Physics 102: Lecture 09

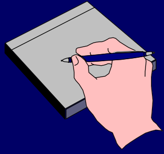
Currents and Magnetism

Summary of Today

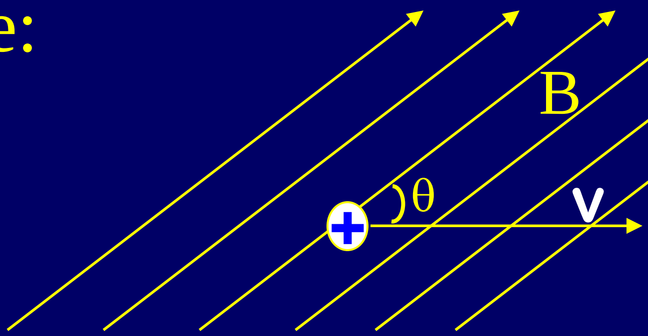
- Magnetic forces on currents and current loops

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

Force of magnetic field on Current



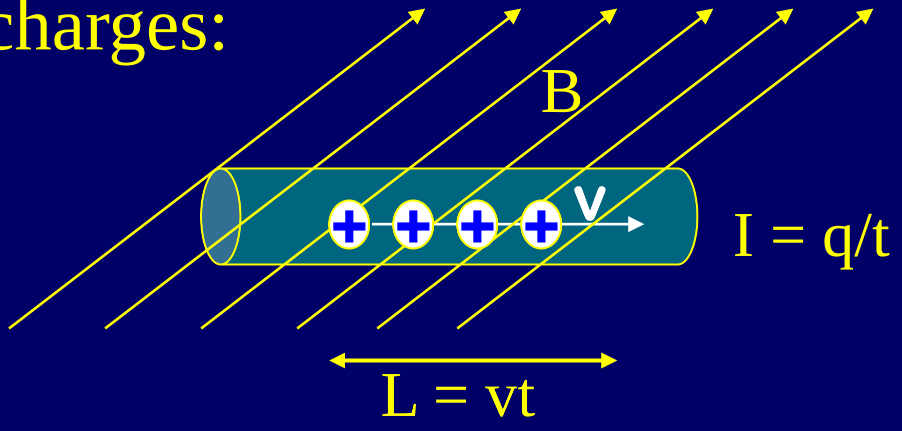
- Force on 1 moving charge:
  - $F = q\, v\, B \sin(\theta)$
  - Out of the page (RHR)



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

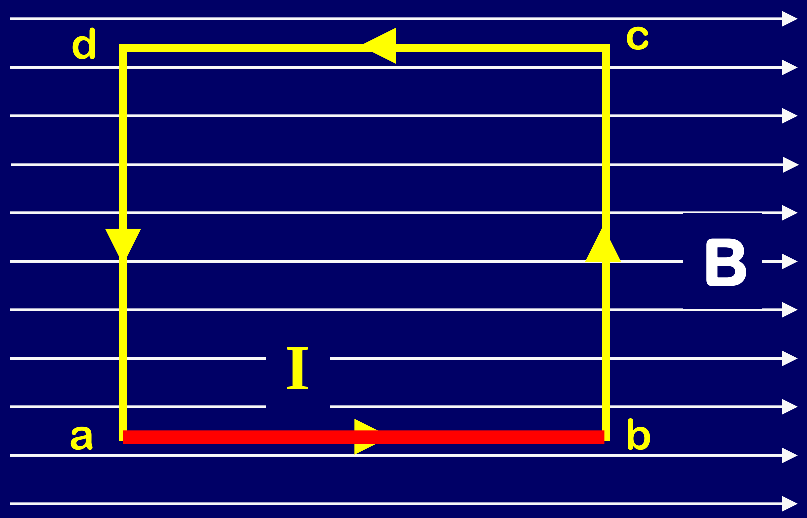
    $= (q/t)\,(vt)\, B \sin(\theta)$

    $= I\, L\, B \sin(\theta)$
  - 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.

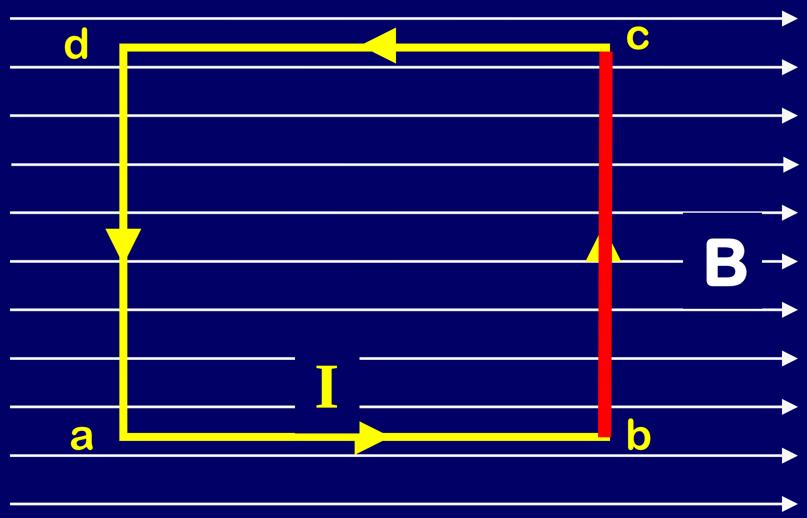


What is the direction of the force on section a-b of the wire?

force is zero
out of the page
into the page

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.

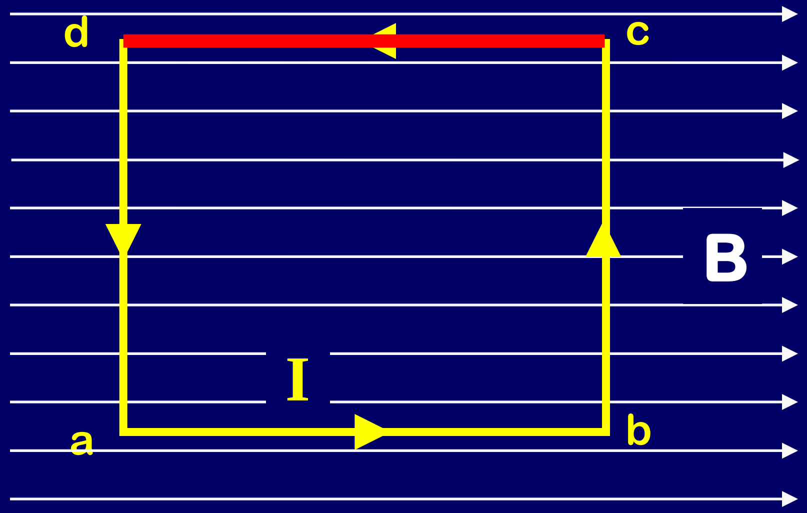


What is the direction of the force on section b-c of the wire?

force is zero
out of the page
into the page

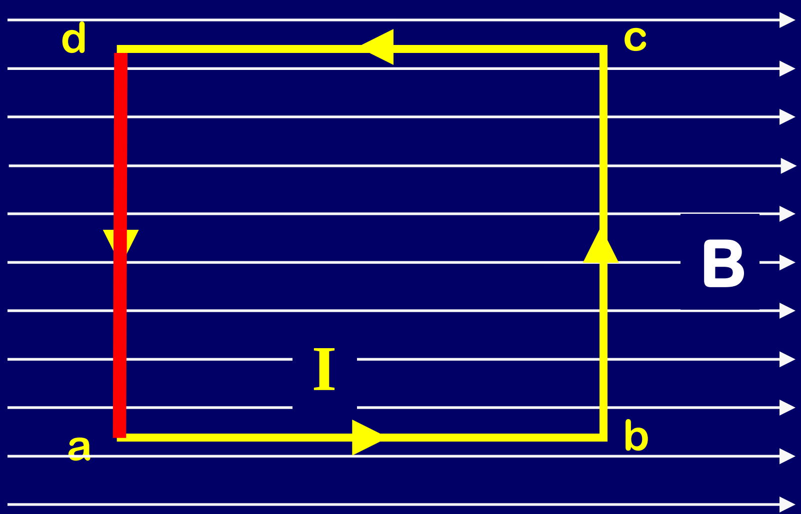
Force on loop

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.



ACT: Force on loop (cont'd)

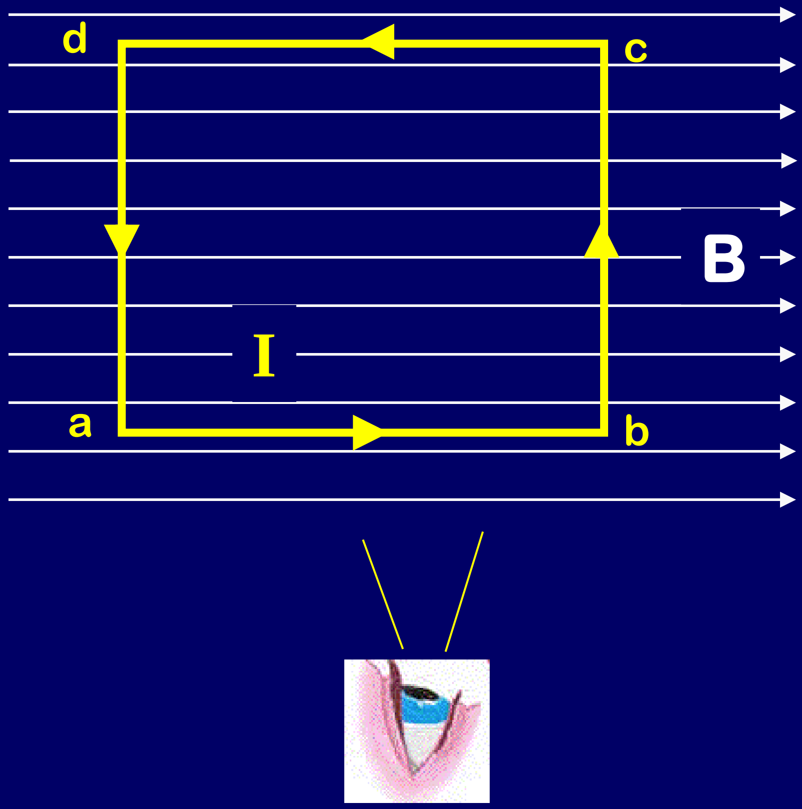
A rectangular loop of wire is carrying current as shown. There is a uniform magnetic field parallel to the sides a-b and c-d.



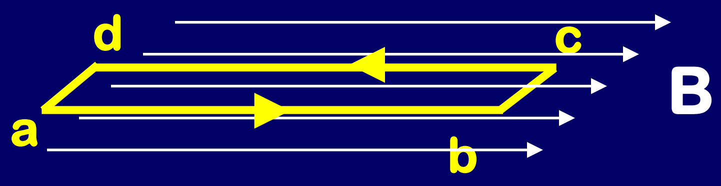
What is the direction of the force on section d-a of the wire?

force is zero
out of the page
into the page

Torque on Current Loop in magnetic field

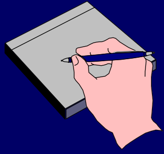


Look from here



The loop will spin in place!

Torque on Current Loop



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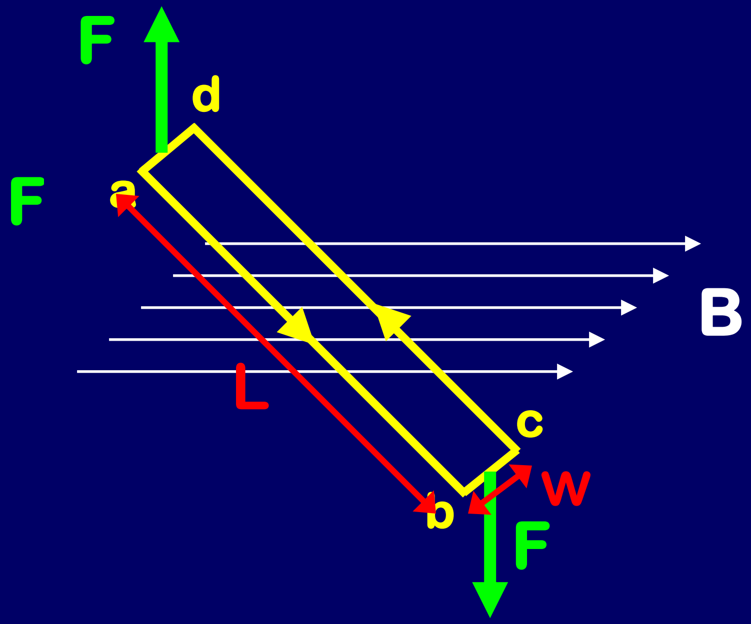
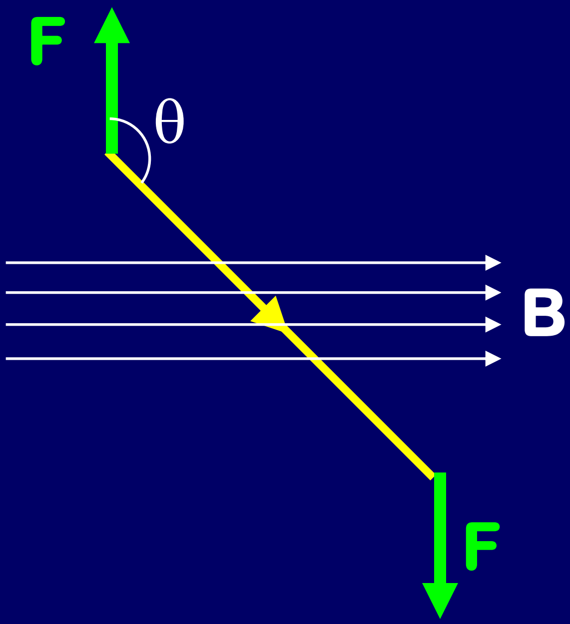


Recall from Phys 101:

$$\tau = FL\sin\theta$$



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)**

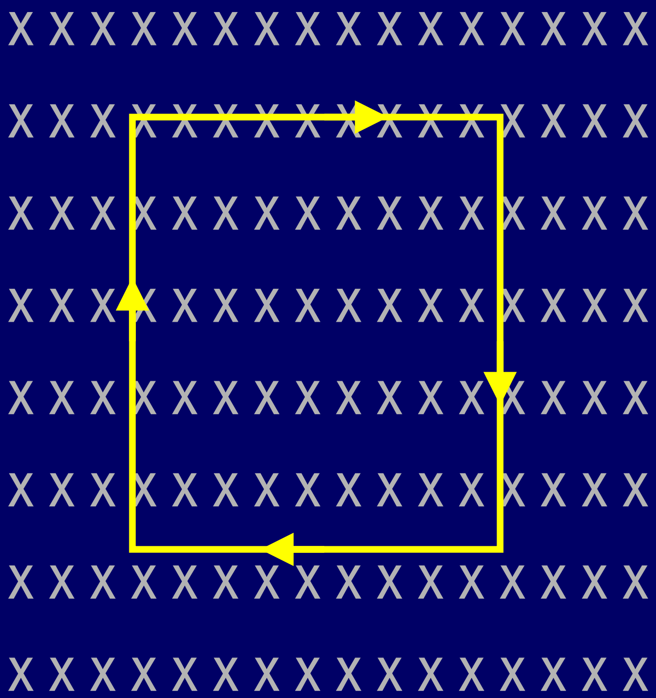
Lw = A !

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

ACT: Torque on Current Loop

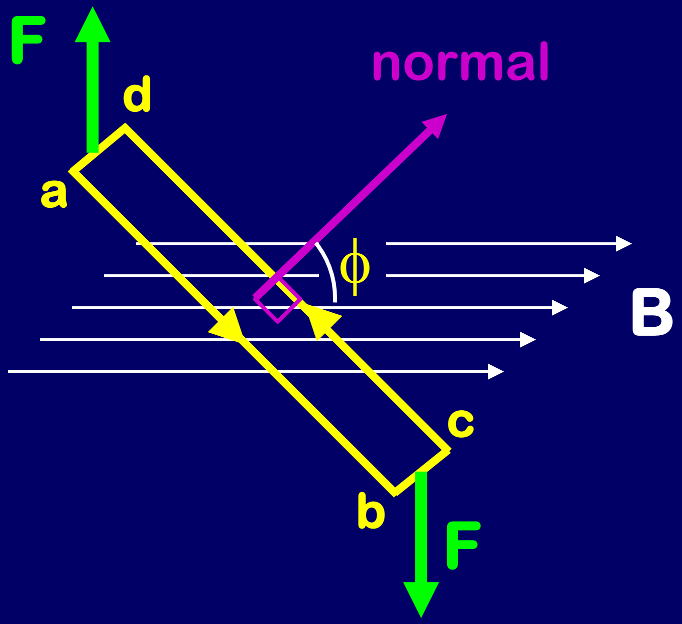
What is the torque on the loop below?

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

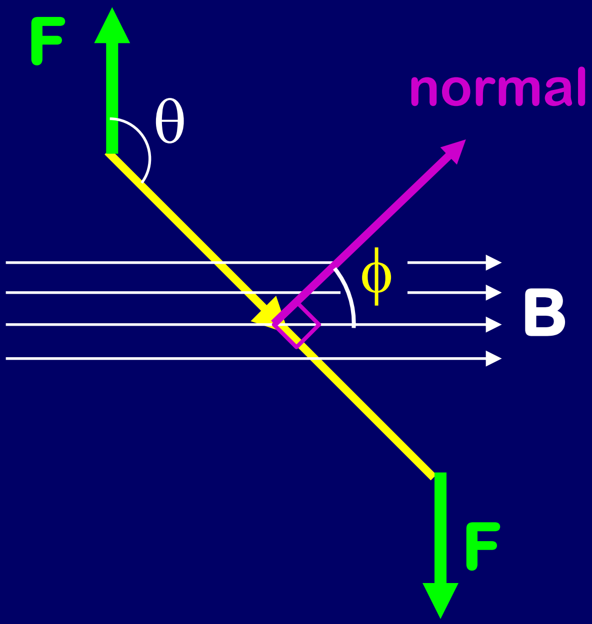


Torque on Current Loop

It is useful to define normal vector ⊥ to loop



$\phi = 180 - \theta$



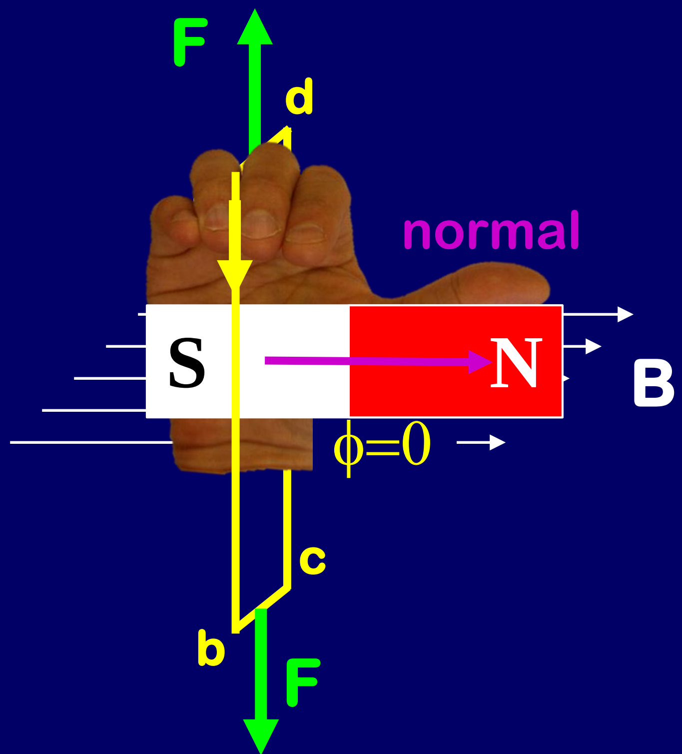
Torque is: $\tau = IAB \sin\theta = IAB \sin\varphi$

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

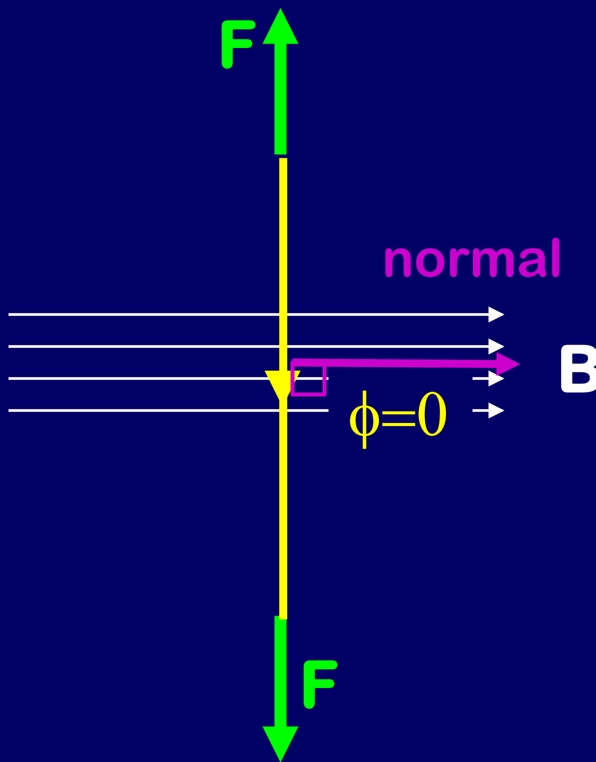
Even if loop is not rectangular, as long as it is flat

Torque on Current Loop

It is useful to define normal vector ⊥ to loop



$\phi = 180 - \theta$



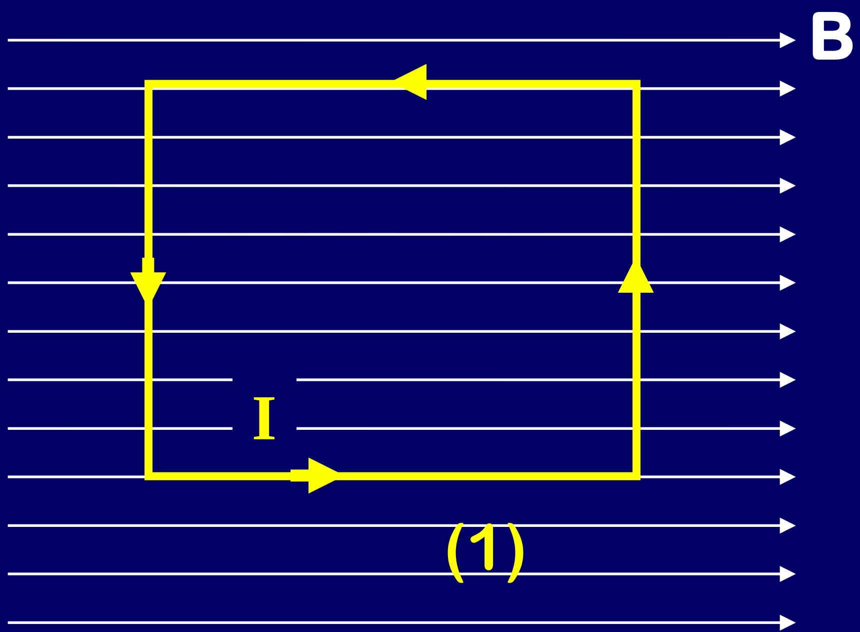
Torque is: $\tau = IAB \sin\theta = IAB \sin\varphi$

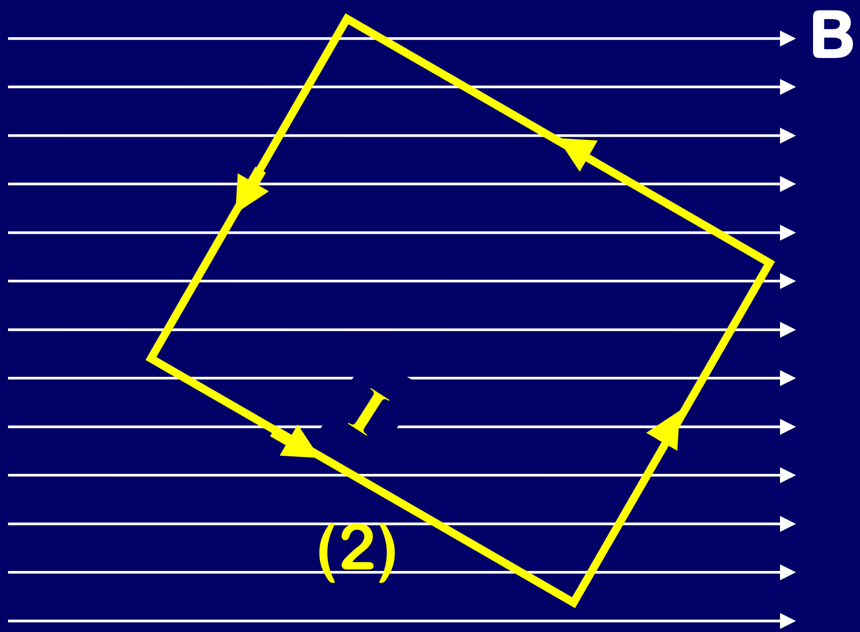
If there are N loops: $\boxed{\tau = NIAB \sin\varphi}$

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



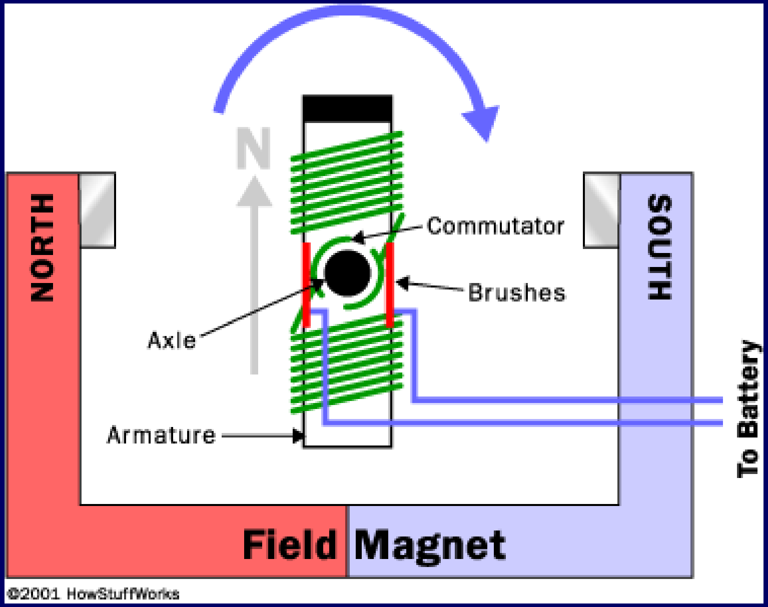


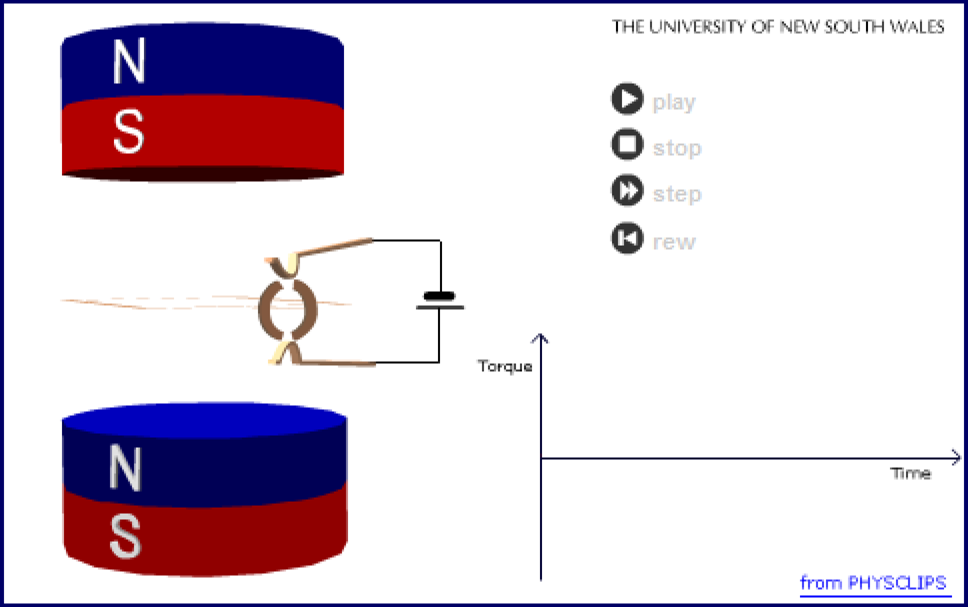
Compare the torque on loop 1 and 2 which have identical area, and current.

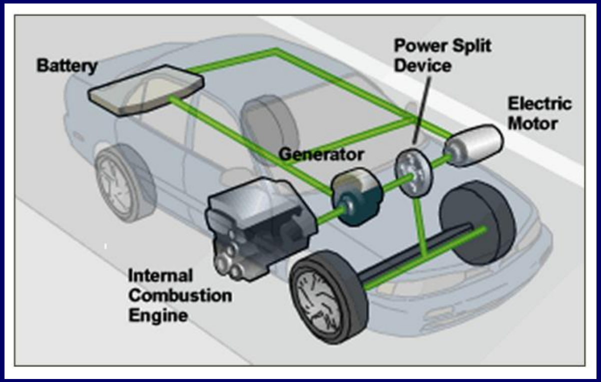
1) $\tau_1 > \tau_2$ **2)** $\tau_1 = \tau_2$ **3)** $\tau_1 < \tau_2$

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:

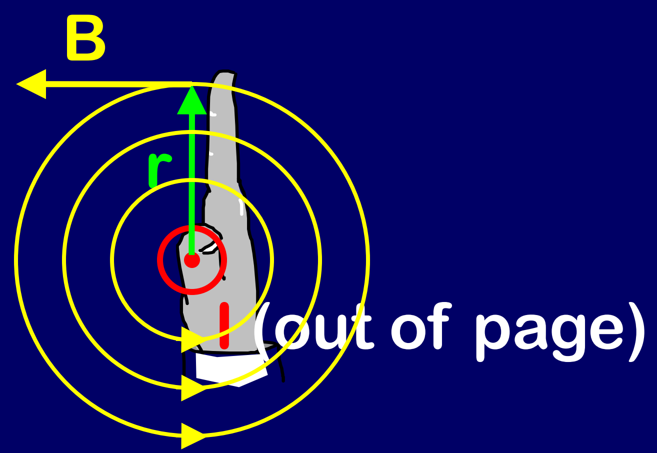
$$B = \frac{\mu_0 I}{2\pi r}$$

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

"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**

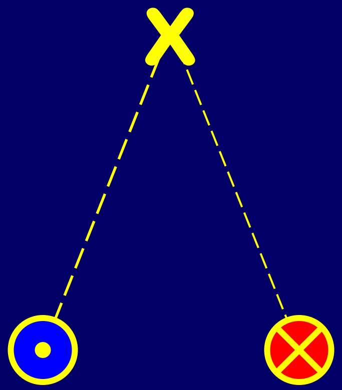


B field circles wire

Note: there are different versions of RHR

ACT: Adding Magnetic Fields

Two long wires carry opposite current

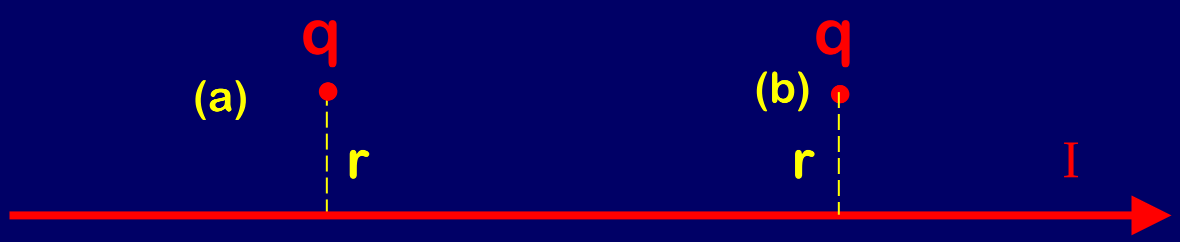


What is the direction of the magnetic field above, and midway between the two wires carrying current – at the point marked "X"?

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

Solenoids

Magnitude

- A solenoid consists of N loops of wire

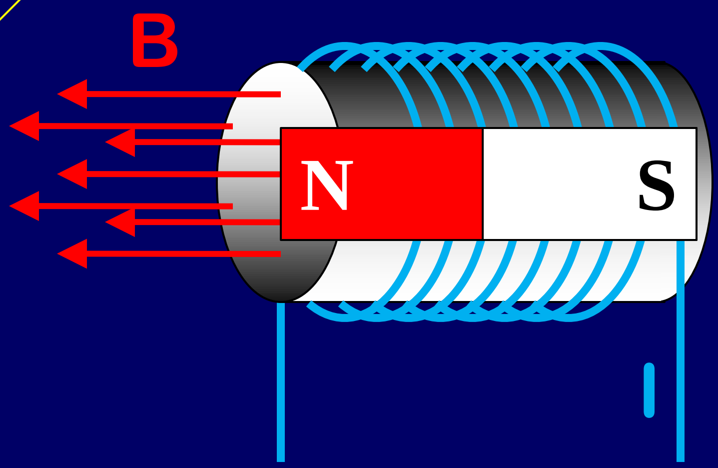
B is uniform everywhere inside of solenoid:

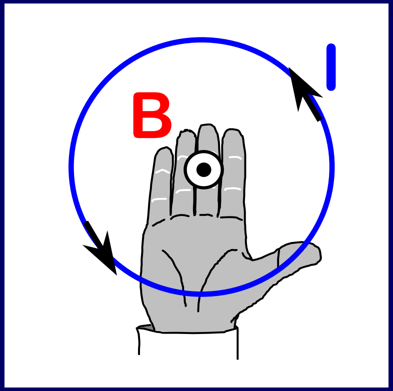
$$\boxed{B = \mu_0 n I} \qquad \mu_0 = 4\pi \times 10^{-7} Tm/A$$

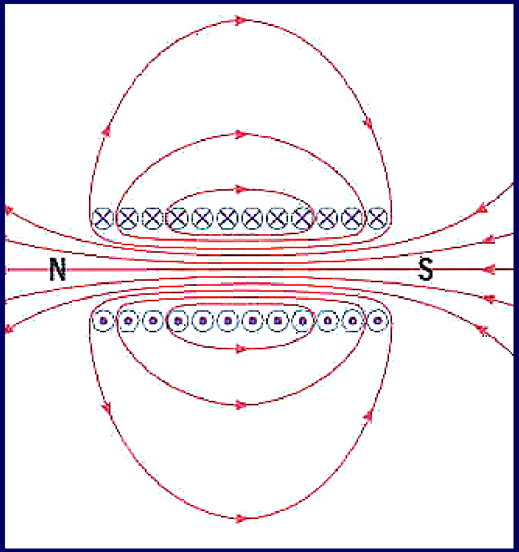
n is the number of turns of wire/meter (n = N/L)

Direction

- Use "Right-hand rule 2"



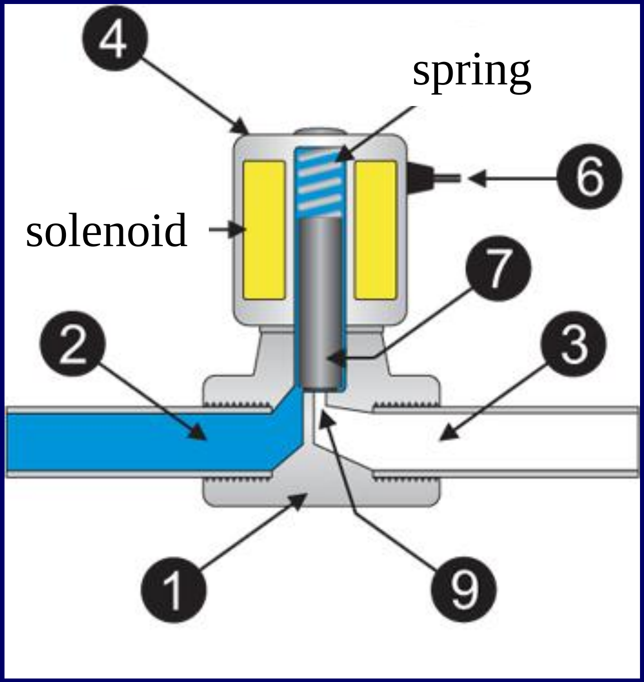




B field lines look like bar magnet!
Solenoid has N and S poles! (Checkpoint 3.1)

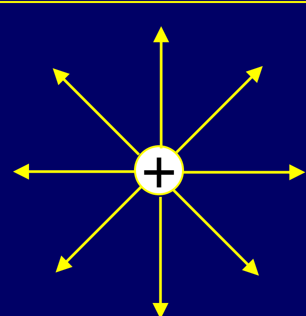
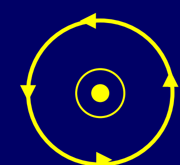
Electromagnets

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



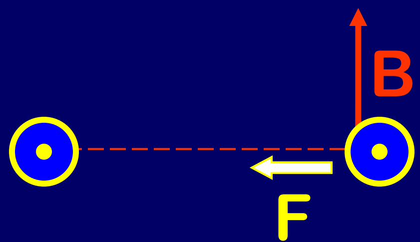
Solenoid valve

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	

Force between current-carrying wires

Currents in same direction

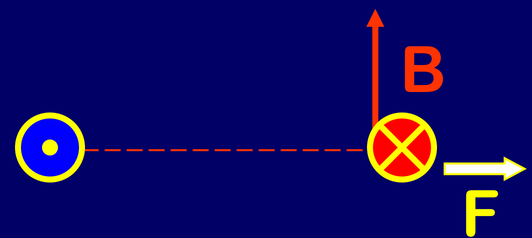


I towards us

Another I towards us

Currents in same direction attract!

Currents opposite direction

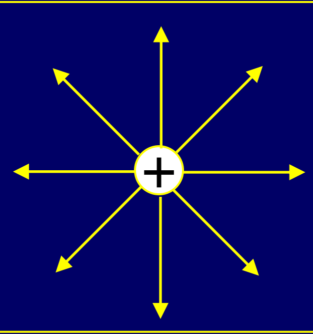
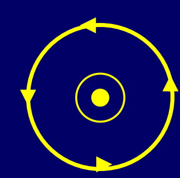


I towards us

Another I away from us

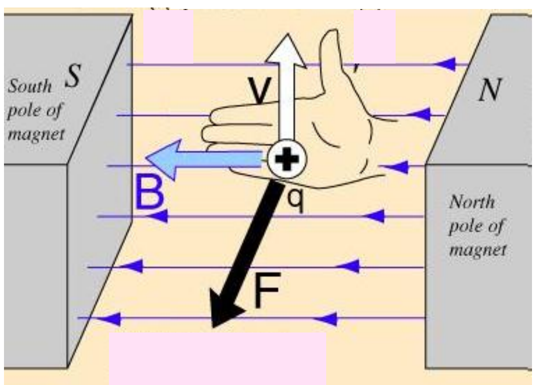
Currents in opposite direction repel!

Comparison:
Electric Field vs. *Magnetic* Field

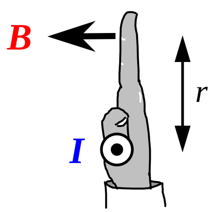
	Electric	Magnetic
Source	Charges	Moving Charges
Acts on	Charges	Moving Charges
Force	F = Eq	F = q v B sin(θ)
Direction	Parallel E	Perpendicular to v,B
Field Lines		
Opposites	Charges Attract	Currents Repel

Summary of Right-Hand Rules

RHR 1	RHR 2	Alternate
Force on moving q	**B field from current I**	



Straight wire



Solenoid