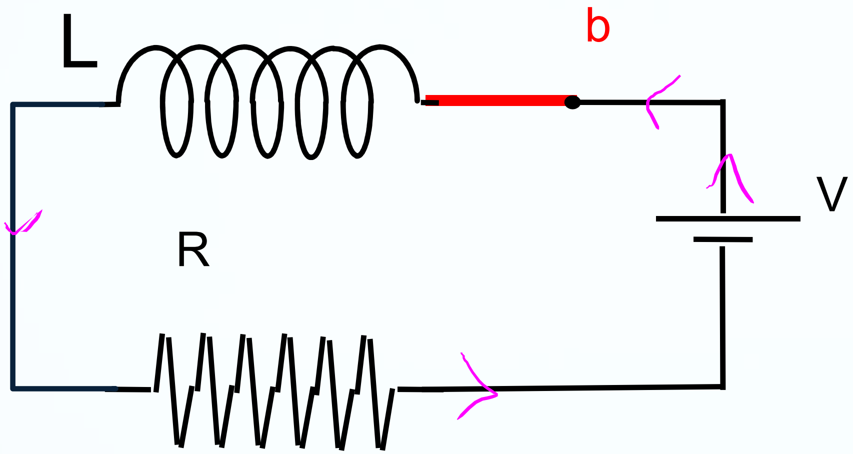
Electricity and Magnetism

- Physics 259 – L02
- Lecture 49

~~Chapter 29:~~ Magnetic field due to current

chapter 30

30.6: R-L Circuit



$$\boxed{V - L\frac{di}{dt} - iR = 0}$$

$V = -L\frac{di}{dt}$ $\quad$ $V = -iR$

If the switch is moved to position b, to initiate the current flow, what happens?

$C = \frac{q}{V}$ $\quad$ $V = \frac{q}{C}$

Faraday's law applies and so the change in the Magnetic Field in the inductor L means there is a back EMF induced in L.

Discharging ⇒

The components have all been connected for a very long time. At t=0 the switch S is opened. The current through R_1 and R are 0 and $^{\varepsilon}/_{R}$

Using the loop rules

$$-L\frac{di}{dt} - iR = 0$$

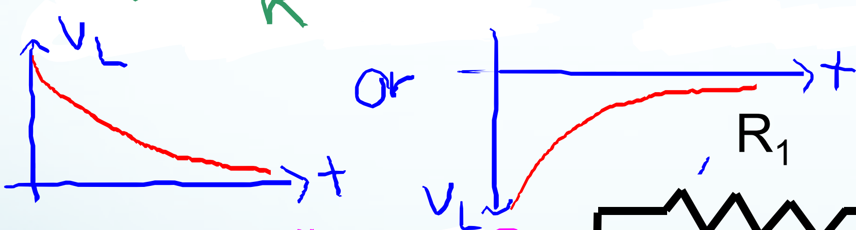
Solving with the method we used for a discharging capacitor

$\tau_L = \frac{L}{R}$ inductive time constant

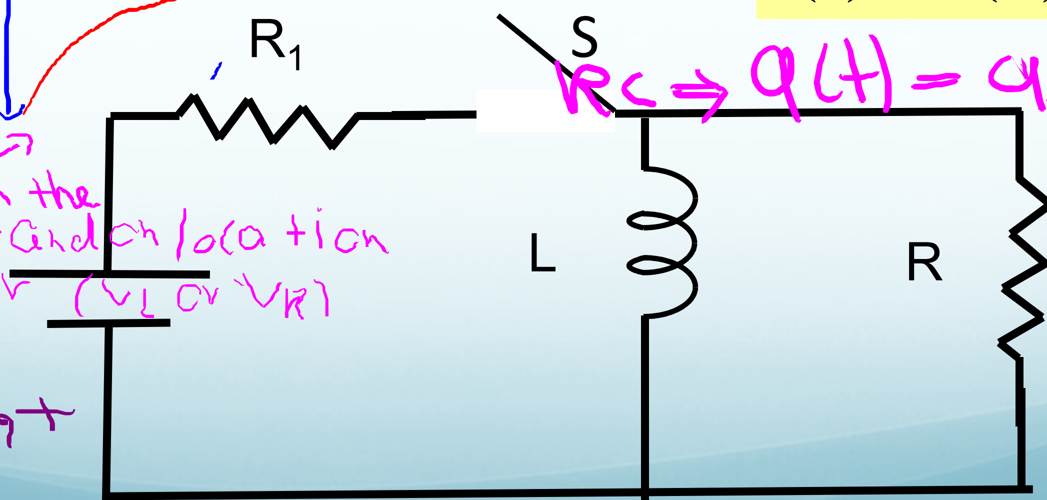
$i = \frac{V}{R}$

$$i(t) = i(0)\,e^{-\left(\frac{Rt}{L}\right)}$$

RC ⇒ $q(t) = q_0 e^{-t/RC}$



based on the direction and on location v-meter (V_L or V_R)



Charging

At t=0 the switch S is closed.

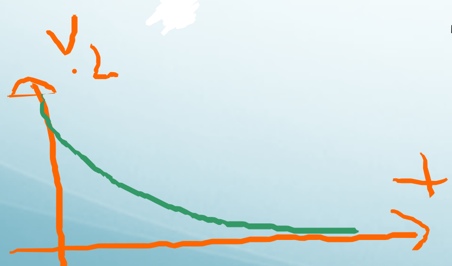
Using the loop rules

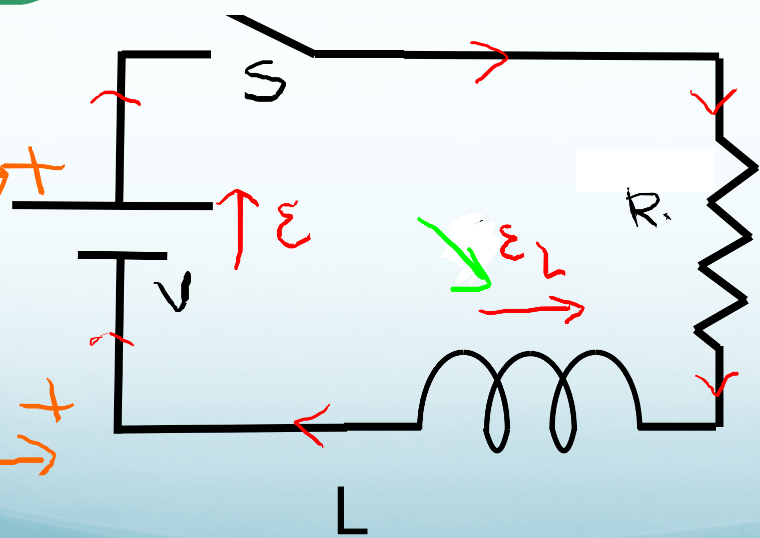
$$V - iR - L\frac{di}{dt} = 0$$

Solving using the method we used for the charging capacitor

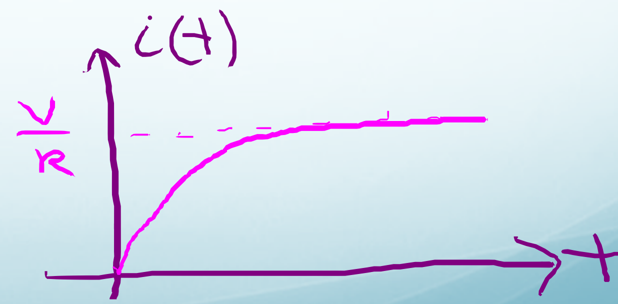
So in this case at t = 0, $i(0) = 0$. Inductor acts like a BATTERY

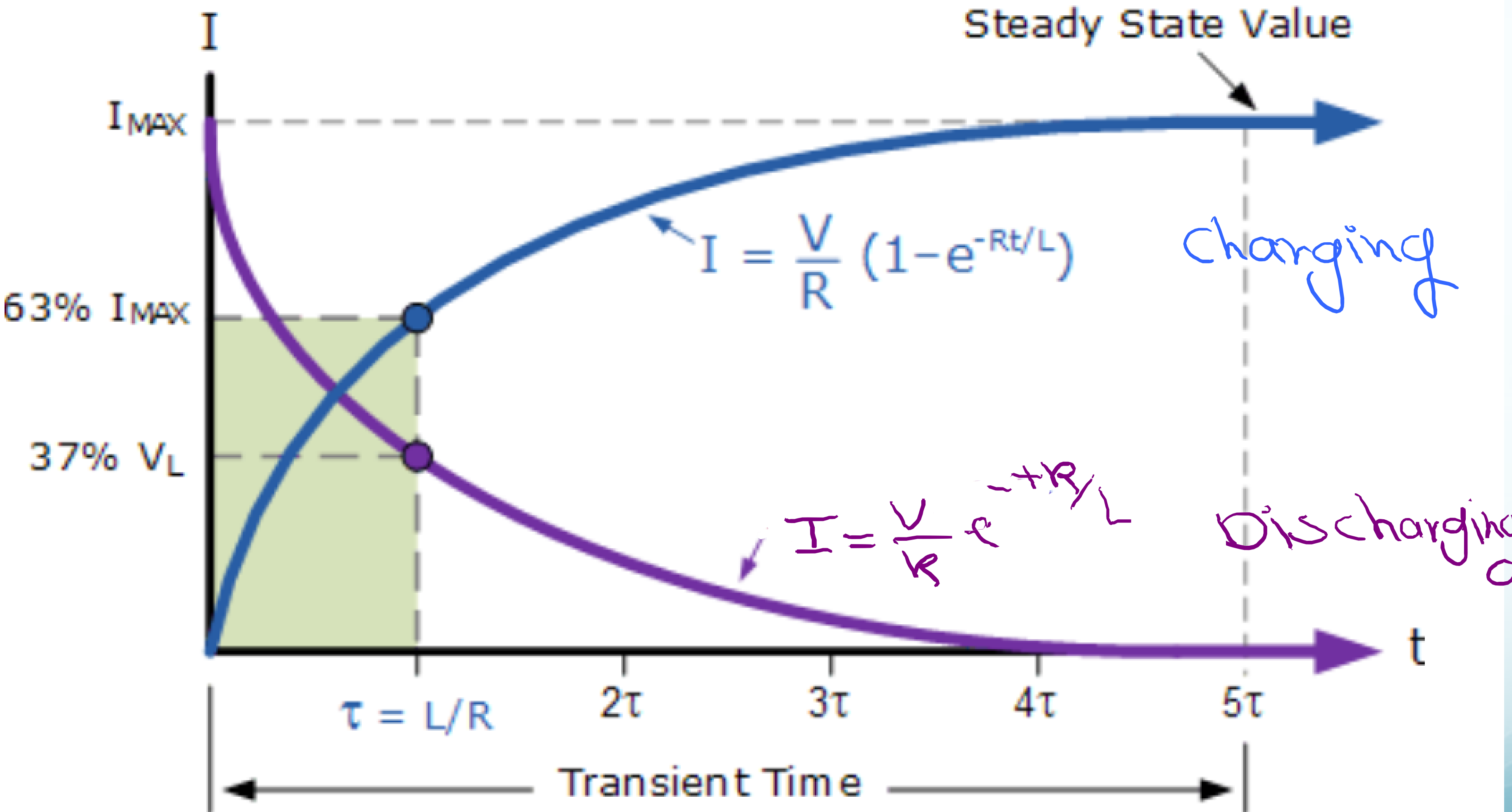
After a long time, $i = V/R$ Inductor acts like a WIRE





$$i(t) = i_{\max}\left(1 - e^{-\left(\frac{Rt}{L}\right)}\right)$$





https://tinyurl.com/msfn7b5

Top Hat Question

The switch in the series circuit below is closed at t=0.

What is the initial rate of change of current di/dt in the inductor, immediately after the switch is closed (time = 0+) ?

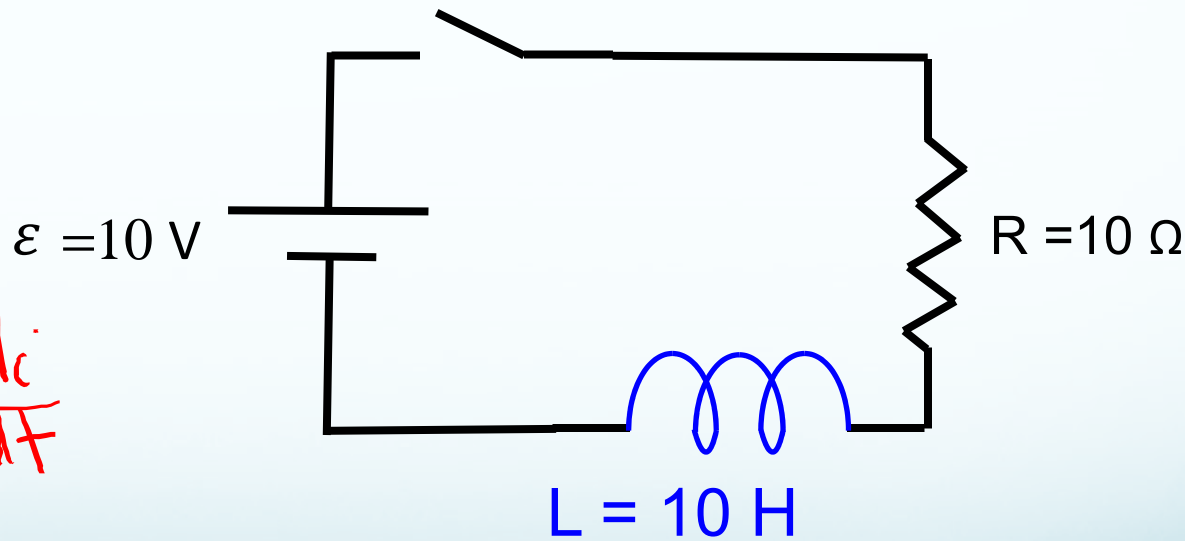
A. 0 A/s

B. 0.5 A/s

C. 1 A/s

D. 10 A/s

$\frac{di}{dt}$

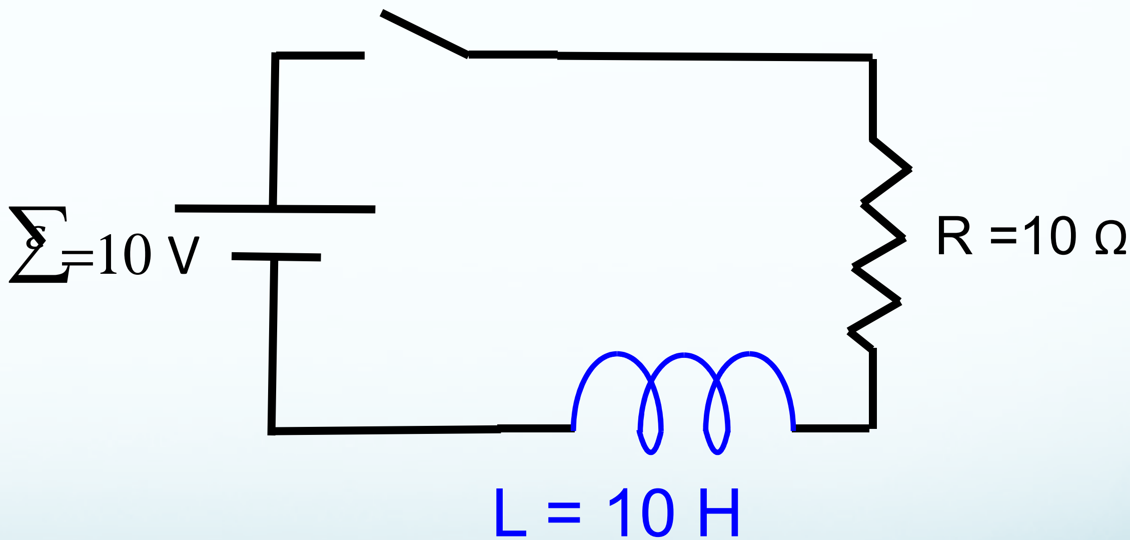


$V_R = 0$, $V_L = L\,di/dt$

Top Hat Question

The switch in the series circuit below is closed at t=0.

What is the initial rate of change of current di/dt in the inductor, immediately after the switch is closed (time = 0+) ?



A. 0 A/s

B. 0.5 A/s

C. 1 A/s

D. 10 A/s

i = 0 at t = 0 so V_R(0)= 0 which means

10 V = V_L= Ldi/dt so di/dt = 10V/10H = 1 A/s

8

Top Hat Question

The switch in the series circuit below is closed at t=0.

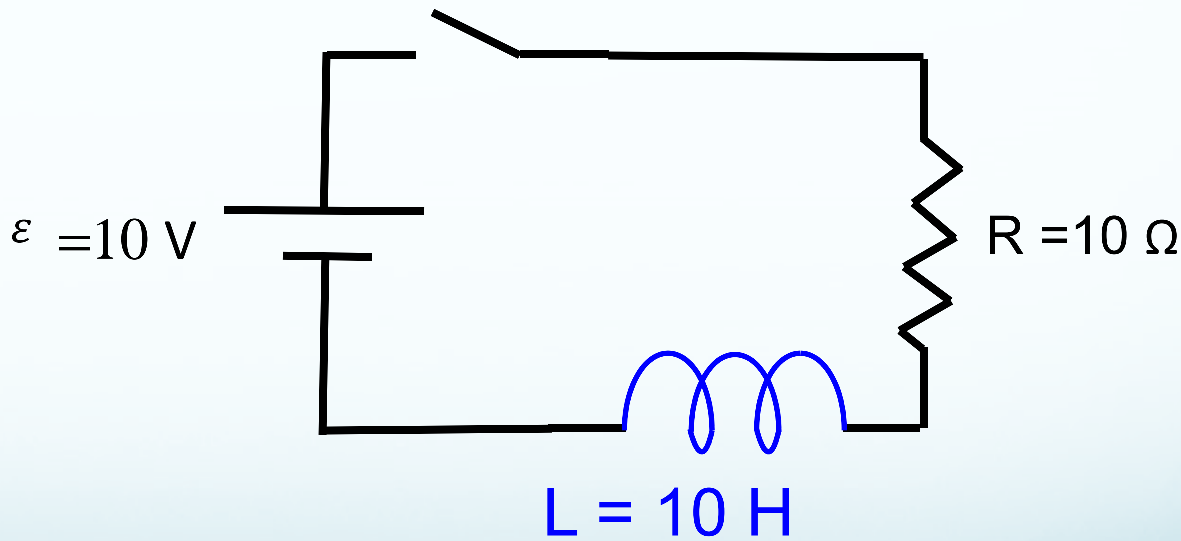
What is the current in the circuit after a time t = 3.0 s?

A. 0 A

B. 0.63 A

C. 0.86 A

D. 0.95 A



$$i(t) = i_0\left(1 - e^{-tR/L}\right)$$

Top Hat Question

The switch in the series circuit below is closed at t=0.

What is the current in the circuit after a time t = 3.0 s?

A. 0 A

B. 0.63 A

C. 0.86 A

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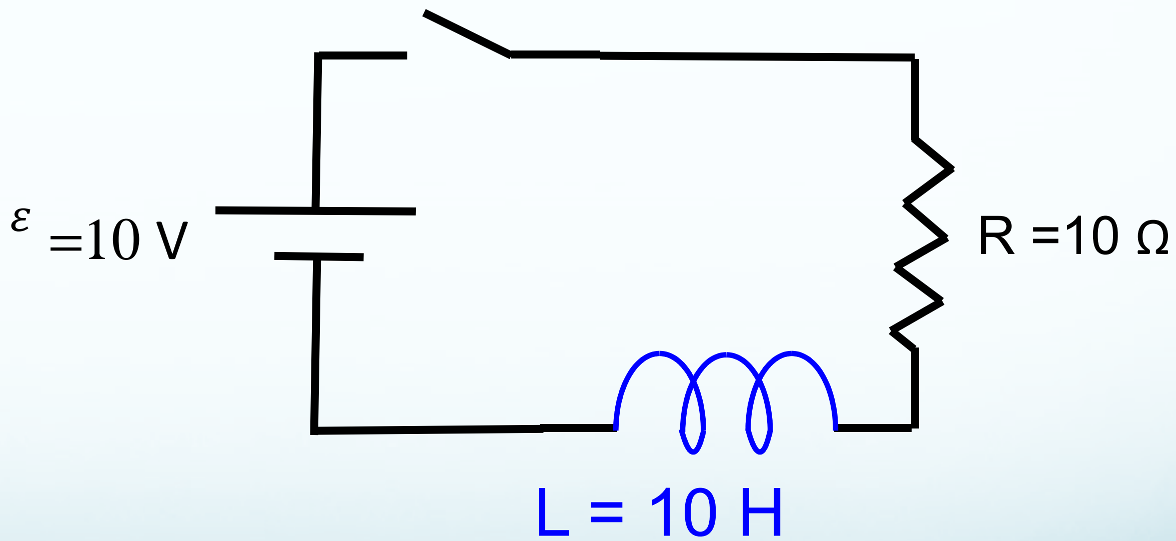
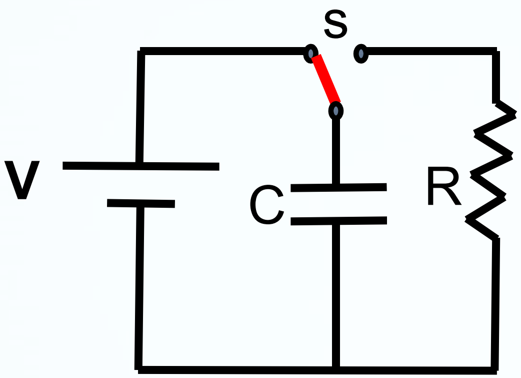


$$i(3\text{s}) = \frac{10V}{10\Omega}\left(1 - e^{-3}\right)$$

10

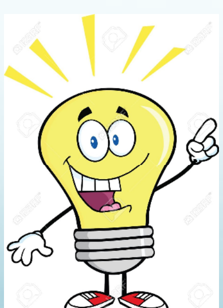
Final review

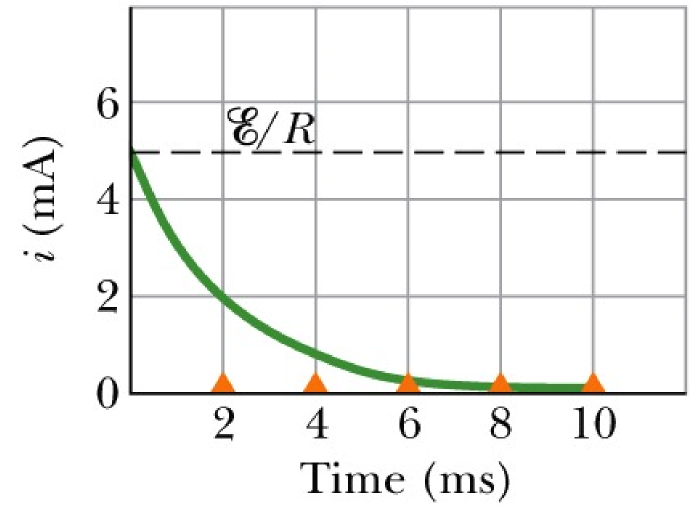
RC circuit: Charging a capacitor

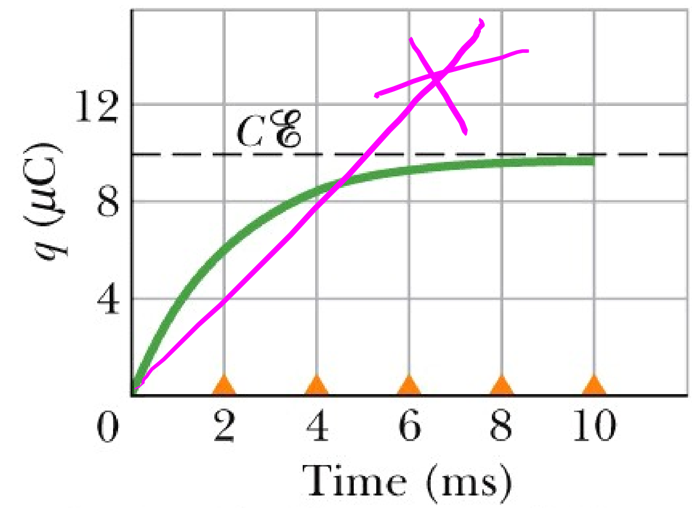


$$i = i_0 e^{-t/RC}$$

$$q = \varepsilon C\left(1 - e^{-t/RC}\right) = Q_f\left(1 - e^{-t/RC}\right)$$

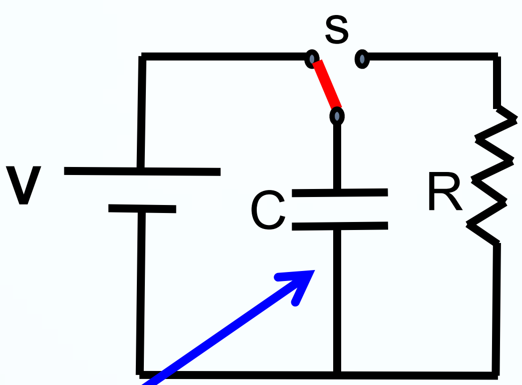






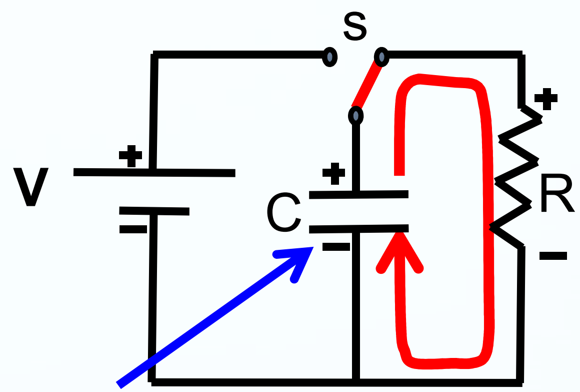
RC circuit: Discharging a capacitor

Switch is connected to the left for a long time until t=0-



Capacitor charges up to voltage V

Switch is suddenly flipped to the right at t=0+

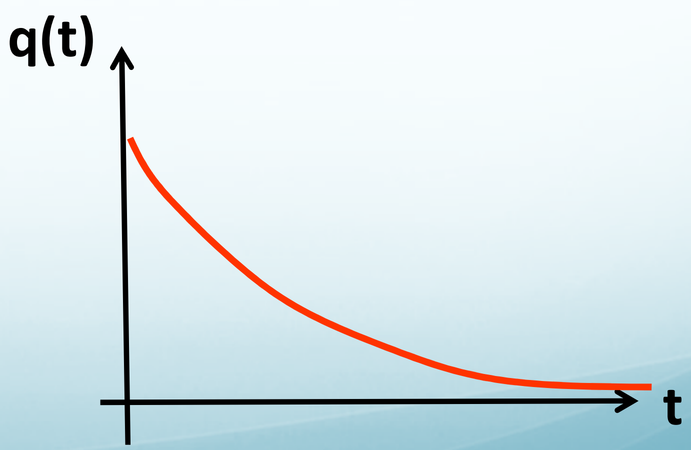


Capacitor discharges

$$q(t) = q_0 e^{-t/RC}$$

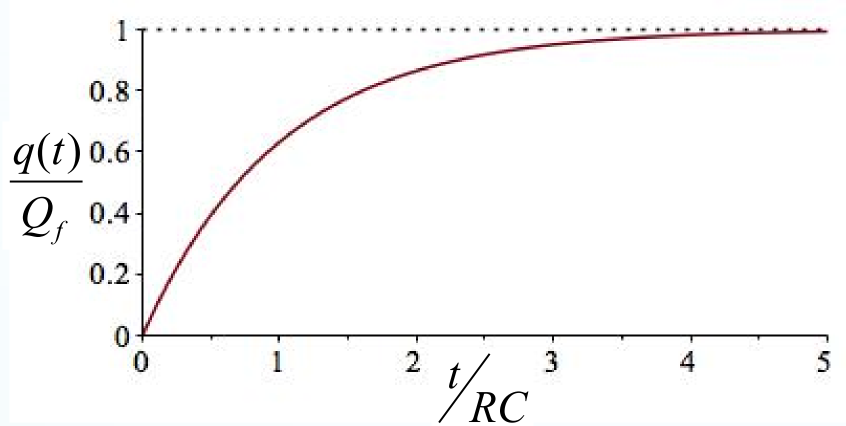
$$i(t) = i_0 e^{-t/RC}$$

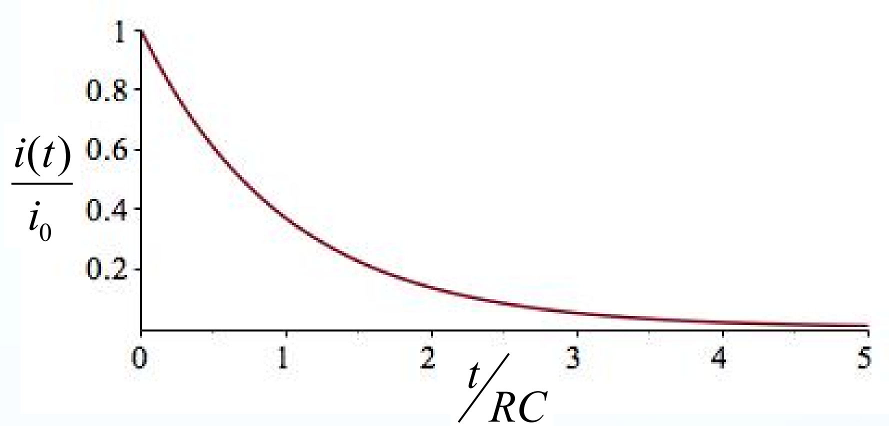
$$q_0 = CV$$



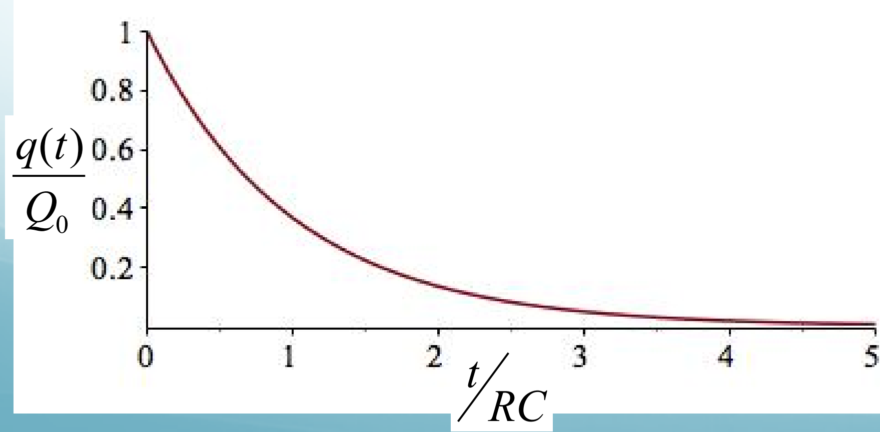
Charging/Discharging Capacitors

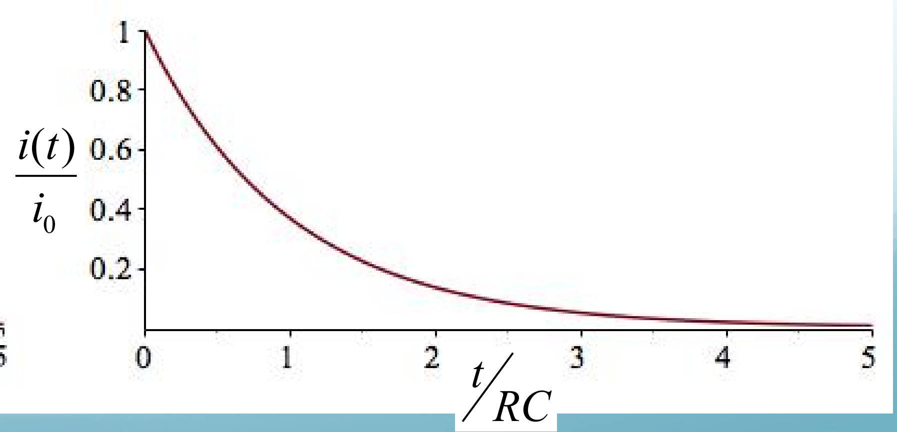
Charging: $$q(t) = Q_f\left(1 - e^{-\frac{t}{RC}}\right)$$ $$i(t) = i_0 e^{-\frac{t}{RC}}$$





Discharging: $$q(t) = Q_0 e^{-\frac{t}{RC}}$$ $$i(t) = i_0 e^{-\frac{t}{RC}}$$





The RC time constant

The constant RC pops up in the exponential factor for both charging and discharging capacitors. What does it represent?

The units of RC is seconds: $$[RC] = \frac{V}{A}\frac{C}{V} = \frac{C}{C/s} = s$$

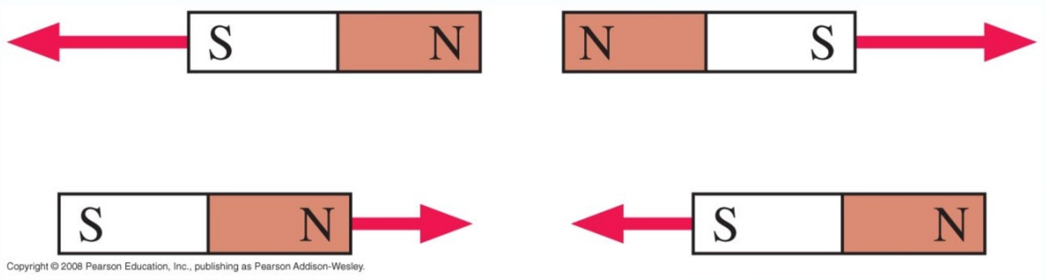
We call RC the "**RC time constant**" and it tells us how quickly a capacitor can charge or discharge.

$$\boxed{RC \equiv \tau}$$

After a time τ, the charge on a discharging capacitor is reduced by a factor of 1/e. After a time $N\tau$, it is reduced by a factor of $1/e^N$

$$\boxed{q(t) = Q_0 e^{-\frac{t}{\tau}}}$$

28.1: Magnetic fields



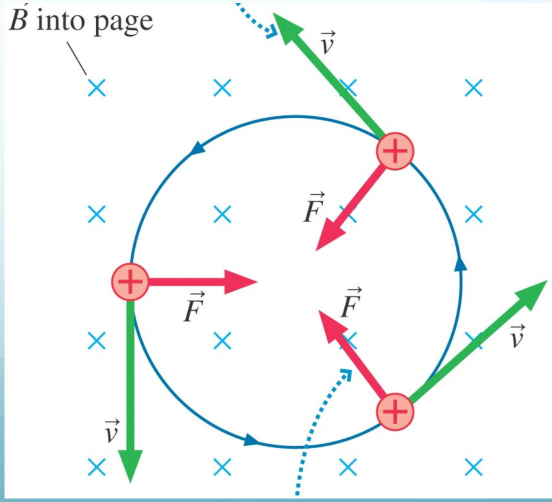
Magnetic force acts only on a moving charge.

$$\vec{F}_B = q\,\vec{v}\times\vec{B}$$

The Tesla

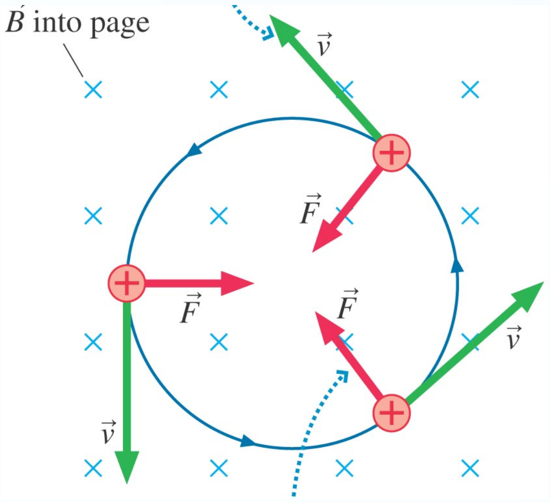
The Gauss

28.4: A circulating charged particle

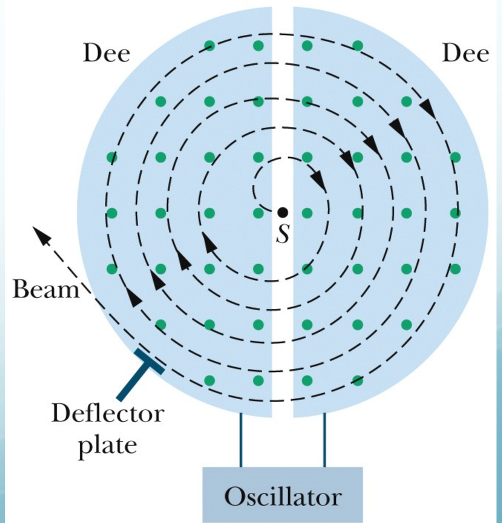


28.4: A circulating charged particle

$$\boxed{R=\frac{mv}{|q|B}}\qquad \boxed{T_{cyc}=\frac{2\pi m}{|q|B}}\qquad \boxed{f_{cyc}=\frac{|q|B}{2\pi m}}$$



28.5: Cyclotrons and Synchrotrons

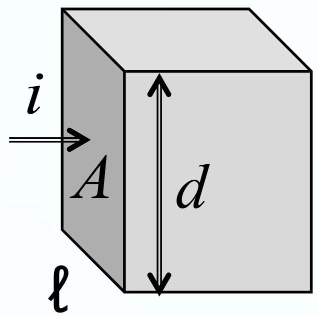


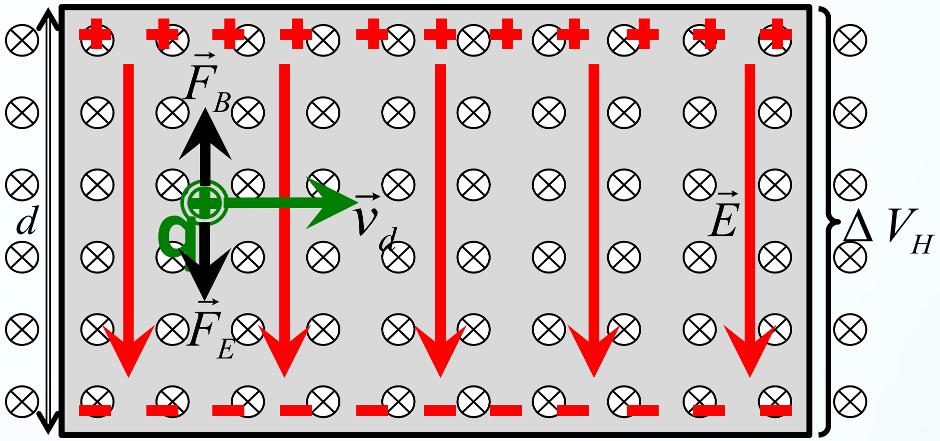
Application: Mass Spectrometer

$$\boxed{R=\frac{mv}{|q|B}}$$

28-2 Crossed Fields: Discovery of The Electron

28-3 Crossed Fields: The Hall Effect





$$F_B = q v_d B$$

$$v_d = \frac{i}{neA} \qquad A = \ell d$$

$$\boxed{\Delta V_H = v_d B d}$$

$$\boxed{B = \frac{ne\ell}{i} \Delta V_H}$$

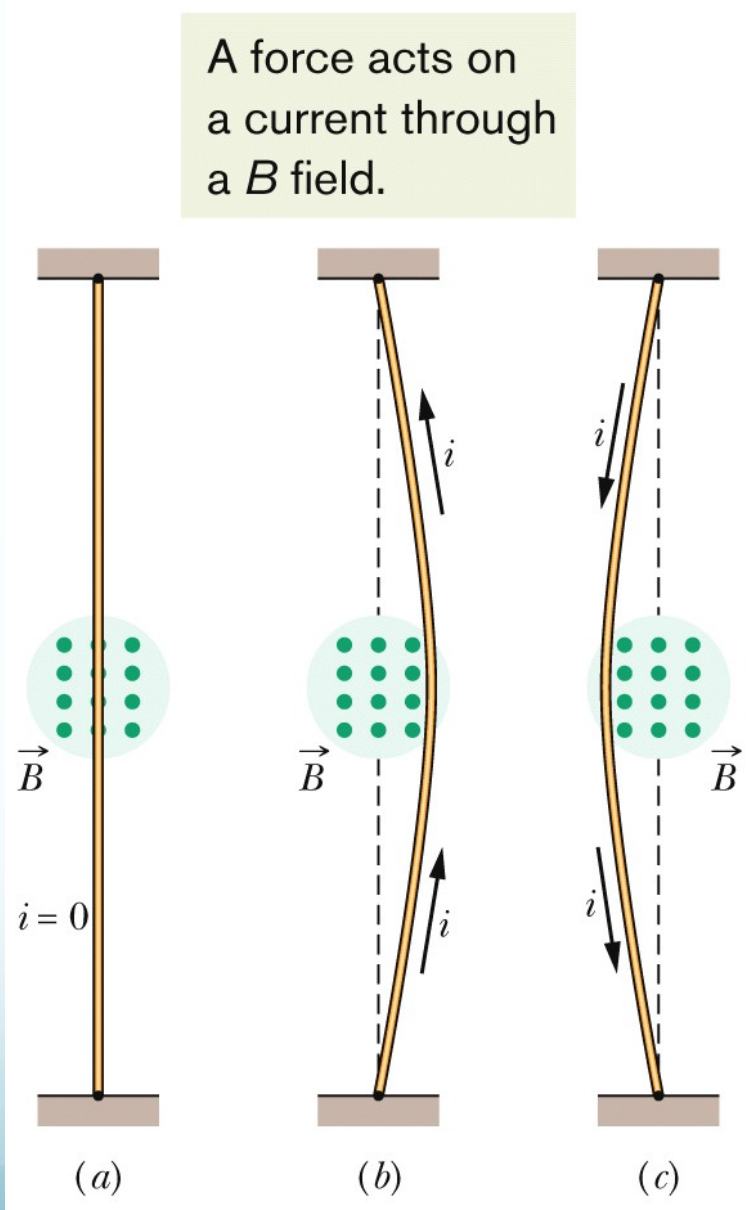
n is a material property

28-6 Magnetic Force on a Current-Carrying Wire

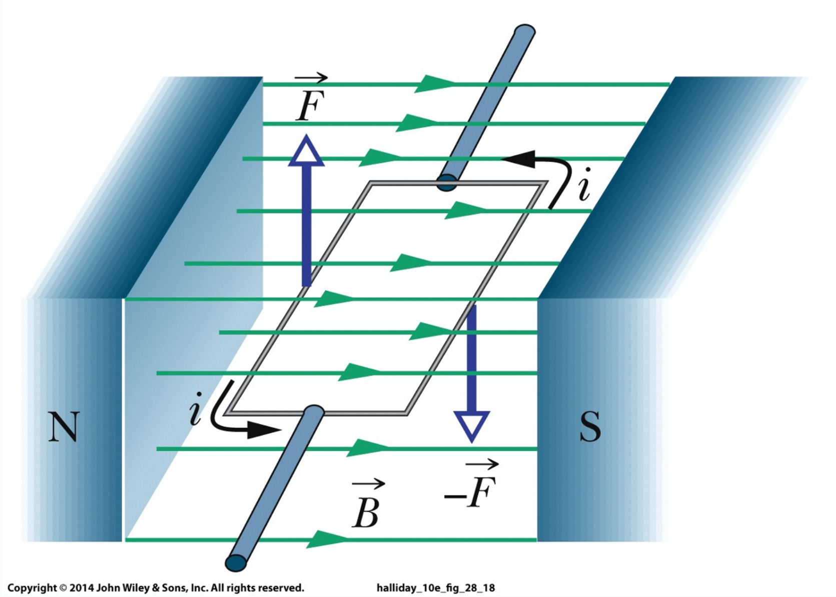
A straight wire carrying a current *i* in a uniform magnetic field experiences a sideways force

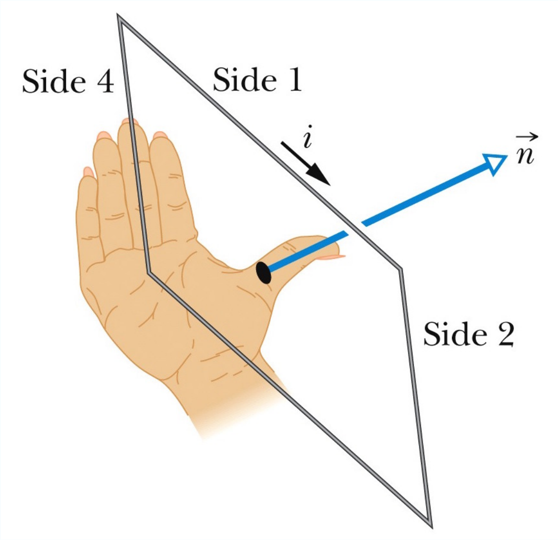
$$\vec{F}_B = i\vec{L} \times \vec{B} \quad \text{(force on a current).}$$

Here ***L*** is a length vector that has magnitude *L* and is directed along the wire segment in the direction of the (conventional) current.



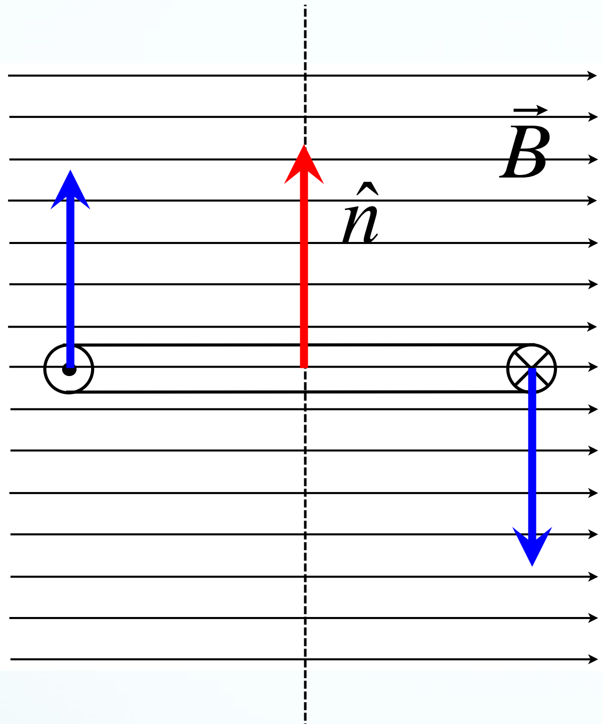
28-7 Torque on a Current Loop



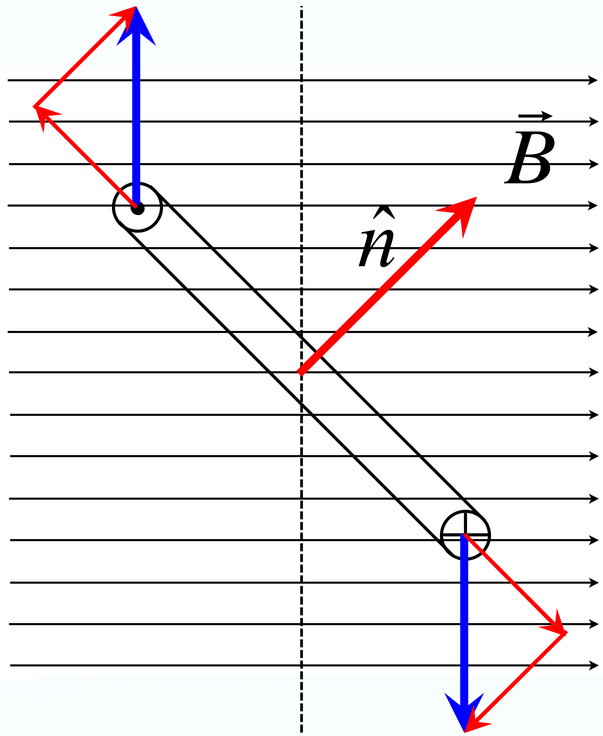


$$\vec{F}_B = i\vec{L} \times \vec{B} \quad \text{(force on a current).}$$

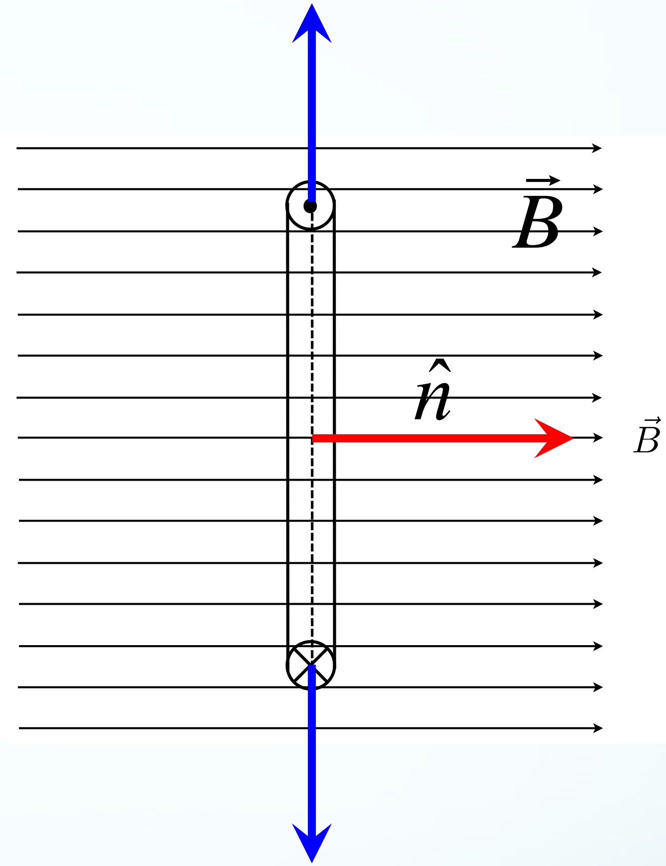
$$\tau = NiAB \sin\theta,$$



The normal vector is at right angles to the B-field: all magnetic force causes rotation of the loop

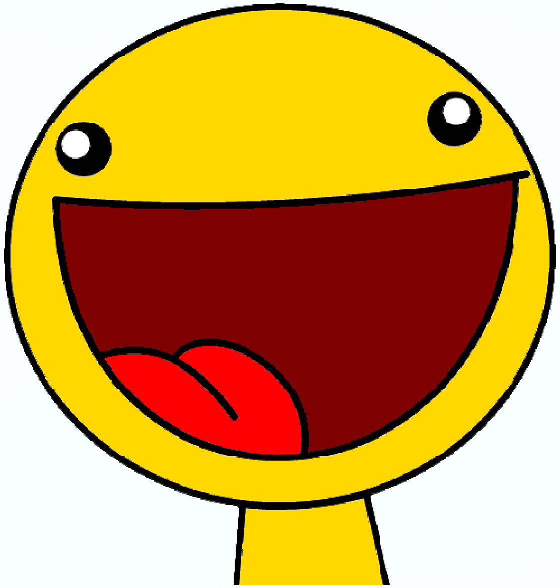


The normal vector is at some angle to the B-field: some of the magnetic force causes rotation of the loop



The normal vector is parallel to the B-field: none of the magnetic force causes rotation of the loop

Conclusion: components of magnetic force (anti)parallel to normal vector cause torque



For a single charge→ $\boxed{\vec{F}_B = q\vec{v}_d \times \vec{B}}$

For N charges moving through the wire (current carrying wire)→ $\boxed{\vec{F}_B = i\vec{\ell} \times \vec{B}}$

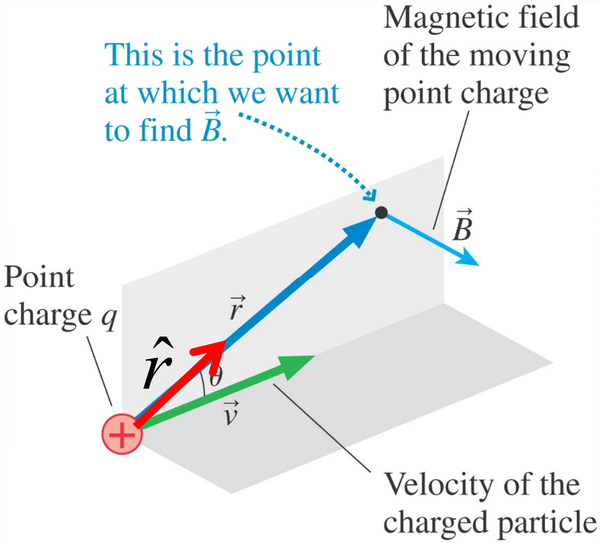
The Biot-Savart Law

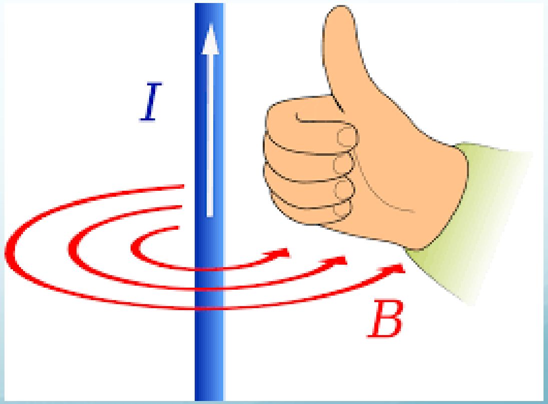
Magnetic fields are caused by **moving charges**.*

$$\vec{B}_{\text{point charge}} = \frac{\mu_0}{4\pi}\frac{q\vec{v}\times\hat{r}}{r^2}$$

$$\vec{B}_{\text{point charge}} = \frac{\mu_0}{4\pi}\frac{q\vec{v}\times\vec{r}}{r^3}$$

$$\vec{B}_{\text{current segment}} = \frac{\mu_0}{4\pi}\frac{I\,\Delta\vec{s}\times\hat{r}}{r^2}$$





This section we talked about:

Chapter 30

See you on Monday