# October 20th

Induction and Inductance

Chapter 31

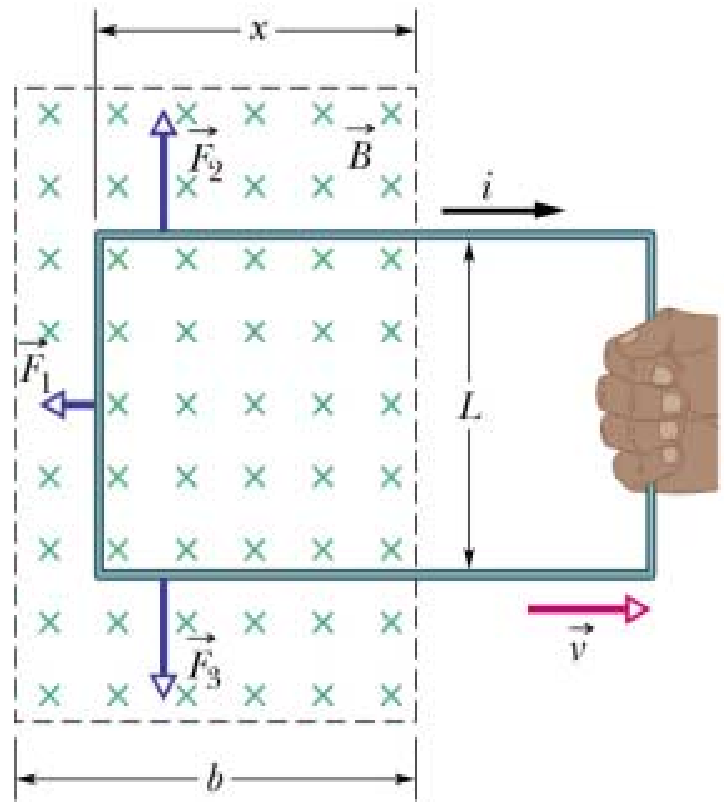

Math phobic's nightmare

# Review

- We can produce an induced current and induced emf in a loop of wire when the number of magnetic field lines passing through the loop is changing.
- Magnetic flux $$\Phi_B = \int \vec{B} \bullet d\vec{A}$$
- Faraday's law - the emf is given by
  - Also called induced voltage $$\mathcal{E} = -\frac{d\Phi_B}{dt}$$
- Lenz's law – An induced emf gives rise to a current whose *B* field opposes the change in flux that produced it.

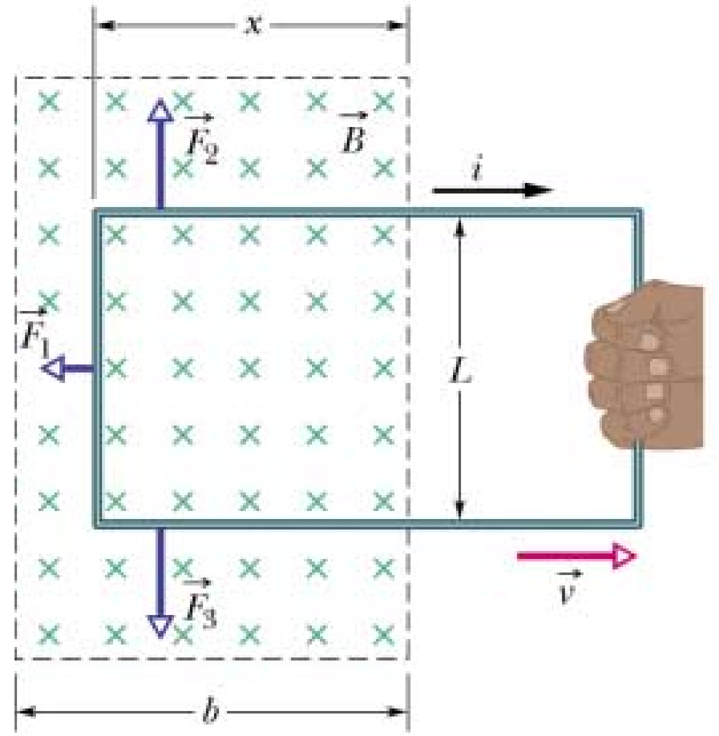
# Loop + magnet (Fig.31-10)

- If you pull a loop at a constant velocity, *v*, through a *B* field, you must apply a constant force, *F*
- As you move loop to right, less area is in *B* field so magnetic flux decreases and current is induced in loop
- Magnetic flux when *B* is ⊥ and constant to area is




$$\Phi_B = BA = BLx$$

# Loop + magnet (Fig.31-10)




- Using Faraday's law

$$\mathcal{E} = \frac{d\Phi_B}{dt} = \frac{d}{dt} BLx = BL\frac{dx}{dt}$$

- Remember $v = dx/dt$ so

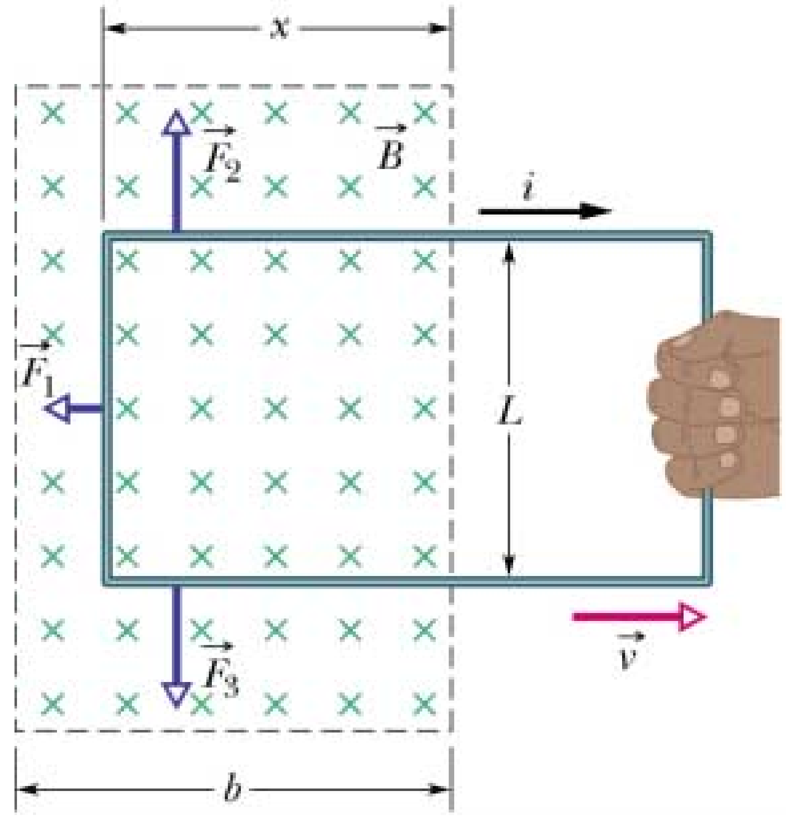
$$\mathcal{E} = BLv$$

- where $L$ is the length of the loop and $v$ is ⊥ to $B$ field
- $B$ is decreasing so $B_i$ is in same direction (into page), so the current is clockwise

# Loop + magnet (Fig.31-10)

- Since loop carries current through a *B* field there is a force given by

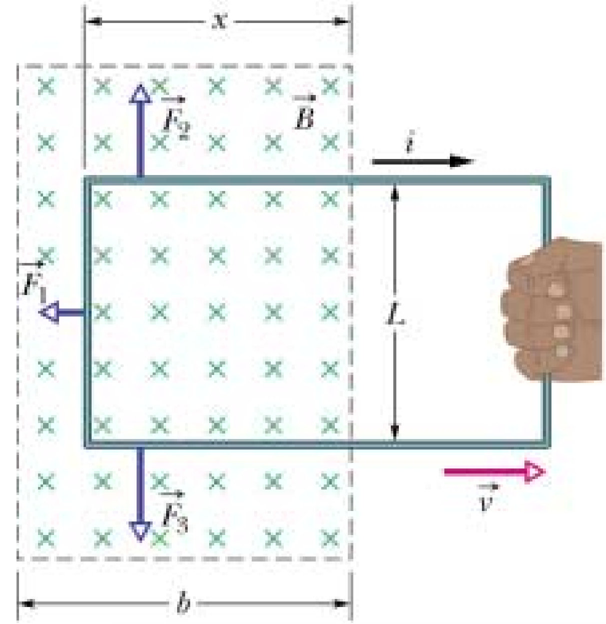
$$\vec{F}_B = i\vec{L} \times \vec{B}$$



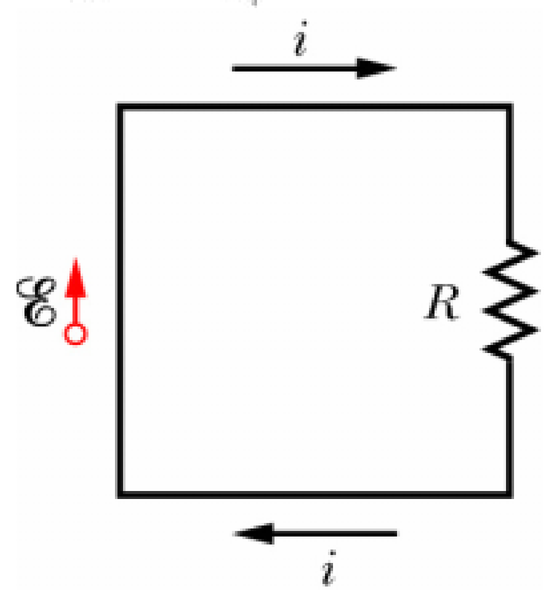

- Use right-hand rule to find direction of $F_B$ on segments of loop in *B* field
- Find forces, $F_2$ and $F_3$, cancel each other
- Force, $F_1 = iLB$ opposes your force $\vec{F}_{app} = -\vec{F}_1$

# Loop + magnet (Fig.31-10)

$$\mathcal{E} = BLv$$



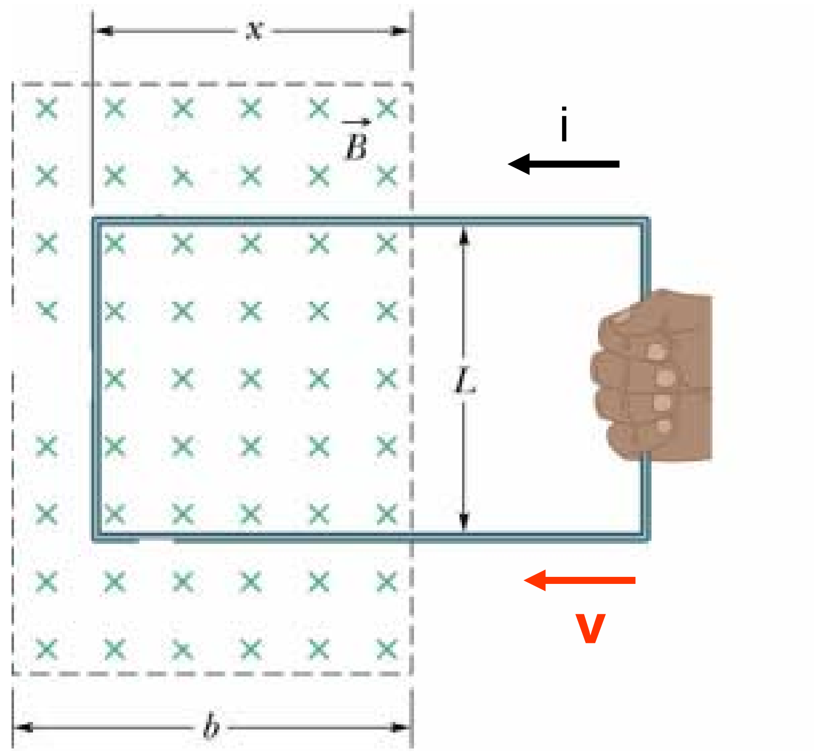

- The circuit diagram is
- With $\mathcal{E} = iR$
- Then $i = \dfrac{\mathcal{E}}{R} = \dfrac{BLv}{R}$
- And $F_1 = iLB = \dfrac{B^2L^2v}{R}$



# Loop + magnet (Fig.31-10)

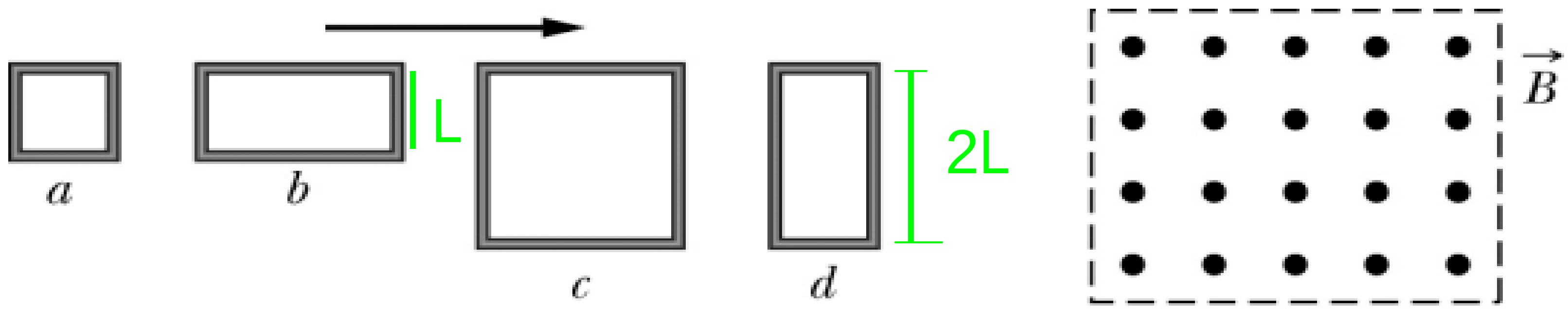
- What happens if we push the wire in?

- *B* is increasing so $B_i$ is in the opposite direction (out of page), so the current is counter-clockwise.



# Inductance (19)

- Checkpoint #3 – Four wire loops with edge lengths of either L or 2L. All loops move through uniform *B* field at same velocity. Rank the four loops according to maximum magnitude of induced emf, greatest first.

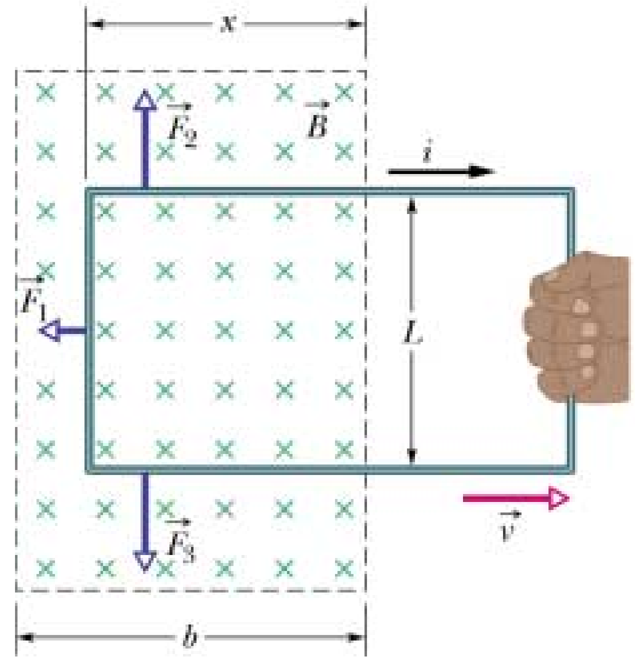



$$\mathcal{E} = BLv$$

c & d tie, then
a & b tie

# Loop + magnet (Fig.31-10)

- Energy is conserved - so where does the work you do moving the loop in and out go?




- The current flowing through the resistance produces heat at the rate

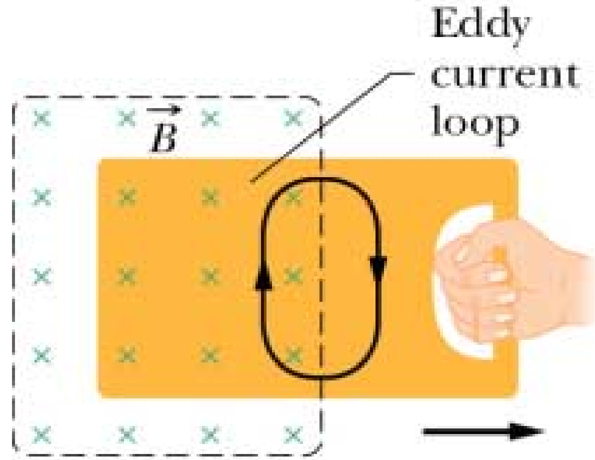
$$P = i^2 R = \frac{B^2 L^2 v^2}{R}$$

since

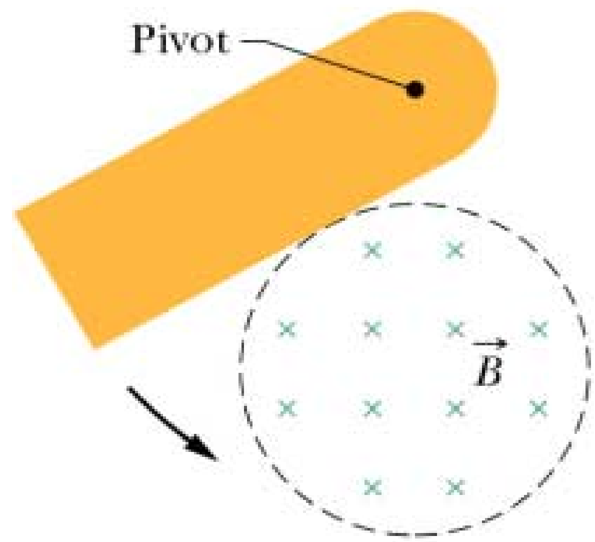
$$i = \frac{BLv}{R}$$

# Eddy currents (Fig. 31-12)

- Instead of a loop of wire, what happens when a bulk piece of metal moves through a *B* field?
- Free electrons in metal move in circles as if caught in a whirlpool called eddy currents
- A metal plate swinging through a *B* field will generate eddy currents



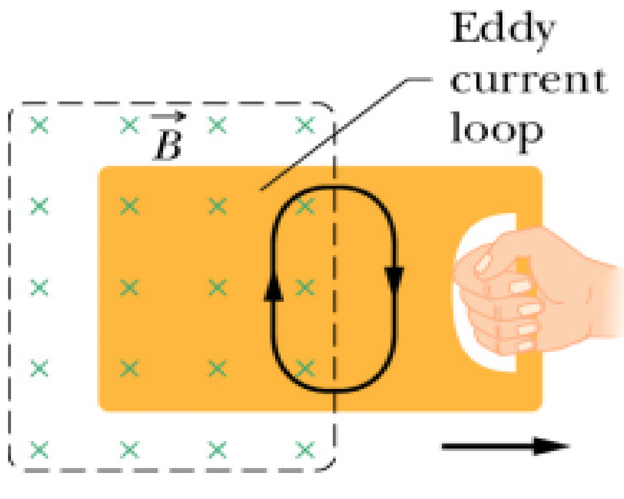
(a)



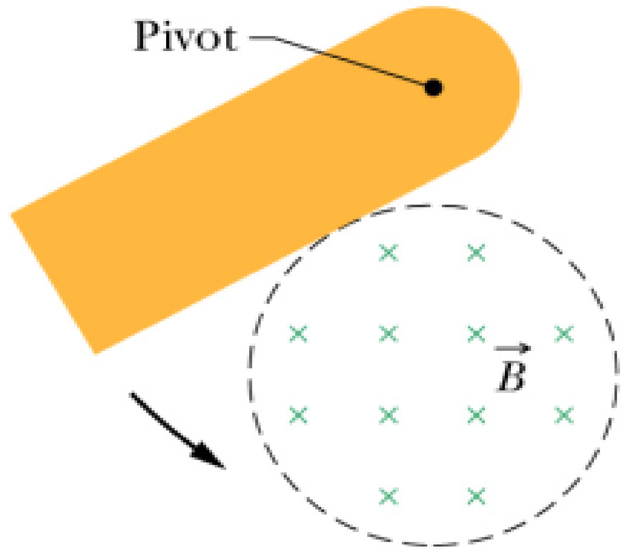
(b)

# Eddy currents (Fig. 31-12)

- Eddy currents will oppose the change that caused them – Lenz's law
- Induced eddy currents will always produce a retarding force when plate enters or leaves *B* field causing the plate to come to rest
- Cutting slots in metal plate will greatly reduce the eddy currents



(a)



(b)

# Eddy currents

- Induction and eddy currents are used for braking systems on some subways and rapid transit cars
- Moving vehicle has electromagnet (e.g. solenoid) which is positioned near steel rails
- Current in electromagnet generates $B$ field
- Relative motion of $B$ field to rails induces eddy currents in rails
- Eddy currents produce a drag force on the moving vehicle
- Eddy currents decrease steadily as car slows giving a smooth stop

# Eddy currents

- Eddy currents often undesirable since they dissipate energy in form of heat
- Moving conducting parts often laminated
  - Build up several thin layers separated by nonconducting material
  - Layered structure confines eddy currents to individual layers
- Used in transformers and motors to minimize eddy currents and improve efficiency

# Inductance (units)

- Inductor is a device used to produce and store a desired *B* field (e.g. solenoid)
- A current, *i*, in an inductor with *N* turns produces a magnetic flux, $\Phi_B$, in its central region
- Inductance, *L* is defined as

$$L = \frac{N\Phi_B}{i}$$

- SI unit is henry, H

$$H = T \cdot m^2 / A$$

# Inductance of a solenoid

- What is inductance of a solenoid? $$L = \frac{N\Phi_B}{i}$$

- First find flux of single loop in solenoid

$$\Phi_B = \int \vec{B} \bullet d\vec{A} = BA = \mu_0 niA$$

- # of turns ($N$) per unit length ($l$) $$n = N / l$$

- Thus $$L = l\mu_0 n^2 A$$ or $$\frac{L}{l} = \mu_0 n^2 A$$

- Depends only on the physical properties of the solenoid