrich Lenz
…on a "bad hair" day

Direction of current flow

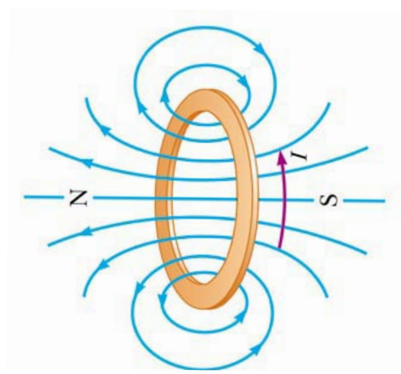
I push the magnet in; the coil is pushing back





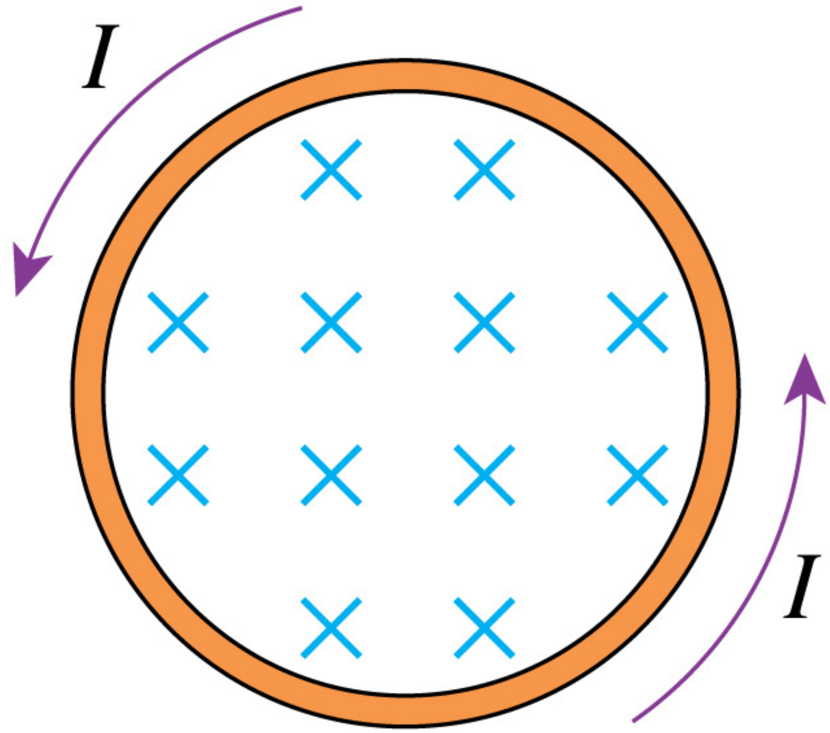
What can I say about the work I have to do moving the magnet in and out?

I pull the magnet out; the coil is pulling back



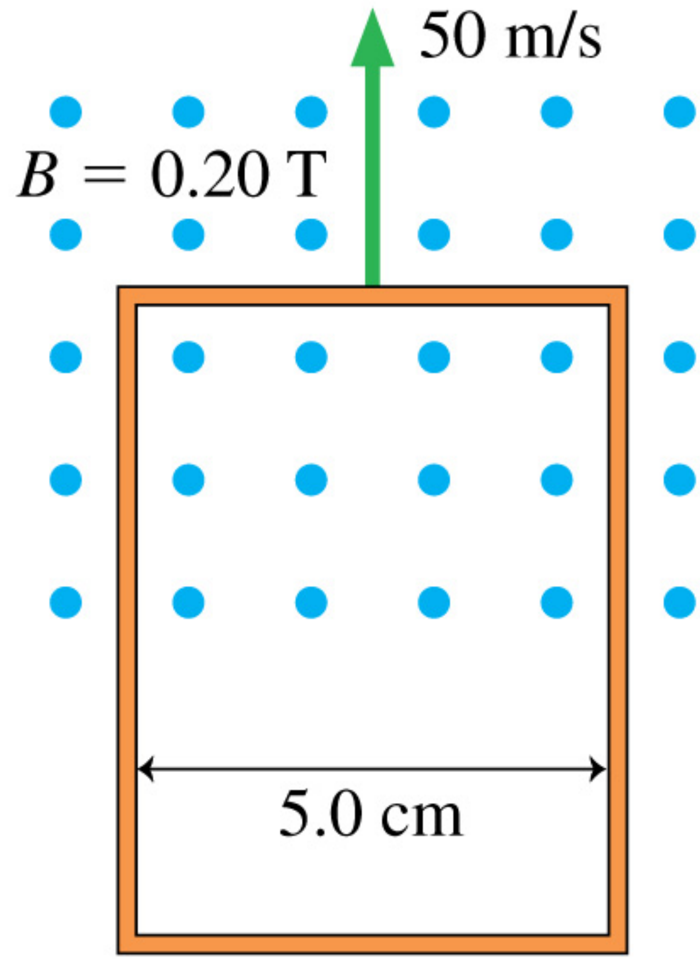
Example

- We observe that a counter-clockwise current is induced in a conducting loop sitting in a magnetic field
- Is the magnetic field inside the loop increasing, decreasing or stable?



Example

- A conducting loop is moving into a region of magnetic field at a speed of 50 m/s
- What is
  - the emf induced in the loop
- Note that if the emf is induced in a conducting medium, a current will result
  - what is the current that flows in the loop if the resistance of the loop is 0.10 Ω
- What is the direction of the current?



Example

- I have a flexible wire loop in a region of uniform magnetic field B = 1.0 T into the plane of the page
- I push in on the two sides of the loop so that the loop collapses to zero area in 0.25 s
- What is the emf induced in the loop?
- What is the direction of the induced current?