Course Updates

http://www.phys.hawaii.edu/~varner/PHYS272-Spr10/physics272.html

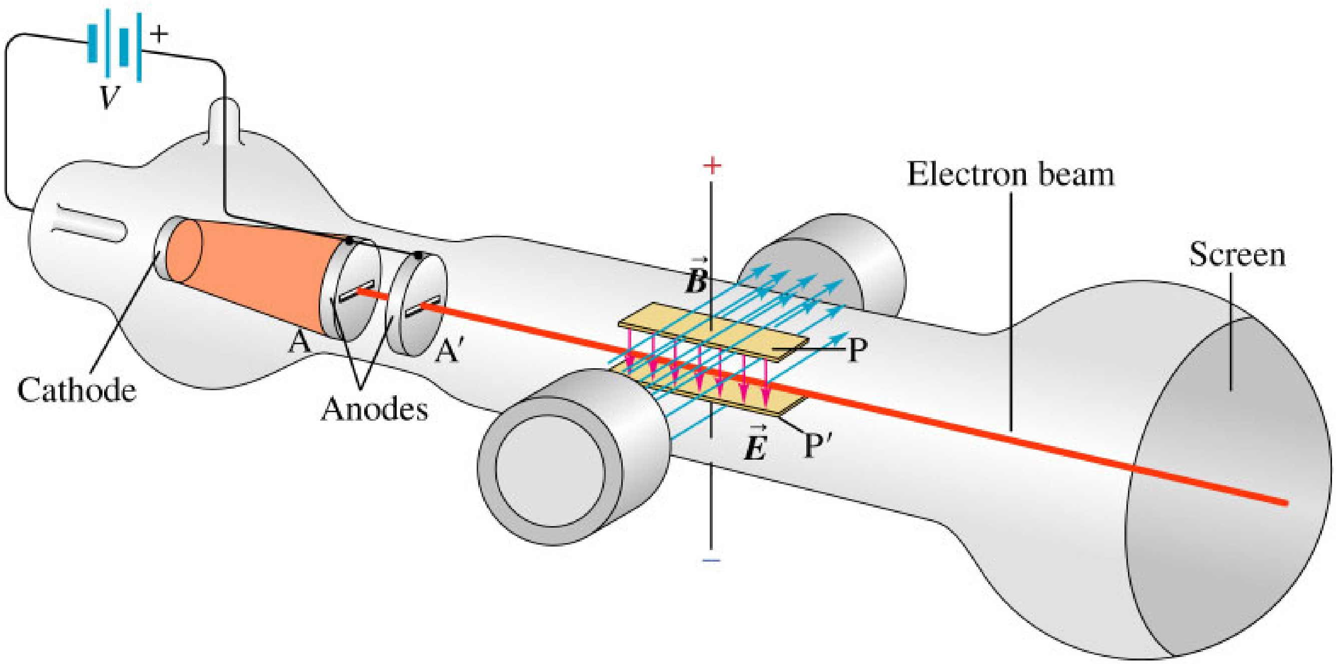
Notes for today:

1) Assignment #7 due Monday

2) This week: Finish Chap 27 (magnetic fields and forces)

3) Next week Chap 28 (Sources of B fields)

Thompson's charge/mass ratio of electron measurement

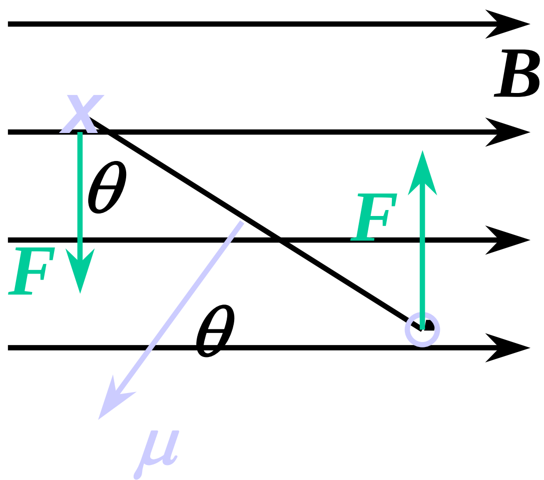


Found single value of e/m independent of cathode material. This led to discovery of electrons.

$e/m = 1.7588 \times 10^{11}$ C/kg

Magnetism

Forces & Magnetic Dipoles

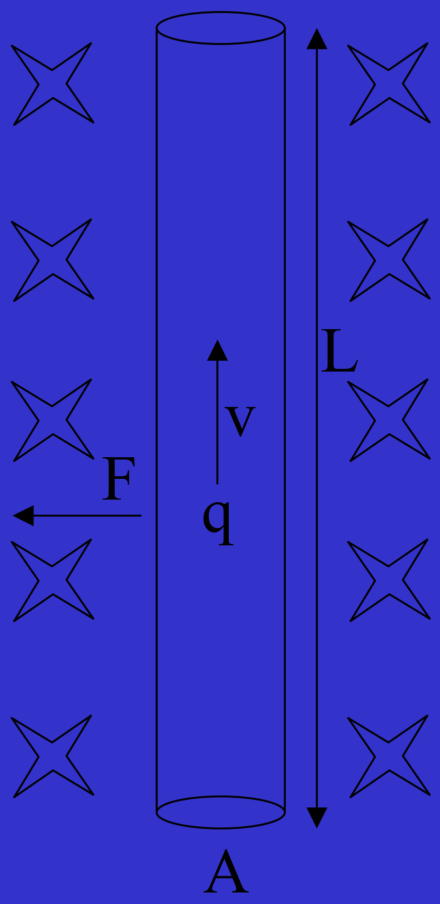


$$\mu = AI$$

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

$$U = -\vec{\mu} \bullet \vec{B}$$

Magnetic force on current carrying wire



Suppose we have a straight wire with current where charges q are moving upwards and there is a B field pointing into this slide. There is a $\vec{F} = q\vec{v} \times \vec{B}$ force tending to push the wire to the left.

Recall that current is I = n q v A (Eqn 25.2) with n=#charge/vol, v=velocity and A=area. In a length, L, the #charges = n L A, so the total force magnitude is,

$$F = (nLA)qvB = (nqvA)LB = ILB$$

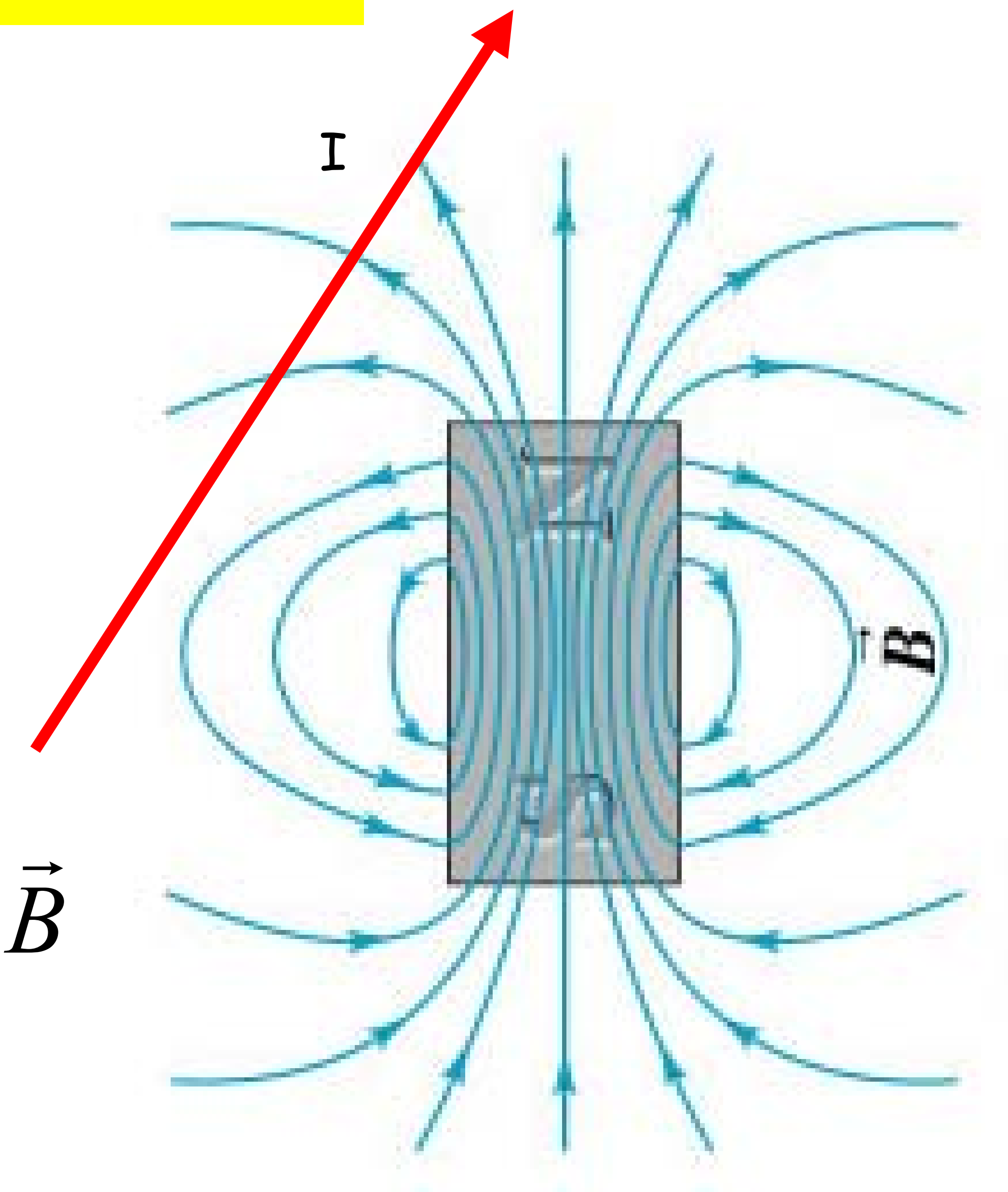
If we consider a small line segment, *dl*, we can write the vector force eqn. as,

$$d\vec{F} = Id\vec{l} \times \vec{B}$$

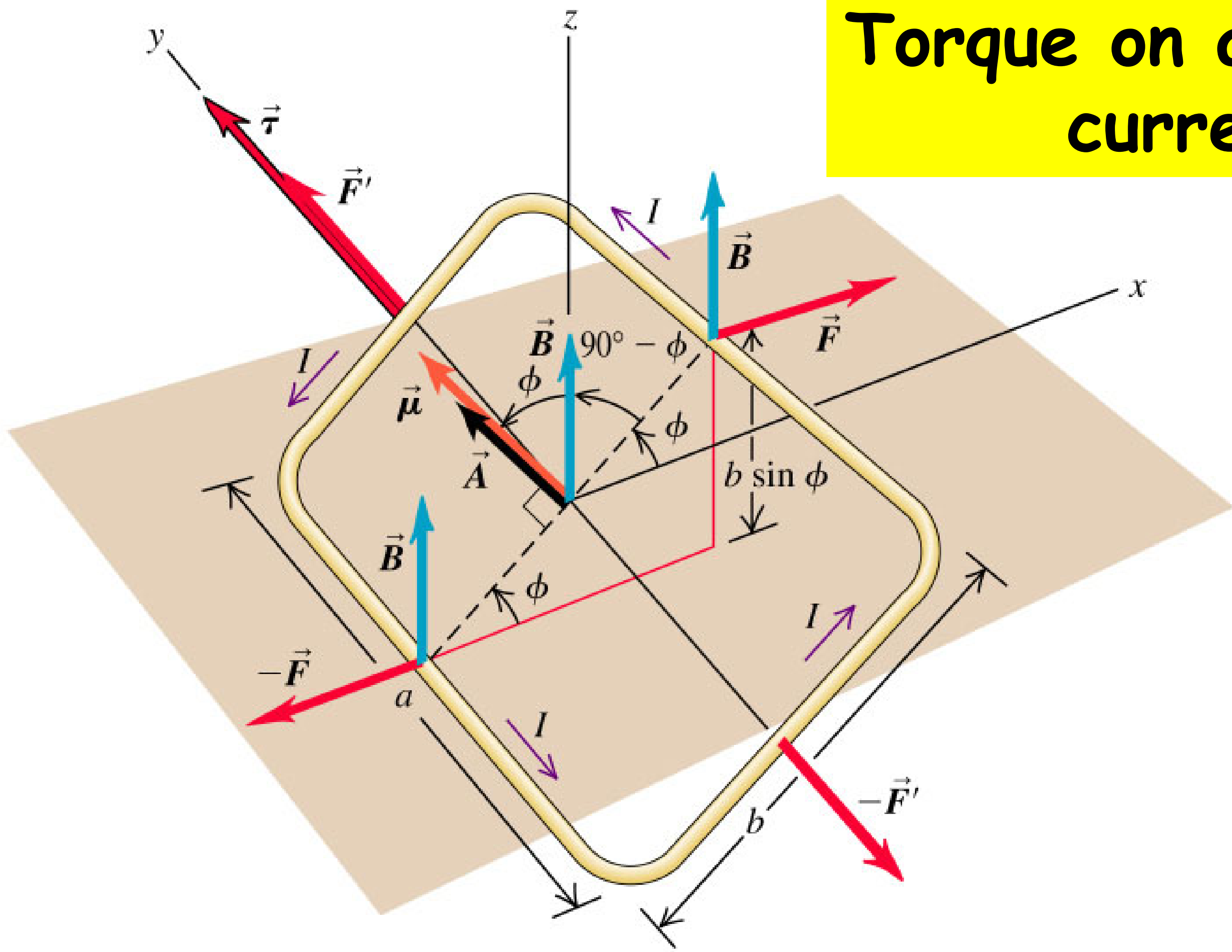
More general.

Faraday's motor

Wire with current rotates around a Permanent magnet



$$d\vec{F} = I\, d\vec{l} \times \vec{B}$$



Torque on a rectangular current loop

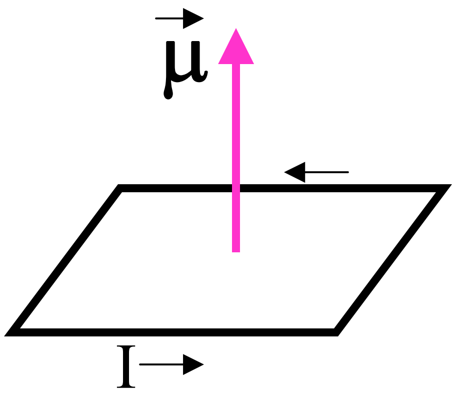
The loop will feel a torque which tends to rotate the loop, back into plane

Consider a wire loop dimensions a x b whose plane is an angle ϕ relative to a constant B field. There will be a net torque whose magnitude on this loop is given by,

$$|\vec{\tau}| = IBab \sin\phi = IB(area)\sin\phi$$

Magnetic Moment, μ , of a rectangular current loop

Definition ; μ = current×area= I A



μ is vector quantity, whose direction is normal to loop plane, use right hand rule to define direction.

We can define vector torque more conveniently in terms of **vector magnetic moment** crossed by B field

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

Another name for a current loop is "magnetic dipole"

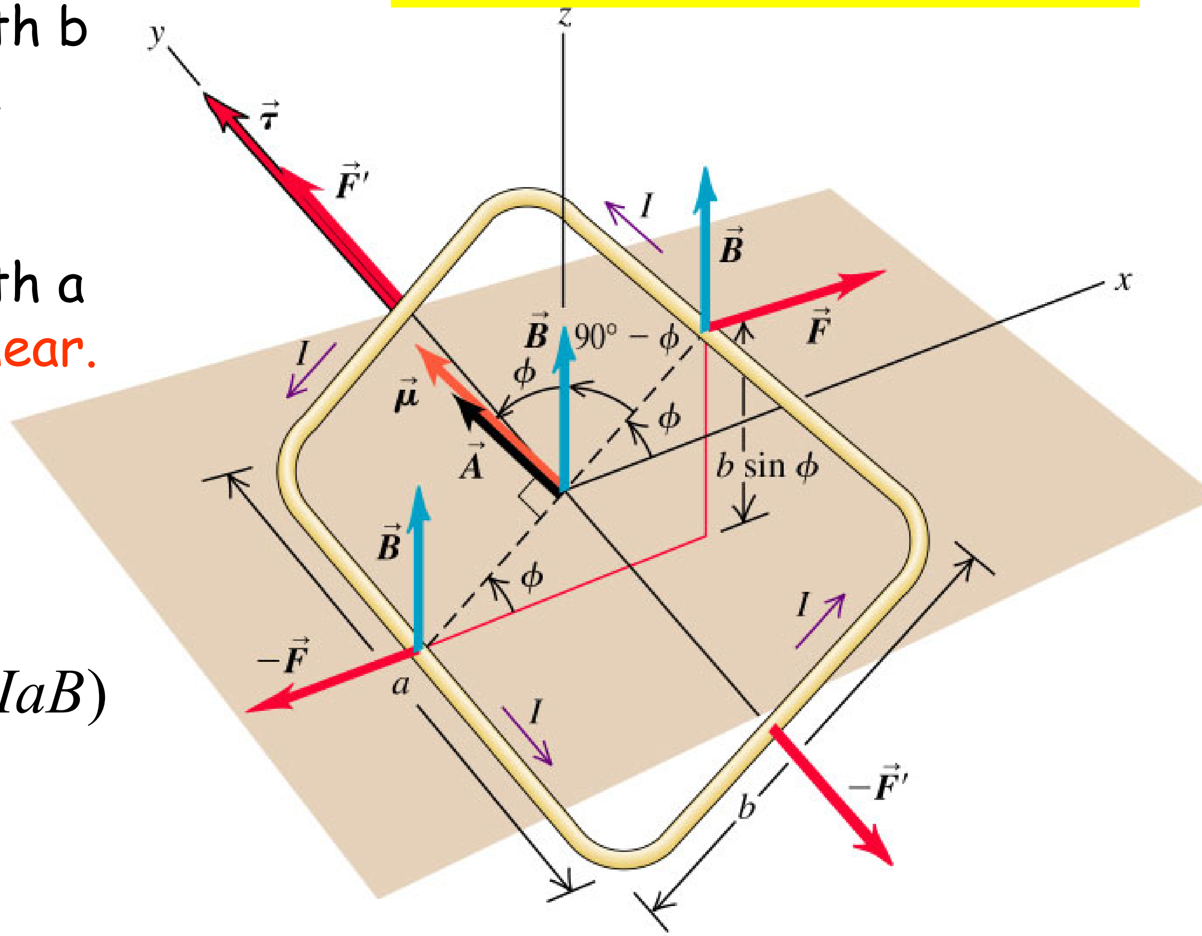
Derivation of $\vec{\tau} = \vec{\mu} \times \vec{B}$

Torque on a rectangular current loop

Forces on wires of length b are collinear and cancel.

$$\vec{F} = I\,\vec{l} \times \vec{B}$$

Forces on wires of length a cancel but are not collinear. There will be a torque.



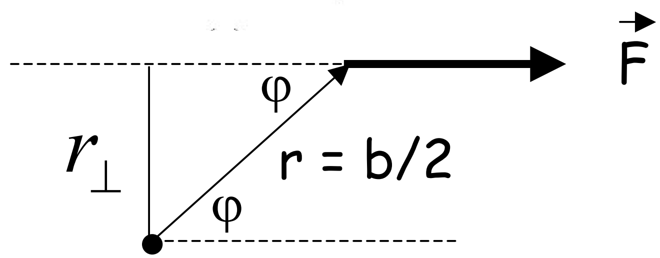
$$F = I\left|\vec{l} \times \vec{B}\right| = IaB$$

$$\tau = 2r_{\perp}F = 2\left(\frac{b}{2}\sin\phi\right)(IaB)$$

$$\left|\vec{\tau}\right| \quad = IB(ab)\sin\phi$$

$$\left|\vec{\tau}\right| = \mu B\sin\phi = \left|\vec{\mu} \times \vec{B}\right|$$

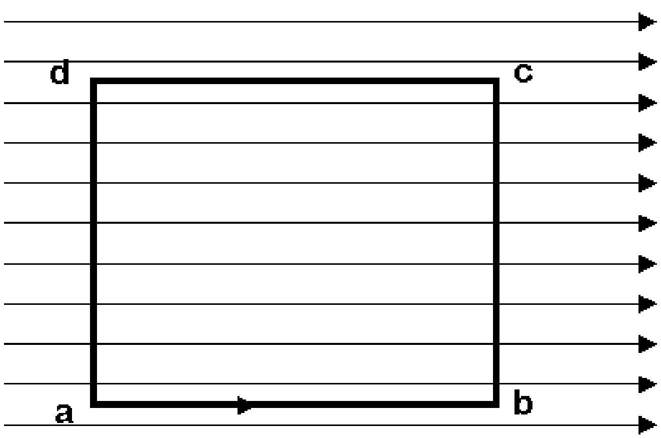
$$\vec{\tau} = \vec{\mu} \times \vec{B}$$



Question 1:

$$\vec{F} = I\vec{L} \times \vec{B}$$

A square loop of wire is carrying current in the counterclockwise direction. There is a horizontal uniform magnetic field pointing to the right.



What is the force on section a-b of the loop?

a) zero   b) out of the page   c) into the page

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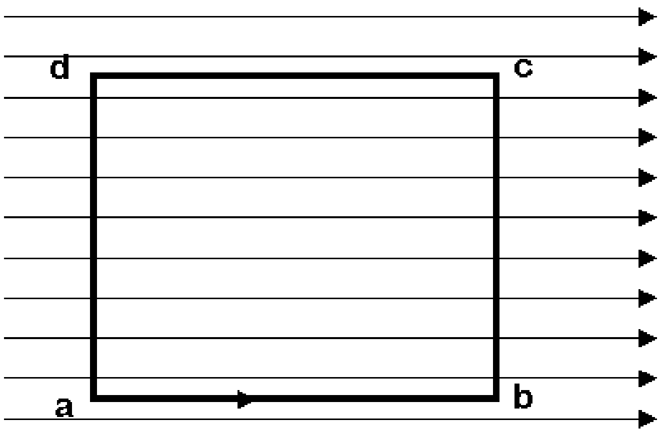

What is the force on section a-b of the loop?

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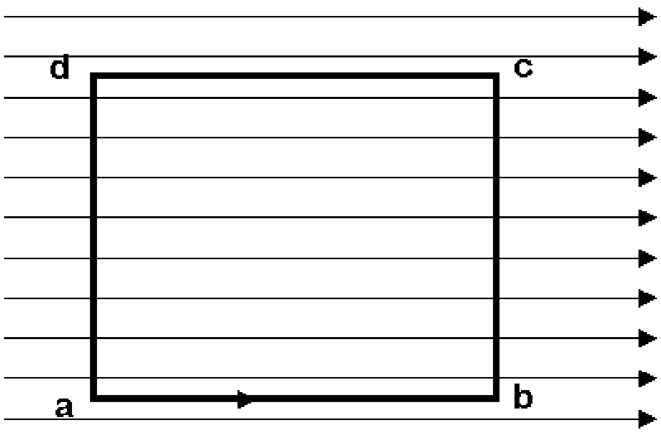
ab: $F_{ab} = 0 = F_{cd}$ since the wire is parallel to B.

Question 2:

$$\vec{F} = I\vec{L} \times \vec{B}$$

A square loop of wire is carrying current in the counterclockwise direction. There is a horizontal uniform magnetic field pointing to the right.



What is the force on section b-c of the loop?

a) zero b) out of the page c) into the page

Question 2:

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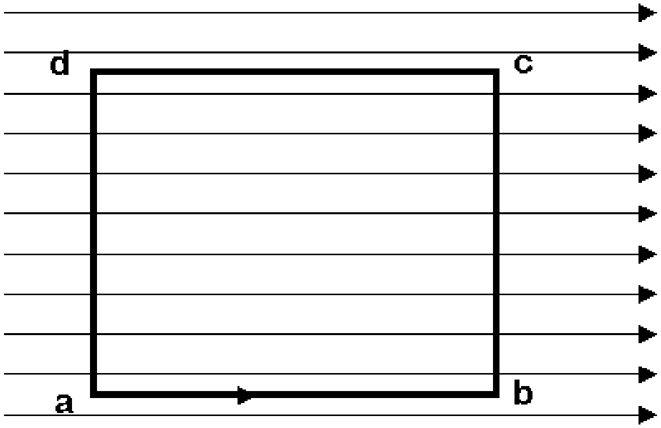
A square loop of wire is carrying current in the counterclockwise direction. There is a horizontal uniform magnetic field pointing to the right.



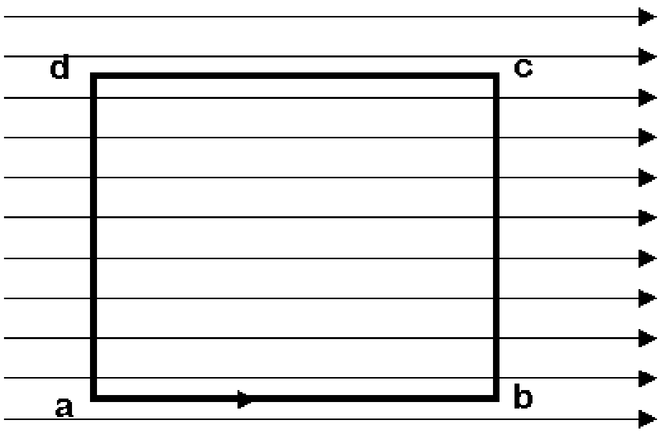
What is the force on section b-c of the loop?

a) zero   b) out of the page   c) into the page

bc: $F_{bc} = ILB$ RHR: I is up, B is to the right, so F points into the screen.

Question 3:

$$\vec{F} = I\vec{L} \times \vec{B}$$



A square loop of wire is carrying current in the counterclockwise direction. There is a horizontal uniform magnetic field pointing to the right.

What is the net force on the loop?

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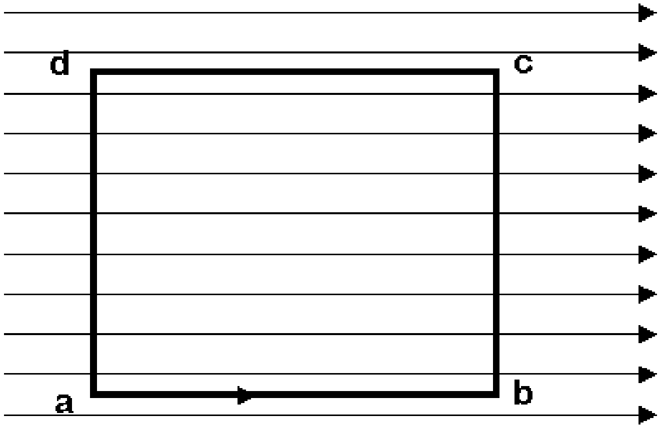

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What is the net force on the loop?

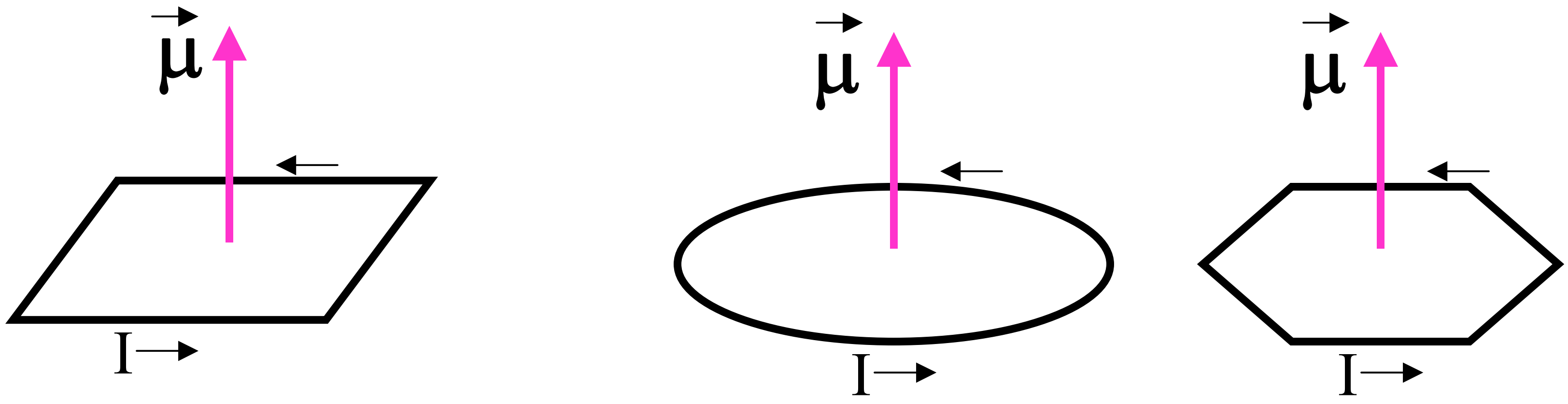
a) zero b) out of the page c) into the page

By symmetry: $\vec{F}_{da} = -\vec{F}_{bc} \quad \Rightarrow \quad \vec{F}_{net} = \vec{F}_{ab} + \vec{F}_{bc} + \vec{F}_{cd} + \vec{F}_{da} = 0$

Magnetic Moment, μ , of arbitrary loop

Definition ; μ = current×area= I A
We can more generally define magnetic moments only by area and do not need to know the actual dimensions.

This is general

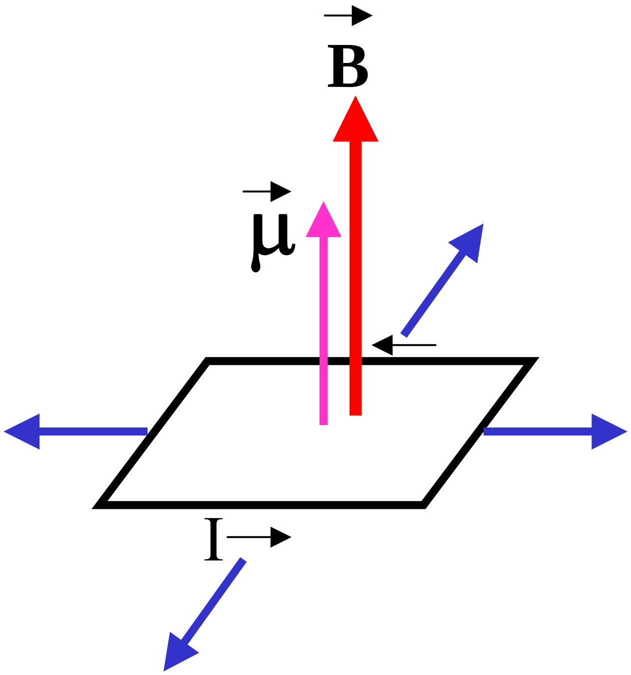


For any shape, μ = current×area= I A
and

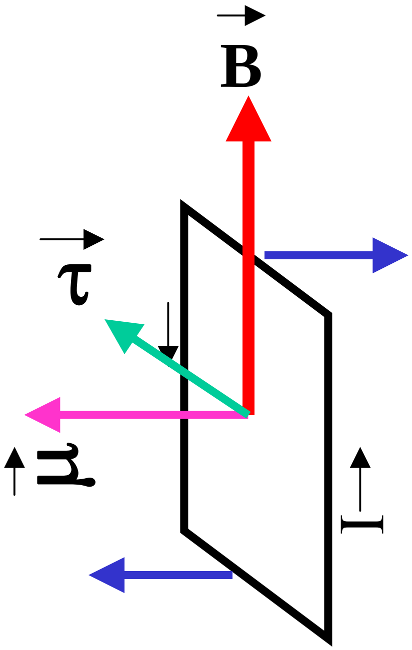
$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

Note: if loop consists of N turns, $\mu = NAI$

Torque on loop in different angular positions



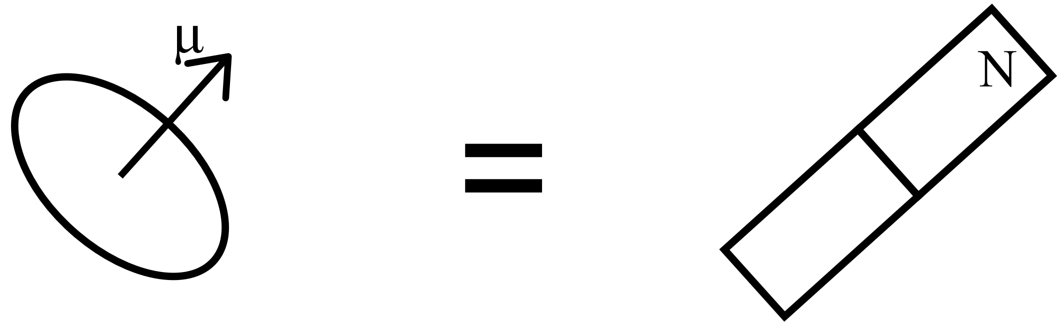
Net torque is **zero** when
B is parallel to μ



Net torque is **maximum** when
B is perpendicular to μ

Bar Magnet Analogy

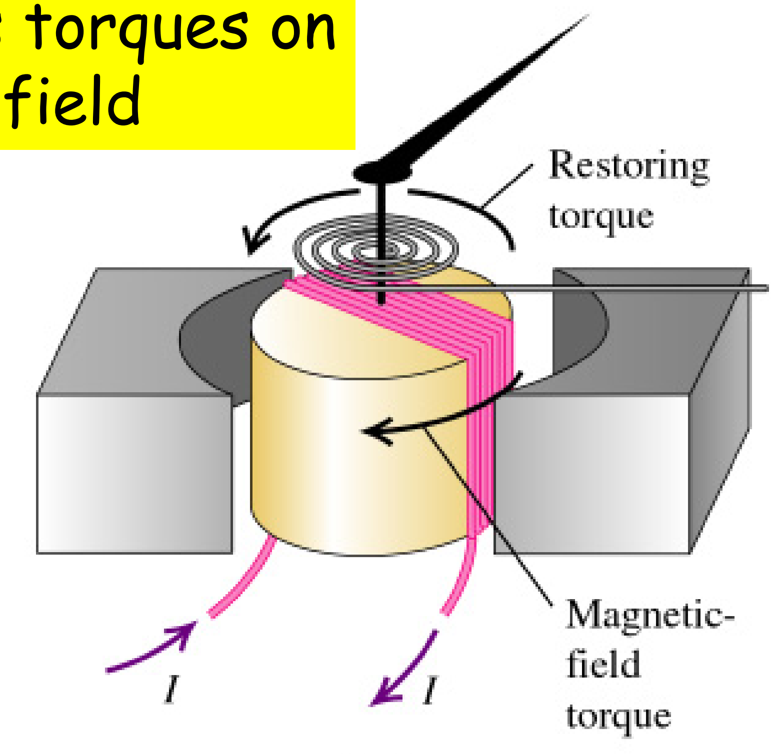
- You can think of a magnetic dipole moment as a bar magnet:



  - In a magnetic field they both experience a torque trying to line them up with the field
  - As you increase I of the loop → stronger bar magnet

- We will see that such a current loop *does* produce magnetic fields, similar to a bar magnet.

Application; galvanometer uses torques on coiled loops in magnetic field



Torque is produced about the needle axis and this counter acts the restoring spring and enables the needle to rotate

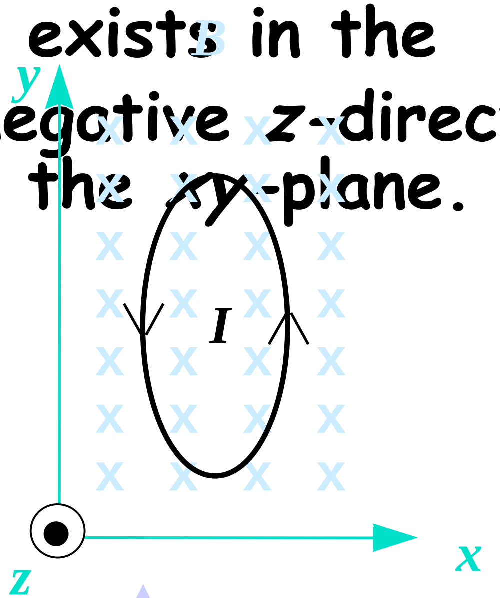
Current increased
→ $\mu = I \cdot \text{Area}$ increases
→ Torque from ***B*** increases
→ Angle of needle increases

Current decreased
→ μ decreases
→ Torque from ***B*** decreases
→ Angle of needle decreases

This is how almost all dial meters work—voltmeters, ammeters, speedometers, RPMs, etc.

Example: Loop in a B-Field

A circular loop has radius R = 5 cm and carries current I = 2 A in the counterclockwise direction. A magnetic field B =0.5 T exists in the negative z-direction. The loop is at an angle $\theta = 30°$ to the xy-plane.

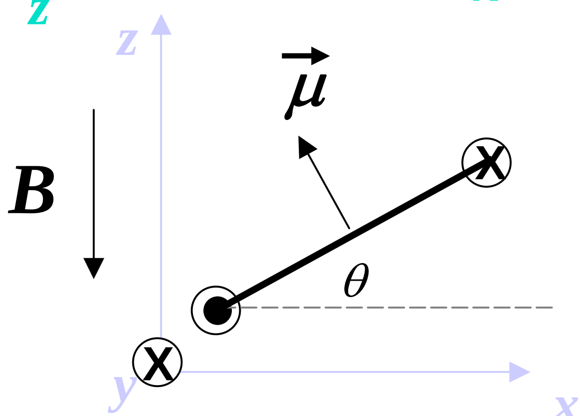


What is the magnetic moment μ of the loop?

$$\mu = \pi r^2 I = .0157 \text{ Am}^2$$

The direction of μ is perpendicular to the plane of the loop as in the figure.

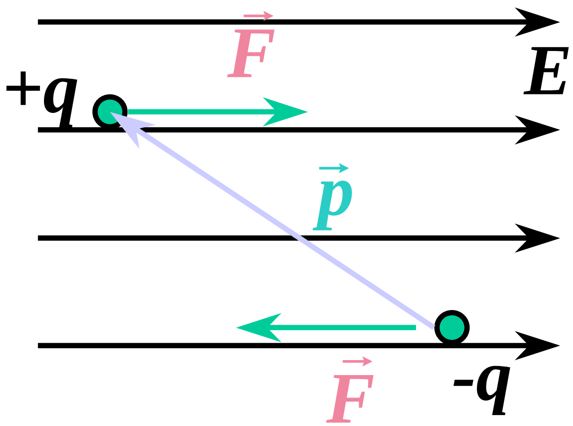
Find the x and z components of $\vec{\mu}$:

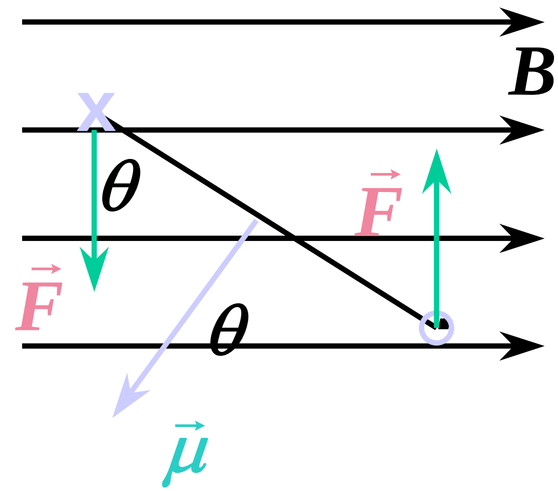


$$\mu_x = -\mu \sin 30° = -.0079 \text{ Am}^2$$

$$\mu_z = \mu \cos 30° = .0136 \text{ Am}^2$$

Electric Dipole Analogy





$$\vec{\tau} = \vec{r} \times \vec{F}$$

$$\vec{F} = q\vec{E}$$

$$\vec{p} = 2q\vec{a}$$

$$\boxed{\vec{\tau} = \vec{p} \times \vec{E}}$$

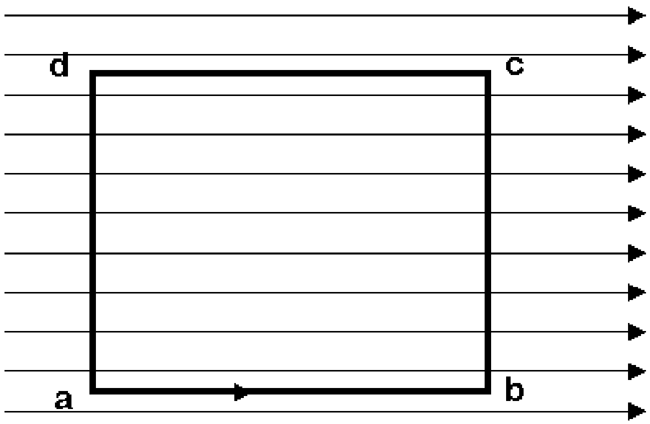
$$\vec{\tau} = \vec{r} \times \vec{F}$$

$\vec{F} = I\vec{L} \times \vec{B}$ (per turn)

$$\mu = NAI$$

$$\boxed{\vec{\tau} = \vec{\mu} \times \vec{B}}$$

Question 4:



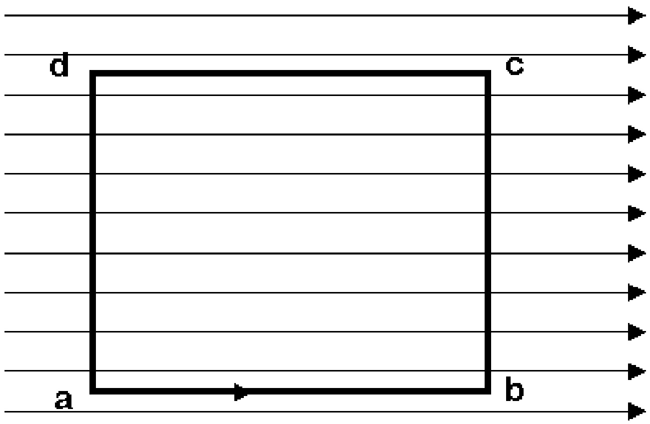
A square loop of wire is carrying current in the counterclockwise direction. There is a horizontal uniform magnetic field pointing to the right.

6) What is the net torque on the loop?

a) zero b) up c) down d) out of the page e) into the page

Question 4:

A square loop of wire is carrying current in the counterclockwise direction. There is a horizontal uniform magnetic field pointing to the right.

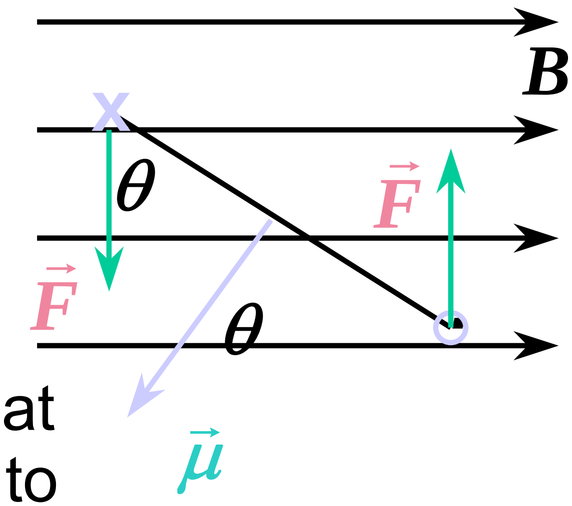


6) What is the net torque on the loop?

a) zero b) up c) down d) out of the page e) into the page

$\vec{\tau} = \vec{\mu} \times \vec{B}$ μ points out of the page (curl your fingers in the direction of the current around the loop, and your thumb gives the direction of μ). Use the RHR to find the direction of τ to be up.

Potential Energy of Dipole



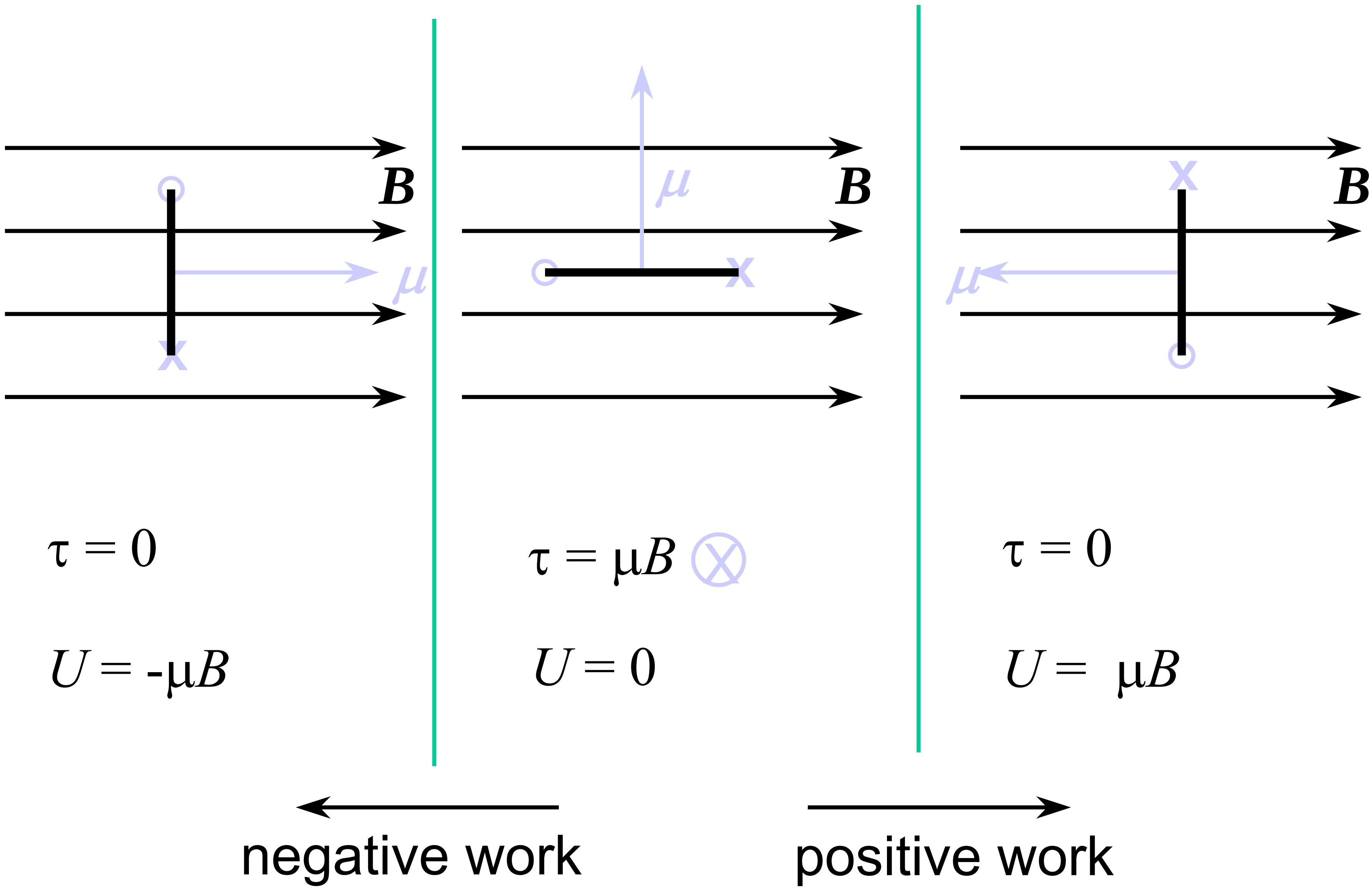
- **Work must be done to change the orientation of a dipole (current loop) in the presence of a magnetic field.**
- Define a potential energy U (with zero at position of max torque) corresponding to this work.

$$U \equiv \int_{90^\circ}^{\theta} \tau d\theta \quad \Rightarrow \quad U = \int_{90^\circ}^{\theta} \mu B \sin\theta d\theta$$

Therefore,

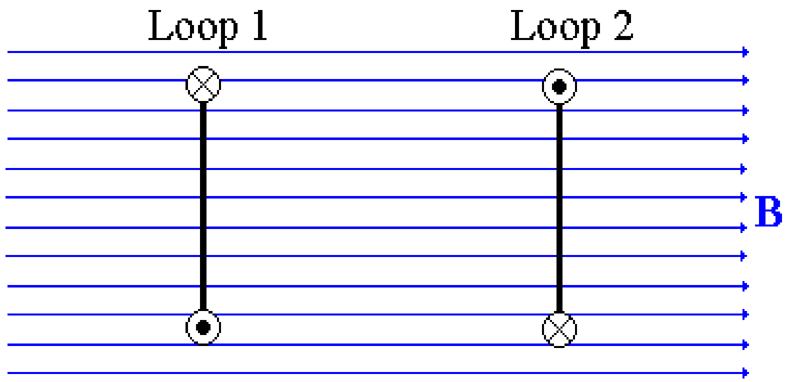
$$U = \mu B\left[-\cos\theta\right]_{90^\circ}^{\theta} \Rightarrow U = -\mu B\cos\theta \Rightarrow \boxed{U = -\vec{\mu} \bullet \vec{B}}$$

Potential Energy of Dipole



Question 5:

Two current carrying loops are oriented in a uniform magnetic field. The loops are nearly identical, except the direction of current is reversed.



What is the torque on loop 1?

a) clockwise   b) counter-clockwise   c) zero

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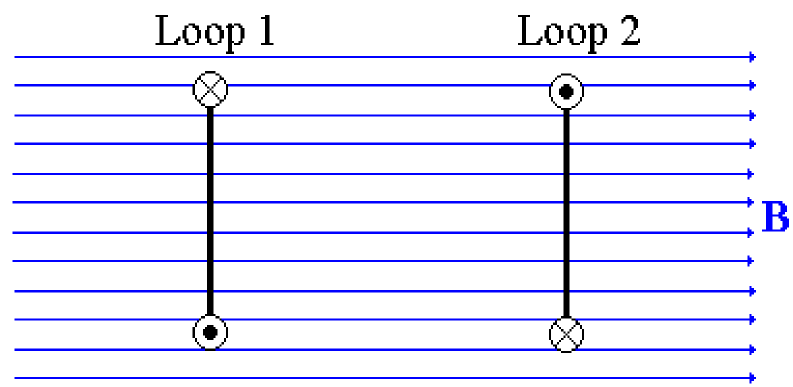

What is the torque on loop 1?

a) clockwise b) counter-clockwise c) zero

Loop 1: μ points to the left, so the angle between μ and B is equal to 180º, hence $\tau = 0$.

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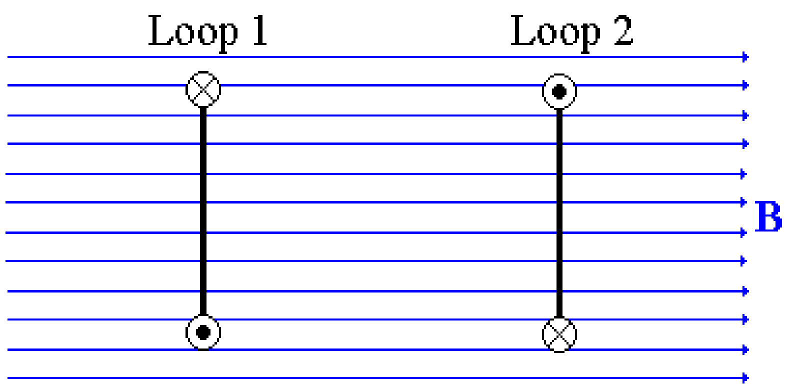

How does the torque on the two loops compare?

a) $\tau_1 > \tau_2$ b) $\tau_1 = \tau_2$ c) $\tau_1 < \tau_2$

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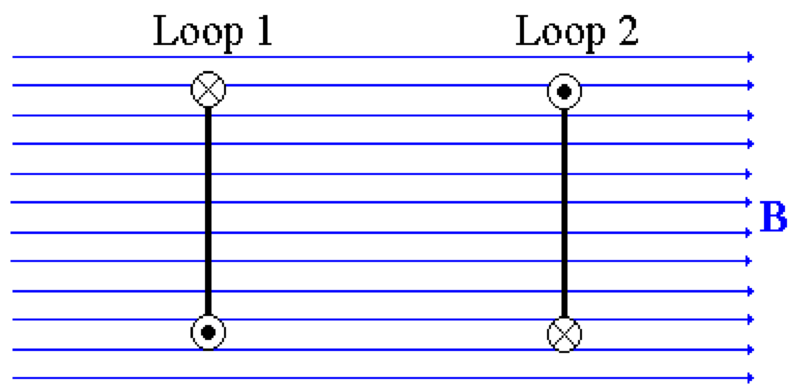


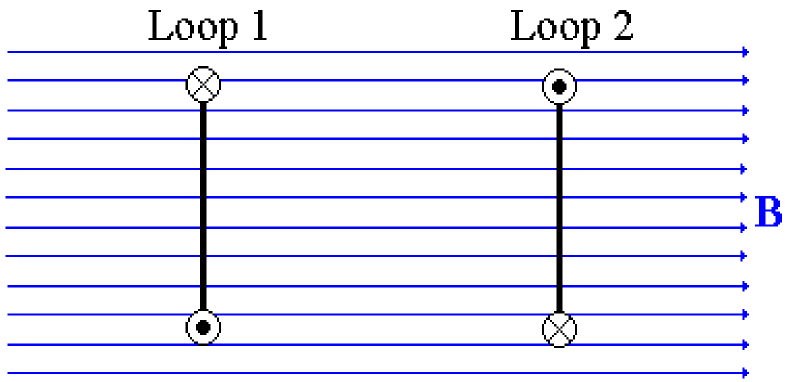
How does the torque on the two loops compare?

a) $\tau_1 > \tau_2$ b) $\tau_1 = \tau_2$ c) $\tau_1 < \tau_2$

Loop 2: μ points to the right, so the angle between μ and B is equal to 0^o, hence $\tau = 0$.

Question 7:

Two current carrying loops are oriented in a uniform magnetic field. The loops are nearly identical, except the direction of current is reversed.



Which loop occupies a potential energy minimum, and is therefore stable?

a) loop 1

b) loop 2

c) the same

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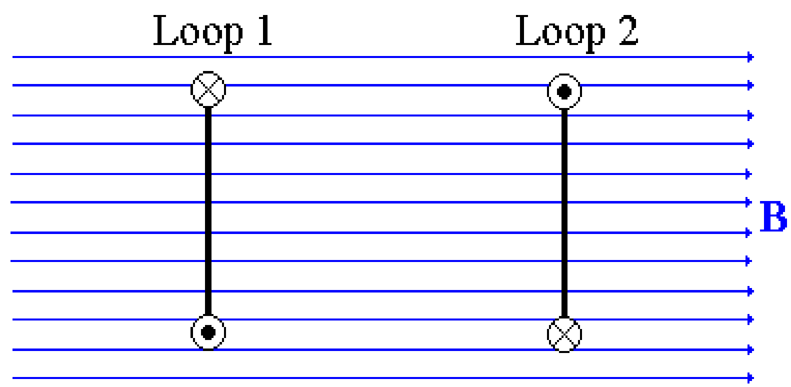


Which loop occupies a potential energy minimum, and is therefore stable?

a) loop 1

b) loop 2

c) the same

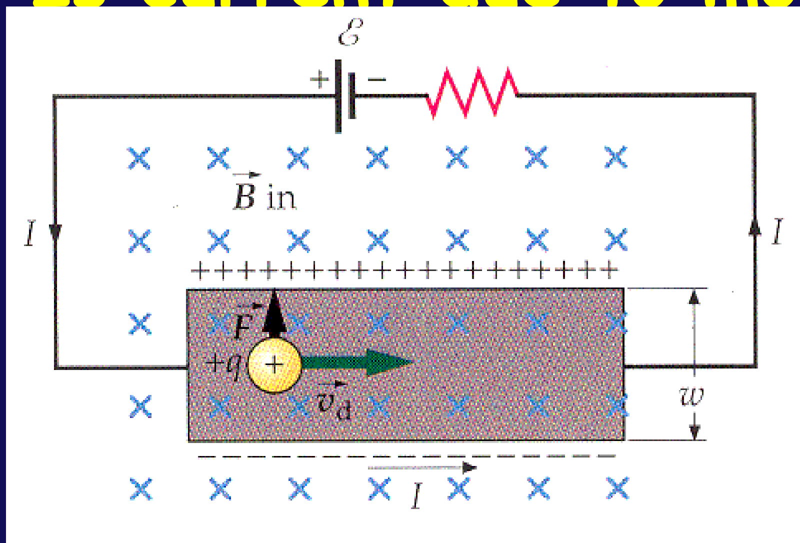
$$U = -\vec{\mu} \bullet \vec{B}$$

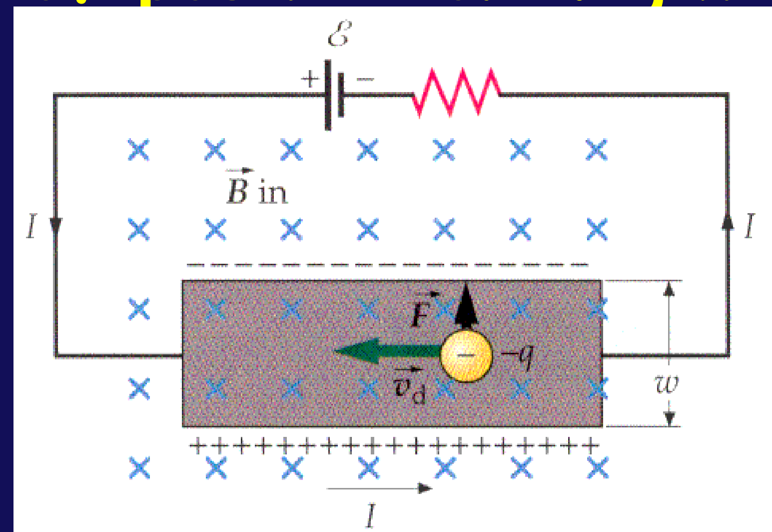
Loop 1: $U_1 = +\mu B$

Loop 2: $U_2 = -\mu B \quad \Rightarrow U_2$ is a minimum.

The Hall Effect

- Is current due to motion of positive or negative





- Positive charges moving CCW experience upward force
- Upper plate at *higher* potential

- Negative charges moving clockwise experience upward force
- Upper plate at *lower* potential

Equilibrium between electrostatic & magnetic forces:

$$F_{up} = q v_{drift} B \qquad F_{down} = qE_{induced} = q\frac{V_H}{w} \qquad V_H = v_{drift} B w = \text{"Hall Voltage"}$$

- This type of experiment led to the discovery (E. Hall, 1879) that current in conductors is carried by negative charges (not always so in semiconductors).
- Can be used as a B-sensor.

For next time

- HW #7 → due Monday
- Well into Magnetism – keep up on reading
- Decision time approaching