Physics 102: Lecture 09

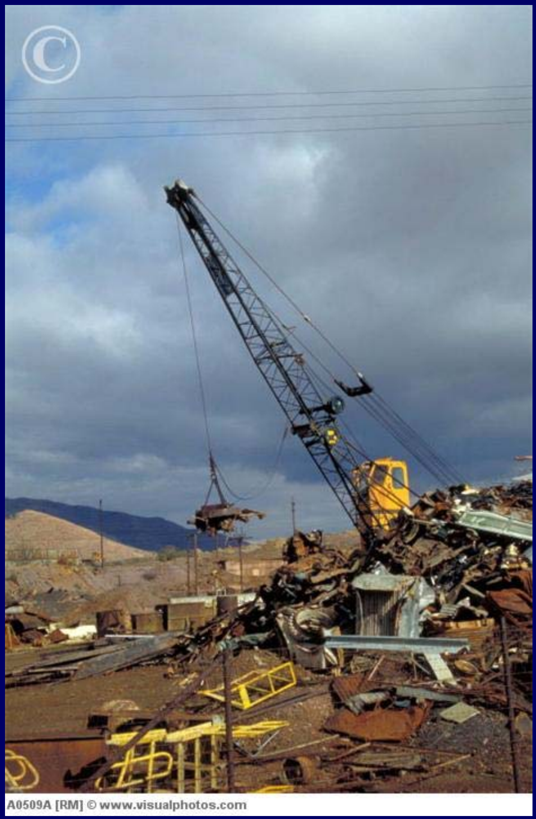
Currents and Magnetism

- Reminder: Exam 1 next Monday
- 5:15pm conflict: sign up in gradebook
- Be sure to bring your ID, a calculator, #2 pencil, and go to the correct room
- Extra office hours start Thursday this week
- Review Sunday, 2-4 PM, Rm. 141

Summary of Today

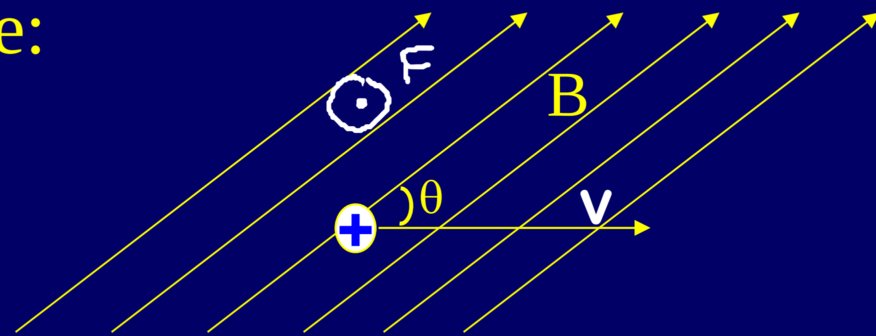
- Magnetic forces on currents and torques on current loops

- Magnetic fields created by currents
    - long straight wire
    - solenoid



Force of magnetic field on Current

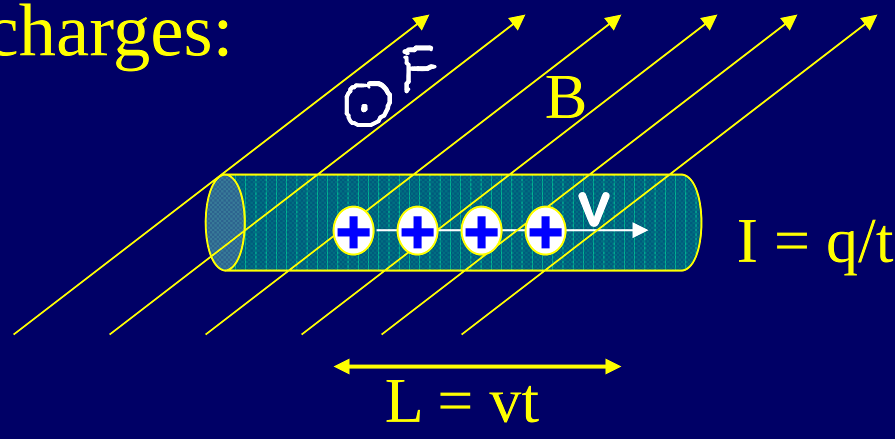
- Force on 1 moving charge:
  - $F = q\,v\,B \sin(\theta)$
  - Out of the page (RHR)



- Force on many moving charges:
  - $F = q\,v\,B \sin(\theta)$

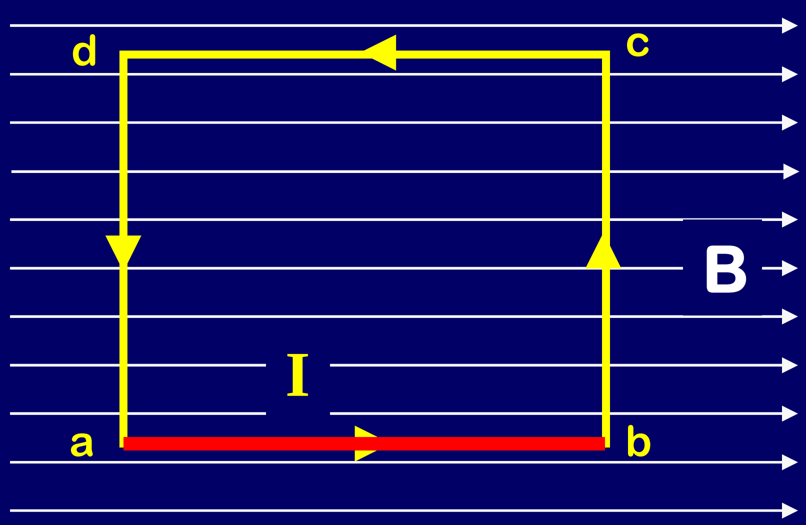
    $= (q/t)\,(vt)\,B \sin(\theta)$

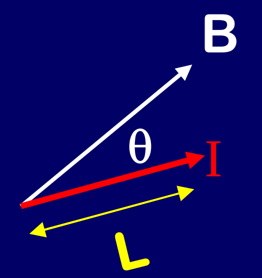
    $= I\,L\,B \sin(\theta)$
  - Out of the page!



CheckPoint 1.1

A rectangular loop of wire is carrying current as shown. There is a uniform magnetic field parallel to the sides a-b and c-d.





$F = IBL\sin\theta$

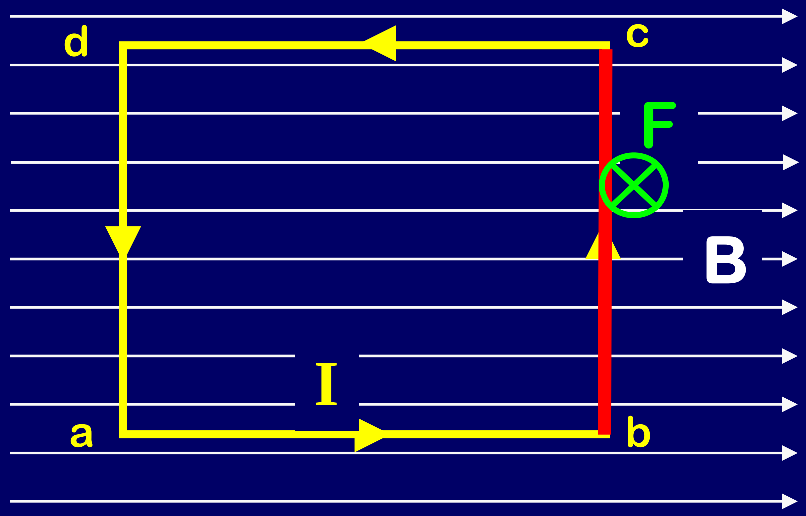
Here $\theta = 0$

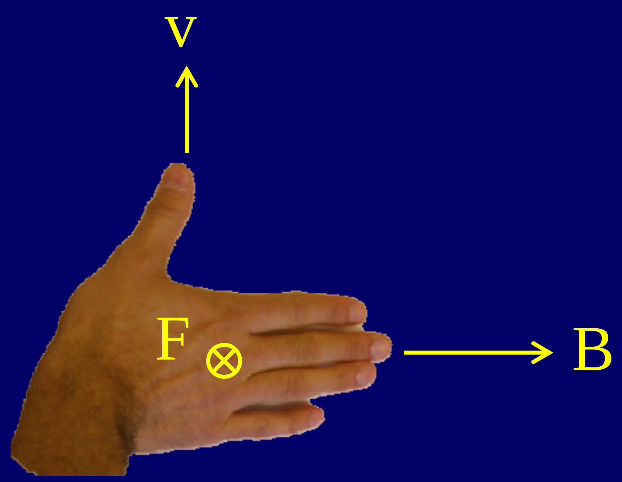
What is the direction of the force on section a-b of the wire?

force is zero	52%
out of the page	30%
into the page	18%

Checkpoint 1.2

A rectangular loop of wire is carrying current as shown. There is a uniform magnetic field parallel to the sides a-b and c-d.



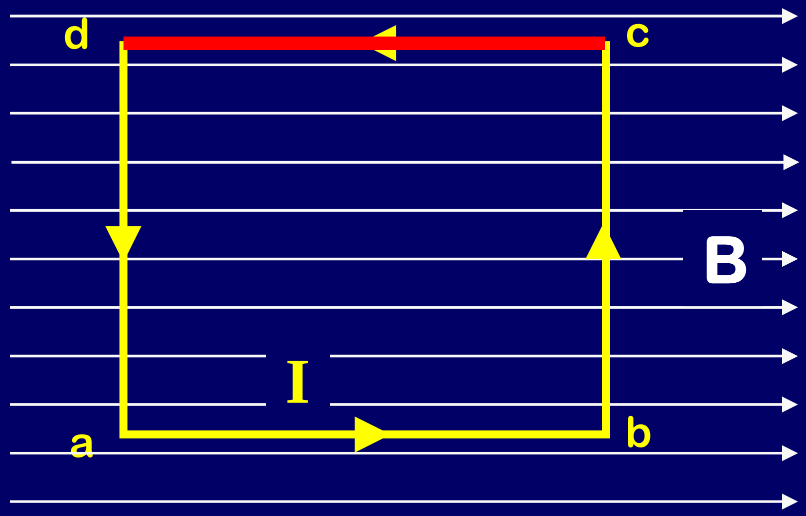


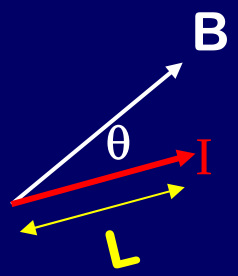
What is the direction of the force on section b-c of the wire?

force is zero	26%
out of the page	26%
into the page	48%

Force on loop

A rectangular loop of wire is carrying current as shown. There is a uniform magnetic field parallel to the sides a-b and c-d.





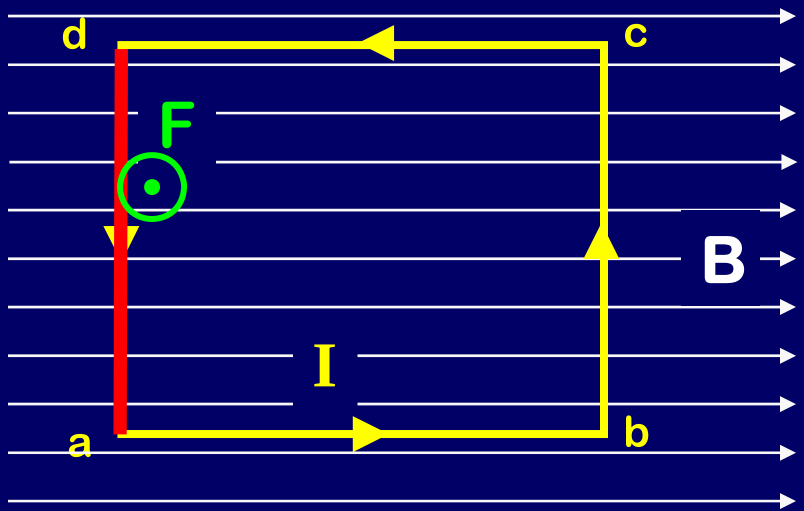
$F = IBL\sin\theta$

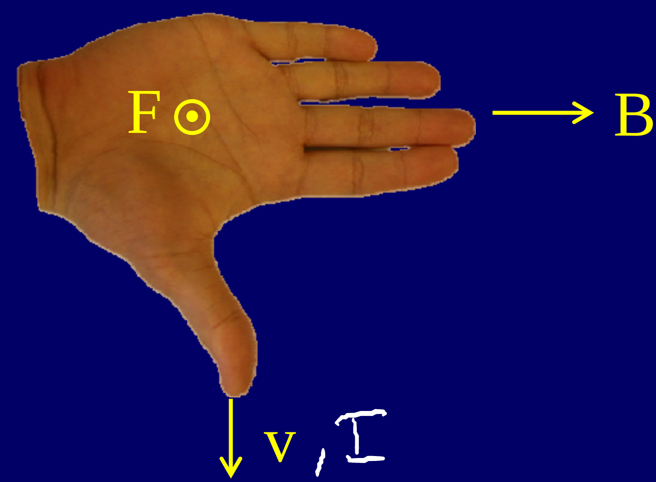
Here $\theta = 180°$

Force on section c-d is zero! Same as a-b

ACT: Force on loop (cont'd)

A rectangular loop of wire is carrying current as shown. There is a uniform magnetic field parallel to the sides a-b and c-d.

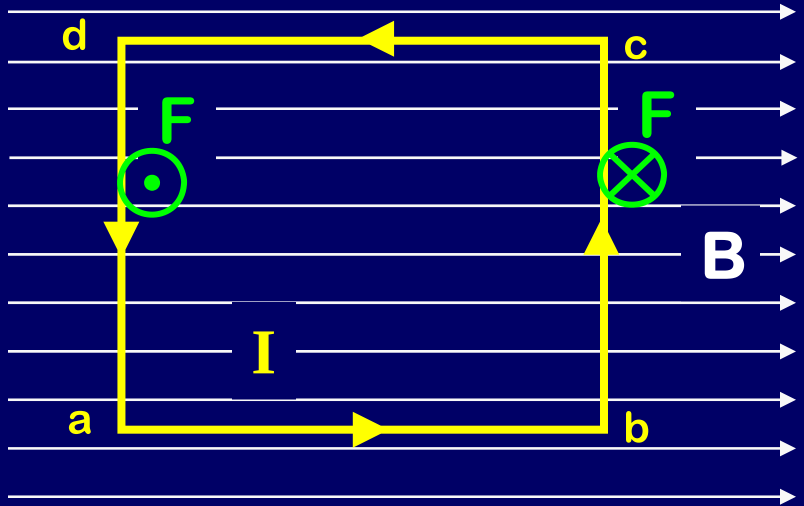


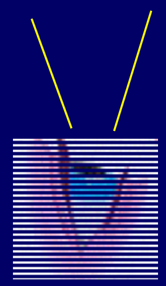


What is the direction of the force on section d-a of the wire?

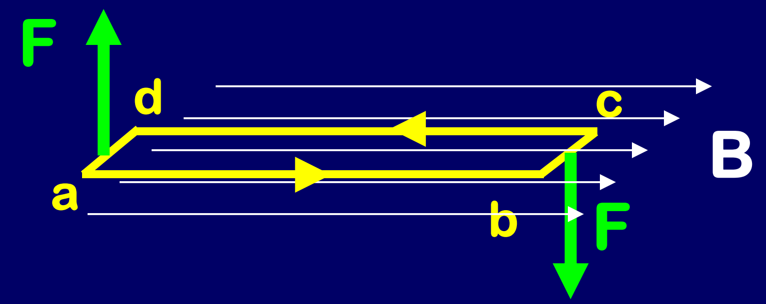
A) force is zero
B) out of the page
C) into the page

Torque on Current Loop in magnetic field





$F = ILB\sin\theta$



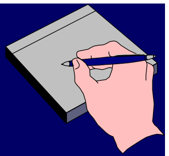
The loop will spin in place!

CheckPoints 1.3, 1.4:

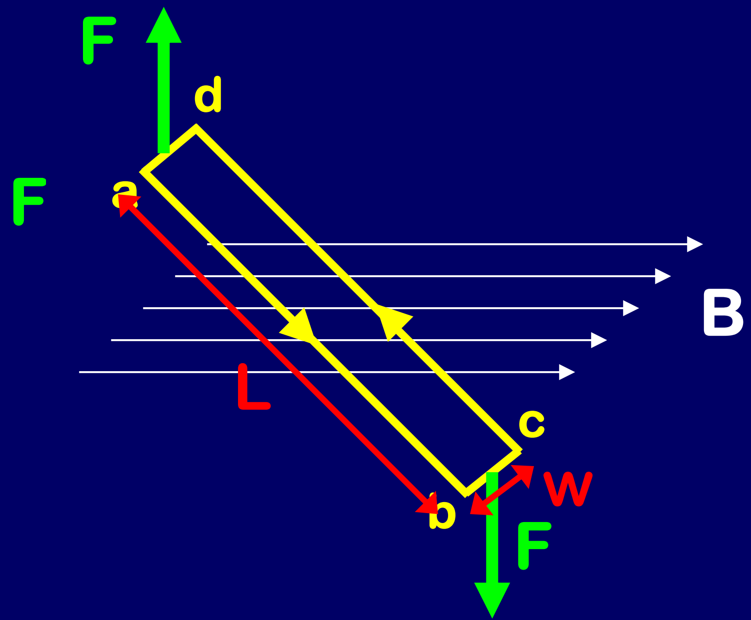
Net force on loop is zero.

But the net <u>torque</u> is not!

Torque on Current Loop

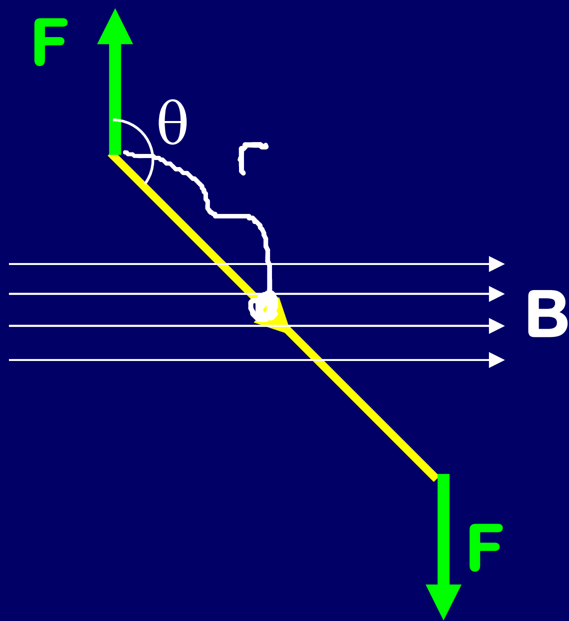


The loop will spin in place!



Recall from Phys 101:

$$\tau = F\, r \sin\theta$$



Force on sections b-c and a-d: **F = IBw**

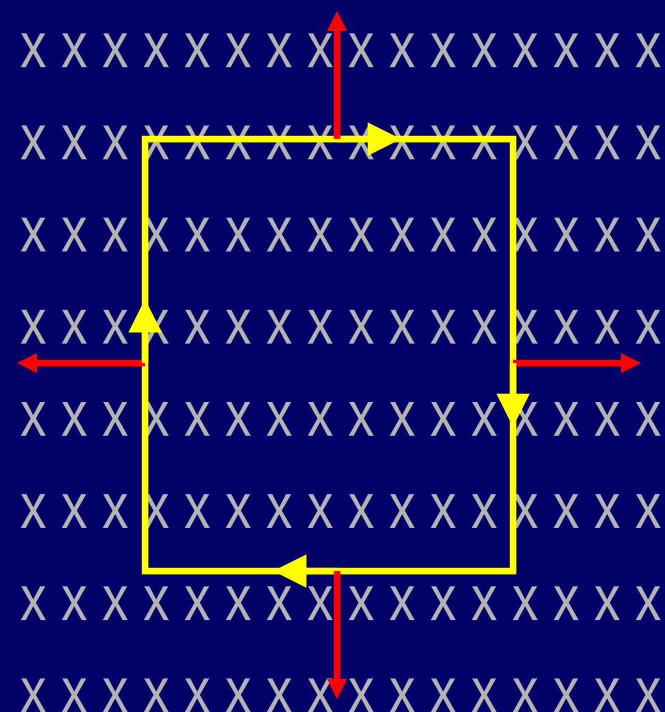
Torque on loop is τ **= 2 (L/2) F sin(θ) =** $\underbrace{I\ Lw}_{Lw\ =\ A\ !}$ **B sin(θ)**

Torque is: $\boxed{\tau = IAB\sin\theta}$

ACT: Torque on Current Loop

What is the torque on the loop below?

1) $\tau < IAB$
2) $\tau = IAB$
3) $\tau > IAB$

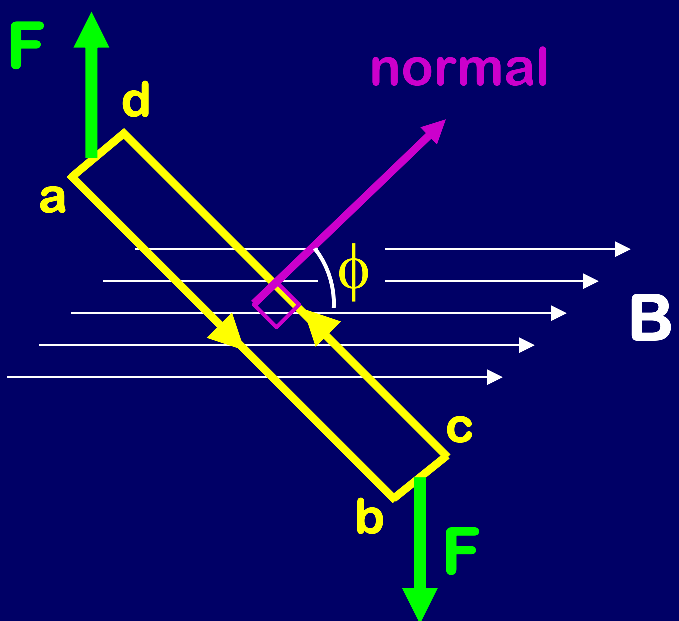


$\tau = IAB\sin\theta$

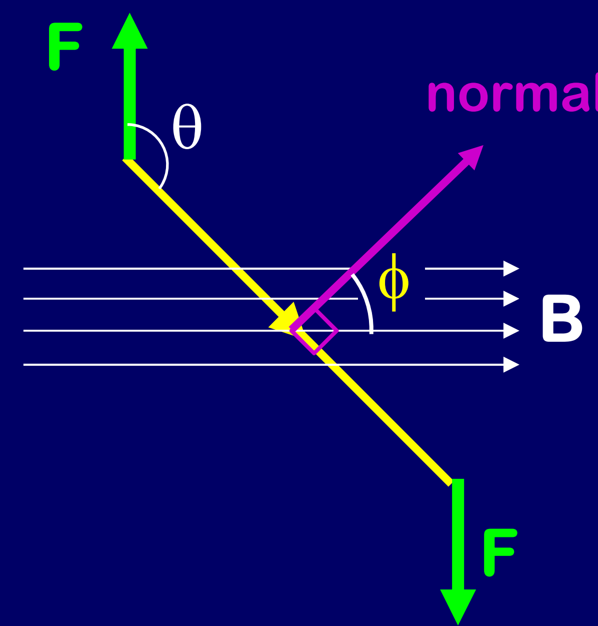
$\tau = 0$

Torque on Current Loop

It is useful to define normal vector $\perp$ to loop



$\phi = 180 - \theta$



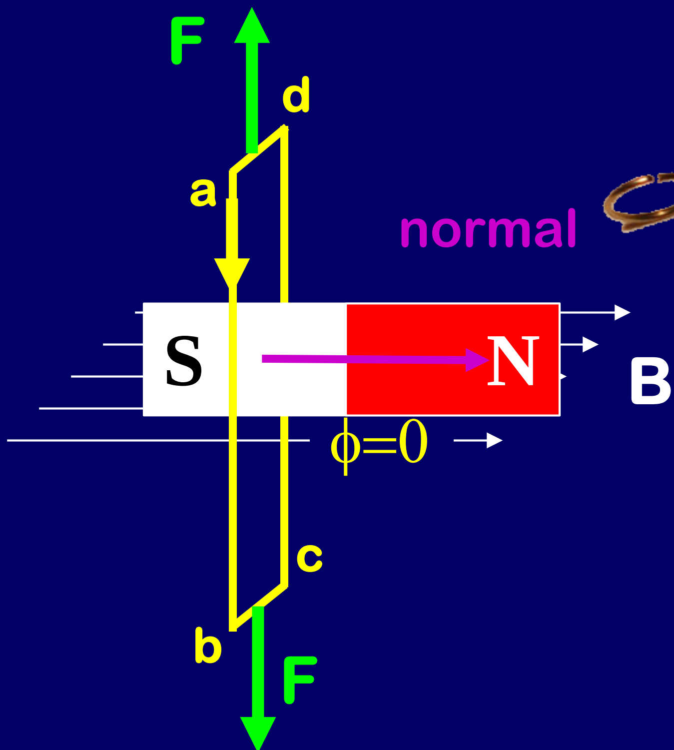
Torque is: $\tau = IAB\sin\theta = IAB\sin\phi$

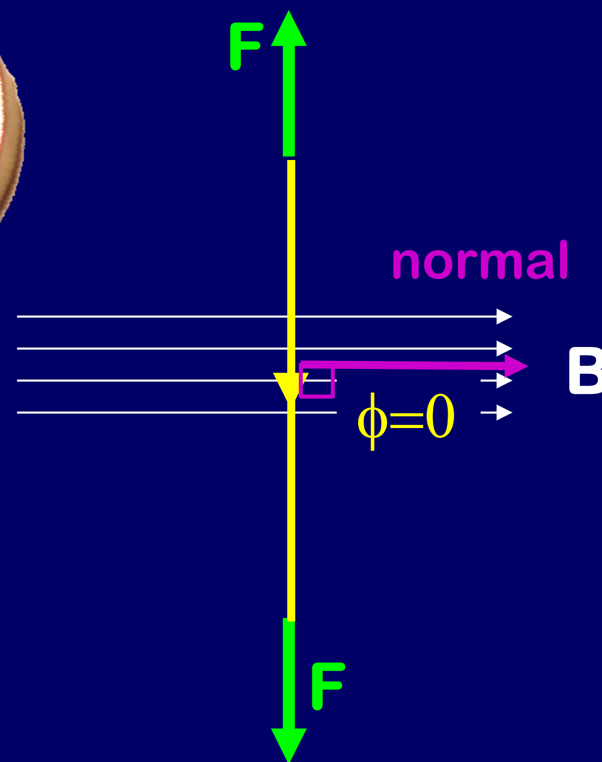
If there are N loops: $\boxed{\tau = NIAB\sin\varphi}$

Even if loop is not rectangular, as long as it is flat

Torque on Current Loop

It is useful to define normal vector ⊥ to loop





$\phi = 180 - \theta$

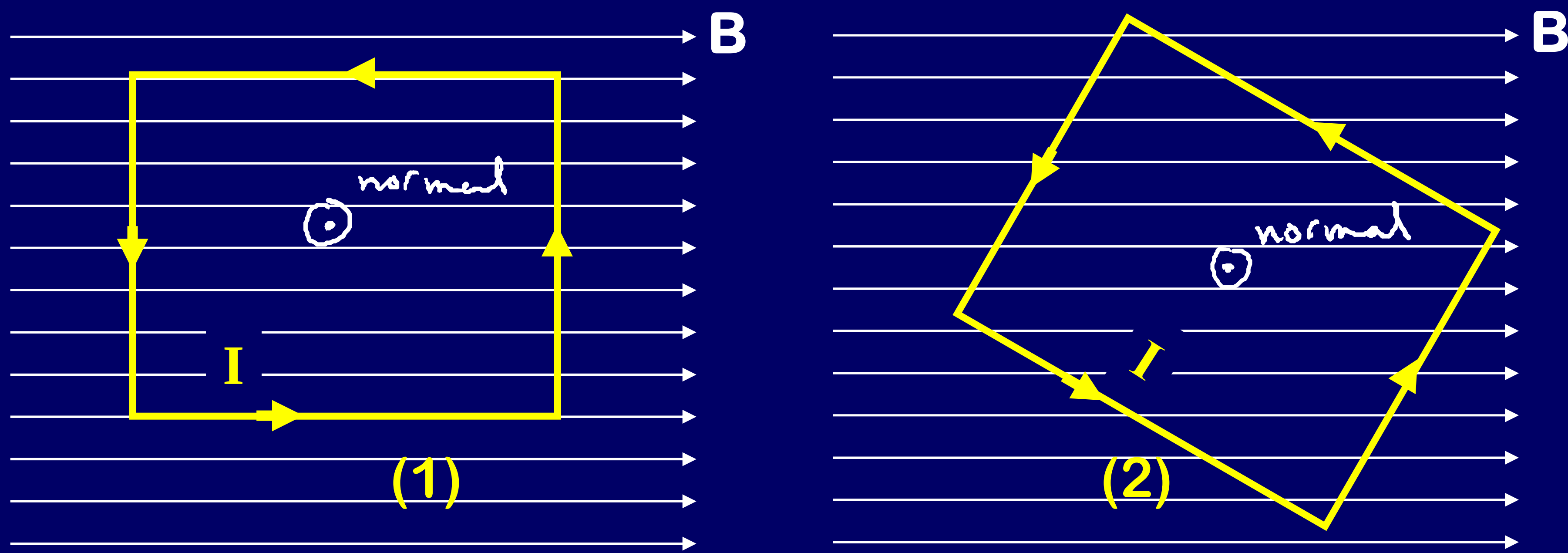
Torque is: $\tau = IAB\sin\theta = IAB\sin\varphi$

If there are N loops: $\boxed{\tau = NIAB\sin\varphi}$

Even if loop is not rectangular, as long as it is flat

Note torque will align normal parallel to B like a magnetic dipole!

ACT: Torque



Compare the torque on loop 1 and 2 which have identical area, and current.

1) $\tau_1 > \tau_2$ **2)** $\tau_1 = \tau_2$ **3)** $\tau_1 < \tau_2$

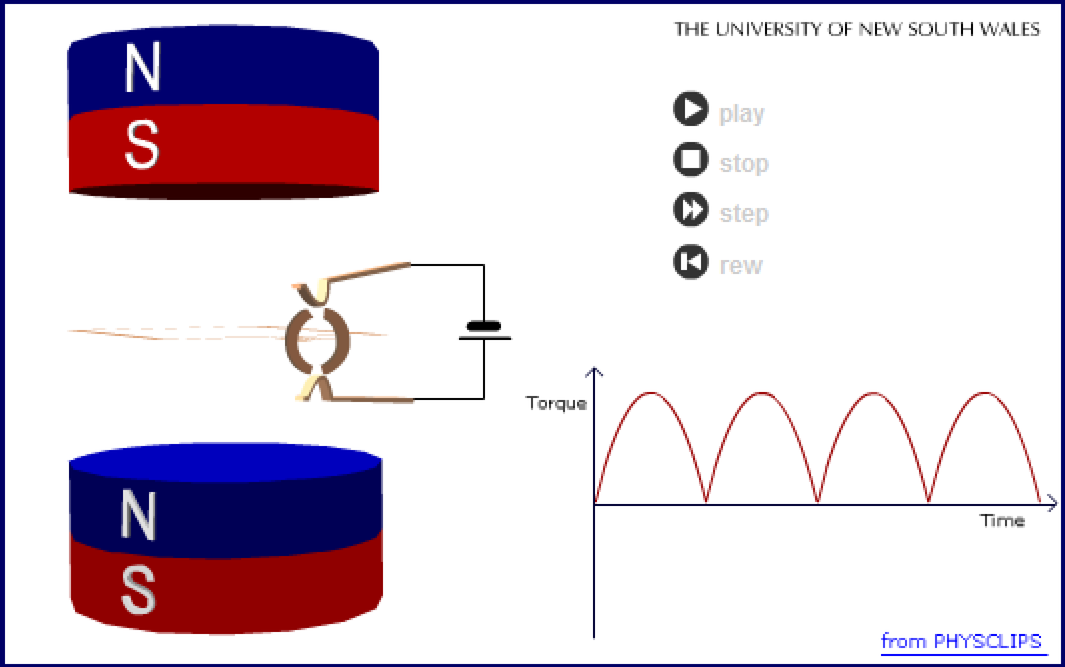
Normal vector points out of page for both!

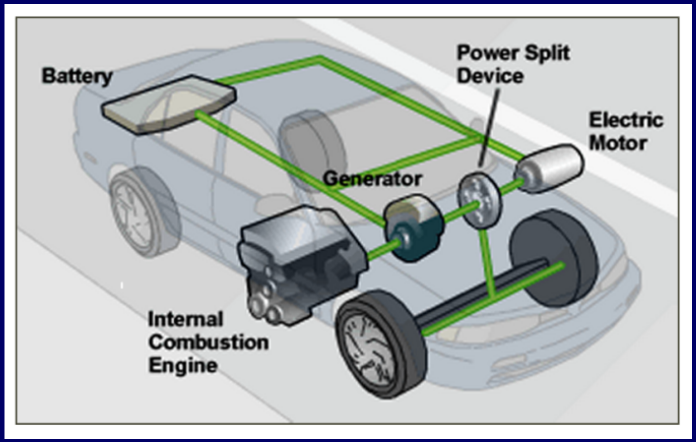
$\phi = 90$

$\tau = I\,A\,B \sin(\phi)$

Motors

DC motors use a clever arrangement of current carrying coils and permanent magnets to turn a shaft:





Currents *create* magnetic fields

Magnitude

- Straight wire carrying current I generates a field B at a distance r:

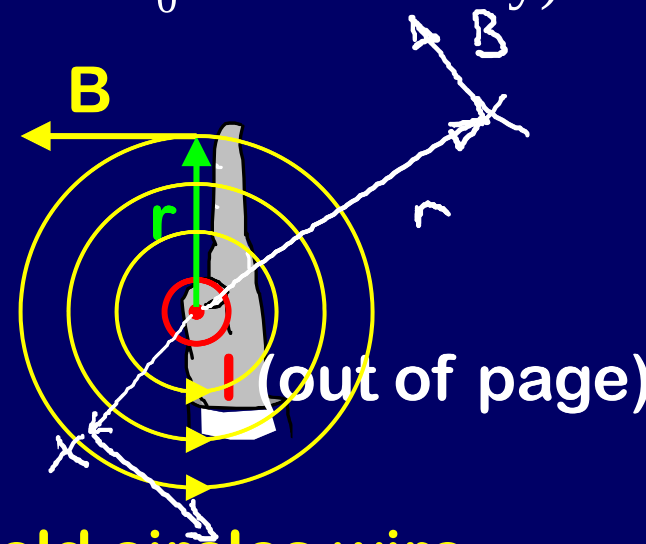
$$\boxed{B = \frac{\mu_0 I}{2\pi r}}$$

$\mu_0 = 4\pi \times 10^{-7} Tm/A$

"Permeability of free space"
(similar to ε_0 for electricity)

Direction

- "Right-hand rule 2":
  - Thumb of right hand along **I**
  - Fingers of right hand along **r**
  - Out-of-palm points along **B**

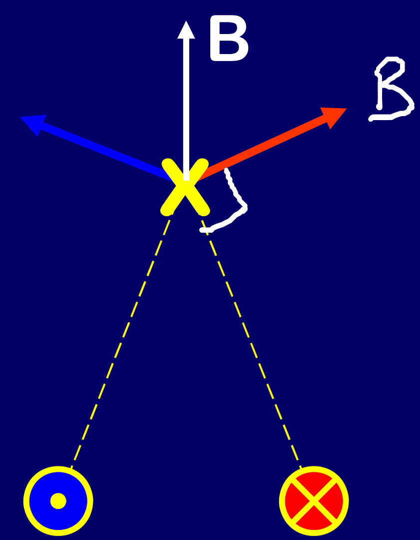


B field circles wire

Note: there are different versions of RHR

ACT: Adding Magnetic Fields

Two long wires carry opposite current (same magnitude)

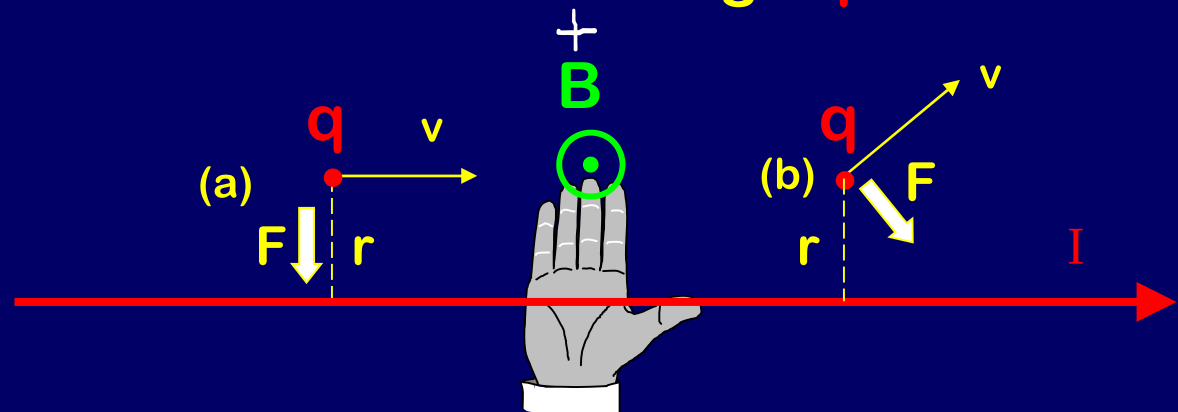


What is the direction of the magnetic field above, and midway between the two wires carrying current – at the point marked "X"?

1) Left 2) Right 3) Up 4) Down 5) Zero

ACT/Checkpoint 2.1

A long straight wire is carrying current from left to right. Near the wire is a charge q with velocity v



Compare magnitude of magnetic force on q at (a) vs. (b)

a) has the larger force	27%
b) has the larger force	47%
c) force is the same for (a) and (b)	26%

Same $B = \dfrac{\mu_0 I}{2\pi r}$

Same $F = qvB\sin\theta$

$\theta = 90$ for (a) and (b)!

Same magnitude
Different directions

Solenoids

Magnitude

- A solenoid consists of N loops of wire

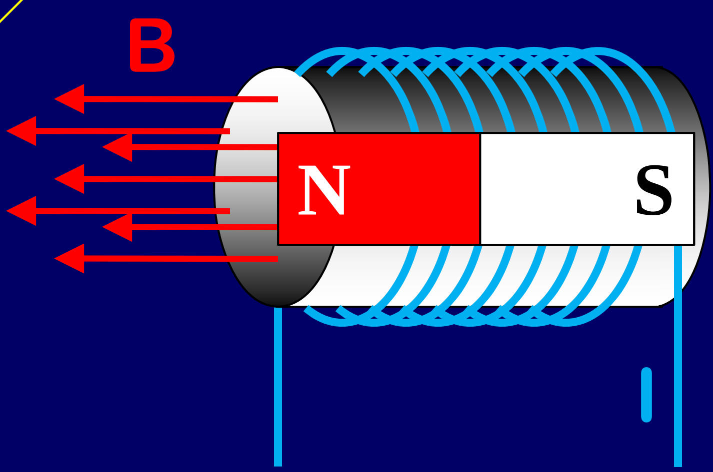
B is uniform everywhere inside of solenoid:

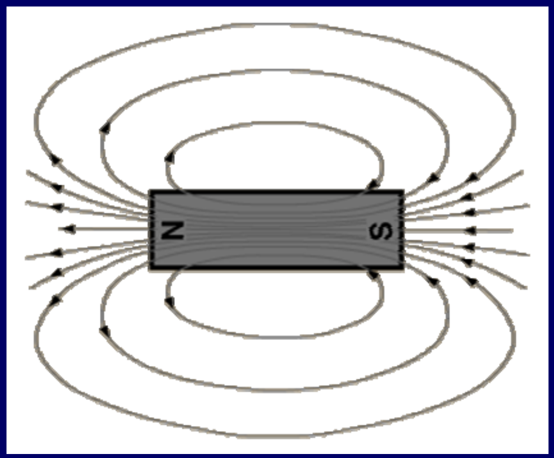
$$\boxed{B = \mu_0 n I} \qquad \mu_0 = 4\pi \times 10^{-7}\, Tm/A$$

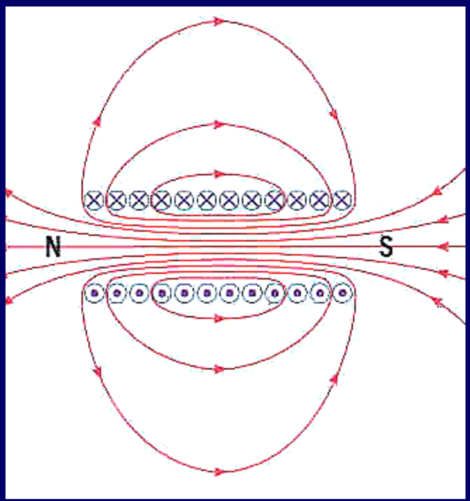
n is the number of turns of wire/meter (n = N/L)

Direction

- Use "Right-hand rule 2"



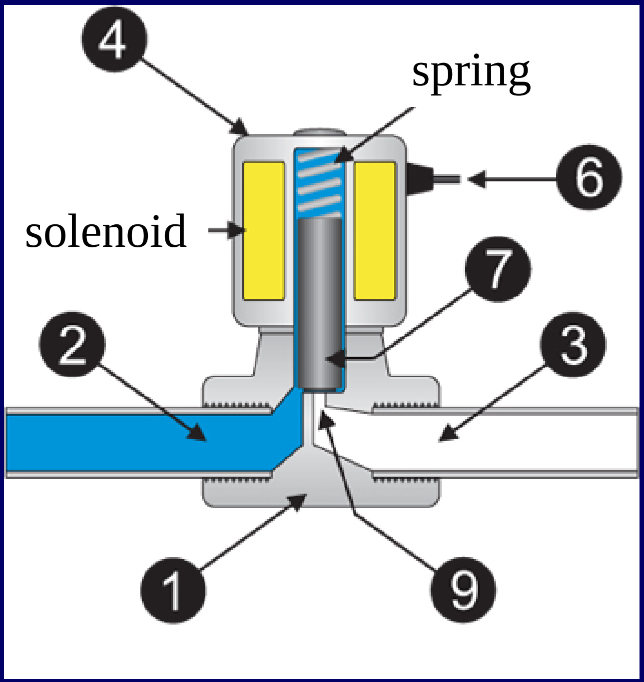




B field lines look like bar magnet!
Solenoid has N and S poles! (Checkpoint 3.1)

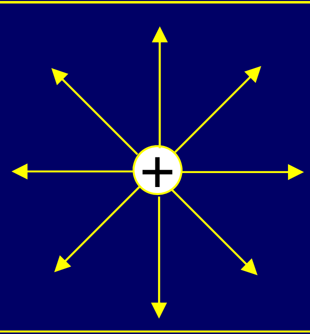
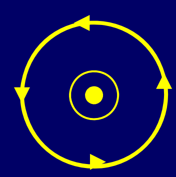
Electromagnets

Solenoids are a way to make powerful magnets that can be turned on and off!



Solenoid valve

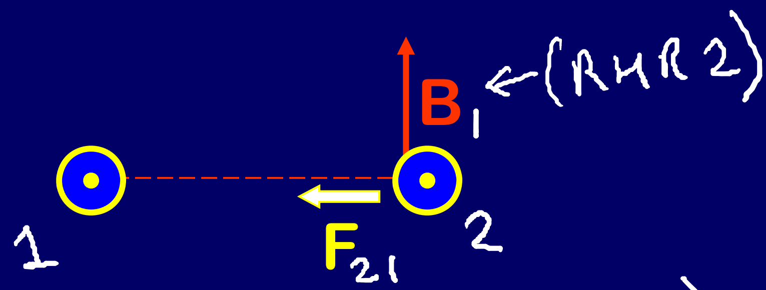
Comparison:
Electric Field vs. *Magnetic* Field

	Electric	Magnetic
Source	Charges	Moving Charges
Acts on	Charges	Moving Charges
Force	F = Eq	F = q v B sin(θ)
Direction	Parallel E	Perpendicular to v,B
Field Lines		
Opposites	Charges Attract	

Example

Force between current-carrying wires

Currents in same direction

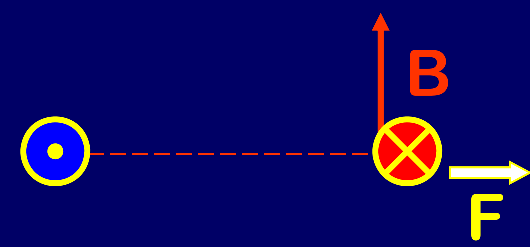


(RHR1)

I towards us

Another I towards us

Currents opposite direction



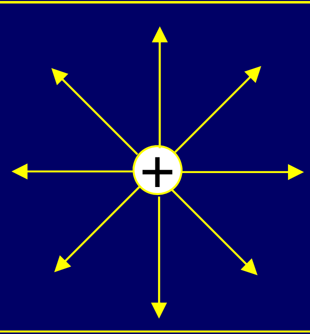
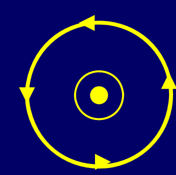
I towards us

Another I away from us

Currents in same direction attract!

Currents in opposite direction repel!

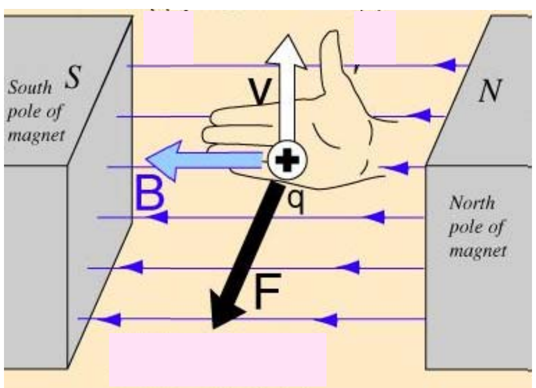
Comparison:
Electric Field vs. *Magnetic* Field

	Electric	Magnetic
Source	Charges	Moving Charges
Acts on	Charges	Moving Charges
Force	$F = Eq$	$F = q\,v\,B\,\sin(\theta)$
Direction	Parallel E	Perpendicular to v,B
Field Lines		
Opposites	Charges Attract	Currents Repel

Summary of Right-Hand Rules

RHR 1

Force on moving q

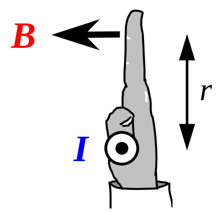


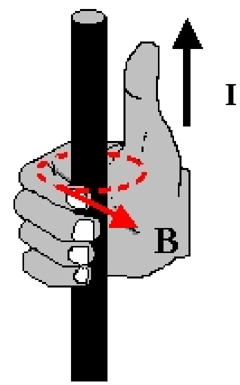
RHR 2

Alternate

B field from current I

Straight wire





Solenoid