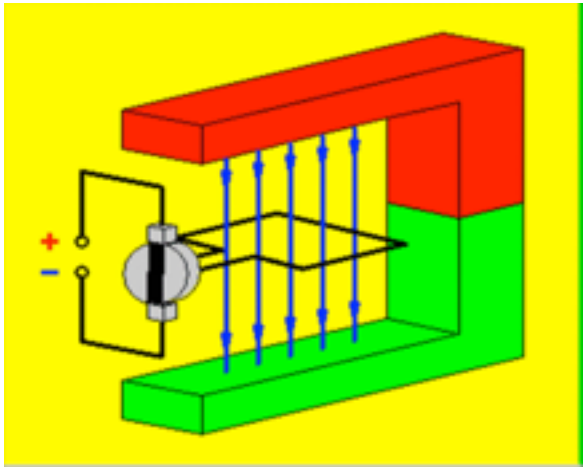
# *Electricity & Magnetism Lecture 13*

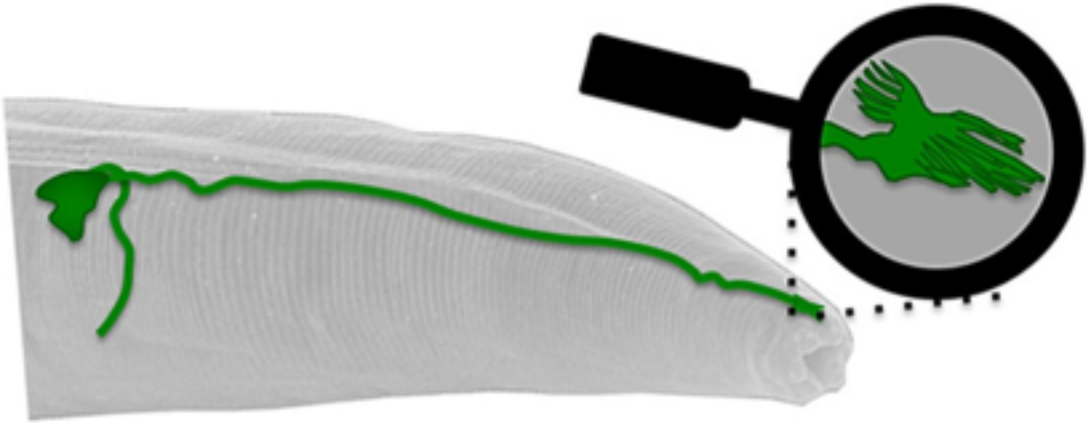
## Today's Concept:

Torques



# Worms Feel B field

Worms (C. elegans) can sense the earth's magnetic field.



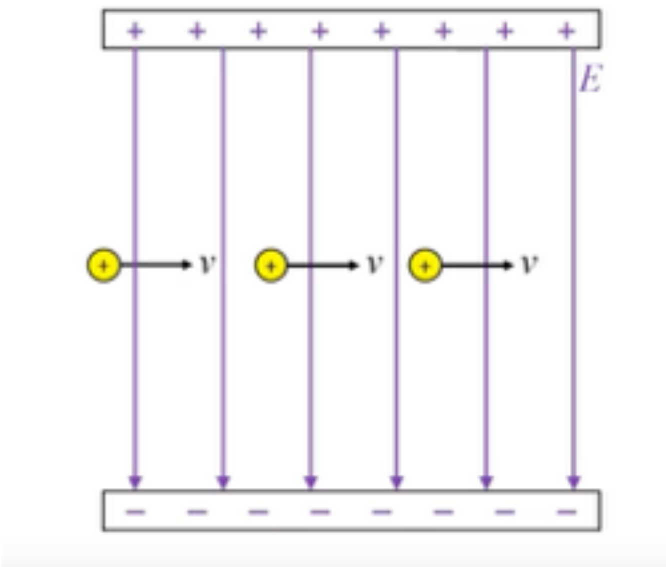
Why is the zero of potential energy for the closed loop taken from where it is perpendicular to the electric field?

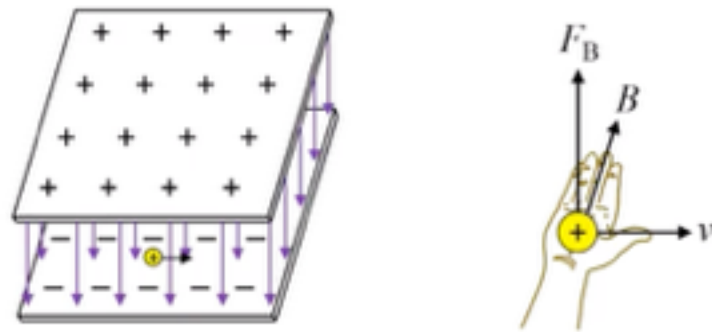
I do not understand if there is no net force on the loop how there can be torque and how the torque doesn't eventually stop.

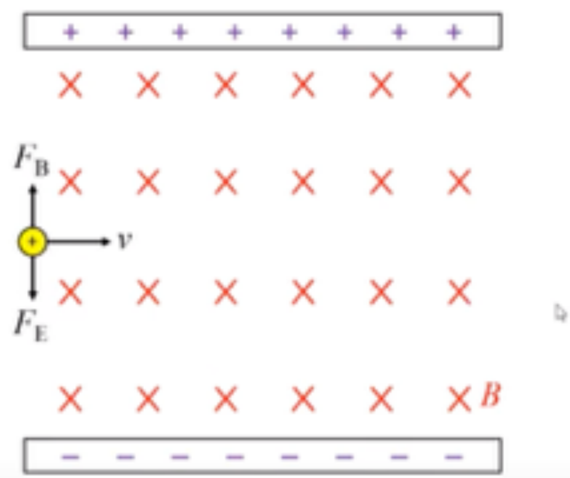
can you prove how the cross product works?

When are we getting our midterm marks back : o

# Velocity Selector



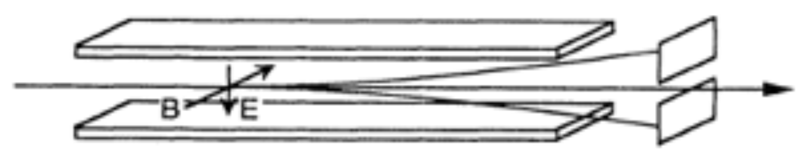




$$F_B = F_E$$

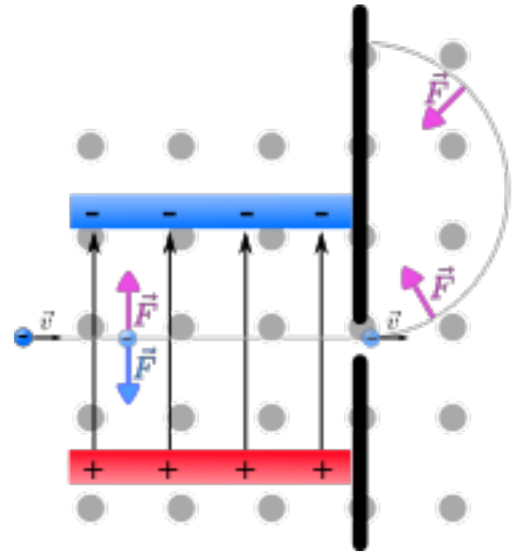
$$qvB = qE$$

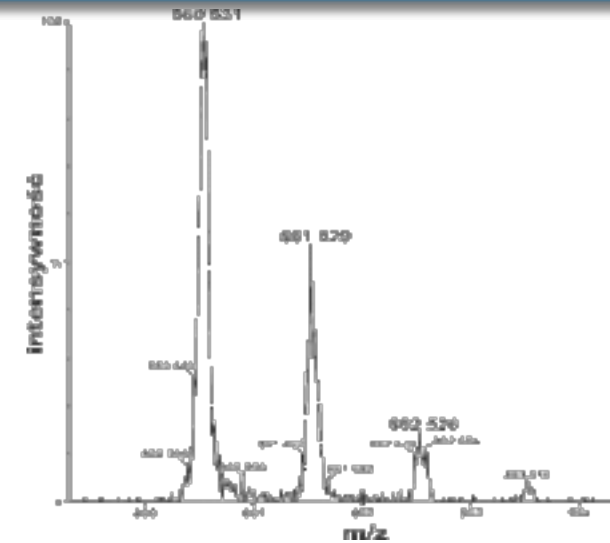
$$v = \frac{E}{B}$$




Source: Wikipedia and youtube

# Application: Mass spectrometer






A velocity selector is used to select ions of given velocity.

Then they are projected into a region of constant B and zero E.

The radius of curvature depends on the ion's mass.

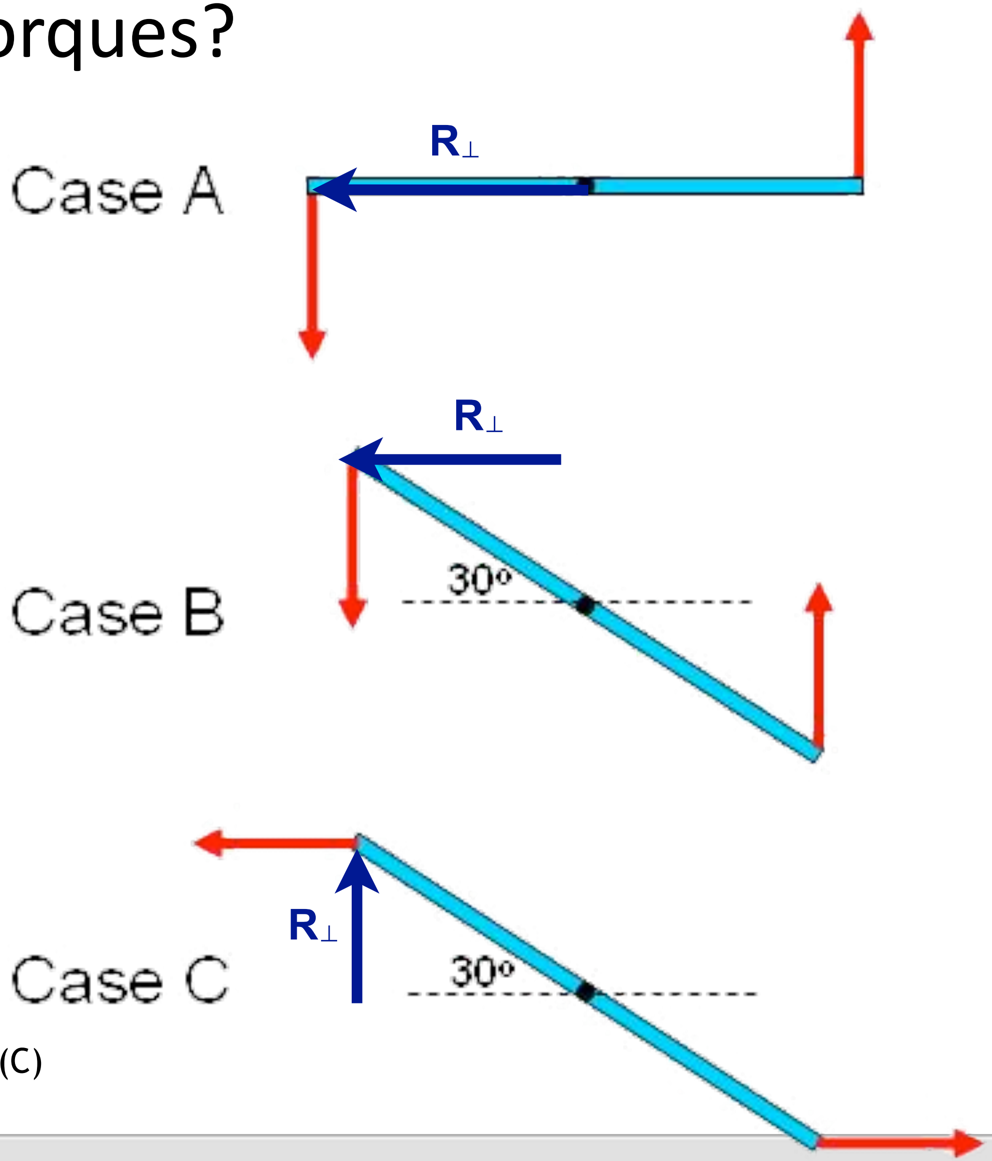
A detector shows the various masses in the beam.

# Torque Review

Compare the torques?

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

$$|\vec{\tau}| = R_{\perp} F$$




Torque(A) > Torque(B) > Torque(C)

## Last Time:

$$\vec{F} = q\vec{v} \times \vec{B}$$

## This Time:

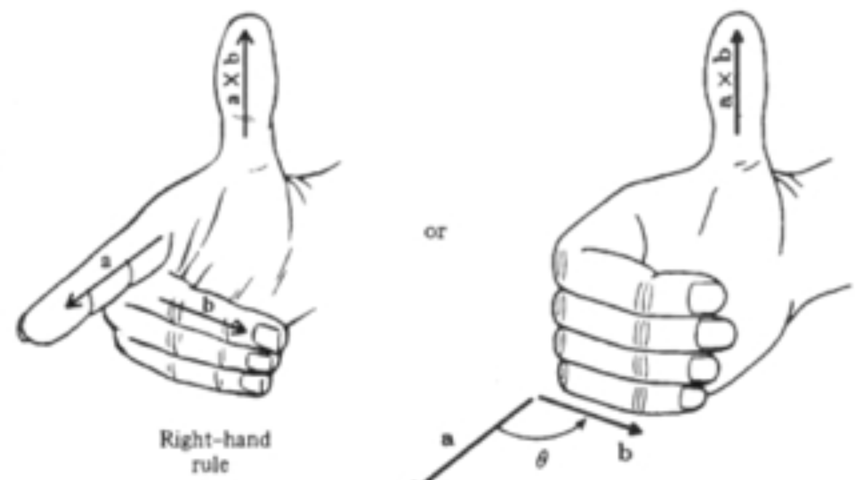
$$\vec{F} = q\sum_i \vec{v}_i \times \vec{B}$$

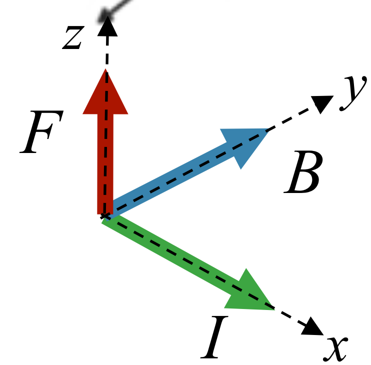
$$\vec{F} = qN\vec{v}_{avg} \times \vec{B} \quad \rightarrow \quad \vec{F} = I\vec{L} \times \vec{B}$$

$$N = nAL$$

$$I = qnAv_{avg}$$

qv and IL have same Dimensions!

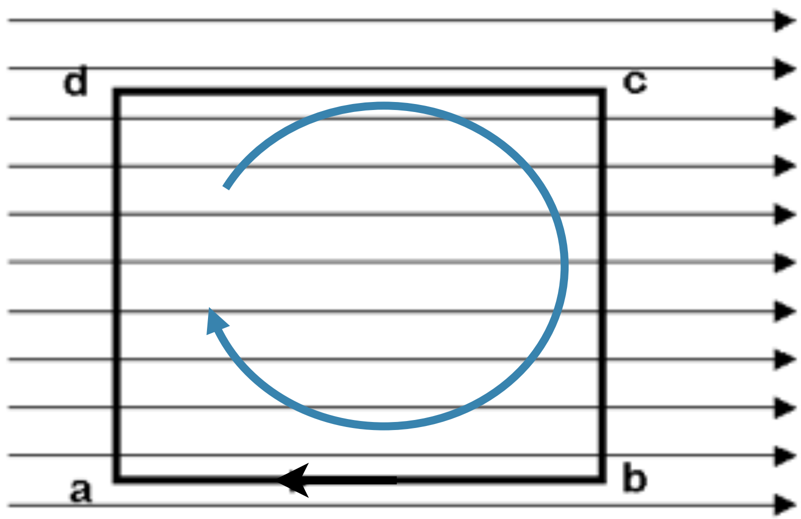


# Clicker Question

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

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



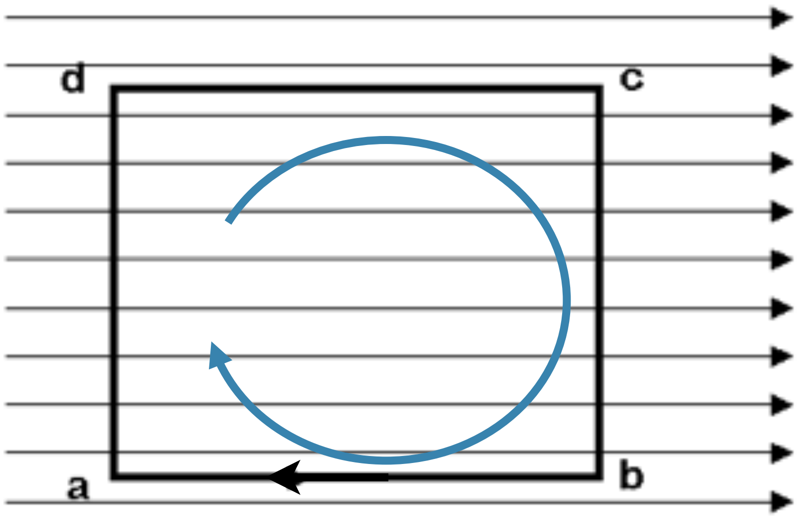

**What is the force on section a-b on the loop?**

A. Zero
B. Out of page
C. Into the Page

# Clicker Question

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

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



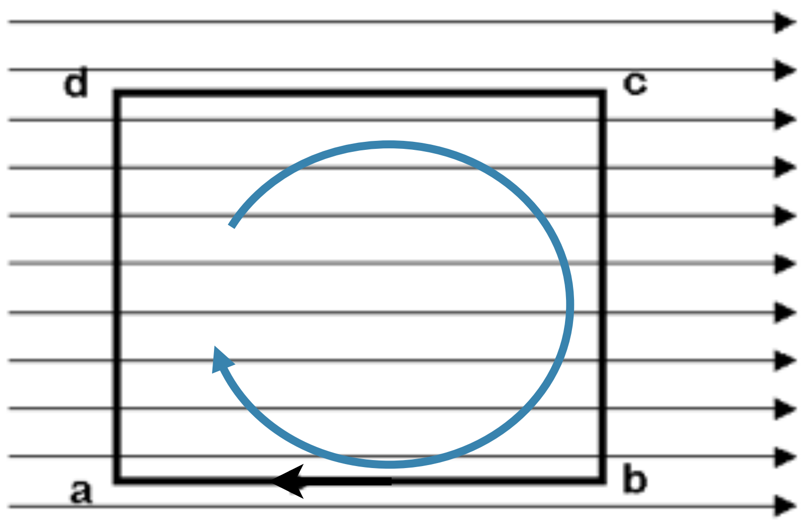

**What is the force on section b-c on the loop?**

A. **Zero**
B. **Out of page**
C. **Into the Page**

# Clicker Question

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

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



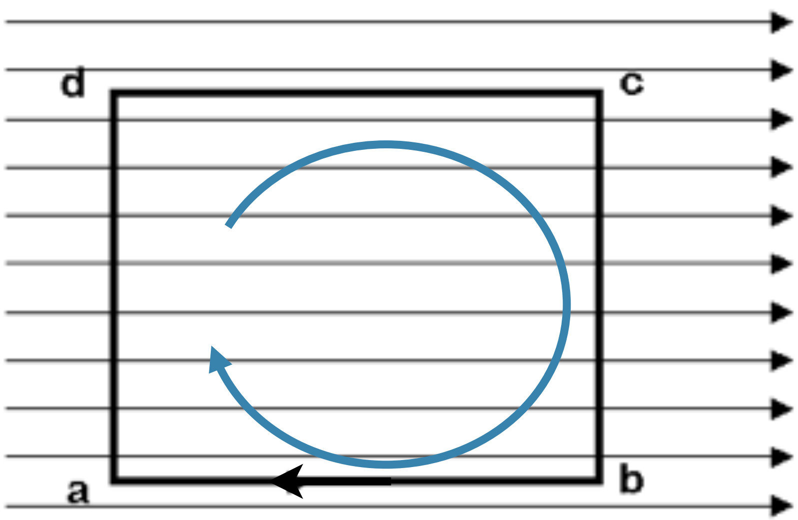

**What is the force on section c-d on the loop?**

**A.** Zero
**B.** Out of page
**C.** Into the Page

# CheckPoint 2

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

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

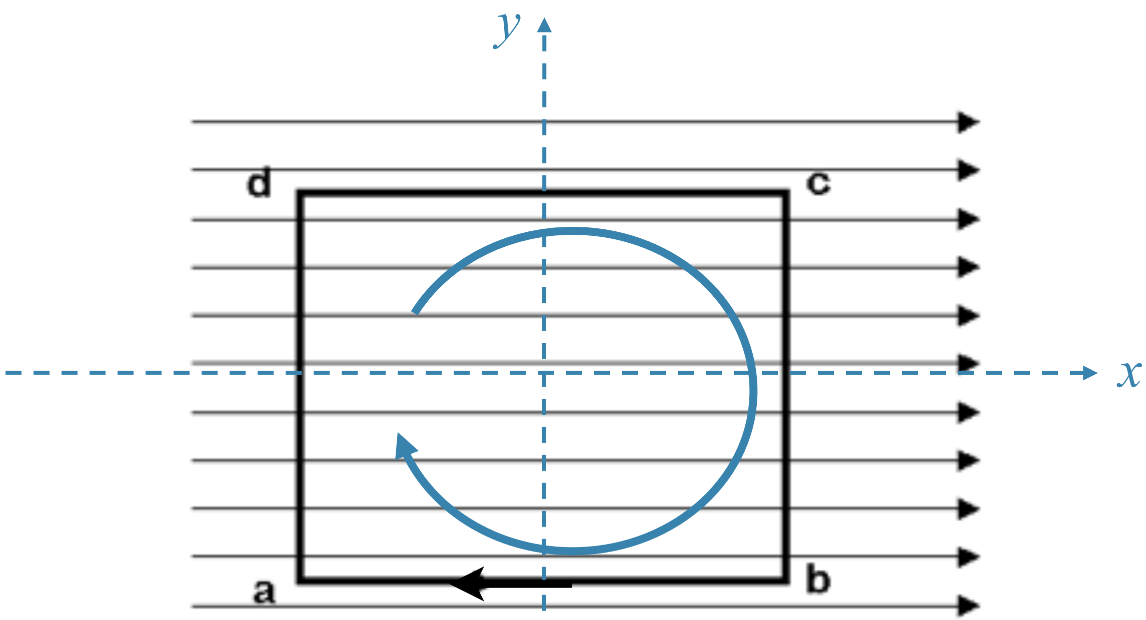



**What is the direction of the net force on the loop?**

A. **Out of page**
B. **Into the Page**
C. **Zero**

# CheckPoint 4

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

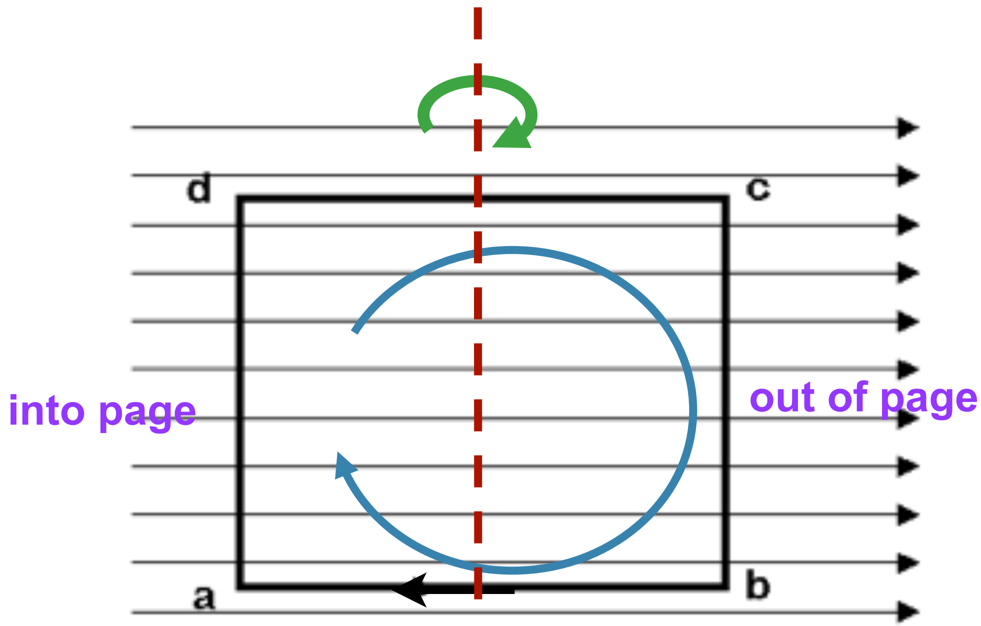



In which direction will the loop rotate?
(assume the z axis is out of the page)

A) Around the x axis
B) Around the y axis
C) Around the z axis
D) It will not rotate

# CheckPoint 6

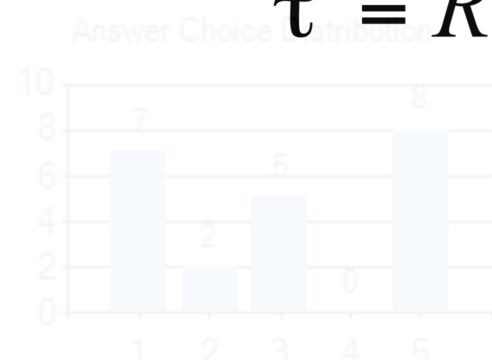
**A square loop of wire is carrying current in the clockwise direction. There is a horizontal uniform magnetic field pointing to the right.**



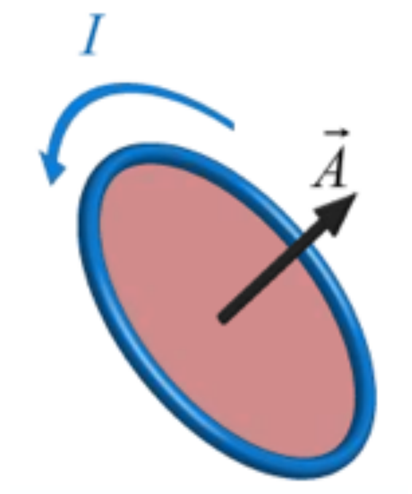

What is the direction of the **net torque** on the loop?

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

A) up (on page)
B) down (on page)
C) out of page
D) into page
E) net torque is zero



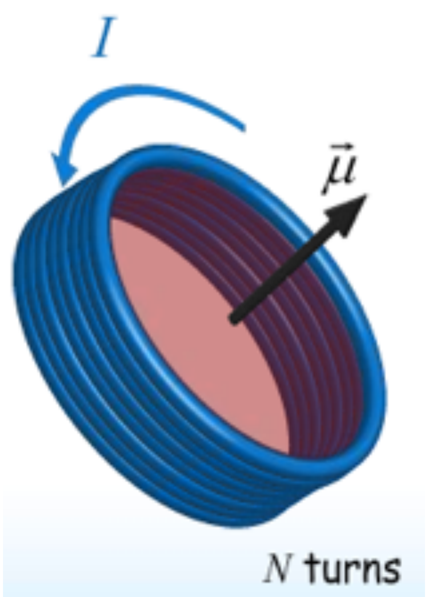
# Magnetic Dipole Moment




Area vector

Magnitude = Area

Direction uses R.H.R.



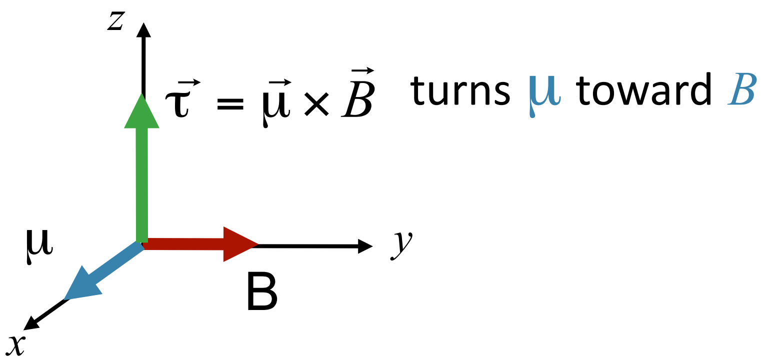

Magnetic Dipole moment

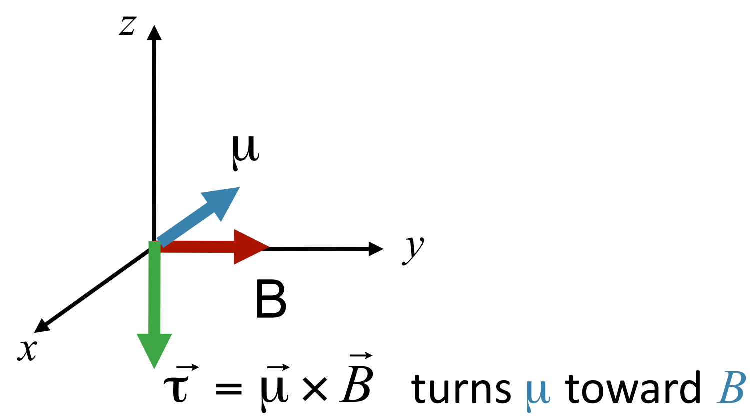
$$\vec{\mu} \equiv NI\vec{A}$$

# μ *Makes Torque Easy!*

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

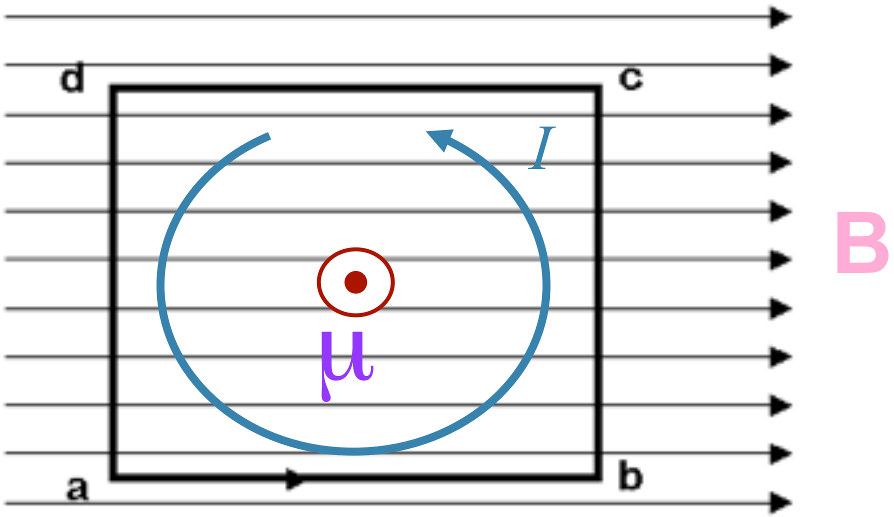
The torque always wants to line μ up with $B$!



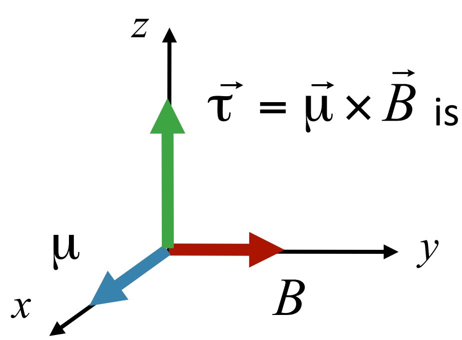



# Practice with μ and τ

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



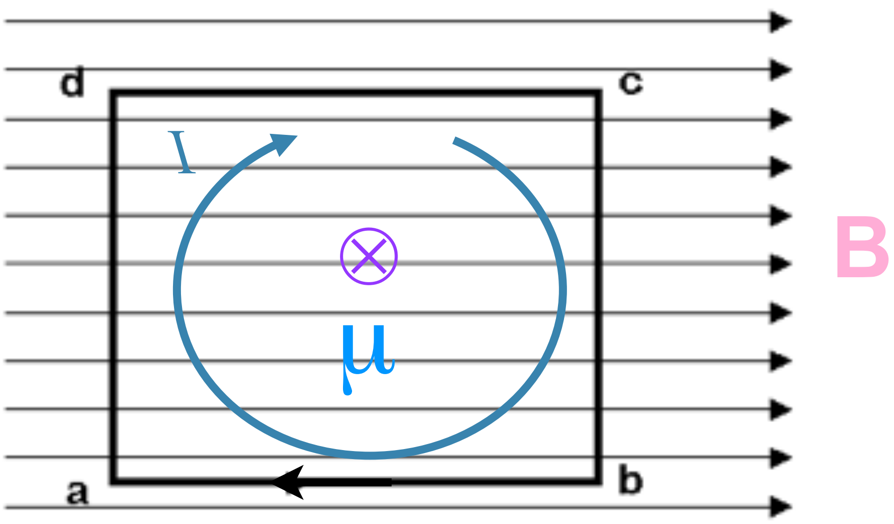

In this case μ is out of the page (using right hand rule)



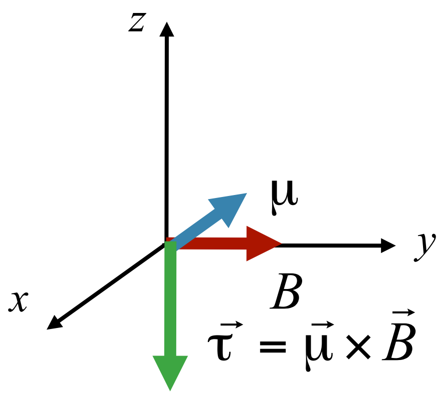

$\vec{\tau} = \vec{\mu} \times \vec{B}$ is up (turns μ toward $B$)

# Practice with μ and τ

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



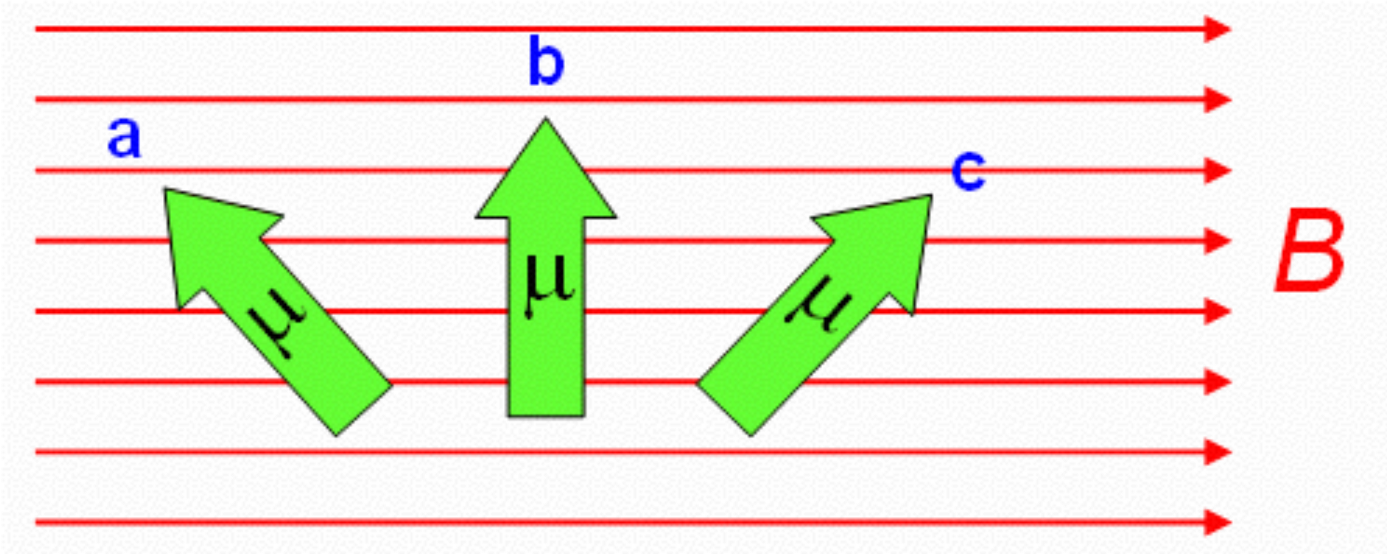

In this case μ is IN to the page (using right hand rule)




is down (turns μ toward $B$)

# CheckPoint 8

Three different orientations of a magnetic dipole moment in a constant magnetic field are shown below. Which orientation results in the largest magnetic torque on the dipole ?



From Physics 120: $W = \int \tau \, d\theta$

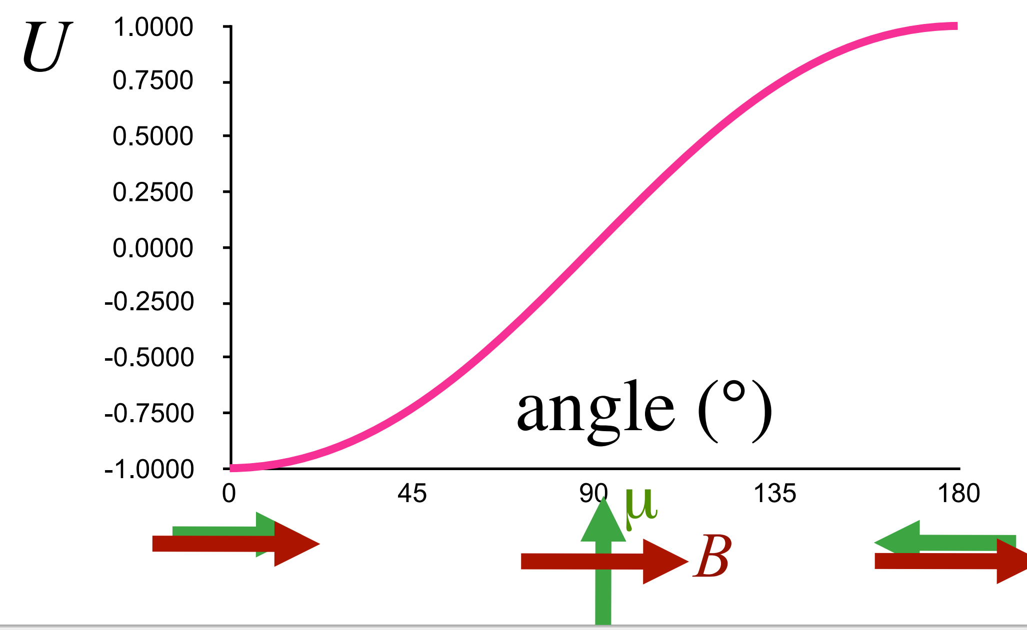
From Physics 121: $\vec{\tau} = \vec{\mu} \times \vec{B} = \mu B \sin(\theta)$

$$W = \int_{\theta}^{\pi/2} \mu B \sin\theta' \, d\theta' = \mu B \cos\theta = \vec{\mu} \cdot \vec{B}$$

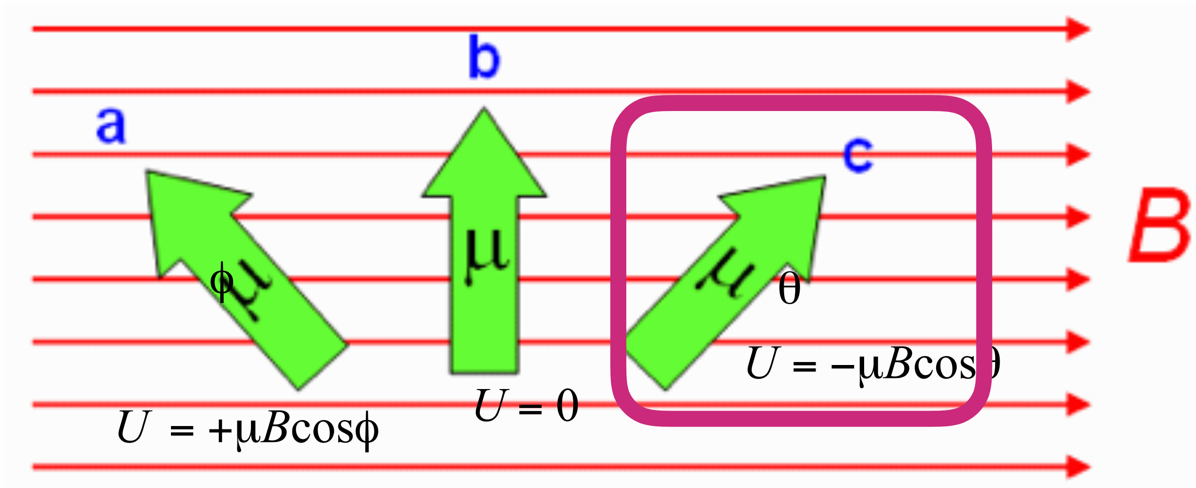
$$\Delta U = -W$$

Define $U = 0$ at position of maximum torque

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

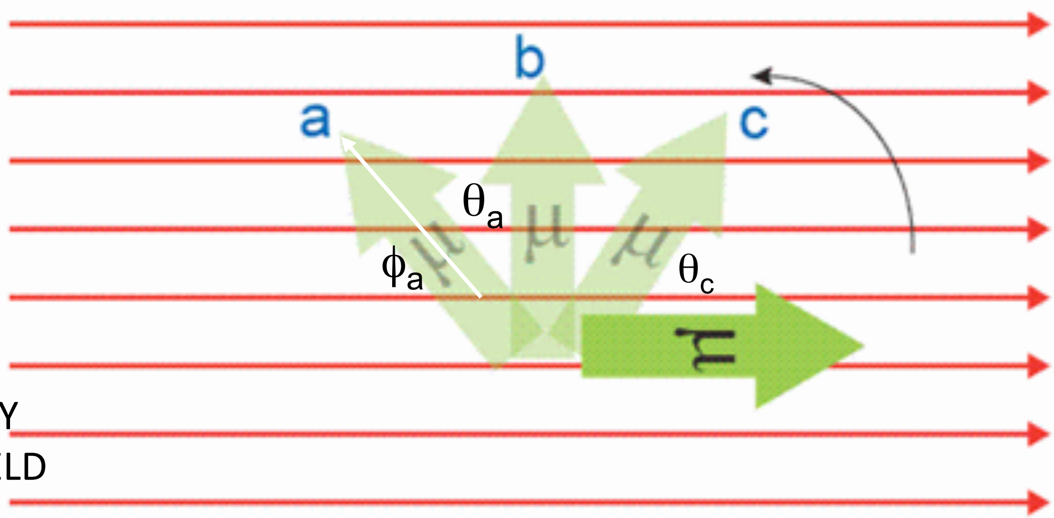


# CheckPoint 10




**Which orientation has the lowest potential energy?**

12) In order to rotate an horizontal magnetic dipole to the three postions shown, which one requires the most work done?




BY YOU    BY FIELD

BY WHOM ?

○a ○b ○c

$$W_{by\ field} = -\Delta U = U_i - U_f$$

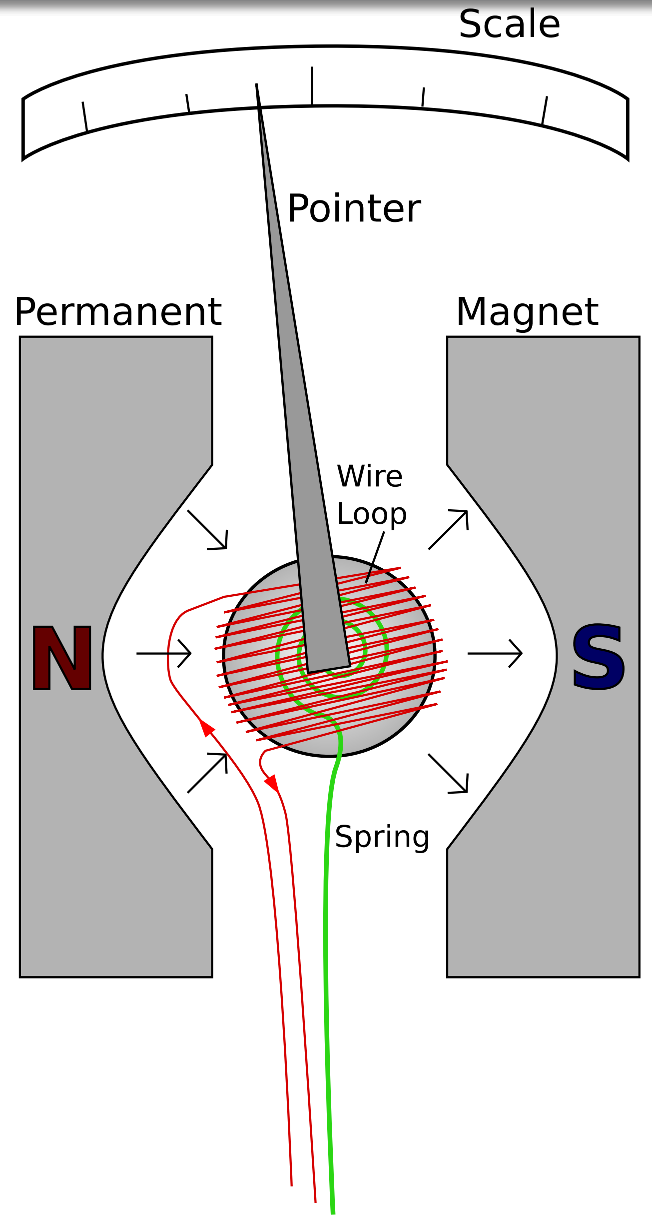
$$U = \vec{\mu} \cdot \vec{B}$$

C): $W_{by\_field} = -\mu B - (-\mu B \cos\theta_c) = -\mu B(1 - \cos\theta_c)$

B): $W_{by\_field} = -\mu B - 0 = -\mu B$

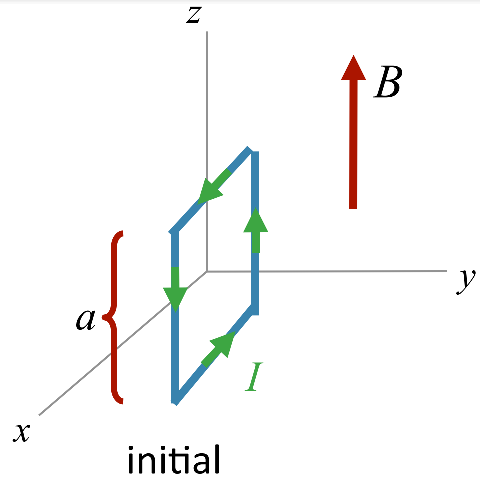
A): $W_{by\_field} = -\mu B - (-\mu B \cos\theta_a) = -\mu B(1 + \cos\phi_a)$

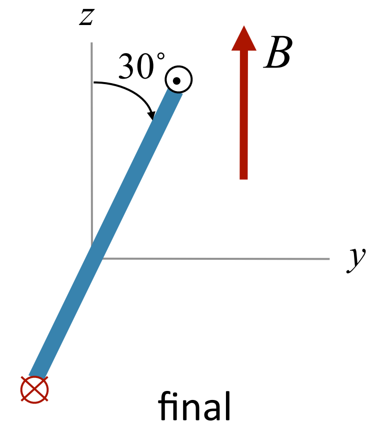
# D'Arsonval Ammeter



# Calculation

A square loop of side $a$ lies in the $x$–$z$ plane with current $I$ as shown. The loop can rotate about $x$ axis without friction. A uniform field $B$ points along the $+z$ axis. Assume $a$, $I$, and $B$ are known.




How much does the potential energy of the system change as the coil moves from its initial position to its final position.

## Conceptual Analysis

A current loop may experience a torque in a constant magnetic field

$$\tau = \mu \times B$$

We can associate a potential energy with the orientation of loop

$$U = -\mu \cdot B$$

## Strategic Analysis

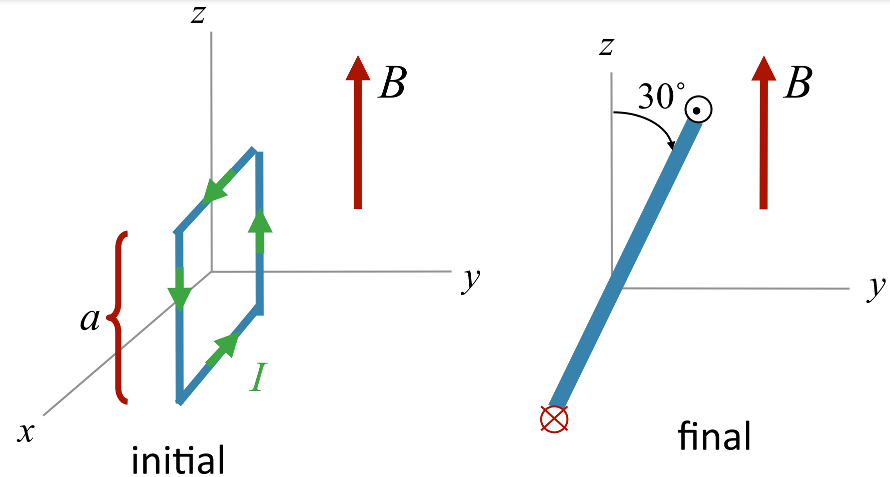
Find $\mu$

Calculate the change in potential energy from initial to final

# Calculation

A square loop of side $a$ lies in the $x$–$z$ plane with current $I$ as shown. The loop can rotate about $x$ axis without friction. A uniform field $B$ points along the $+z$ axis. Assume $a$, $I$, and $B$ are known.

$\vec{\mu} = I\vec{A}$

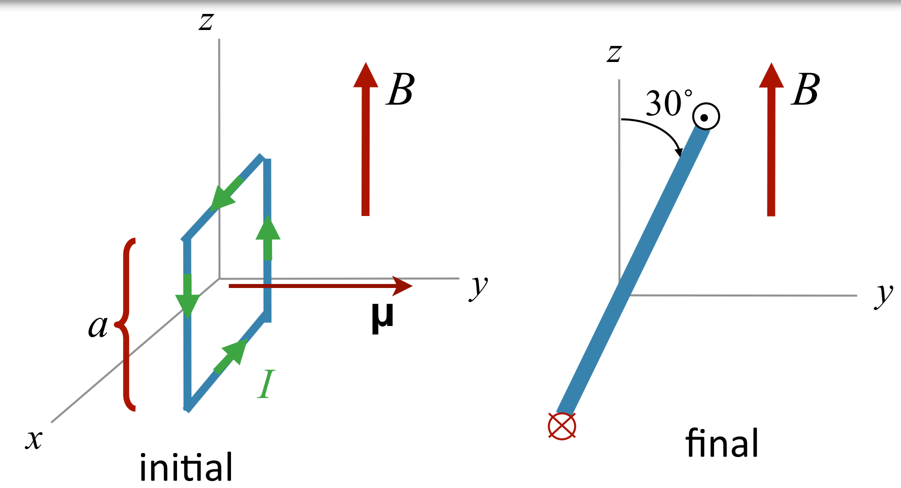



What is the direction of the magnetic moment of this current loop in its initial position?

A) $+x$ B) $-x$ C) $+y$ D) $-y$

# Calculation

A square loop of side $a$ lies in the $x$–$z$ plane with current $I$ as shown. The loop can rotate about $x$ axis without friction. A uniform field $B$ points along the $+z$ axis. Assume $a$, $I$, and $B$ are known.



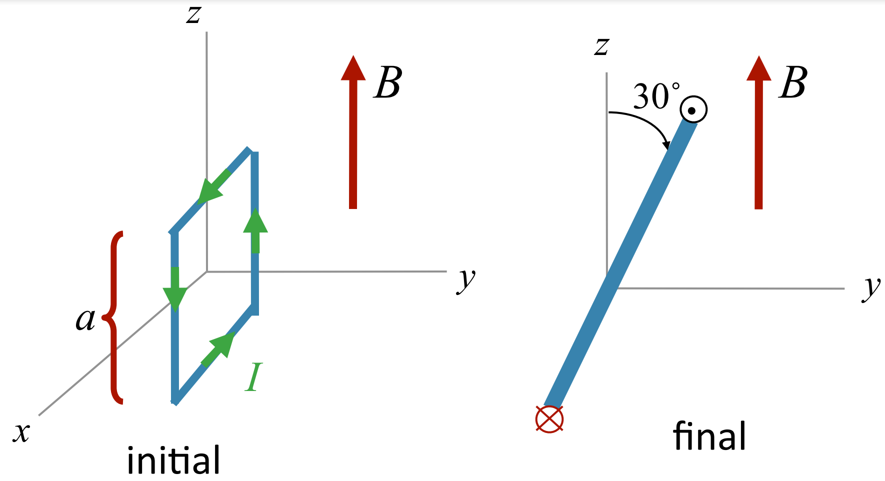

What is the direction of the torque on this current loop in the initial position?

A) $+x$ B) $-x$ C) $+y$ D) $-y$

# Calculation

A square loop of side $a$ lies in the $x$–$z$ plane with current $I$ as shown. The loop can rotate about $x$ axis without friction. A uniform field $B$ points along the $+z$ axis. Assume $a$, $I$, and $B$ are known.

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




What is the potential energy of the initial state?

A) $U_{initial} < 0$

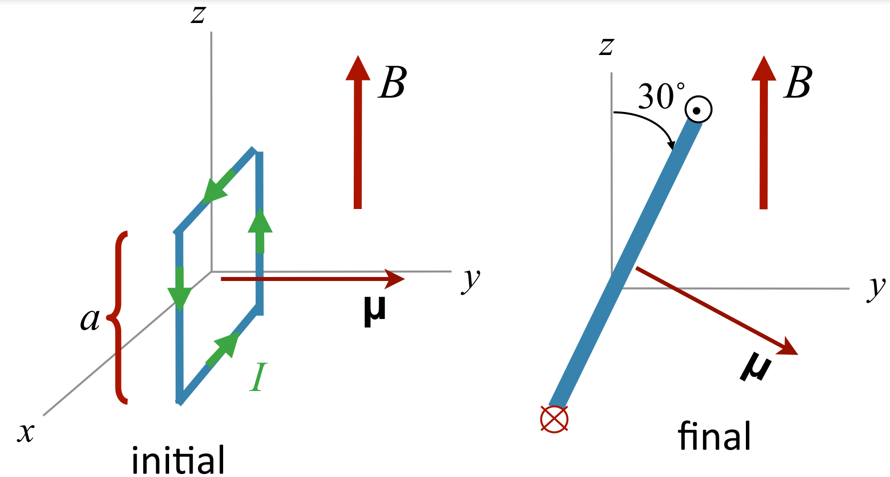
B) $U_{initial} = 0$

C) $U_{initial} > 0$

# Calculation

A square loop of side $a$ lies in the $x$–$z$ plane with current $I$ as shown. The loop can rotate about $x$ axis without friction. A uniform field $B$ points along the $+z$ axis. Assume $a$, $I$, and $B$ are known.

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




What is the potential energy of the final state?

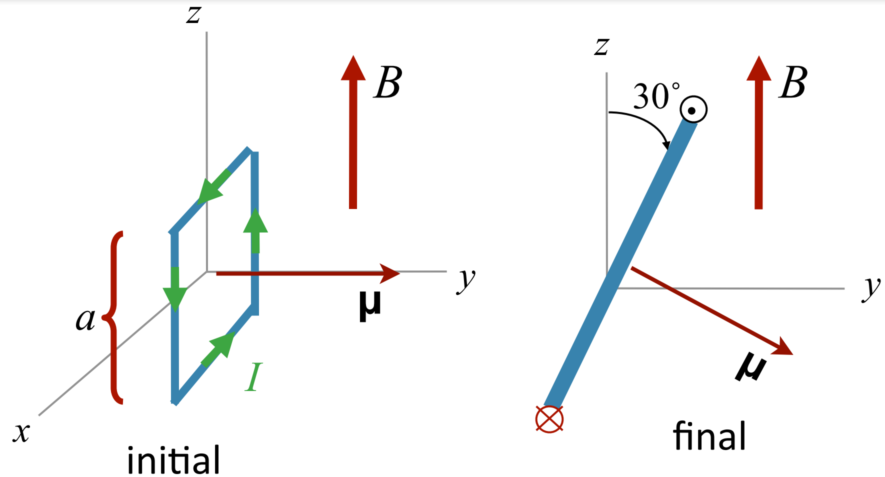
A) $U_{final} < 0$

B) $U_{final} = 0$

C) $U_{final} > 0$

A square loop of side *a* lies in the *x–z* plane with current *I* as shown. The loop can rotate about *x* axis without friction. A uniform field *B* points along the +*z* axis. Assume *a*, *I*, and *B* are known.

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

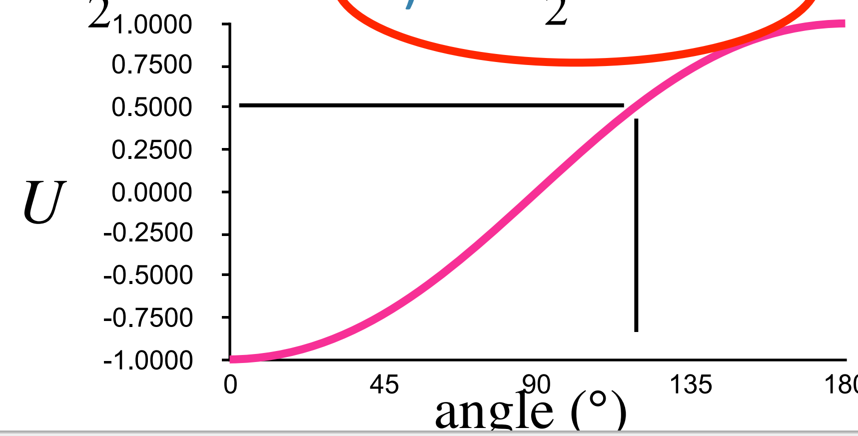



What is the potential energy of the final state?

A) $U = Ia^2 B$

B) $U = \frac{\sqrt{3}}{2} Ia^2 B$

C) $U = \frac{1}{2} Ia^2 B$



Motor Simulation: http://www.physics-chemistry-interactive-flash-animation.com/electricity_electromagnetism_interactive/laplace_lorentz_force_electric_motor_principle_brushes_split_ring.htm

Rail Gun: http://www.physics-chemistry-interactive-flash-animation.com/electricity_electromagnetism_interactive/lorentz_force_rail_gun_three_fingers_right_hand_rule.htm