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 Friday this week
- Video solutions available in byteshelf as unit 8

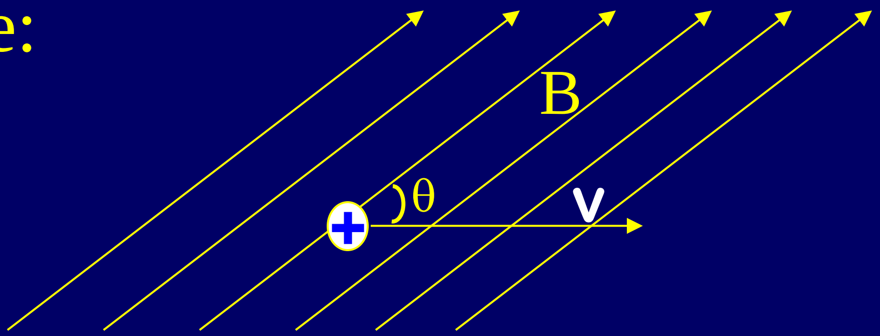
Summary of Today

- Magnetic forces on currents and torques on current loops

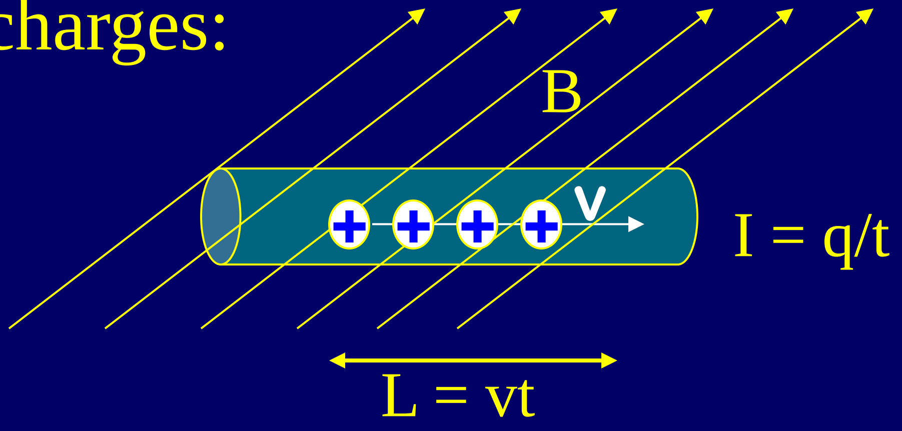
- Magnetic fields created by currents
  - long straight wire
  - solenoid

Force of magnetic field on Current

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

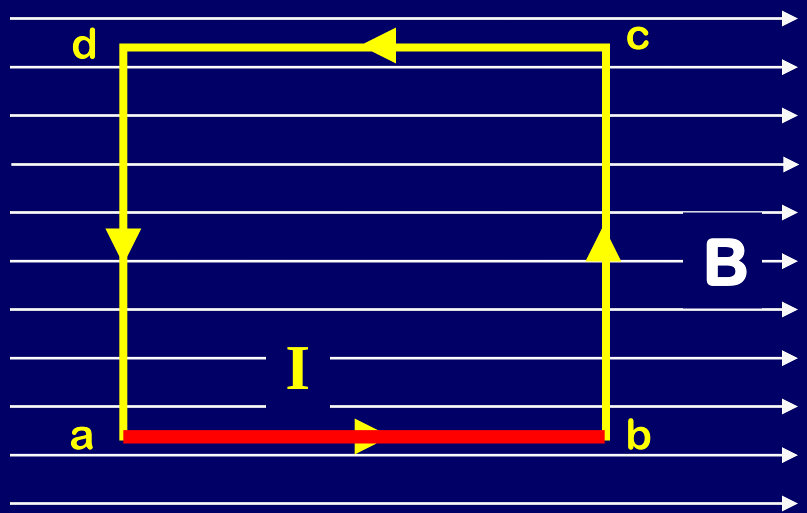


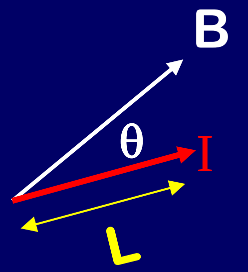
- Force on many moving charges:
  - F = q v B sin(θ)
    = (q/t) (vt) B sin(θ)
    = I L B sin(θ)
  - Out of the page!



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.





$F = IBL\sin\theta$

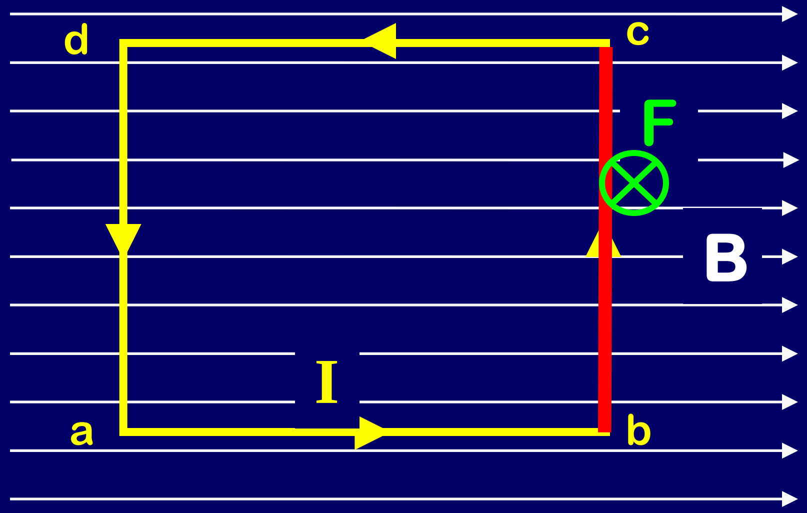
Here $\theta = 0$

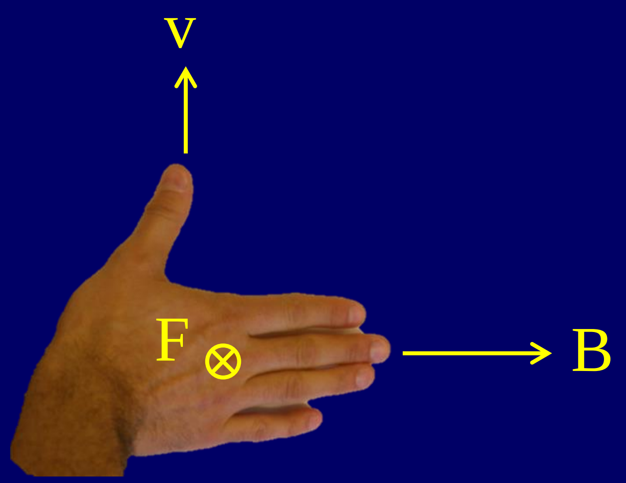
What is the direction of the force on section a-b of the wire?

A) force is zero 62%
B) out of the page 22%
C) into the page 16%

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.



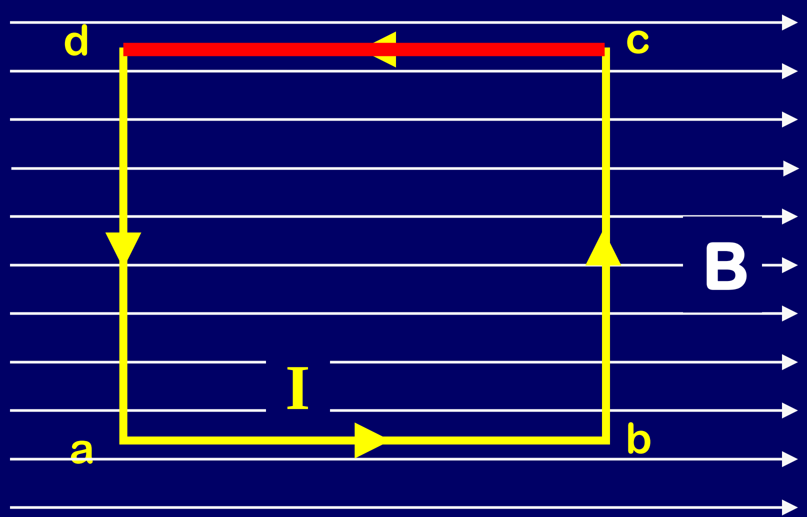


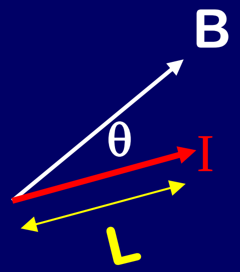
What is the direction of the force on section b-c of the wire?

A) force is zero 14%
B) out of the page 30%
C) into the page 56%

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.





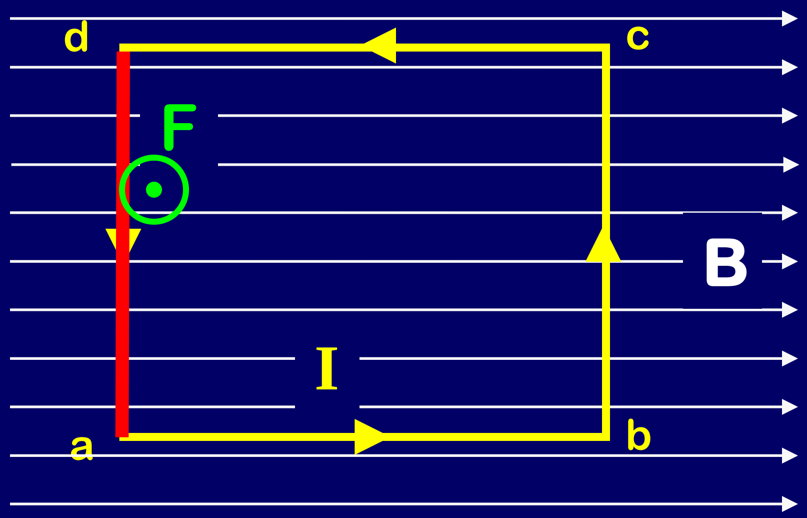
$F = IBL\sin\theta$

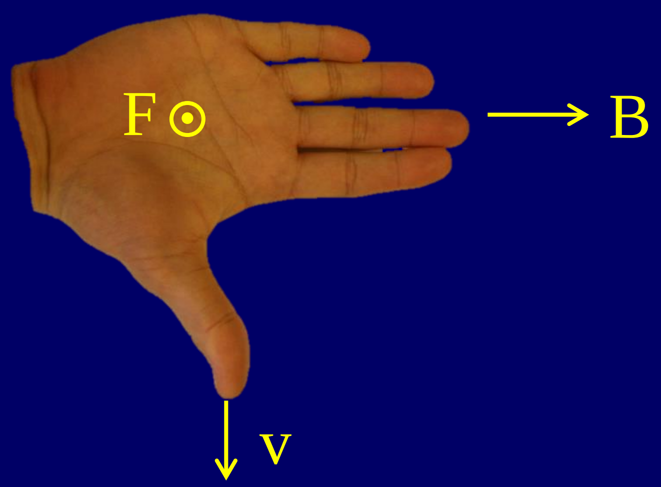
Here $\theta = 180°$

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.

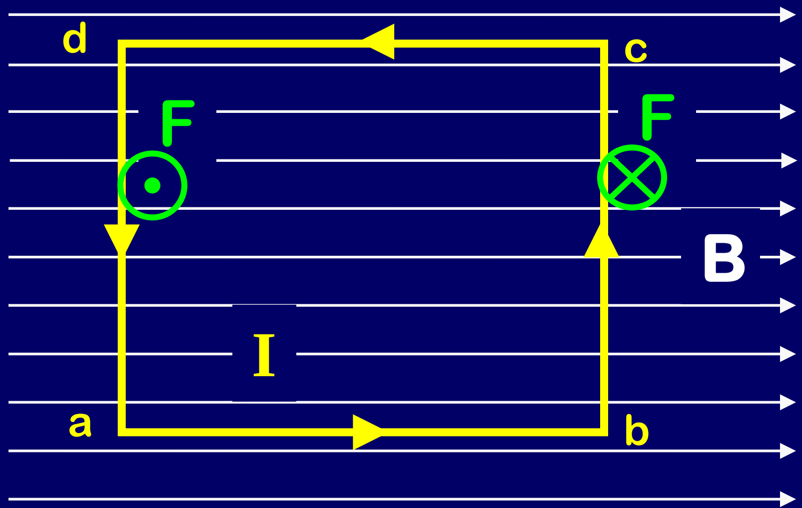


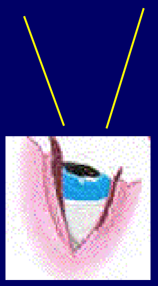


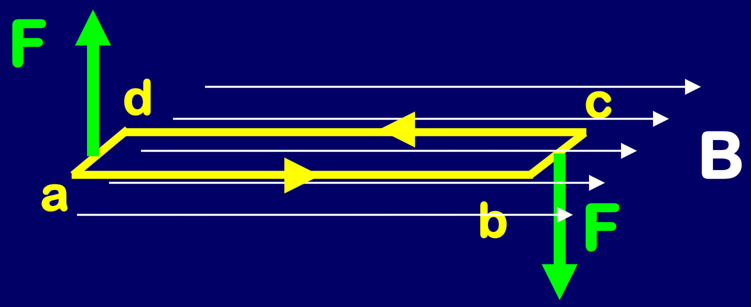
What is the direction of the force on section d-a of the wire?

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

Torque on Current Loop in magnetic field







The loop will spin in place!

Look from here

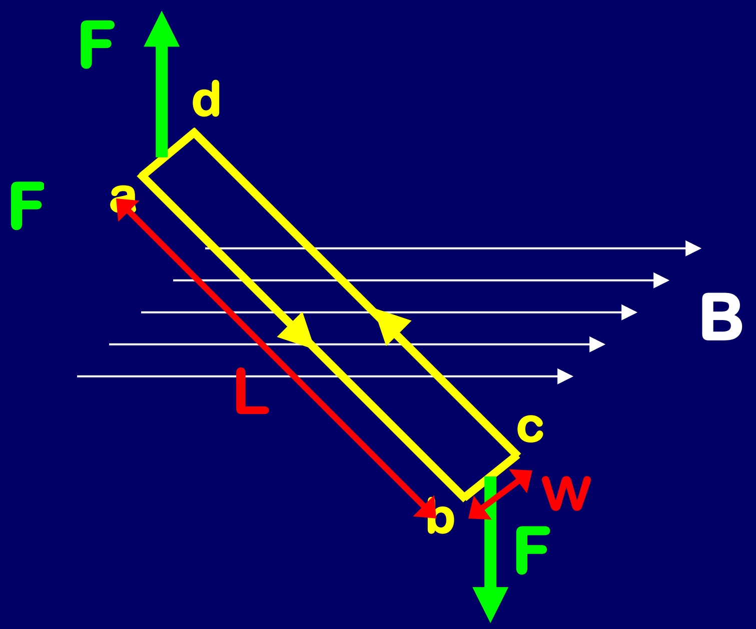
CheckPoints 1.3, 1.4:

Net force on loop is zero.

But the net torque is not!

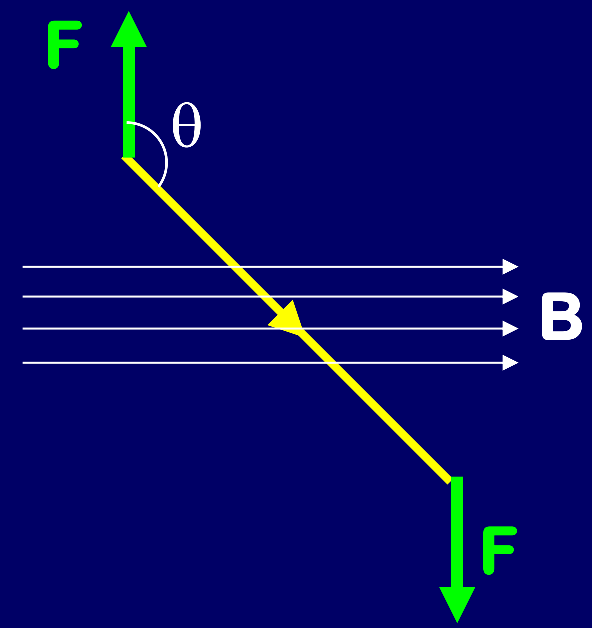
Torque on Current Loop

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) = I Lw B sin(θ)**

Lw = A !

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

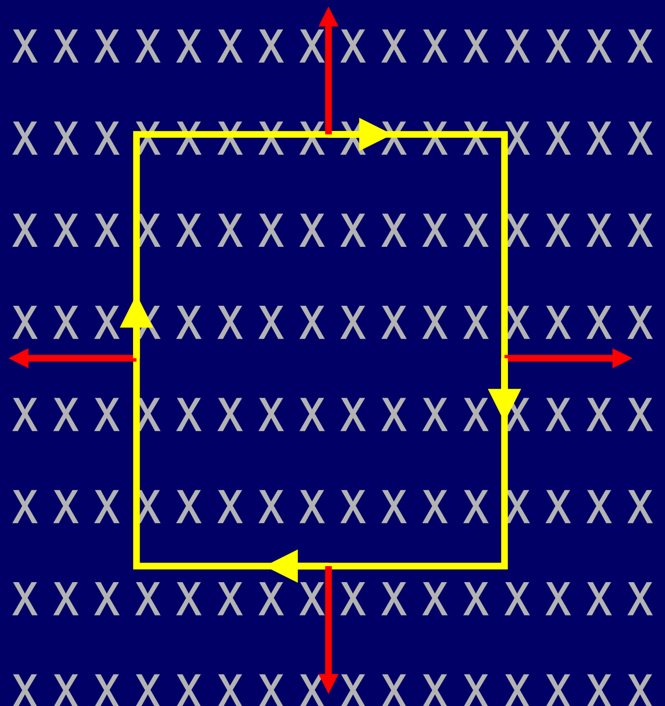
ACT: Torque on Current Loop

What is the torque on the loop below?

A. $\tau < IAB$

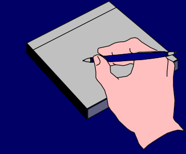
B. $\tau = IAB$

C. $\tau > IAB$

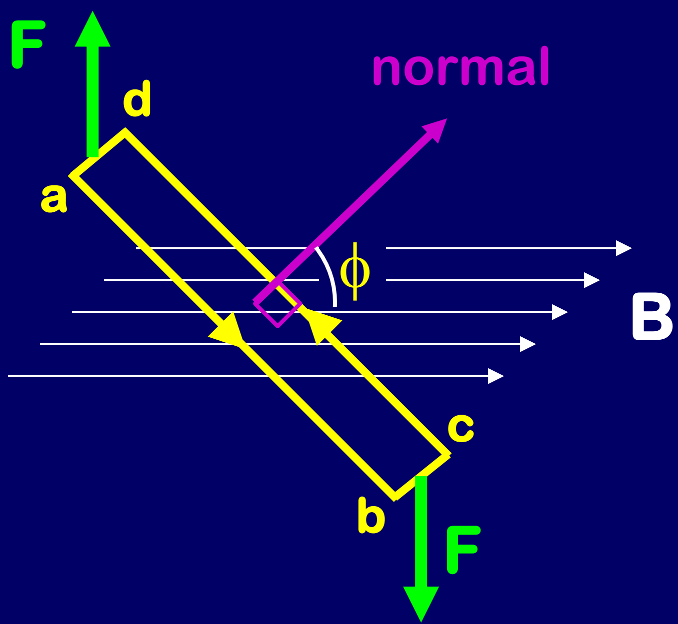


$$\tau = 0$$

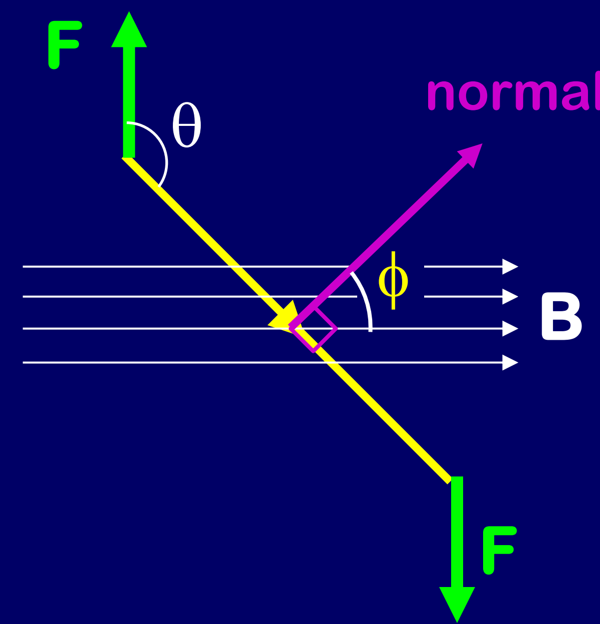
Torque on Current Loop



It is useful to define <u>normal vector</u> ⊥ to loop



$\phi = 180 - \theta$



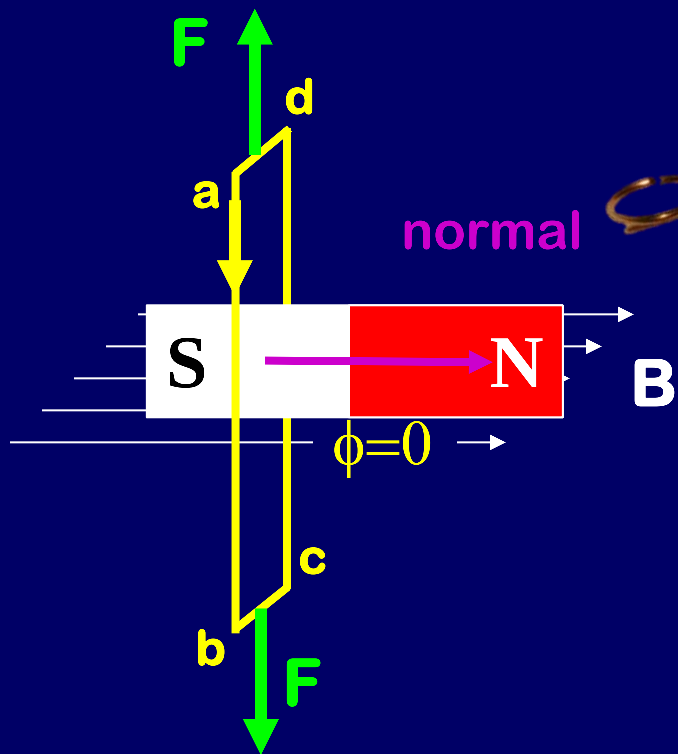
Torque is: $\tau = IAB \sin\theta = IAB \sin\varphi$

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

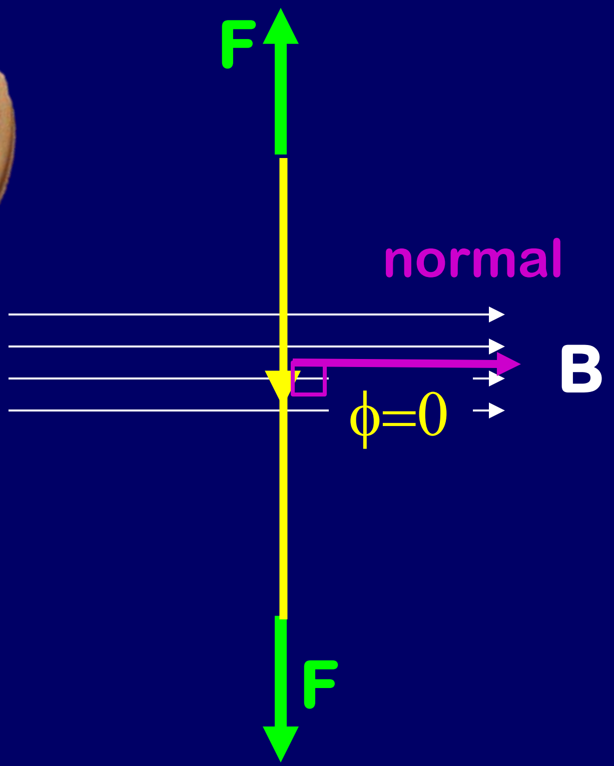
Even if loop is not rectangular, as long as it is flat

Torque on Current Loop

It is useful to define normal vector ⊥ to loop



$\phi = 180 - \theta$



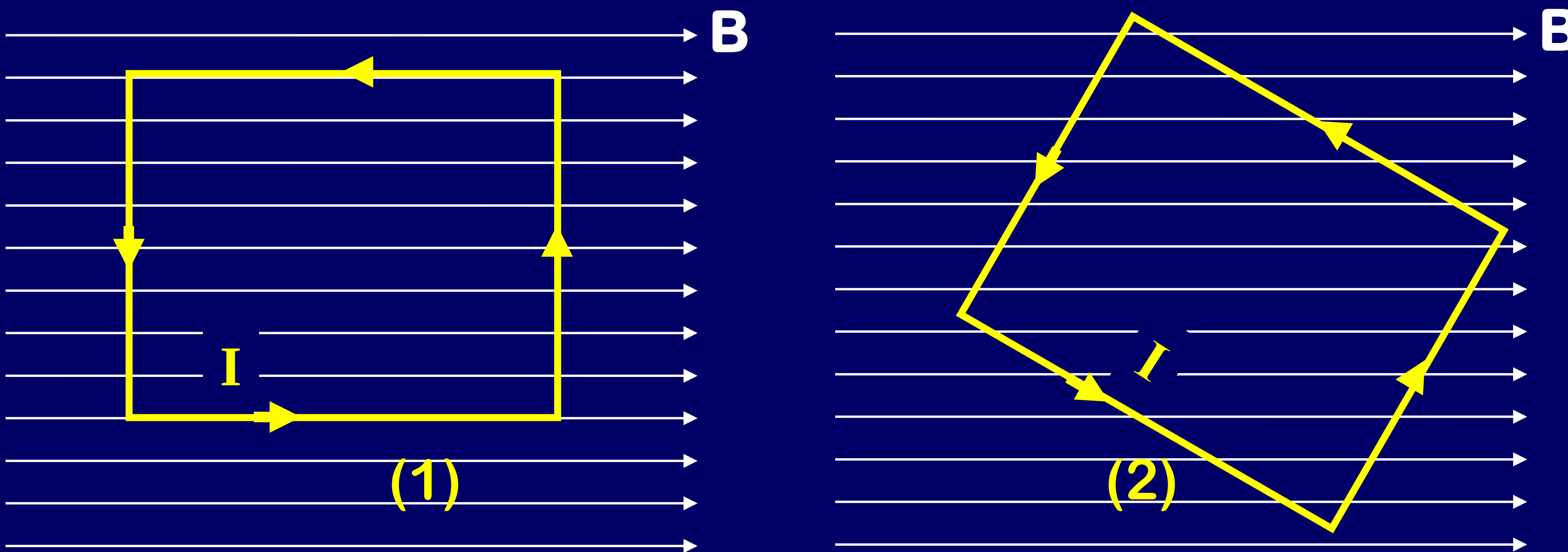
Torque is: $\tau = IAB\sin\theta = IAB\sin\varphi$

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.

Normal vector points out of page for both!

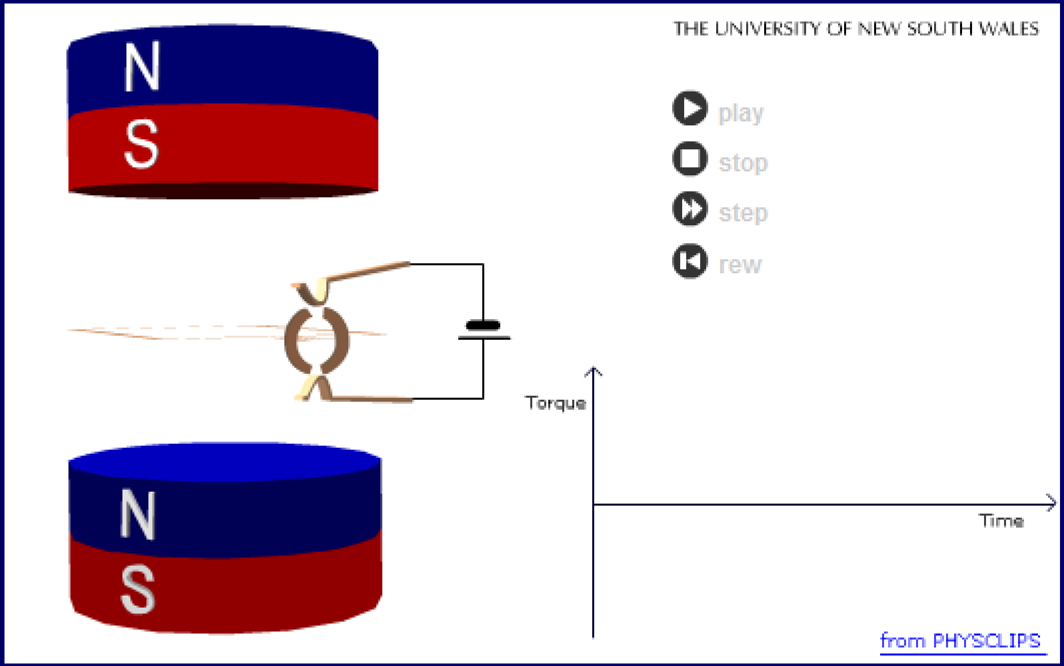
A) $\tau_1 > \tau_2$ B) $\tau_1 = \tau_2$ C) $\tau_1 < \tau_2$

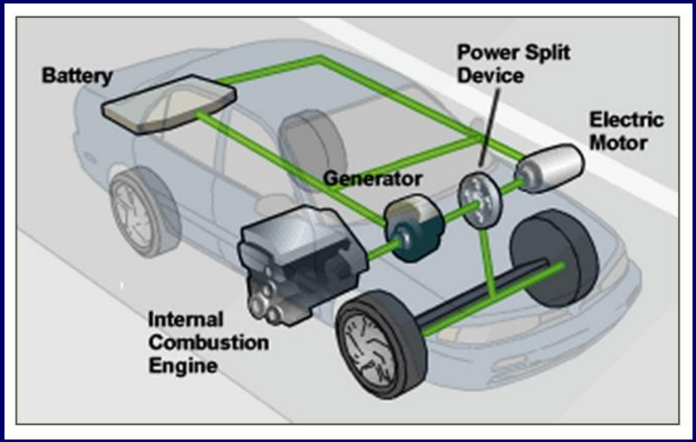
$\phi = 90$

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

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:

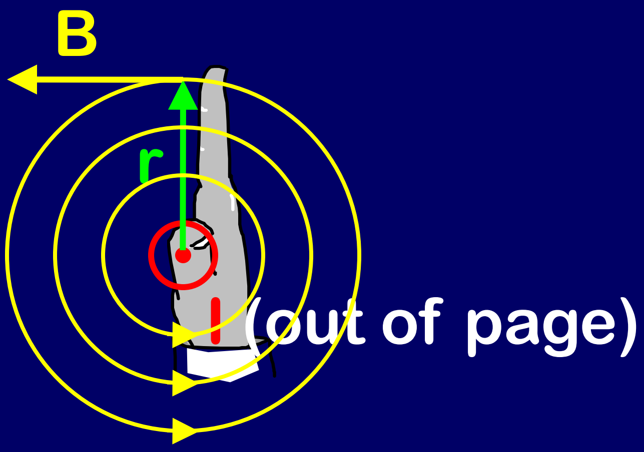
$$B = \frac{\mu_0 I}{2\pi r}$$

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

"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**

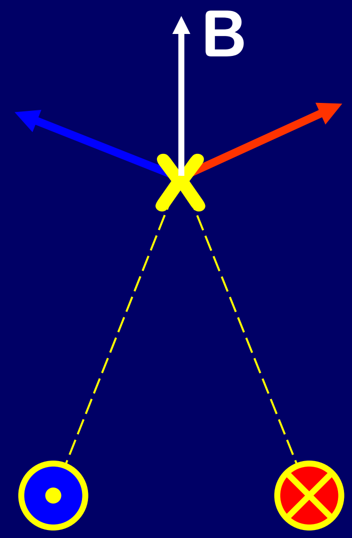


B field circles wire

Note: there are different versions of RHR

ACT: Adding Magnetic Fields

Two long wires carry opposite current (same magnitude)

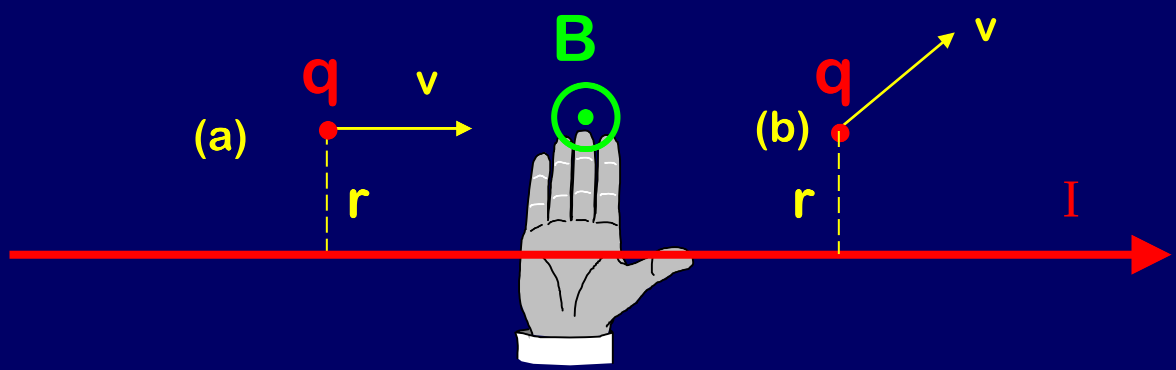


What is the direction of the magnetic field above, and midway between the two wires carrying current – at the point marked "X"?

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

ACT/Checkpoint 2.1-a

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



What is direction of magnetic field above wire

a) Up

b) Down

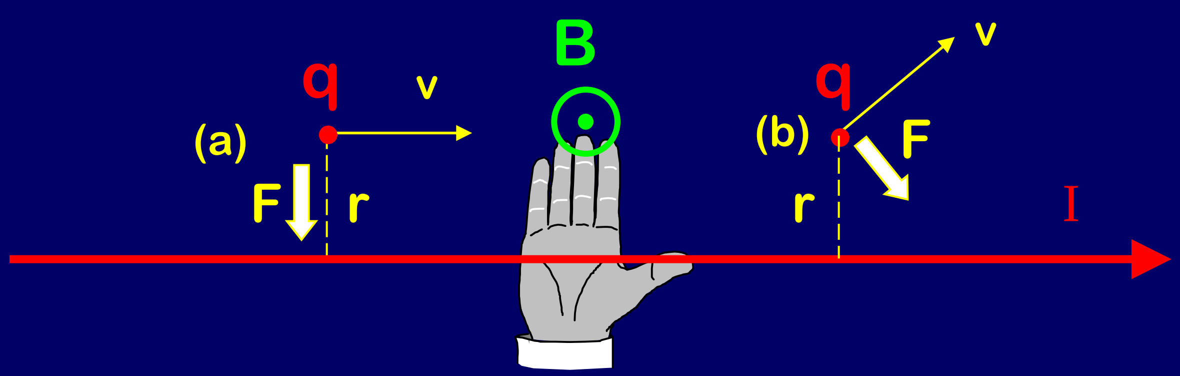
c) Right

d) Left

e) Out of page

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	29%
b) has the larger force	49%
c) force is the same for (a) and (b)	21%

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

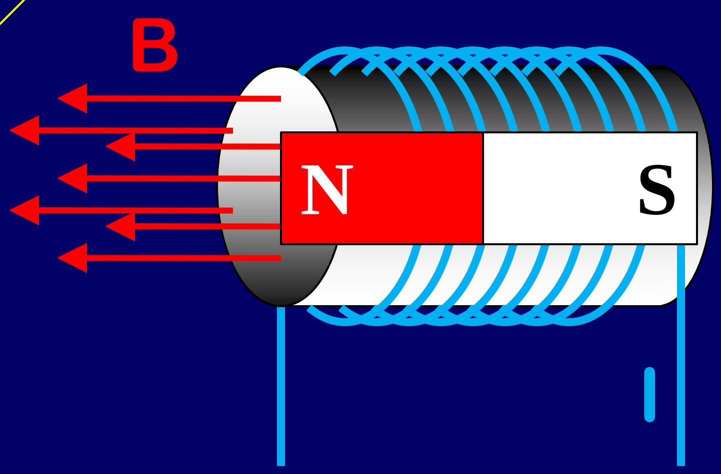
B is uniform everywhere inside of solenoid:

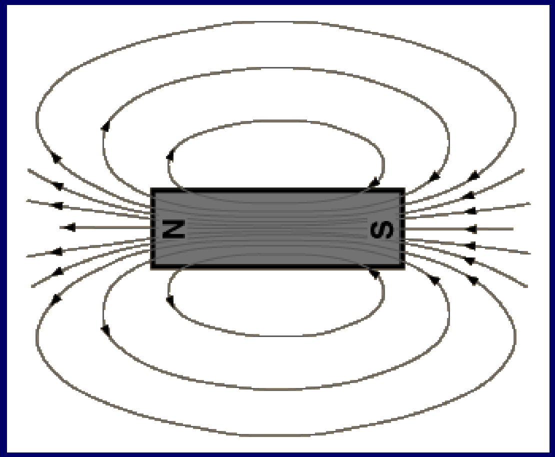
$$\boxed{B = \mu_0 n I} \qquad \mu_0 = 4\pi \times 10^{-7} Tm/A$$

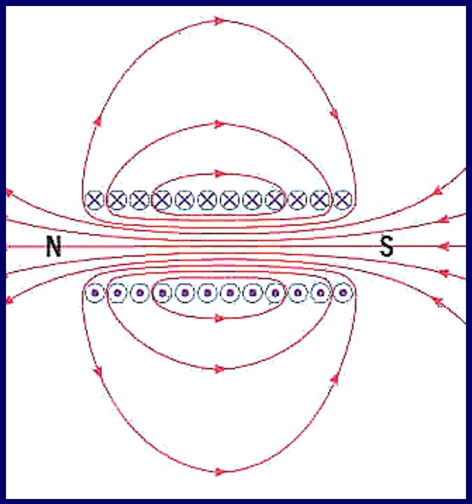
n is the number of turns of wire/meter (n = N/L)

Direction

- Use “Right-hand rule 2”



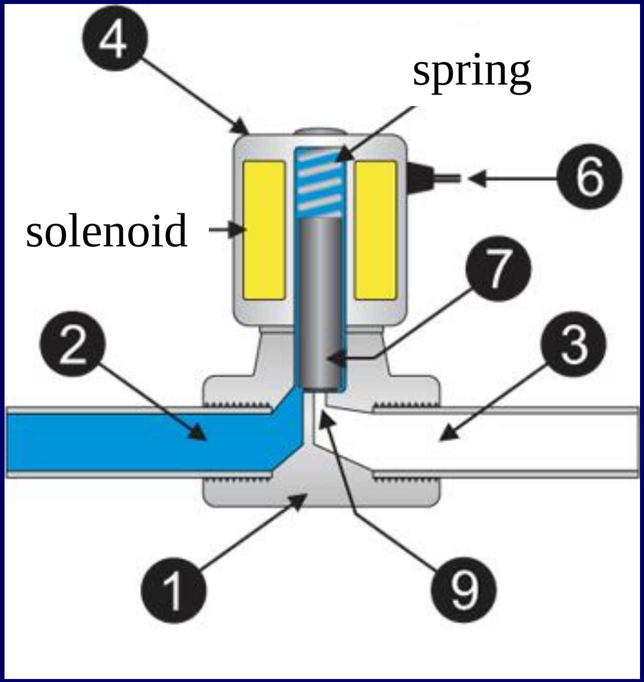




B field lines look like bar magnet!
Solenoid has N and S poles! (Checkpoint 3.1)

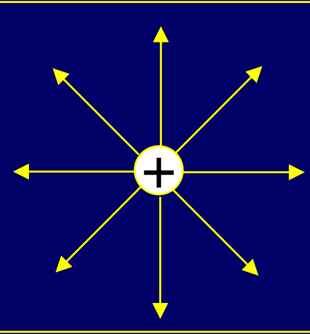
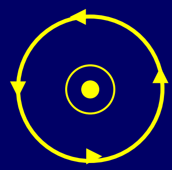
Electromagnets

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



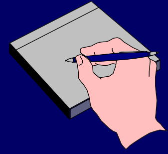
Solenoid valve

Comparison:
Electric Field vs. *Magnetic* Field

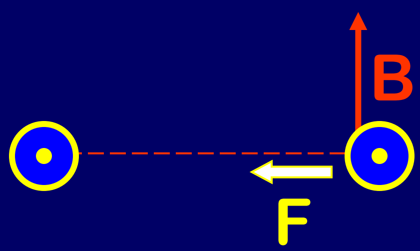
	Electric	Magnetic
Source	Charges	Moving Charges
Acts on	Charges	Moving Charges
Force	F = Eq	F = q v B sin(θ)
Direction	Parallel E	Perpendicular to v,B
Field Lines		
Opposites	Charges Attract	

Example

Force between current-carrying wires



Currents in same direction

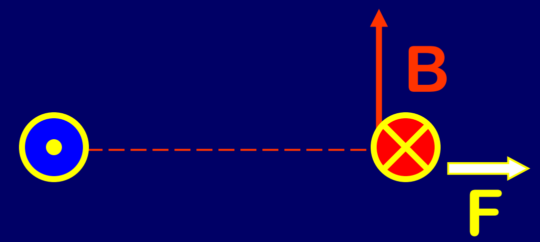


I towards us

Another I towards us

<u>Currents in same direction attract!</u>

Currents opposite direction

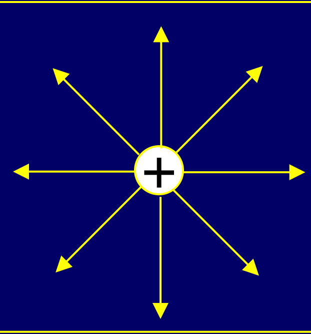
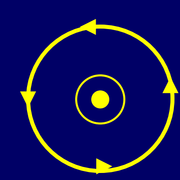


I towards us

Another I away from us

<u>Currents in opposite direction repel!</u>

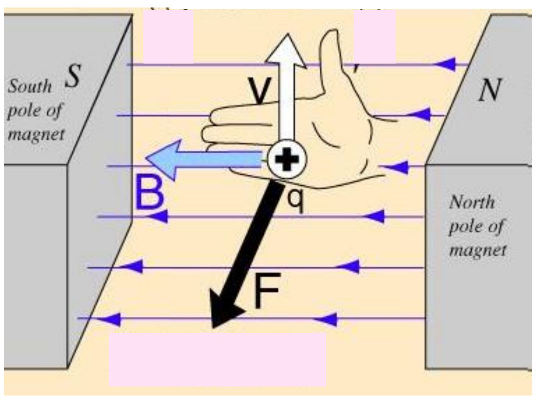
Comparison:
Electric Field vs. *Magnetic* Field

	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	Currents Repel

Summary of Right-Hand Rules

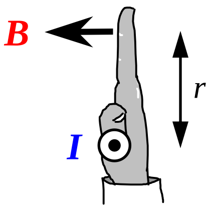
RHR 1 | RHR 2 | Alternate

Force on moving q



B field from current I

Straight wire



Solenoid