

Physics 102: Lecture 09

Currents and Magnetism

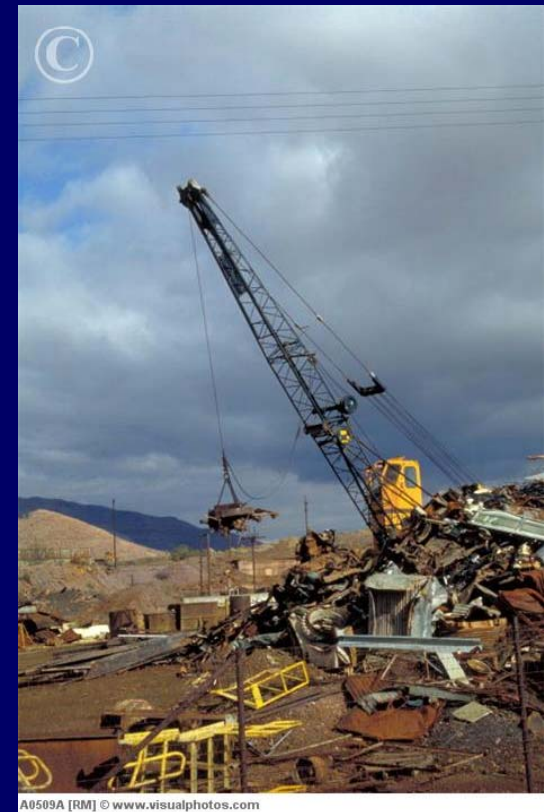
- Reminder: Exam 1 next Monday
- 5:15pm conflict: sign up in gradebook
- Be sure to bring your ID, a calculator, #2 pencil, and go to the correct room
- Review Sunday, 3-5 PM, Rm. 141
- James Scholar Credit – information on course website

Summary of Today

- Magnetic forces on currents and torques on current loops



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

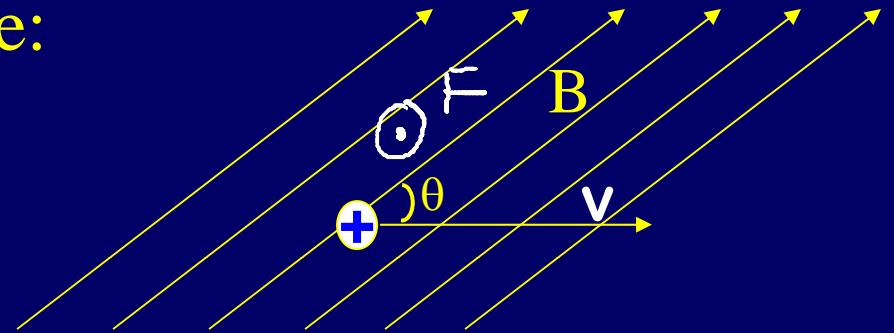


Force of magnetic field on Current



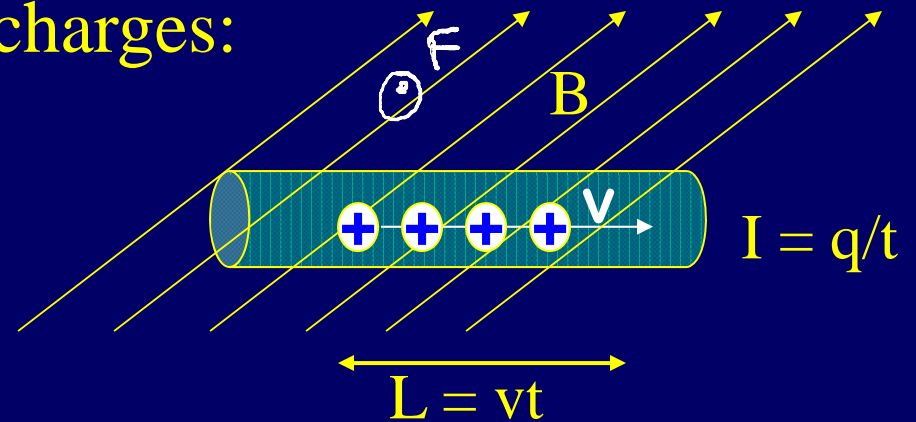
- Force on 1 moving charge:

- $F = q v B \sin(\theta)$
- Out of the page (RHR)



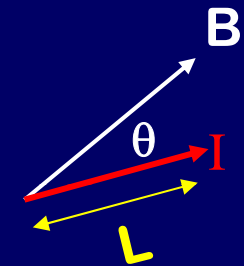
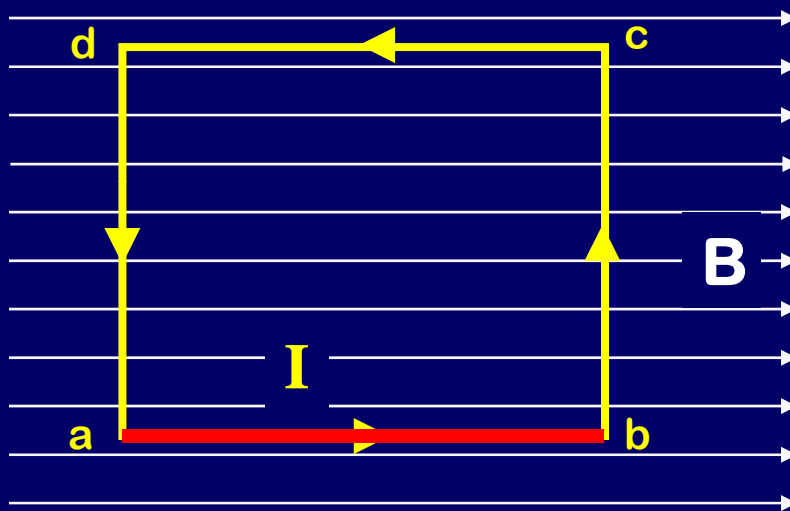
- Force on many moving charges:

- $F = q v B \sin(\theta)$
= $(q/t) (vt) B \sin(\theta)$
= $I L B \sin(\theta)$
- 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.



$$F = IBL \sin \theta$$

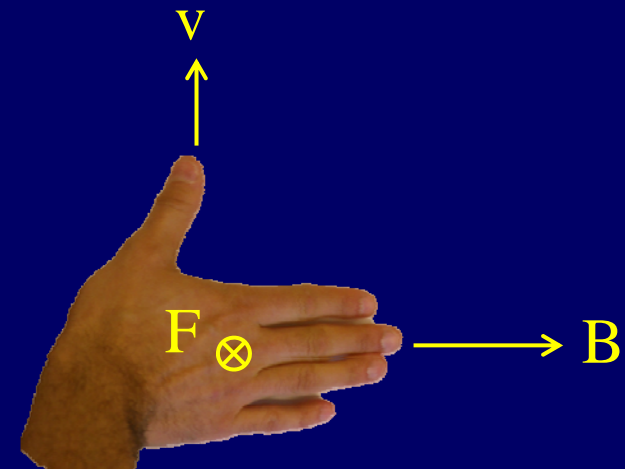
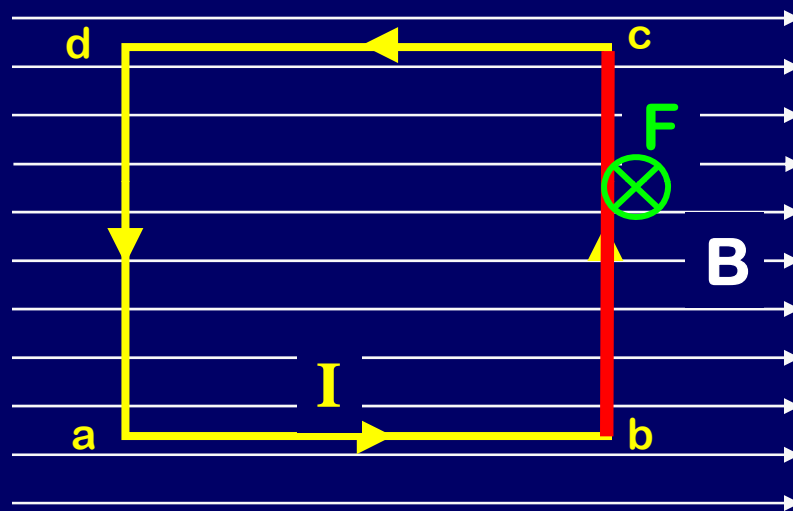
Here $\theta = 0$

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

- force is zero 60%
- out of the page 25%
- into the page 15%

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.

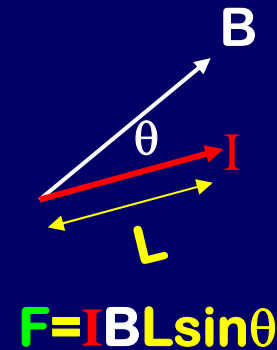
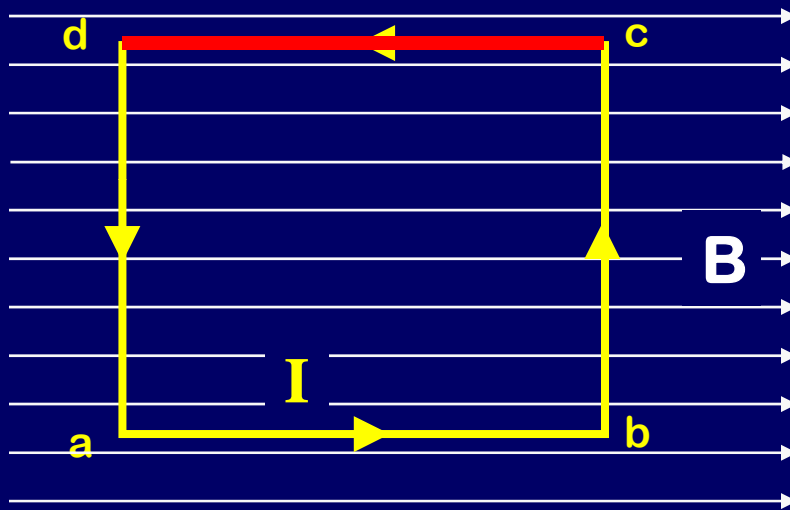


What is the direction of the force on section b-c of the wire?

- force is zero 8%
- out of the page 20%
- into the page 72%

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.



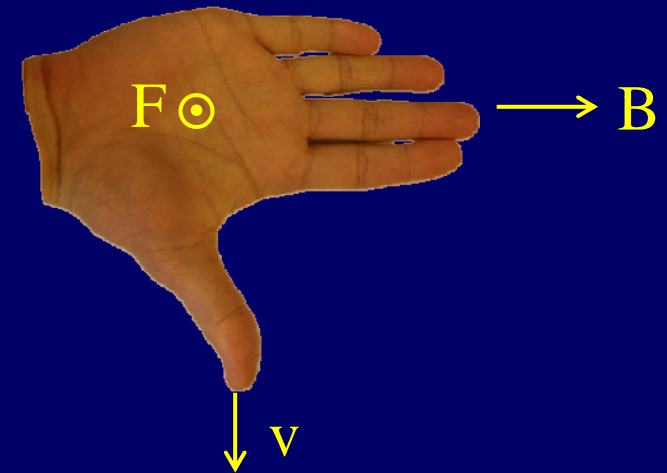
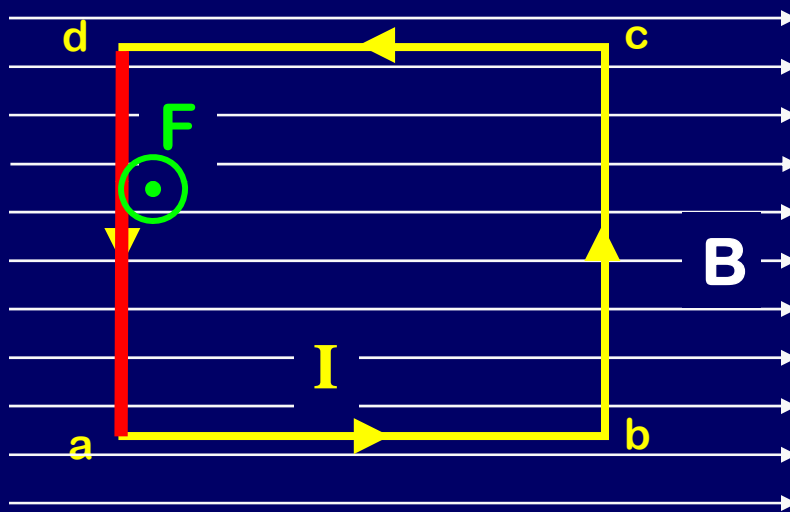
Here $\theta = 180^\circ$

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



ACT: Force on loop (cont'd)

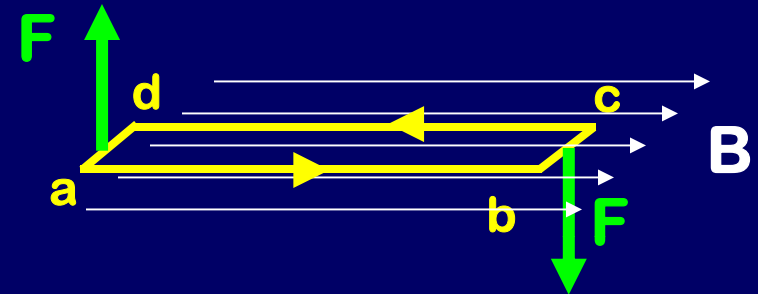
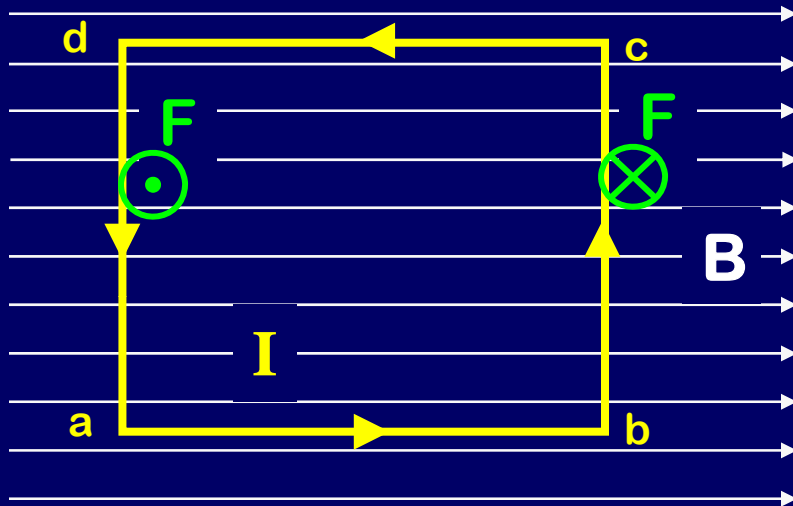
A rectangular loop of wire is carrying current as shown. There is a uniform magnetic field parallel to the sides a-b and c-d.



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!**



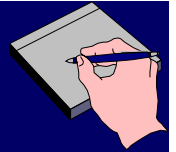
Look from here

CheckPoints 1.3, 1.4:

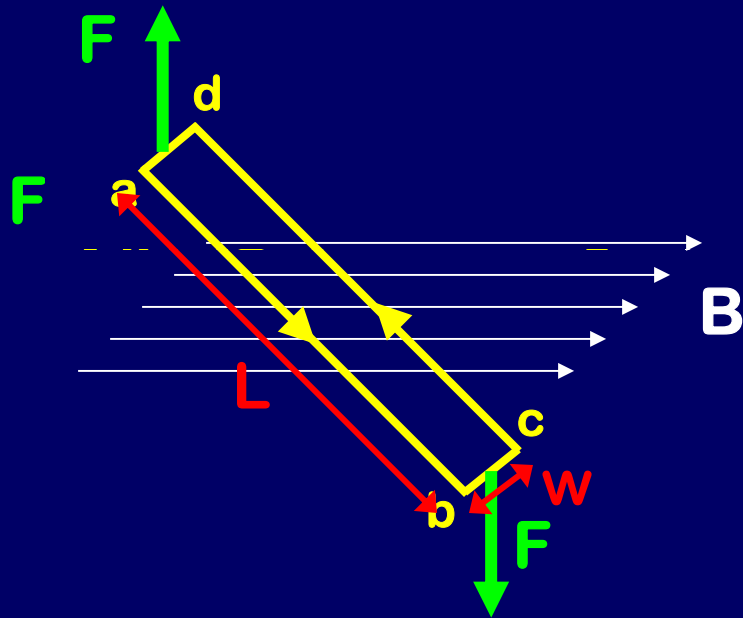
Net force on loop is **zero**.

But the net torque is **not!**

Torque on Current Loop

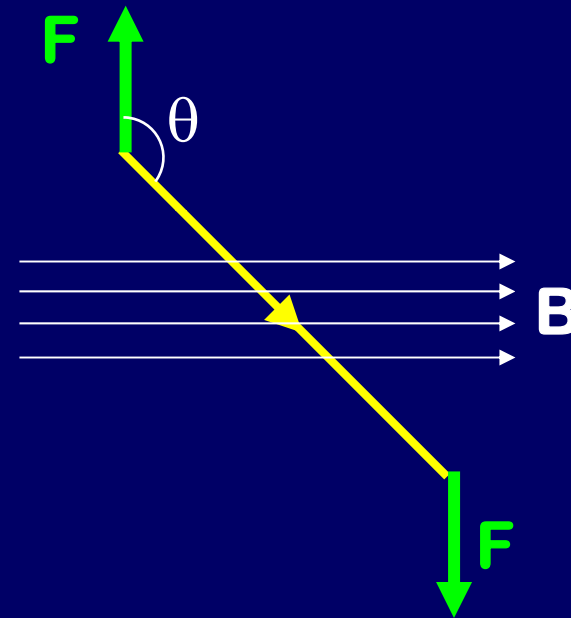


The loop will spin in place!



Recall from Phys 101:

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



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

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

Torque is:

$$\tau = IAB \sin \theta$$

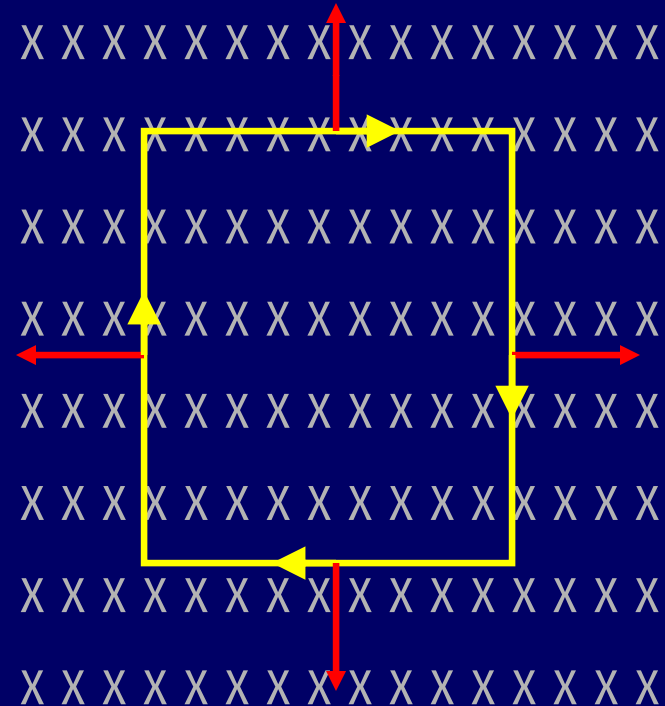


ACT: Torque on Current Loop

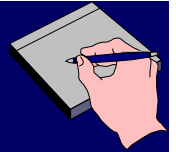
What is the torque on the loop below?

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

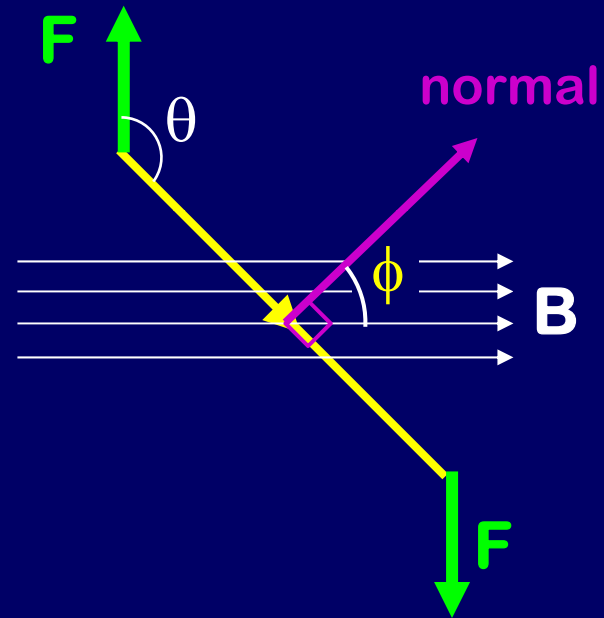
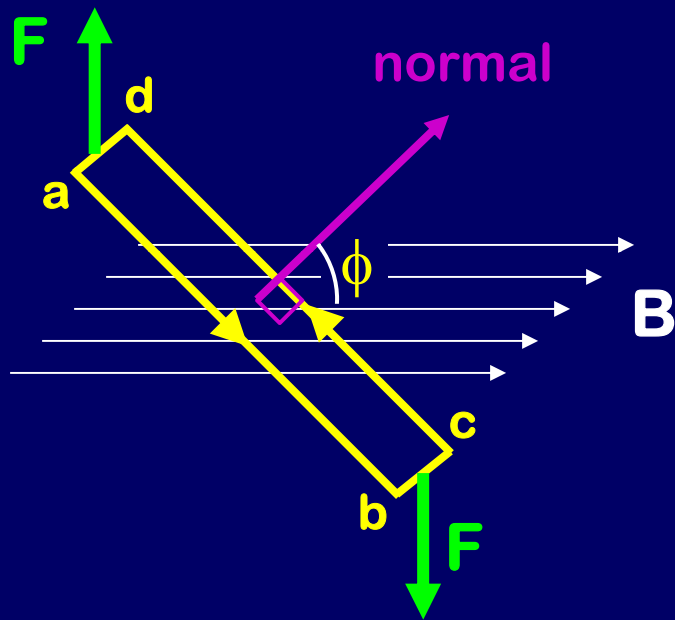
$$\tau = 0$$



Torque on Current Loop



It is useful to define normal vector \perp to loop



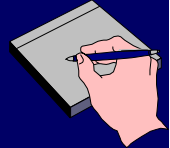
$$\phi = 180 - \theta$$

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

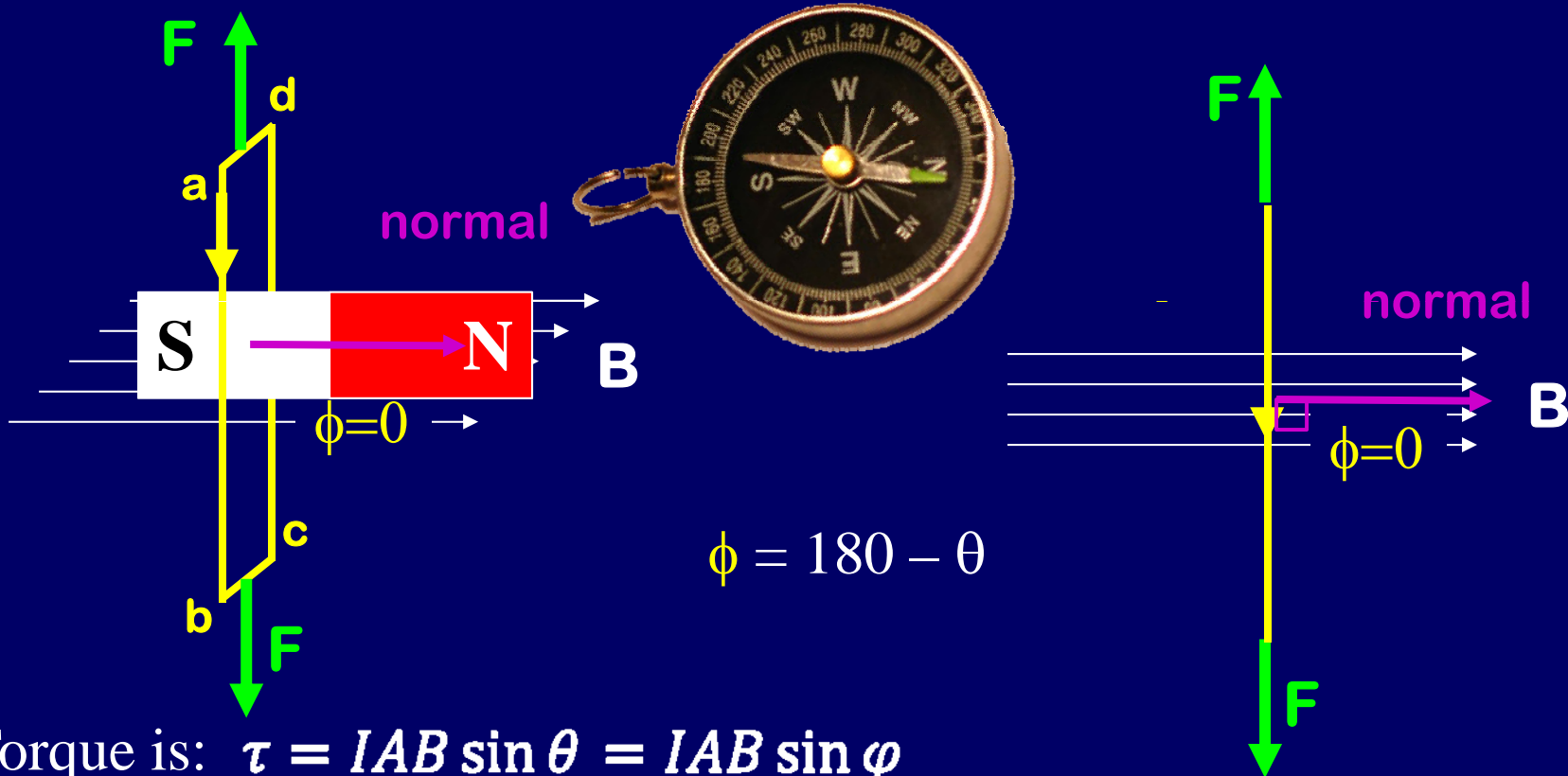
If there are N loops: $\tau = NIAB \sin \phi$

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

Torque on Current Loop



It is useful to define normal vector \perp to loop



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

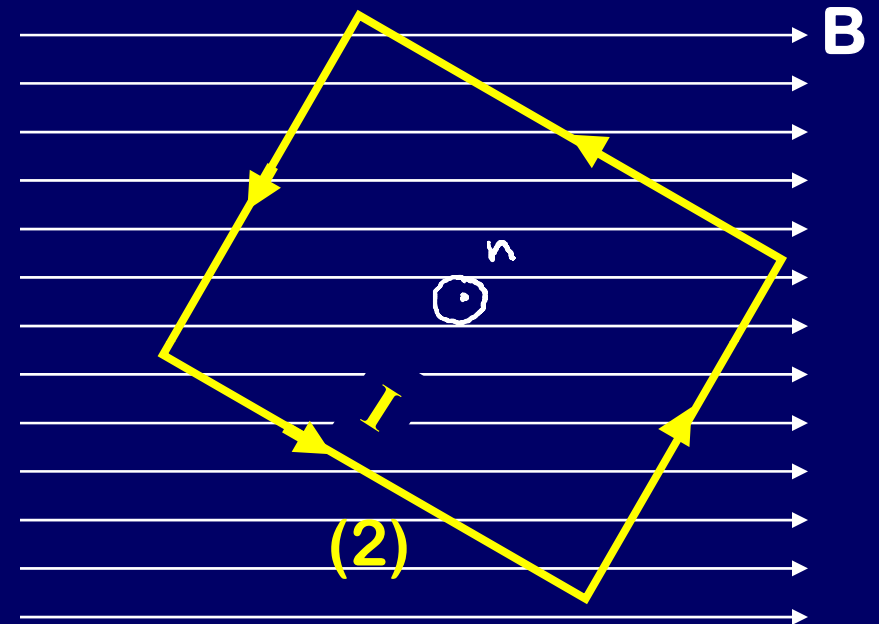
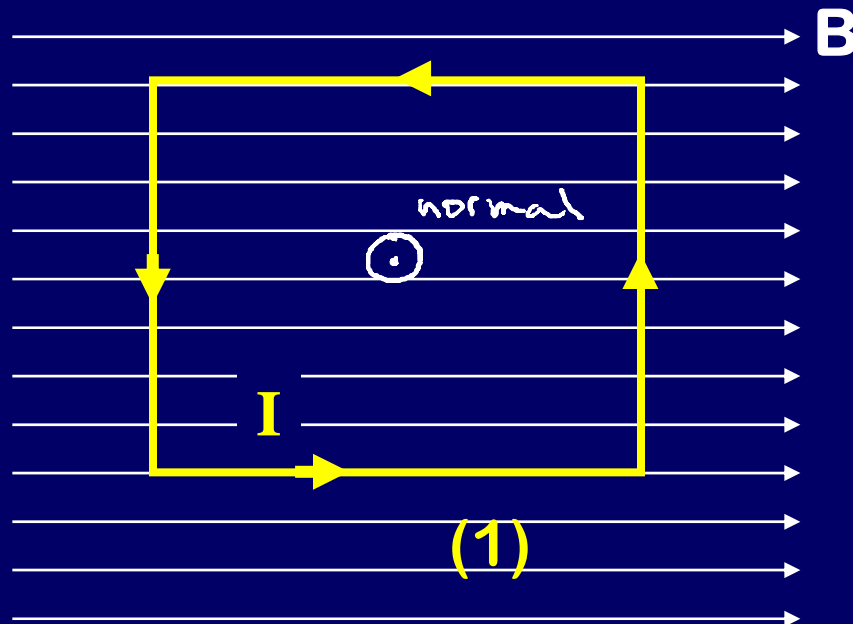
If there are N loops: $\tau = NIAB \sin \varphi$

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) $\tau_1 < \tau_2$

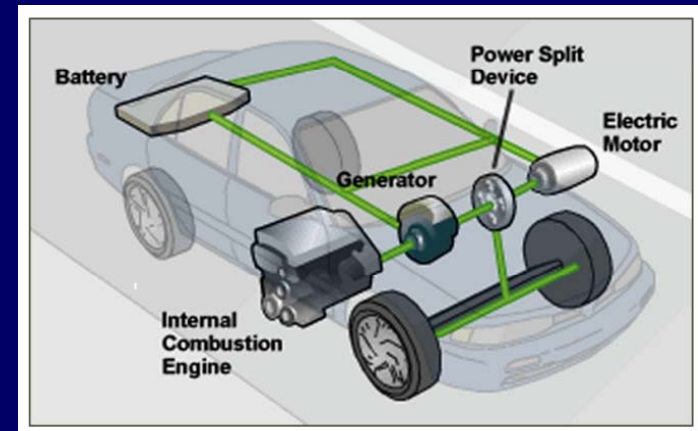
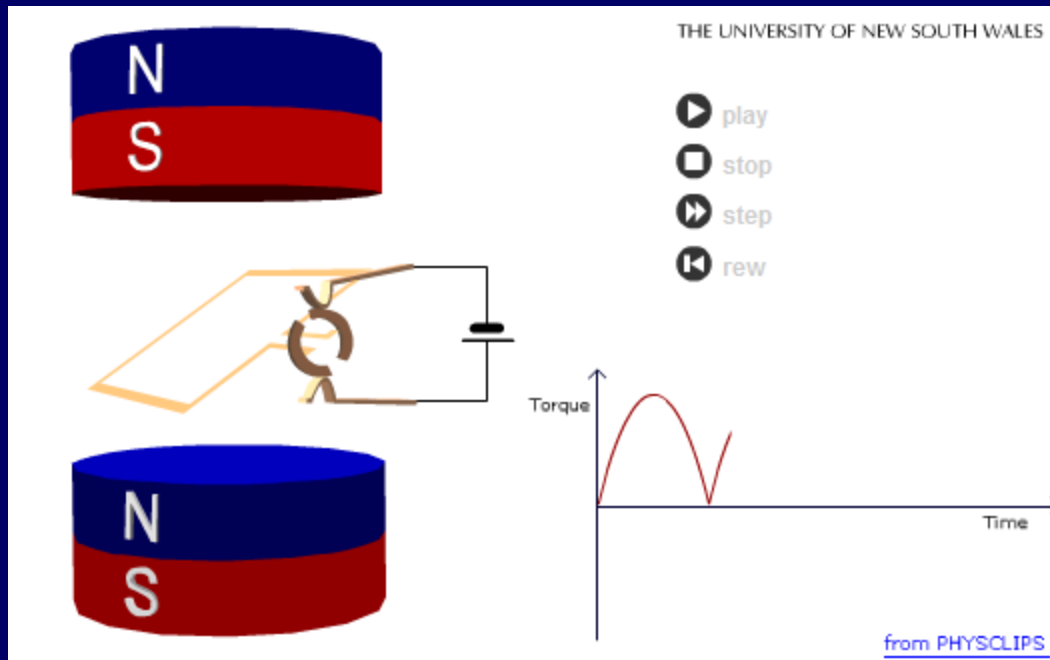
$$\tau = I A B \sin(\phi)$$

Normal vector points out of page for both!

$$\phi = 90$$

Motors

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



Currents *create* magnetic fields

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

Magnitude

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

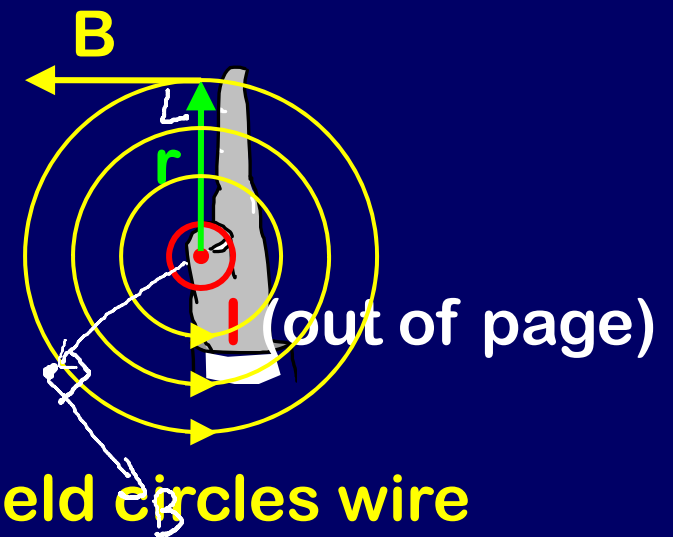
$$\mu_0 = 4\pi \times 10^{-7} \text{ Tm/A}$$

“Permeability of free space”
(similar to ϵ_0 for electricity)

- “Right-hand rule 2”:

Direction

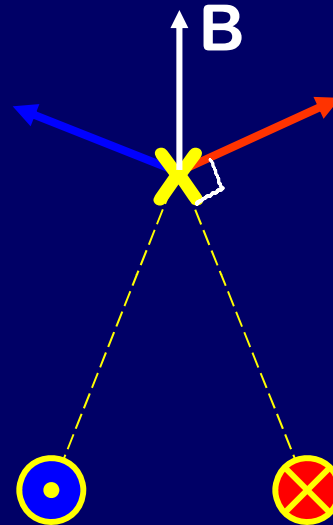
- Thumb of right hand along I
- Fingers of right hand along r
- Out-of-palm points along B





ACT: Adding Magnetic Fields

Two long wires carry opposite current (same magnitude)



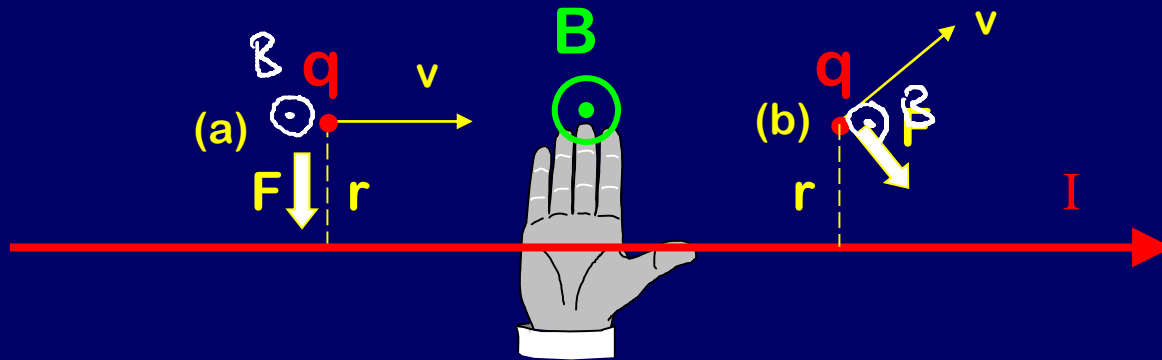
What is the direction of the magnetic field above, and midway between the two wires carrying current – at the point marked “X”?

- 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

34%

b) has the larger force

50%

c) force is the same for (a) and (b)

16%

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

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

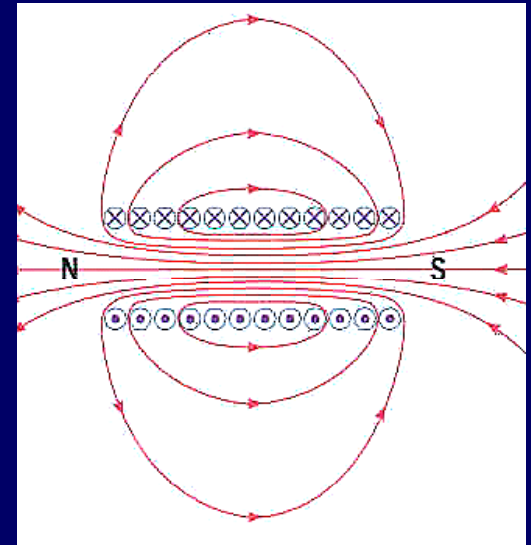
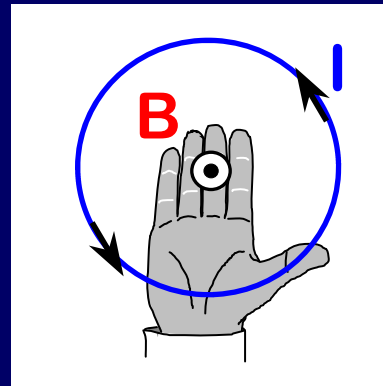
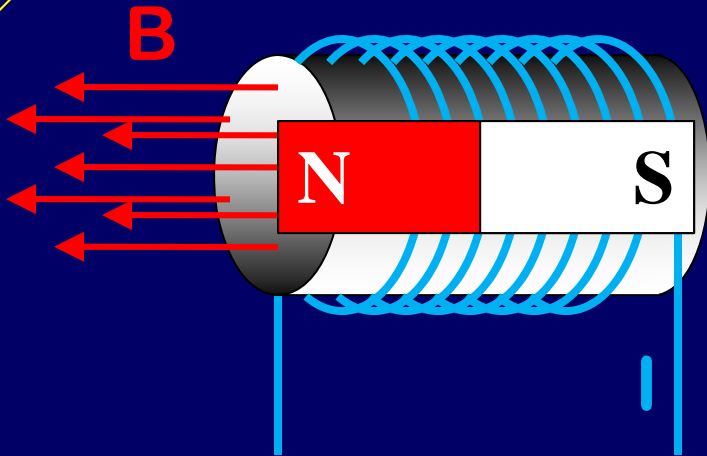
B is uniform everywhere inside of solenoid:

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

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

Direction

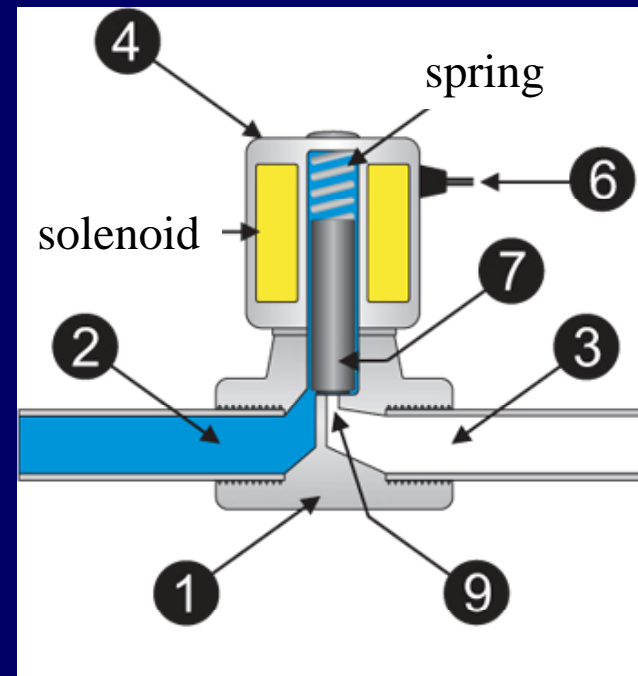
- Use “Right-hand rule 2”



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

Electromagnets

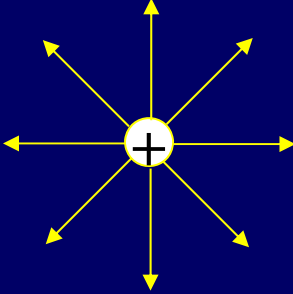
Solenoids are a way to make powerful magnets that can be turned on and off!



Solenoid valve

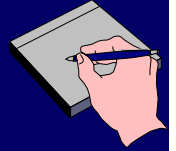
Comparison:

Electric Field vs. Magnetic Field

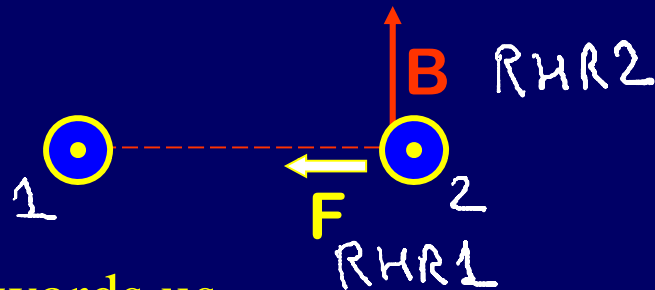
	Electric	Magnetic
Source	Charges	Moving Charges
Acts on	Charges	Moving Charges
Force	$F = Eq$	$F = q v B \sin(\theta)$
Direction	Parallel E	Perpendicular to v,B
Field Lines		
Opposites	Charges Attract	

Example

Force between current-carrying wires



Currents in same direction

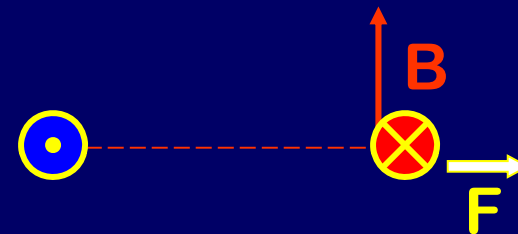


I towards us

Another I towards us

Currents in same direction attract!

Currents opposite direction



I towards us

Another I away from us

Currents in opposite direction repel!

Comparison:

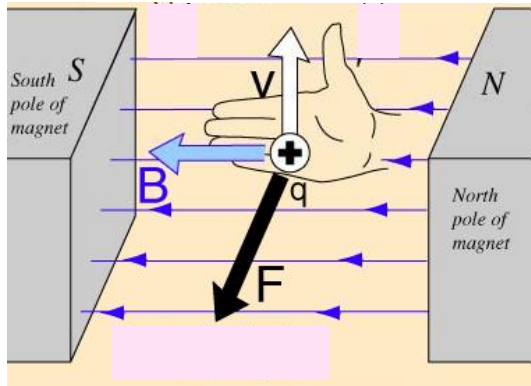
Electric Field vs. Magnetic Field

	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

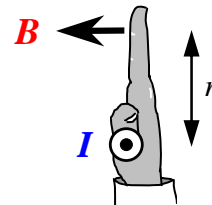
Force on moving q



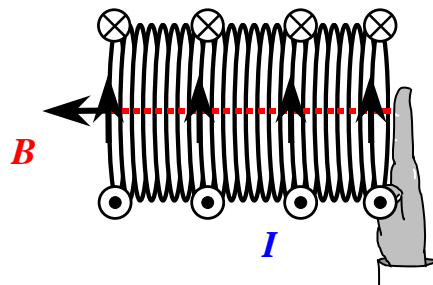
RHR 2

B field from current I

Straight wire



Solenoid



Alternate

