PHY294H

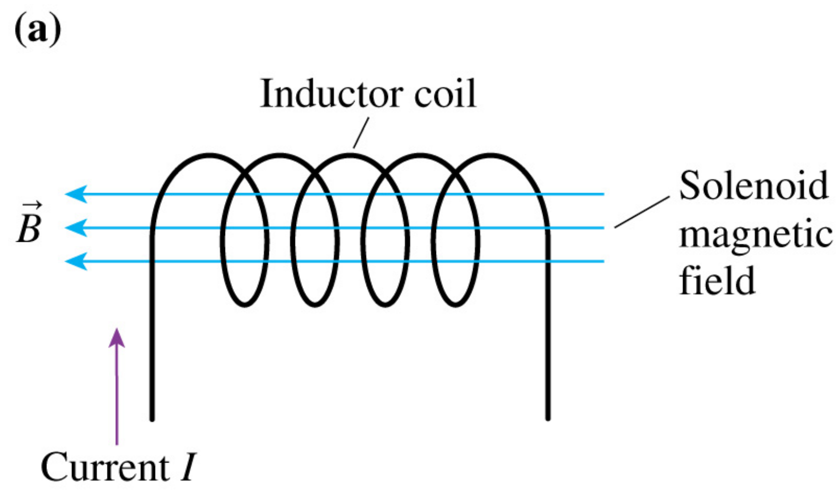
- Professor: Joey Huston
- email:huston@msu.edu
- office: BPS3230
- Homework will be with Mastering Physics (and an average of 1 hand-written problem per week)
  - **Help-room hours: 12:40-2:40 Monday (note change); 3:00-4:00 PM Friday**
  - **hand-in problem for Wed Mar. 16: 33.54**
- Quizzes by iclicker (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

Happy π Day!

Inductors

- A capacitor is a good way of producing a uniform electric field
  - it also stores energy in the form of the electric field
- A solenoid is a useful way of producing a uniform magnetic field
  - and we'll find can also store energy in the form of the magnetic field
- Define the inductance L of a circuit element as the ratio of the magnetic flux it holds to the current flowing through it

$$L = \frac{N\phi_m}{I}$$

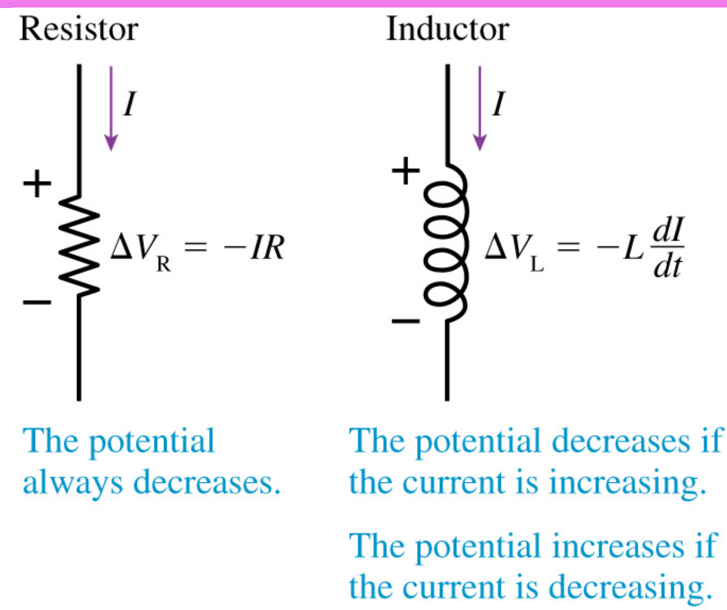


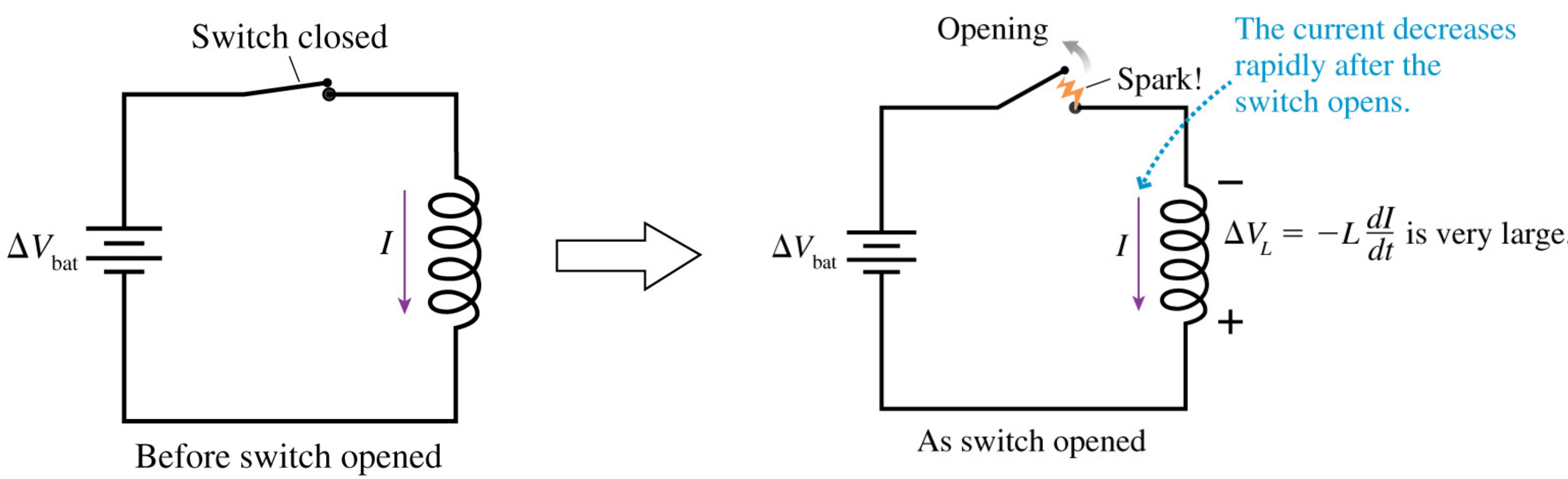
The larger the inductance, the larger flux can be held for a given current. Remember, the larger the capacitance, the larger charge that can be held for a a given voltage.

Unit of inductance is the Henry
1H = 1 Tm^2/A

Inductors in circuits

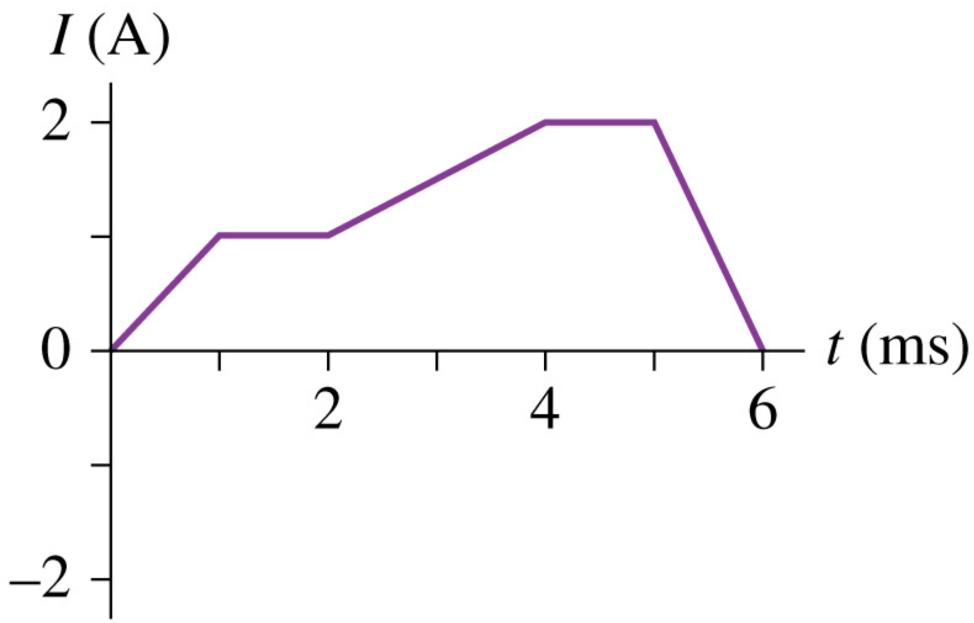
- We'll encounter inductors in circuits in the future
- The voltage drop across an inductor is proportional to the rate of change of current though it (and can be large)
- …and independent of the value of the current





Example

- The figure to the right shows the current through a 10 mH inductor
- What does the voltage drop across the inductor look like



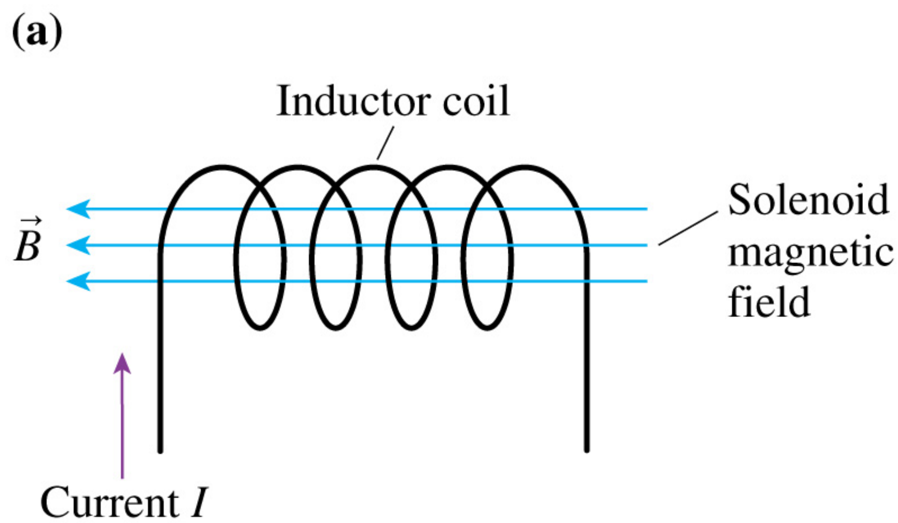
Energy in inductors and magnetic fields

- An inductor stores energy just as a capacitor does

$$P = I\Delta V_L = -LI\frac{dI}{dt}$$

$$\frac{dU_L}{dt} = LI\frac{dI}{dt}$$

$$U_L = L\int_0^L IdI = \frac{1}{2}LI^2$$



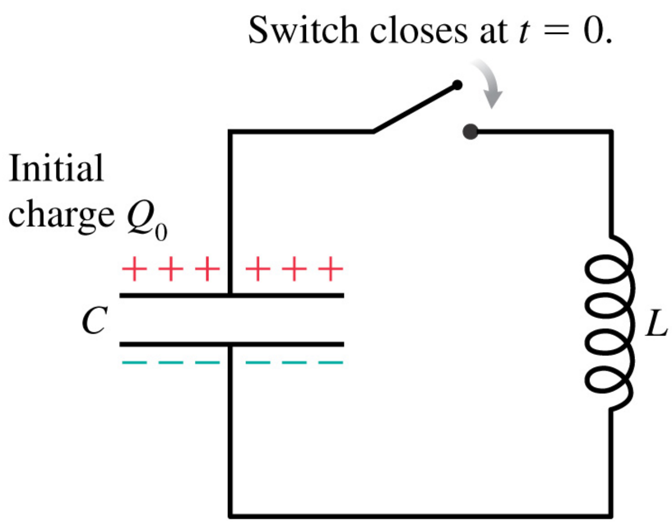
- The energy is stored in the magnetic field with an energy density

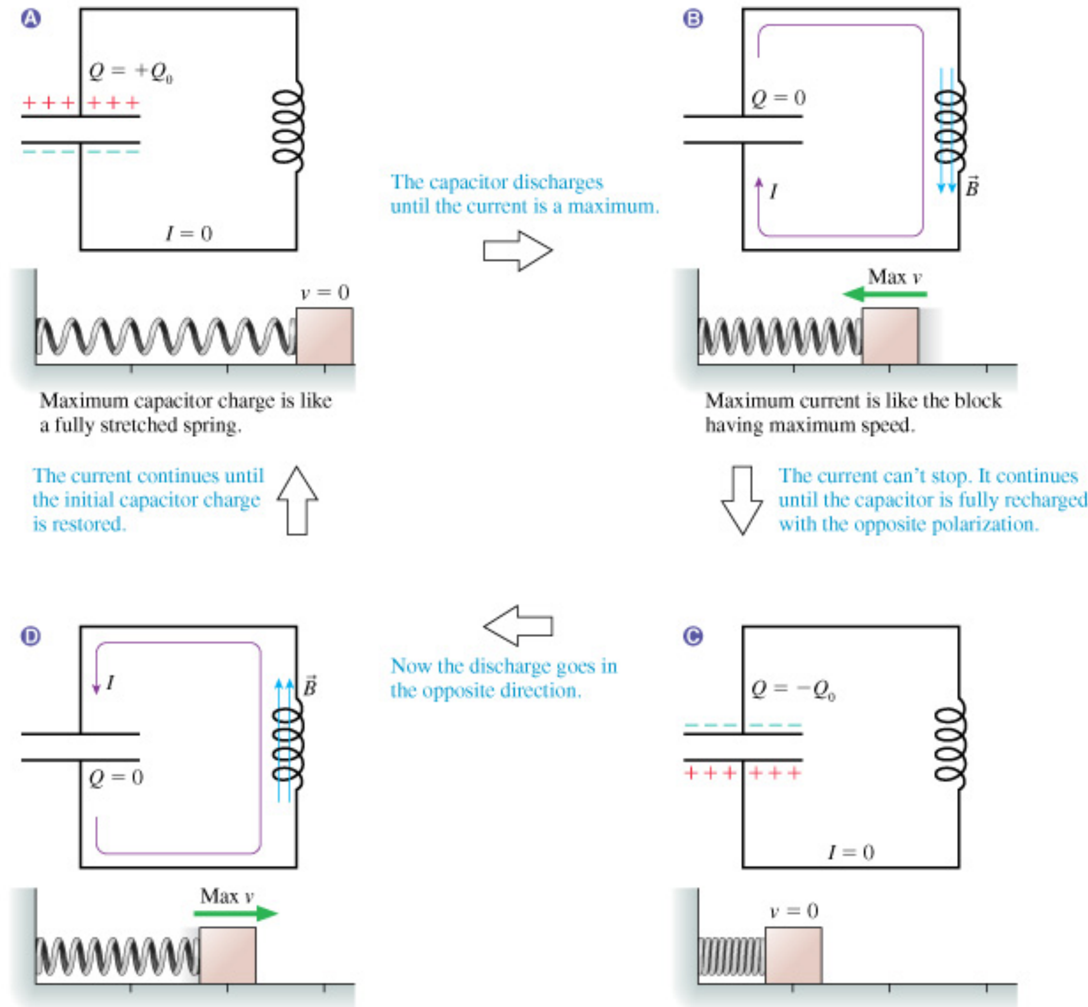
$$\mu_B = \frac{1}{2\mu_o}B^2$$

- Remember

$$\mu_E = \frac{1}{2}\varepsilon_o E^2$$

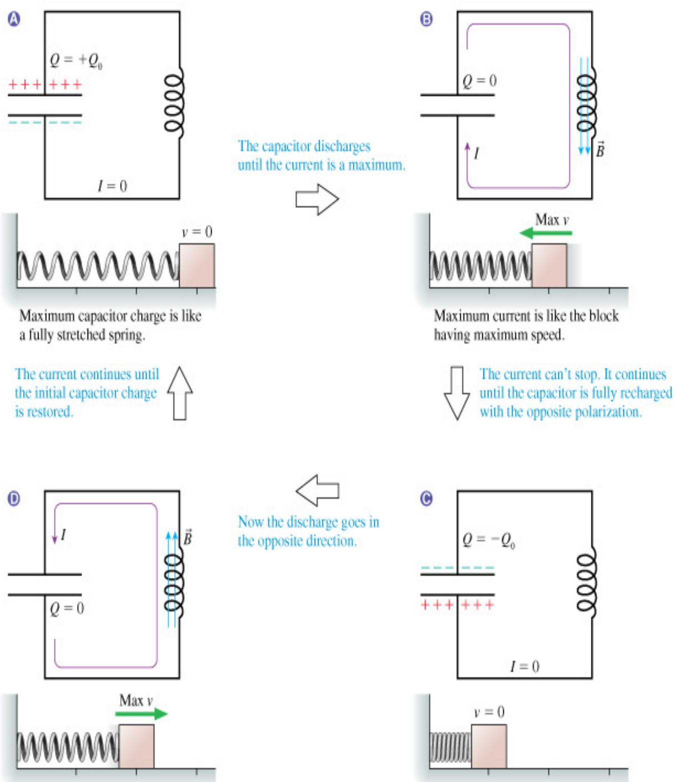
LC circuits

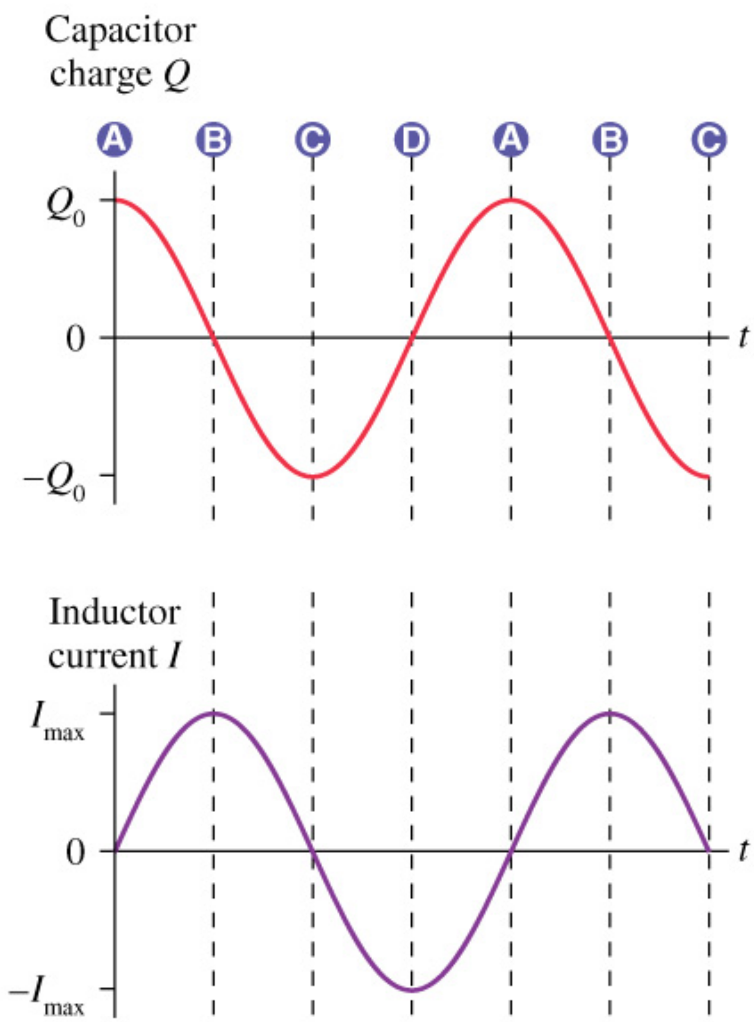




$$\Delta V_C + \Delta V_L = 0$$

LC circuits



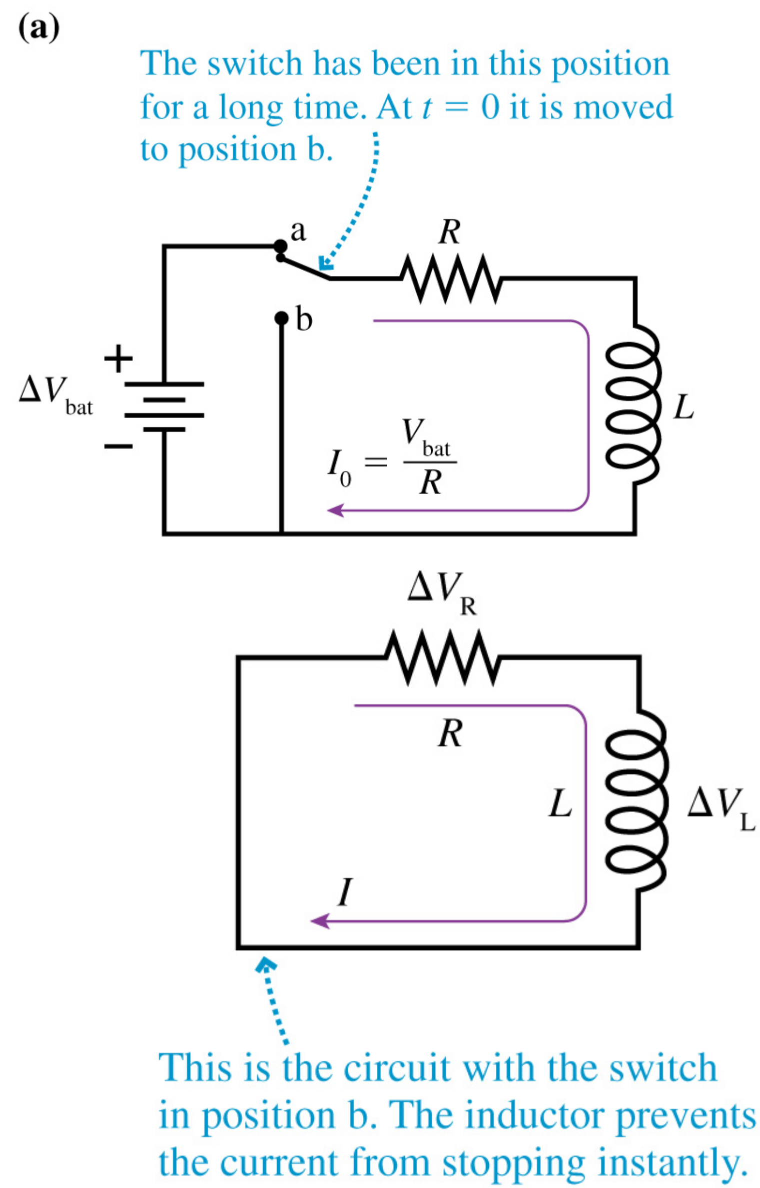


$$Q(t) = Q_o \cos \omega t$$

$$I = \frac{dQ}{dt} = \omega Q \sin \omega t = \mathrm{I}_{\max} \sin \omega t$$

LR circuits

- A circuit that has an inductor and a resistor is imaginatively called an LR circuit
- In the top circuit, the switch has been closed for a "long time", there is no dI/dt and all of the voltage drop is across the resistor
- The switch is then moved to b and the battery is no longer part of the circuit
- A current continues to flow because of the influence of the inductor
- We can still apply Kirchoff's laws



LR circuit

$$\Delta V_R + \Delta V_L = 0$$

$$-RI - L\frac{dI}{dt} = 0$$

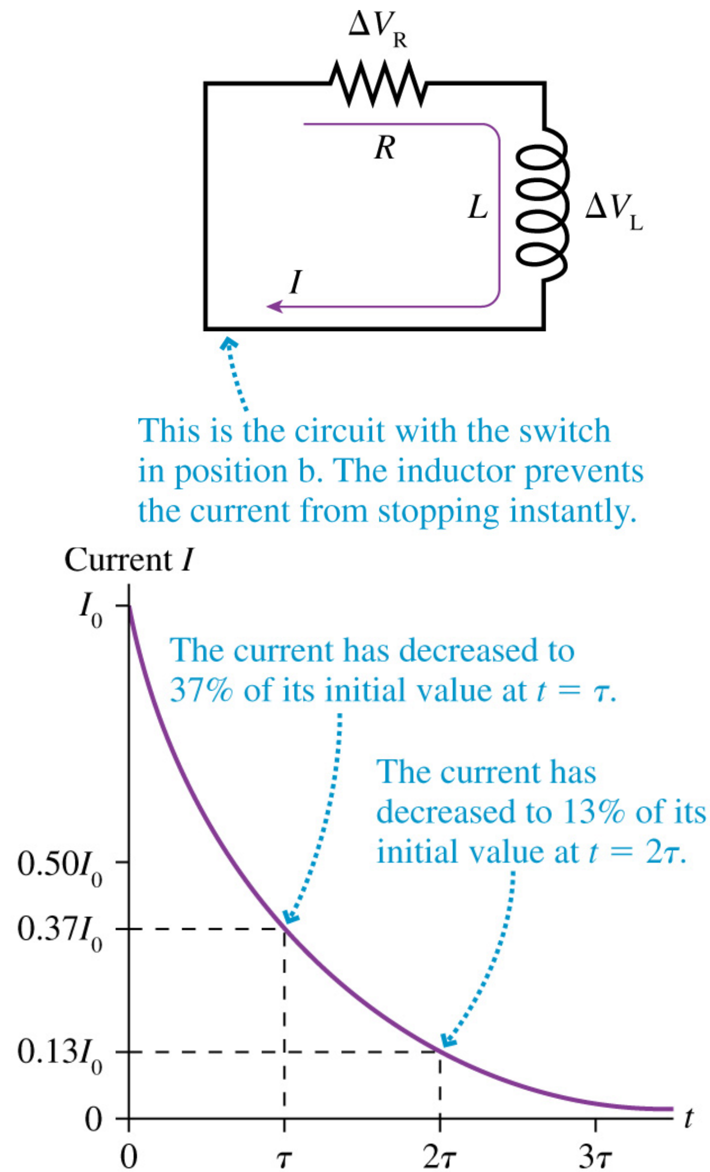
$$\frac{dI}{I} = -\frac{R}{L}dt = -\frac{dt}{(L/R)}$$

$$\int_{Io}^{I}\frac{dI}{I} = -\frac{1}{(L/R)}\int_{0}^{t}dt$$

$$\ln\left(\frac{I}{I_o}\right) = -\frac{t}{(L/R)}$$

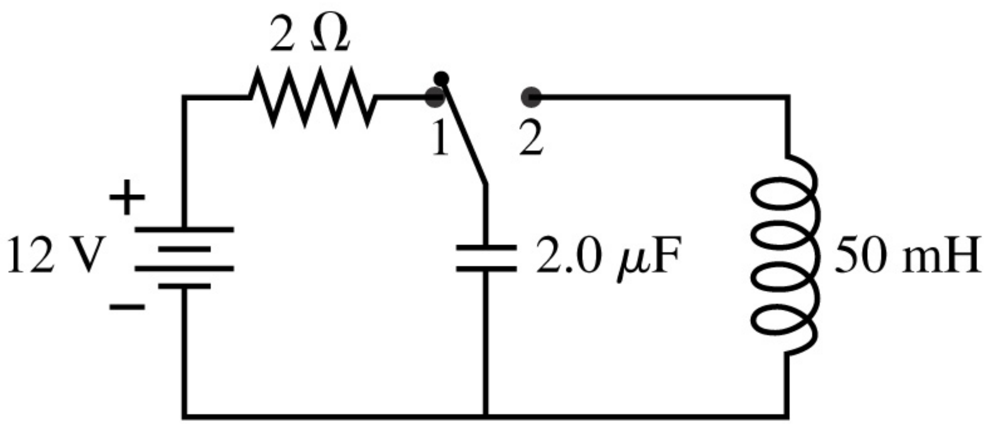
$$I = I_o e^{-t/\tau}$$

τ=L /R



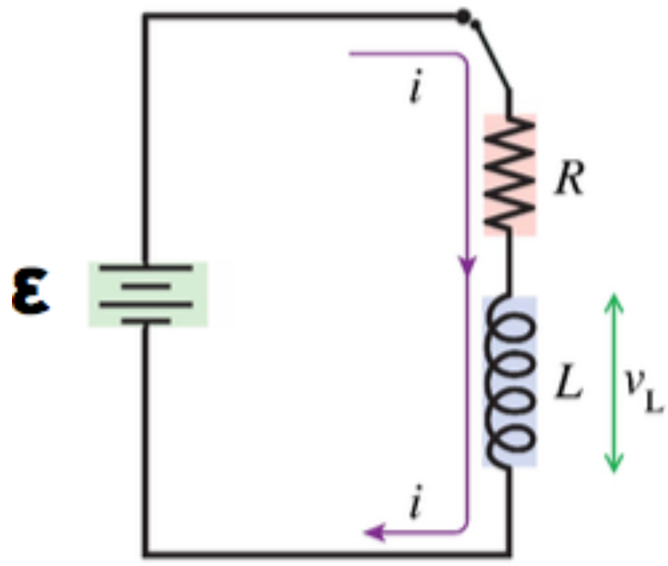
Example

- The switch has been in position 1 for a long time
- Then it is abruptly moved to position 2
  - what is the maximum current through the inductor?
  - when does this maximum current occur?
  - what if the inductor and capacitor changed position?



iclicker question

- Right after the switch is closed what is the voltage across the inductor, V_L? The emf = 12 V, R = 10 Ω and L = 5 H.



A. 0 V
B. 5 V
C. 12 V
D. 50 V
E. 60 V

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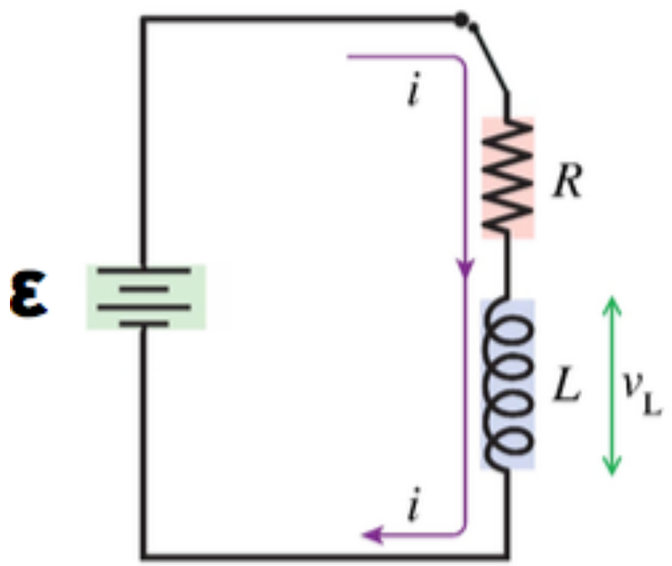

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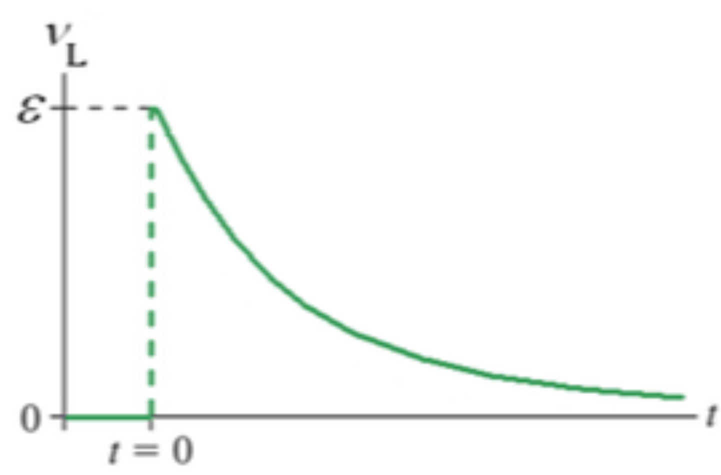
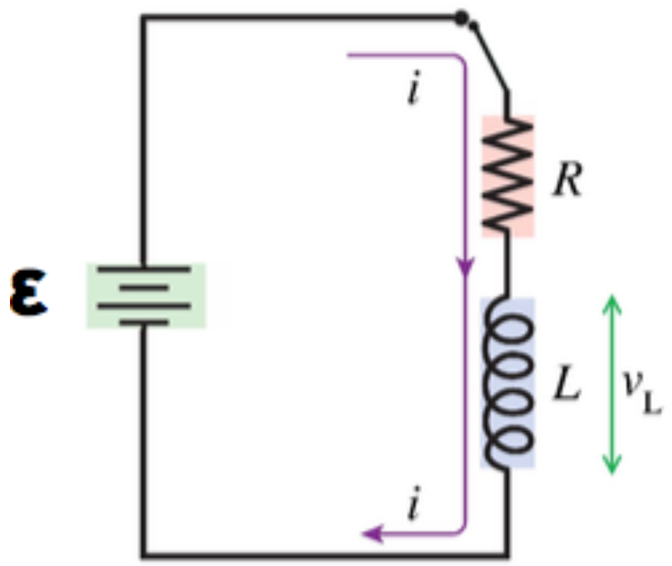


Iclicker question

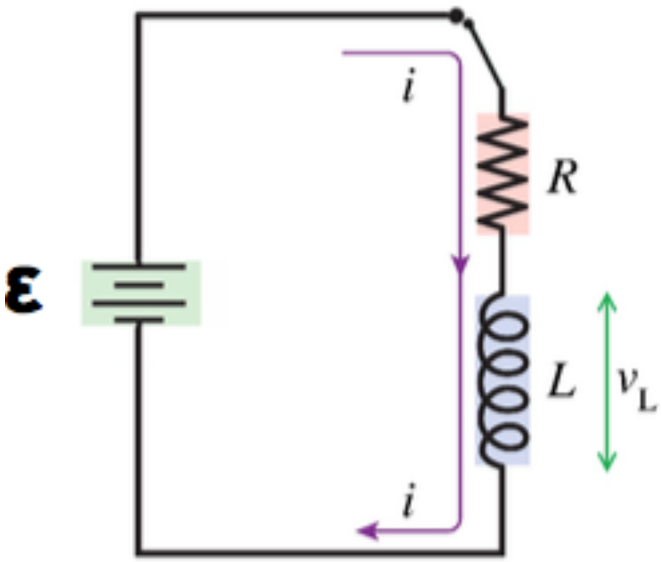
- A long time after the switch is closed what is the current in the circuit? The emf = 12 V, R = 10 Ω and L = 5 H.



A. 0 A
B. 1.2 A
C. 2.0 A
D. 2.4 A
E. 5.0 A

iclicker question

- A long time after the switch is closed what is the current in the circuit? The emf = 12 V, R = 10 Ω and L = 5 H.



A. 0 A
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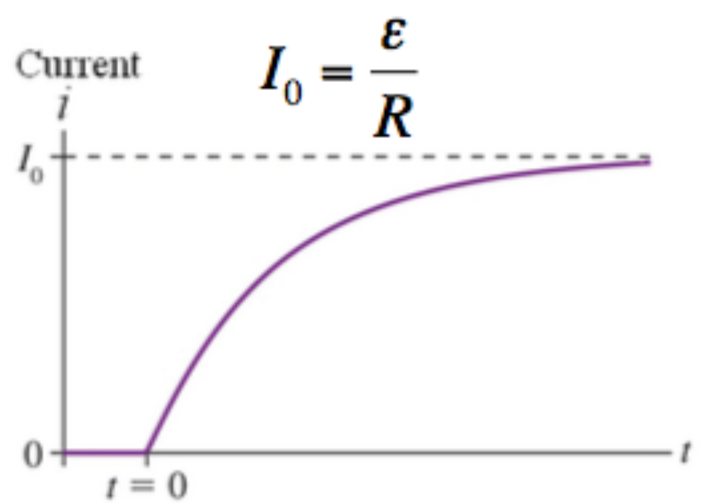


Some odds and ends: Gauss' law revisited

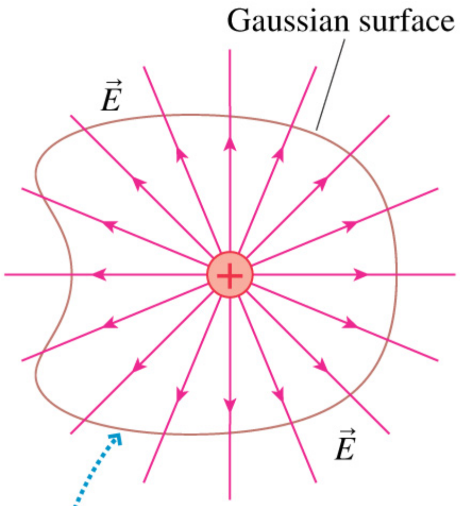
- We've written down Gauss' law for electric fields

$$\Phi_E = \oint \vec{E} \bullet d\vec{A} = \frac{Q_{in}}{\varepsilon_o}$$

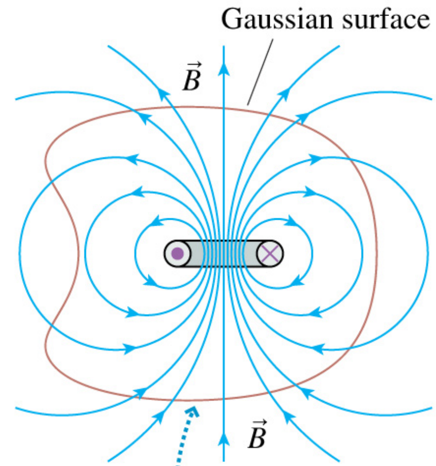
- We can also write down Gauss' law for magnetic fields

$$\Phi_B = \oint \vec{B} \bullet d\vec{A} = 0$$

- To be revised if magnetic monopoles are discovered
    - for the moment, the right-hand side is **always** zero



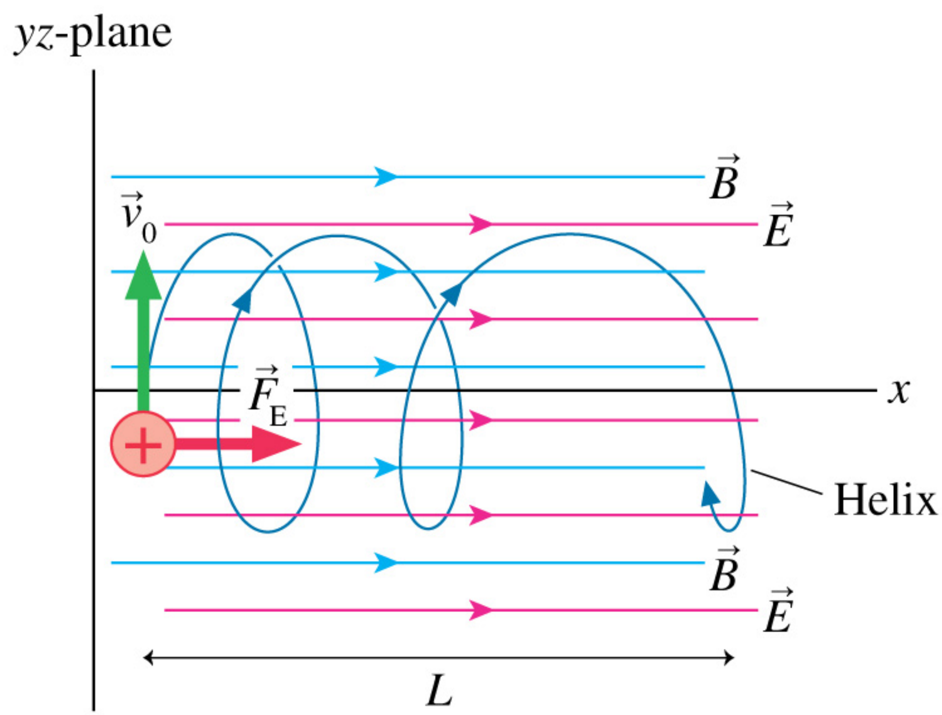
There is a net electric flux through this surface that encloses a charge.



There is no net magnetic flux through this closed surface.

Lorentz force law

- If a particle is moving in a region of space in which there are both an electric and a magnetic field, then it will experience both a Coulomb force and a magnetic force
- The total force acting on a particle will be given by the vector sum of the two forces



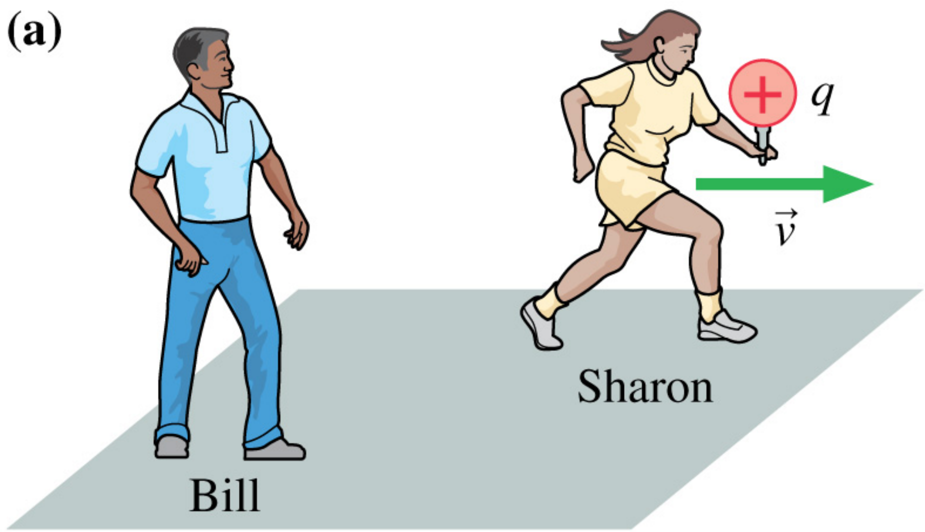
$$\vec{F} = q(\vec{E} + \vec{v} X \vec{B})$$

sometimes called a Lorentz force

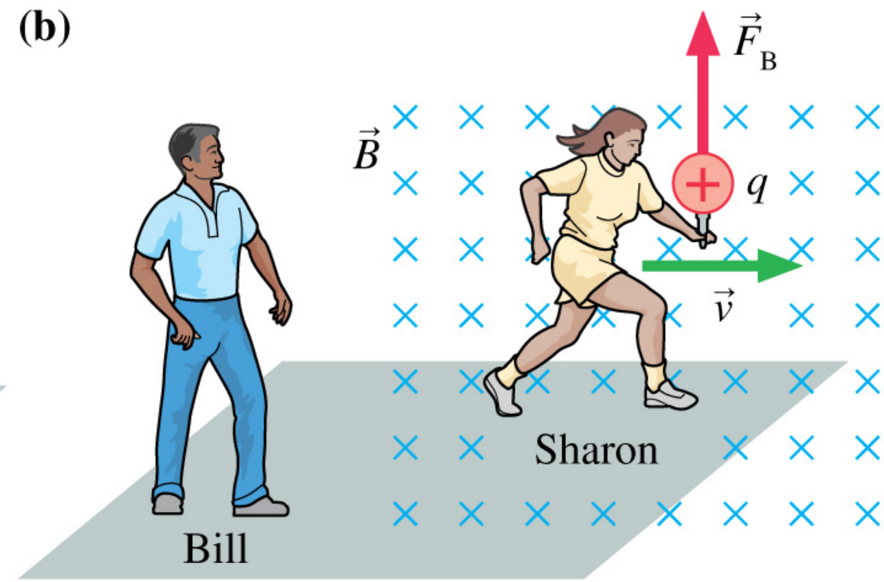
Fun with Dick and Jane: paradox revisited

- Is there or is there not a magnetic field created by the charge Sharon/Jane is carrying?

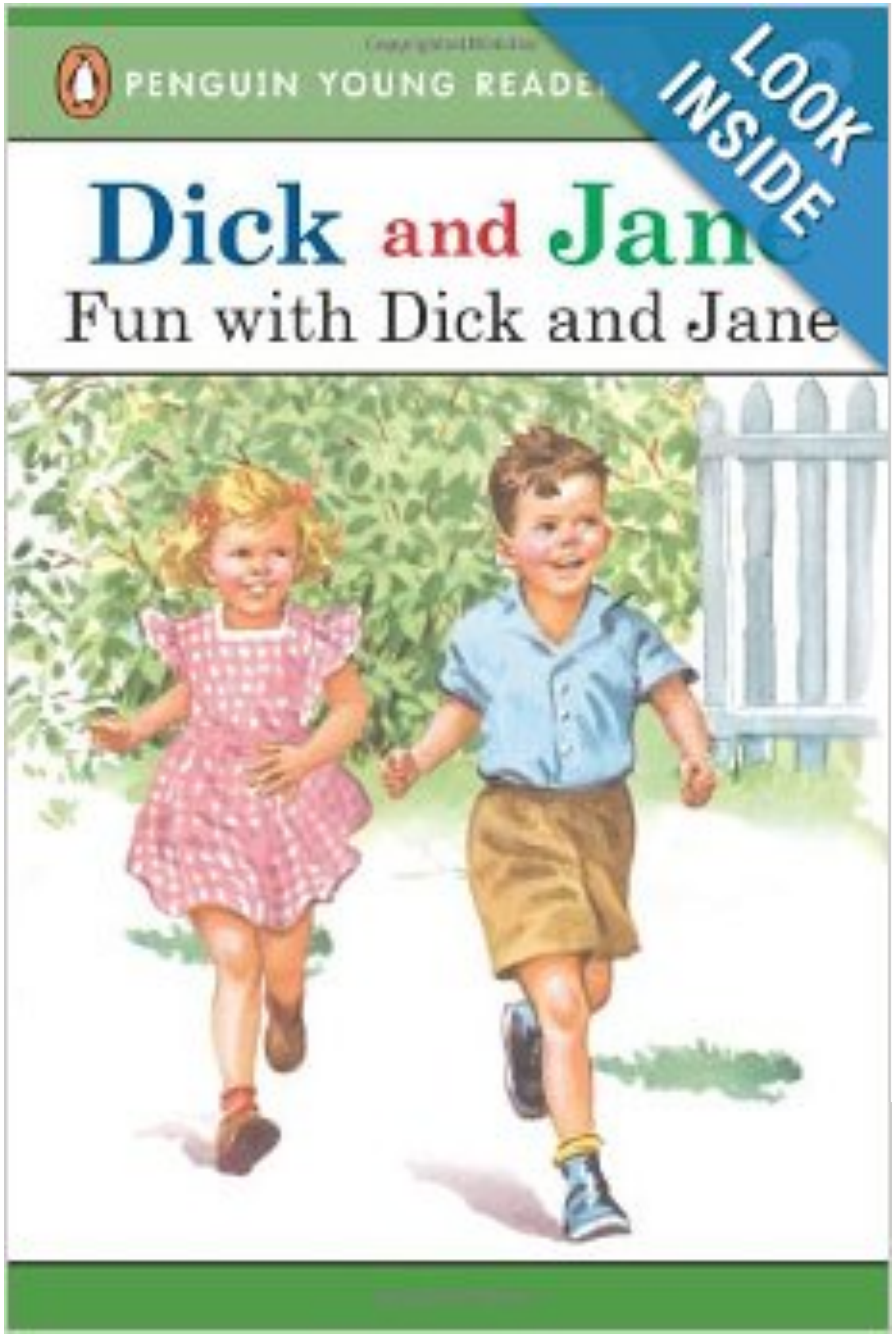
- Is there or is there not a magnetic force on the charge Sharon/Jane is carrying?



Charge q moves with velocity $\vec{v}$ relative to Bill.



Charge q moves through a magnetic field $\vec{B}$ established by Bill.



Jane said, "Run, run.

Run, Dick, run.

Run and see.

See, Dick, see, if there is
a magnetic force on
the electric charge you're carrying?"

Inertial reference frames

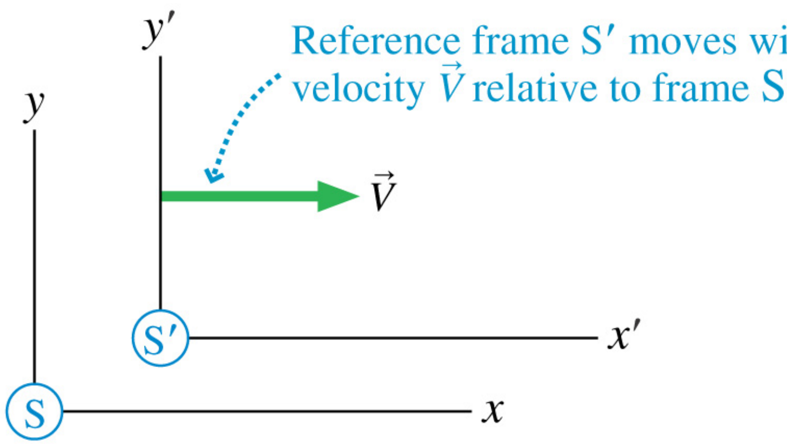
- Consider two frames of reference with the S ‘ frame moving with a velocity V with respect to the S frame

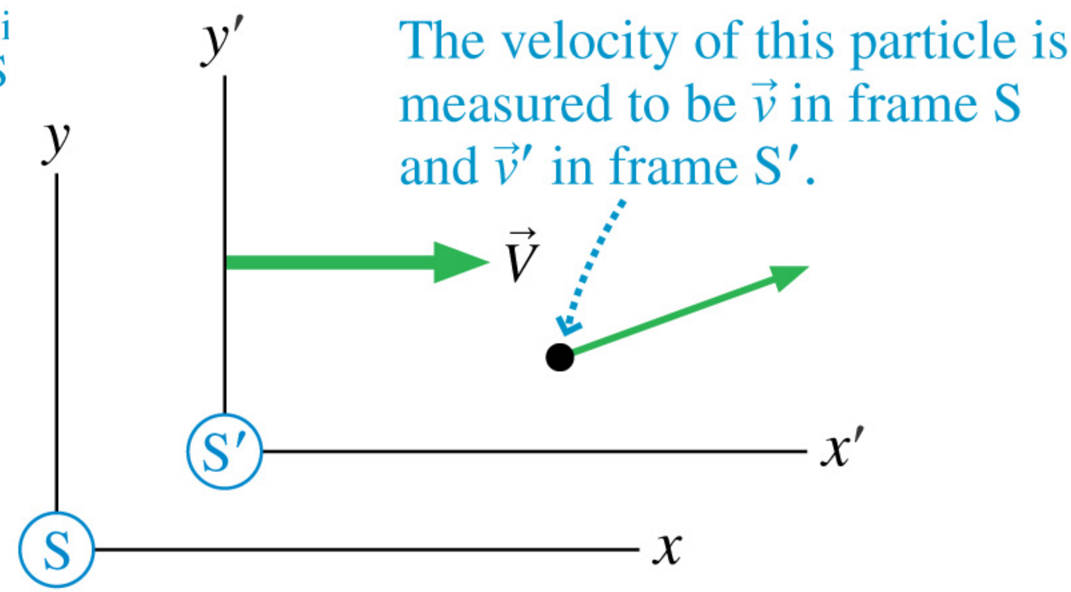
$$\vec{v}' = \vec{v} - \vec{V}$$

$$\vec{v} = \vec{v}' + \vec{V}$$

$$\vec{a} = \vec{a}'$$

$$\vec{F} = \vec{F}'$$

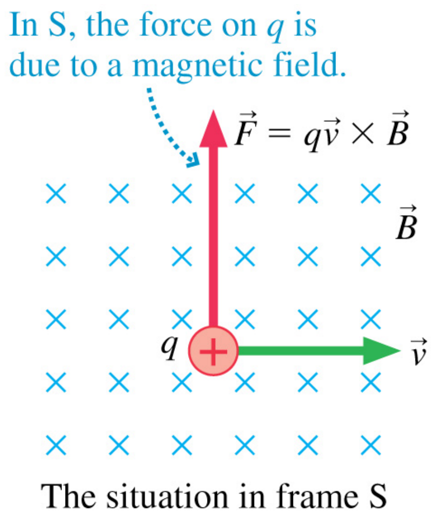


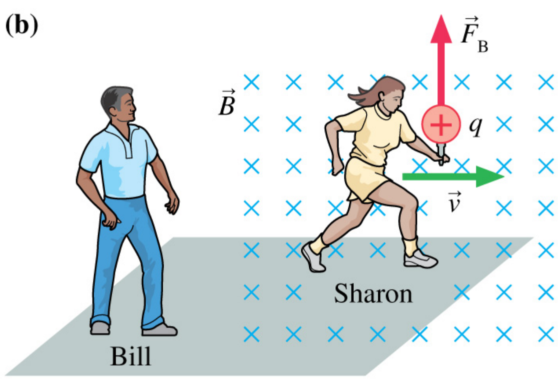


Accelerations and forces are the same in all inertial frames of reference. If they’re not, then something is wrong.

Back to Bill and Sharon

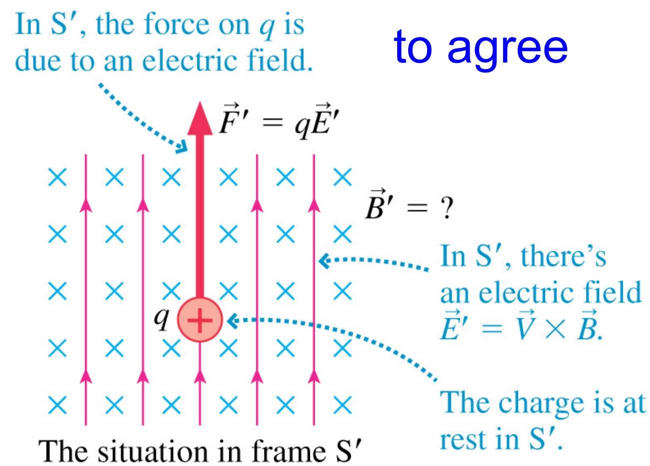
- In S, there is a magnetic force on q
- In S', there is no magnetic force





Charge q moves through a magnetic field $\vec{B}$ established by Bill.

- But the forces have to be the same in the two frames of reference
- In S', if there is no magnetic force then there must be an electric force on q due to an electric field of size $\vec{V}\times\vec{B}$, in order for Bill and Sharon to agree



- At least part of Bill's magnetic field has become an electric field
- Whether a field is seen as electric or magnetic depends on the motion of the reference frame relative to the sources of the field!