Faraday's Law and Lenz's Law

- Michael Faraday (1791-1867) discovered that the amount of induced EMF depends on:
  - → The **rate of change of the magnetic field**
  - → The **angle between the magnetic field and the loop**
  - → The **area of the loop**
- All of these observations indicate that induced current is related to the **change in magnetic flux**, or $\Delta\Phi_B$ through the loop. We know from before that current is produced by an emf. So:

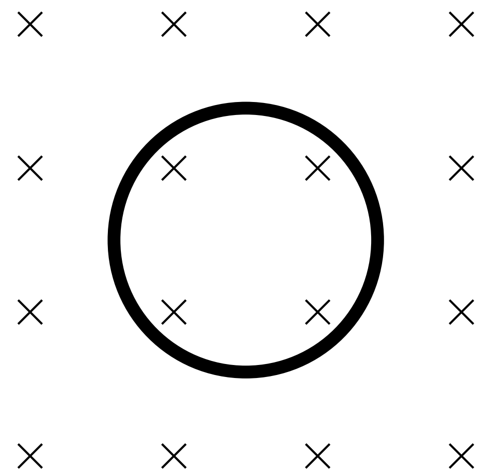
$$\varepsilon = -\frac{\Delta\Phi_B}{\Delta t}$$

If there is more than one loop, then we multiple the right side by "N" (the number of loops).

  - What does the negative sign mean?

Faraday's law - let's try it!

- The coil (face in the plane of the page) is bathed in a0.12 meters. The clock starts at t = 0. At t = 5.0 seconds, the B-fld drops to zero over a 0.2 second period.n 8 T B-fld oriented perpendicularly into the page. The resistance in the coil is 200 ohms. Its radius is



a.) At t = 2 seconds, is there a magnetic flux through the coil?

b.) At t = 2 seconds, is there an induced EMF in the coil? If so, what is it?

c.) At t = 5.1 seconds, is there an induced EMF in the coil? If so, what is it?

d.) At t = 5.1 seconds, what is the induced current in the coil?

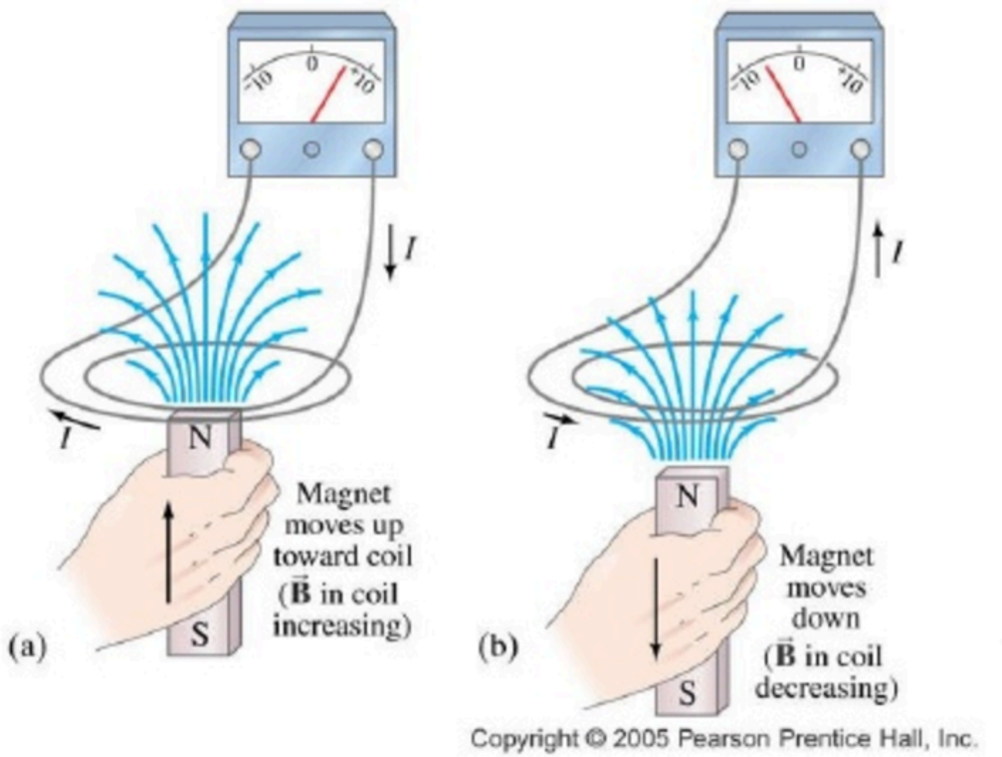
e.) At t = 5.1 seconds, what is the direction of the induced current?

f.) At t = 5.5 seconds, is there an induced EMF in the coil?

g.) At t = 5.5 seconds, what is the magnetic flux?

Lenz's Law

- A current produced by an induced EMF moves in a direction so that its magnetic field opposes the original change in flux.
  - Hence, the negative sign in Lenz's law.
  - Note that this means there are <u>two</u> magnetic fields we care about: the changing one that induces the current, and the one produced by the induced current (this is the opposite one)



Knowing this, how do you think AC is produced in power plants?

Lenz's Law - the formal explanation

- Breaking this down:
  - If there is an externally produced magnetic flux through a coil and that magnetic flux **changes**…
  - That changing magnetic flux will induce a current in the coil (Faraday)…
  - The induced current will set up its own magnetic field through the coil in a way that opposes the change of the external magnetic flux.

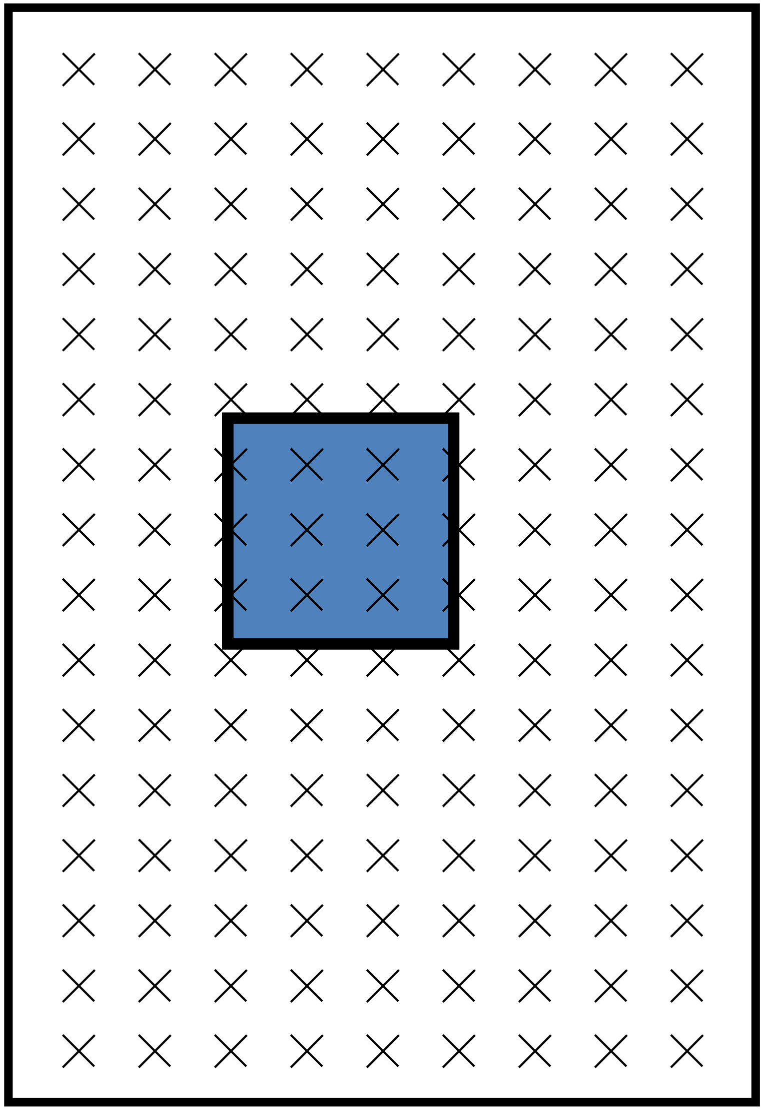
- We use right thumb rule to determine the direction of the induced current, by considering <u>how</u> the external flux is changing.

Lenz's law - in practice

- To apply Lenz's Law with the minimum amount of fuss:
  - 1) ID the direction of the external magnetic field
  - 2) Identify whether the external magnetic flux is increasing or decreasing
  - 3-A) If the external flux is **increasing**, the induced current will set up a magnetic field that is **opposite** the direction of the external magnetic field.
  - 3-B) If the external flux is **decreasing**, the induced current will set up a magnetic field that is **in the same direction** as the external magnetic field.
  - 4) Use the right thumb rule to figure out current direction to match.

Worked-out example

Example: Assume the magnetic field diminishes in strength. In what direction will the induced current in the coil flow?

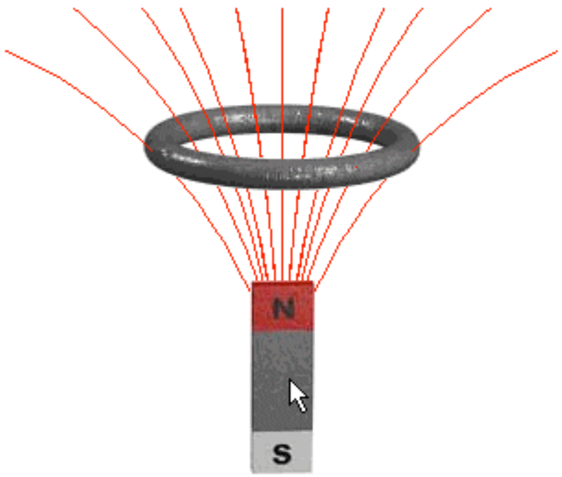


Following the steps:

(1) The direction of the external B-field is into the page.
(2) The magnetic flux is decreasing.
(3) With the decreasing flux, the induced B-field must by WITH the external B-field.
(4) Using the RthumbR, the current has to be **clockwise** to create that induced magnetic field.

Another quick one

- In the diagram below, the magnet is going to be inserted through the middle of the conducting ring. In which direction will the induced current flow through the ring when viewed from above, clockwise or counterclockwise?

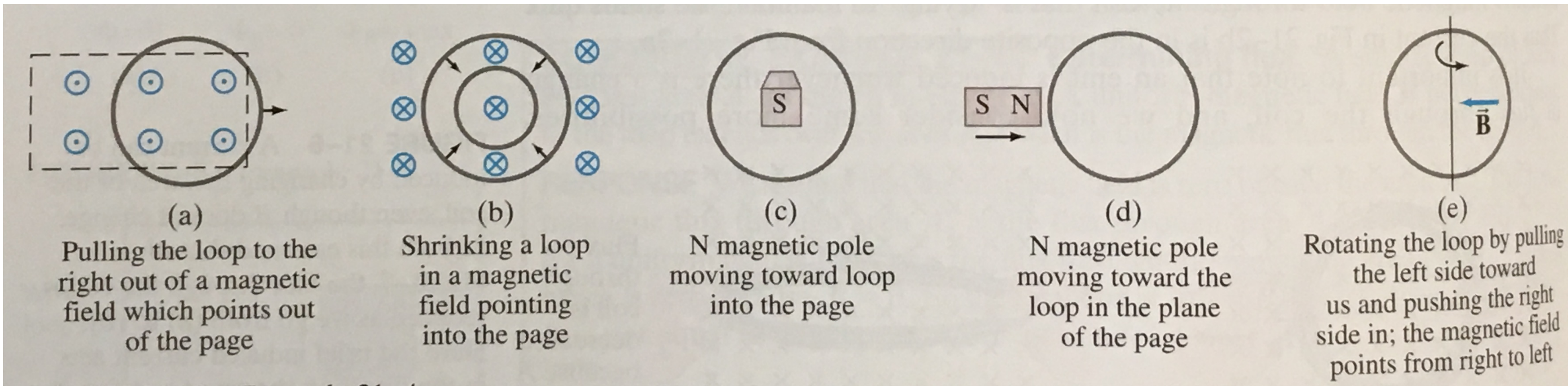


Following the steps:

(1) The direction of the external B-field is towards the top of the page.
(2) The magnetic flux is increasing.
(3) With the increasing flux, the induced B-field must be opposite the external B-field.
(4) Using the RthumbR, the current has to be **clockwise** to create that induced magnetic field(downward).

More Lenz's Law practice

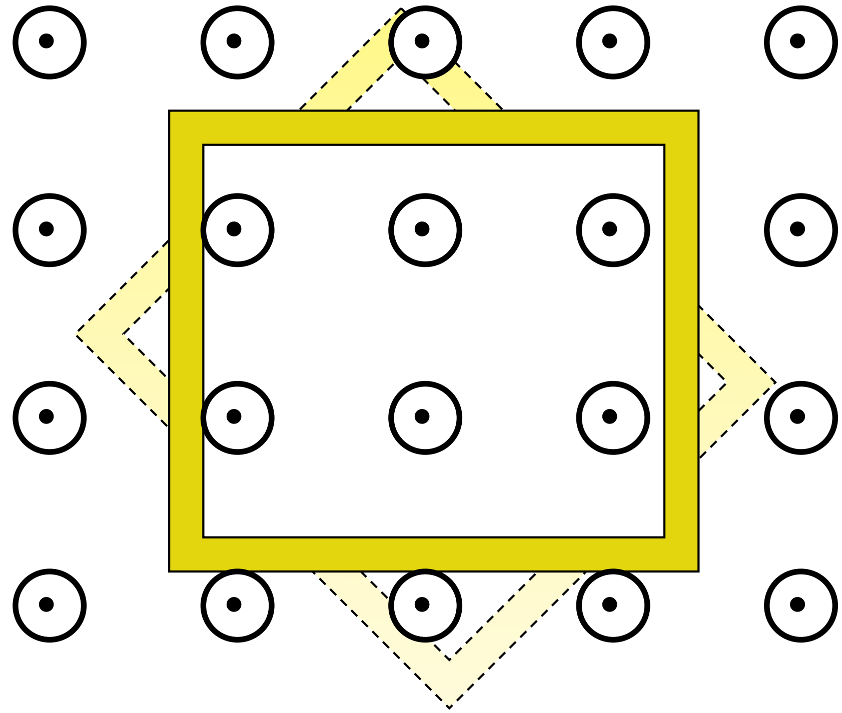
- In what direction is the induced current for each loop situation shown below? **Use the full process - don't just guess!**



a) B out of page, flux decreasing - need B out of page, so **counterclockwise** current
b) B into page, flux decreasing - need B into page, so **clockwise** current
c) B into page, flux increasing - need B out of page, so **counterclockwise**
d) Loop is parallel to field lines - no flux at all, so no current!
e) B is to the left, flux is increasing - need B to the right, so **counterclockwise**

Problem 20.1

Determine the magnetic flux through a rectangular coil (face in the plane of the page) due to a 0.5 T B-fld oriented perpendicular to the page as shown. Assume the coil's dimensions are 0.08 m by 0.12 m.

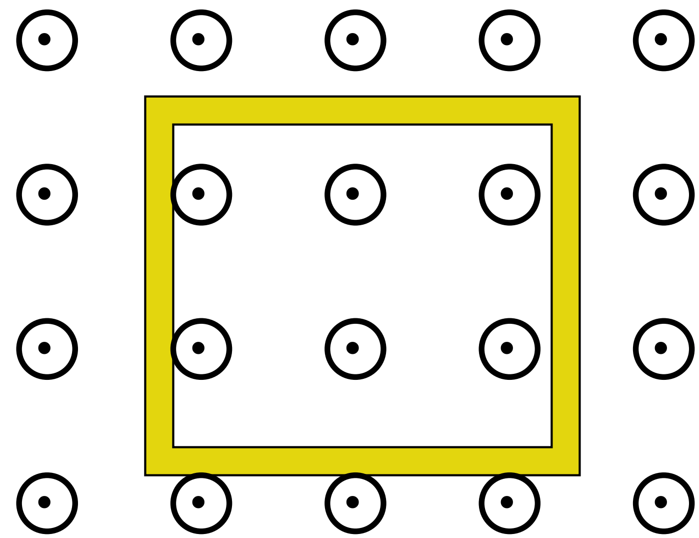


$$\phi_B = B \bullet A$$
$$= B\,A\cos 0^\circ (.08\text{ m})(.12\text{ m}) = 9.6\text{x}10^{-3}\text{ m}^2$$
$$= (.5\text{ T})\ (9.6\text{x}10^{-3}\text{ m}^2)$$
$$= 4.8\text{x}10^{-3}\text{ Webers}$$

Quick extension: How would your answer change if the coil were rotated 45 degrees in the plane of the page (dashed)? What if it was at a 45 degree angle out of the page?

Rotated as shown - no difference. B and the normal to A would both still be out of the page (parallel to each other). If the coil was rotated out of the page, however, there would now be a 45º angle between B and normal to A, so the flux would be less.

Problem 20.1 - additional q's



Remember that the magnetic field has a magnitude of 0.5 T, and the coil is 0.08 m by 0.12 m in dimensions.

a. What would be the induced emf in the coil if the magnetic field turned off over a 0.2 second period?

b. If the coil's resistance was 30 ohms, what would the induced current be?

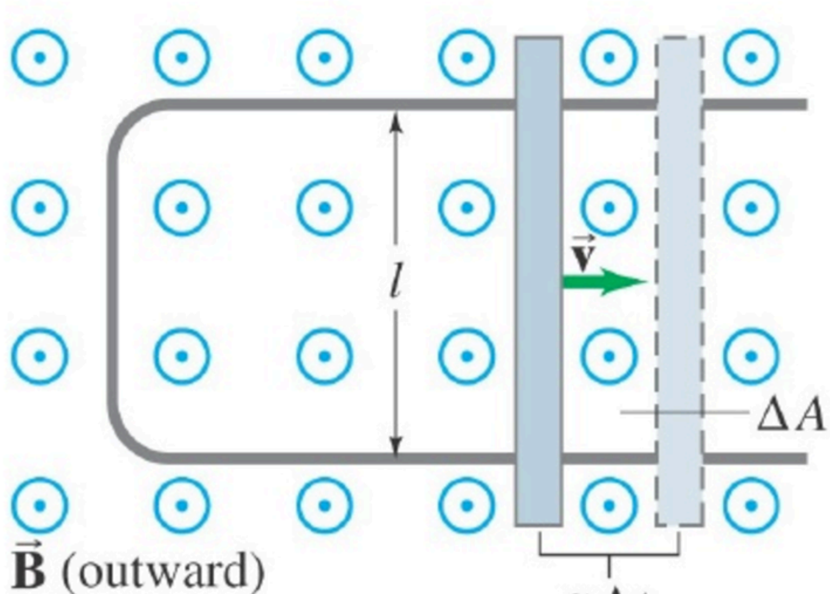
c. For how long would that current flow?

d. In what direction would it flow?

Solutions on class Website

Induced EMF by a moving conductor

- Another way to induce an emf is to move a conductor within a magnetic field.
- Moving the conductor creates a changing area of the loop, thus changing the magnetic flux and inducing an emf.
- An emf induced on a conductor moving in a magnetic field is sometimes called **motional emf**.



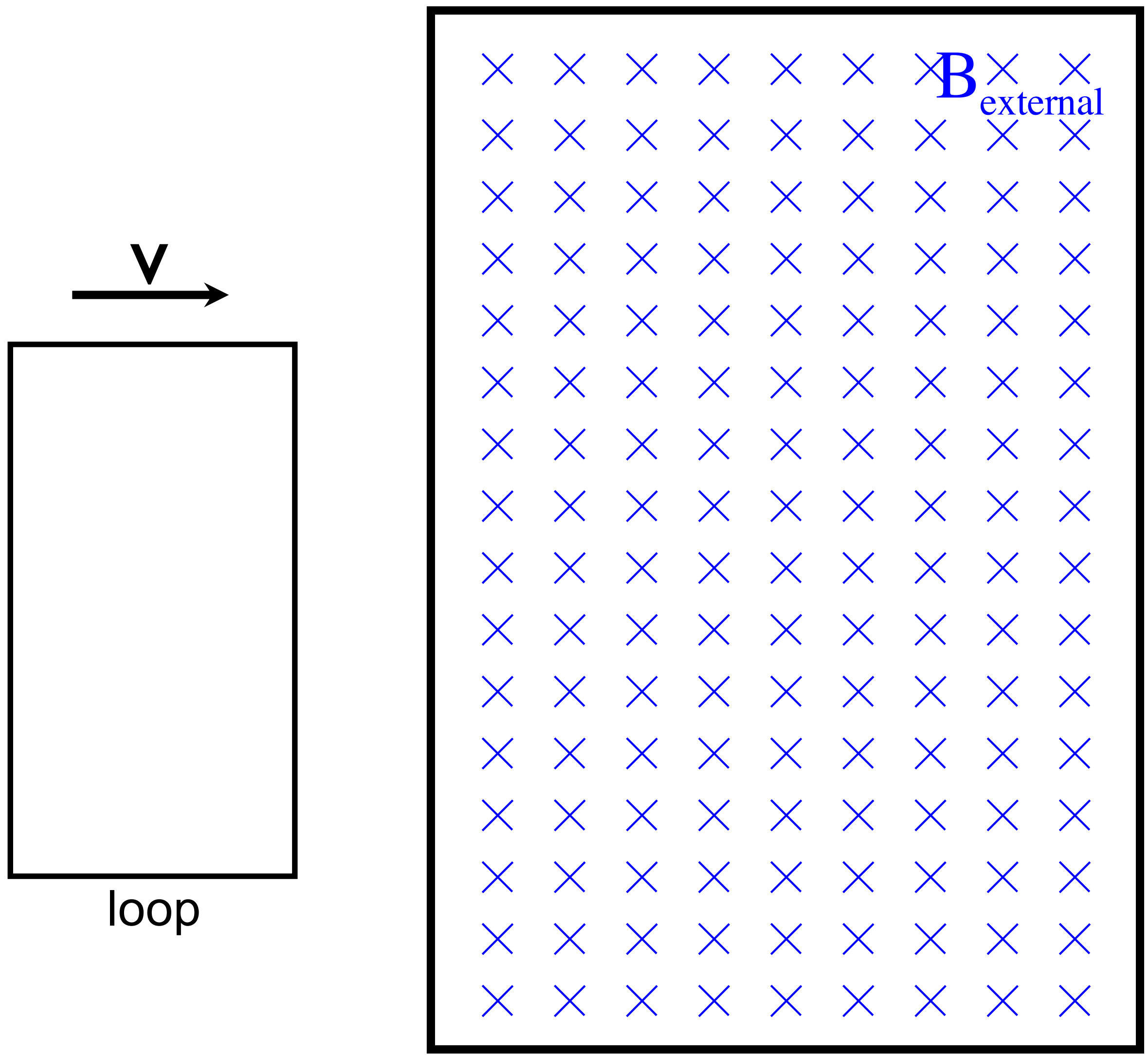
(a)

Motional EMFs

Is there any flux through the loop as shown?

At what point will something begin to happen?

What would you expect to see as the loop enters the magnetic field area until it is fully within that area?



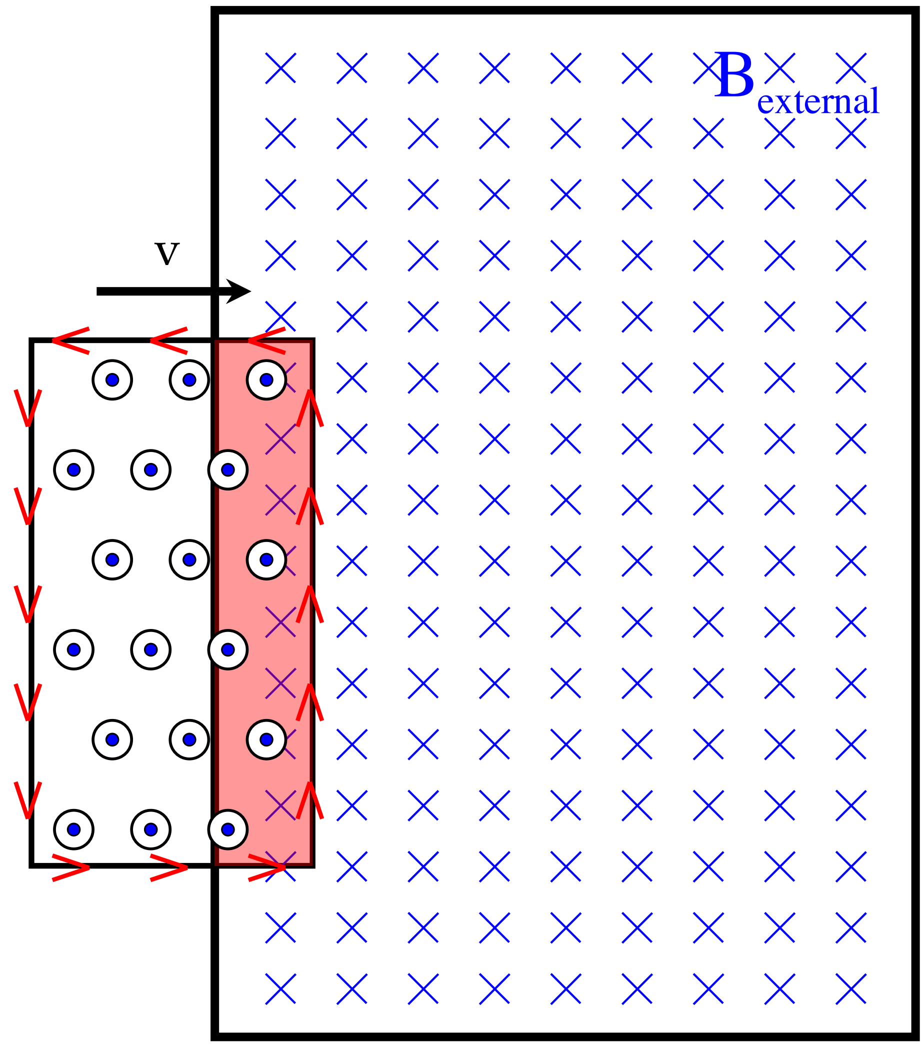
(Thanks to Mr. Fletcher for the following sequence of slides!)

Motional EMF

So what happens here?

--According to Faraday, as the flux changes (increasing in this case) as induced EMF is set up in the coil.

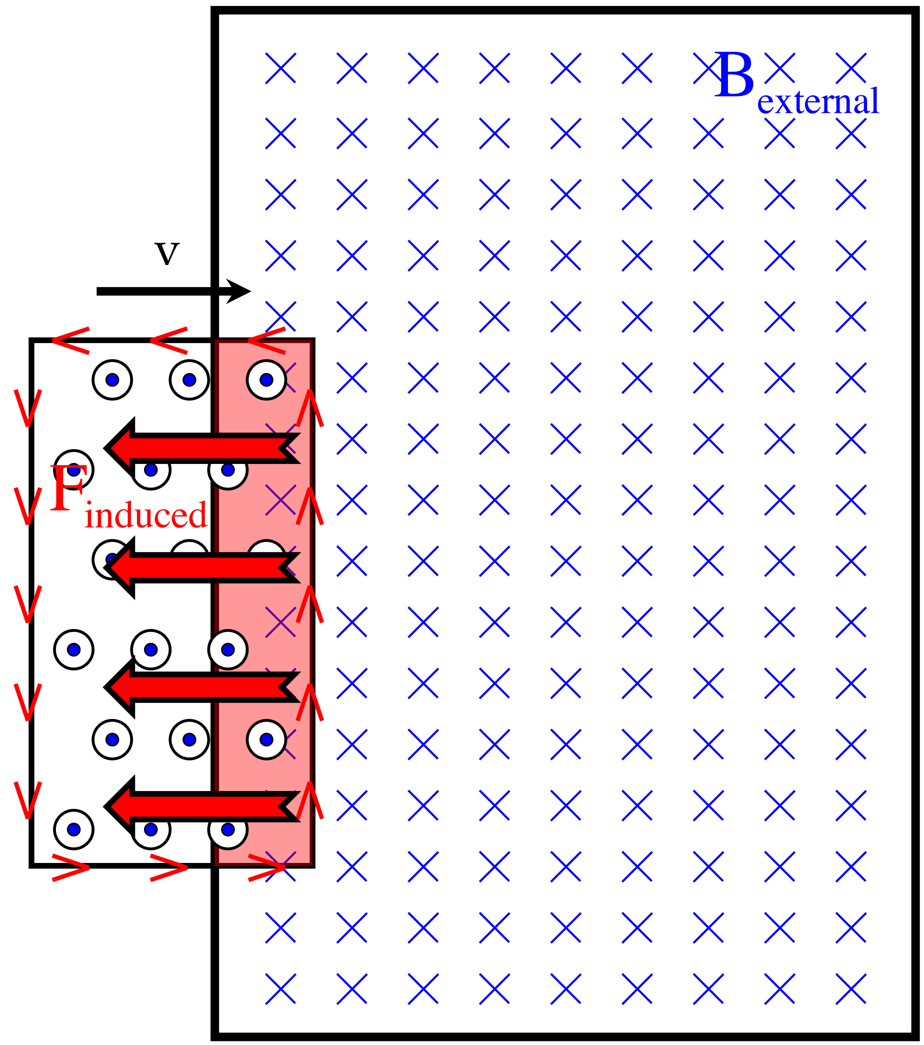
--The induced EMF sets up an induced current which, according to Lenz's Law, sets up a uniform induced B-field thru the coil opposite the direction of the external B-fld.



Motional EMF

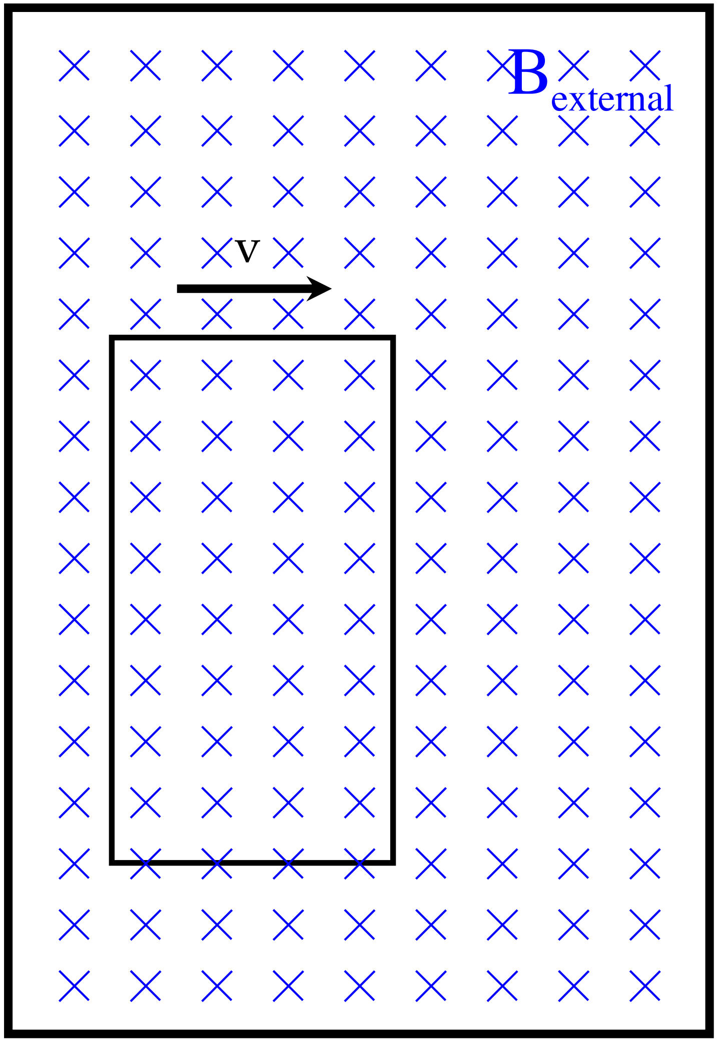
--the induced current will interact with *external* B-fld ($F_{ind} = I_{ind}\vec{L}x\vec{B}_{ext}$) producing a force on coil that FIGHTS the coil's incursion into the region.

--continuing the motion's constant speed, the flux continues to increase at a constant rate, the induced EMF stays constant, the current stays constant as does the induced force opposing motion.



Motional EMF

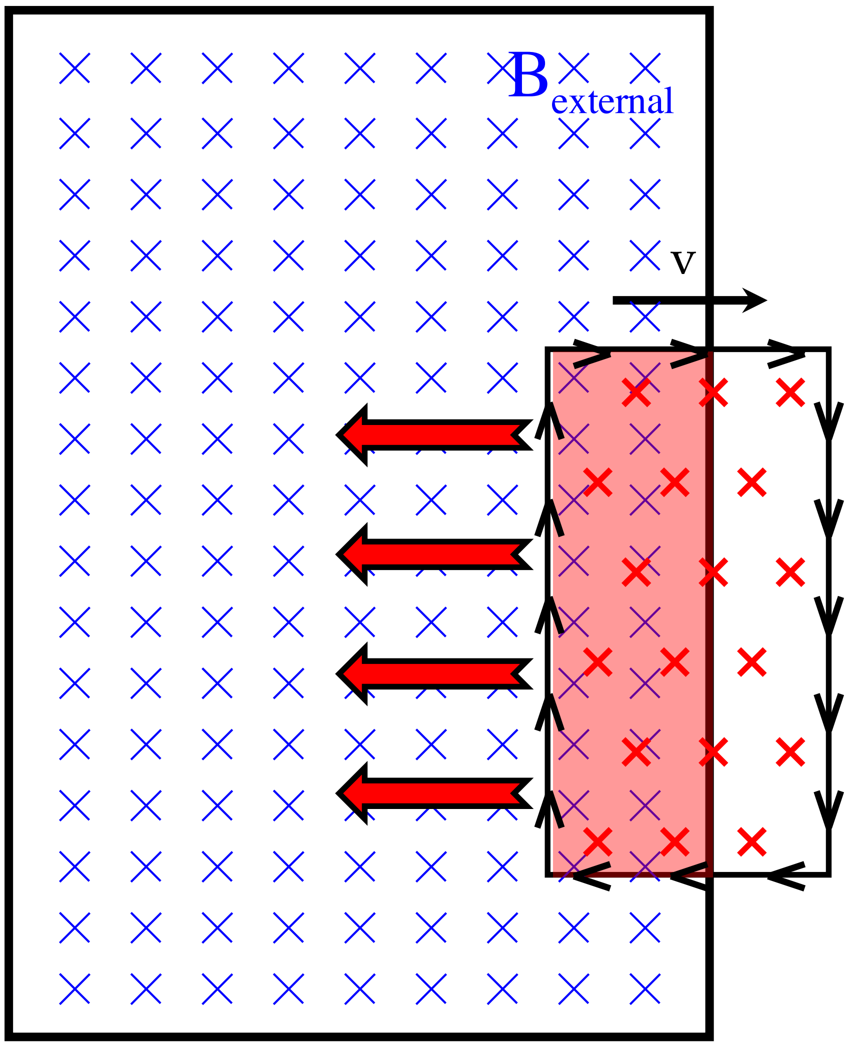
--once completely in the external B-fld, there is no longer a changing magnetic flux so the induced EMF ceases as does the induced current.



Motional EMF

When the coil emerges:

--Now Φ_B decreases thru the coil so the induced B-fld must ADD to the external field to oppose the change. That is produces a current that is CLOCKWISE, which produces an interactive force with the EXTERNAL B-fld that FIGHTS the coil leaving the field.



Motional EMF

- Bottom line: Any coil that moves into or out of an external magnetic field will feel a magnetic force that fights the motion.

  - That is, if the coil is pushed *into* the magnetic field, the force produced by the interaction of the induced current in the coil with the external field will make it harder to do this.
  - If the coil is pulled *out of* the magnetic field, the force produced by the interaction of the induced current in the coil and the external magnetic field will make it harder to do this.

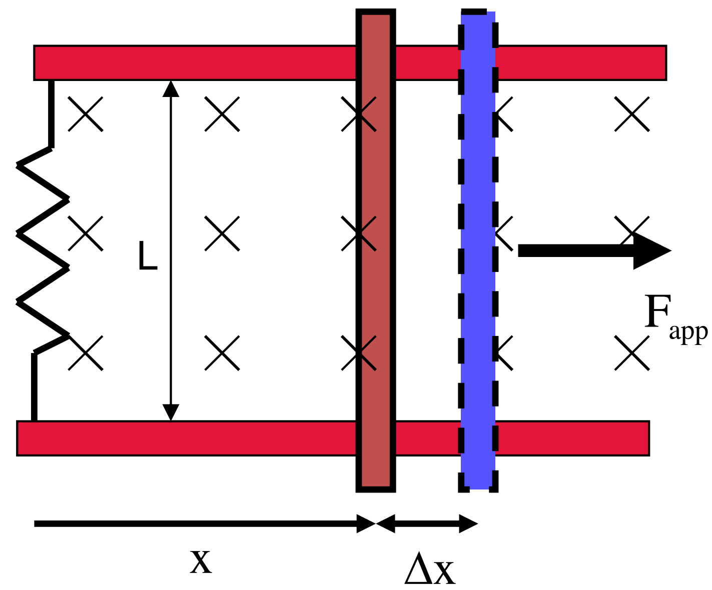
- IN ALL CASES, the interaction of the induced current with the external magnetic field will produce a force on the coil that FIGHTS THE CHANGE.

Problem 20.30

At what speed should the bar move to produce a current of .5 amps in the resistor if:

$R = 6\ \Omega$, $L = 1.2$ m and

$B = 2.5$ Teslas into the page.



Additional questions:

a.) In what direction will the induced flow?

b.) If you want the bar to move with a constant velocity, how large a force would you have to apply to the bar to make that happen?