Module 18:
Magnetic Dipoles

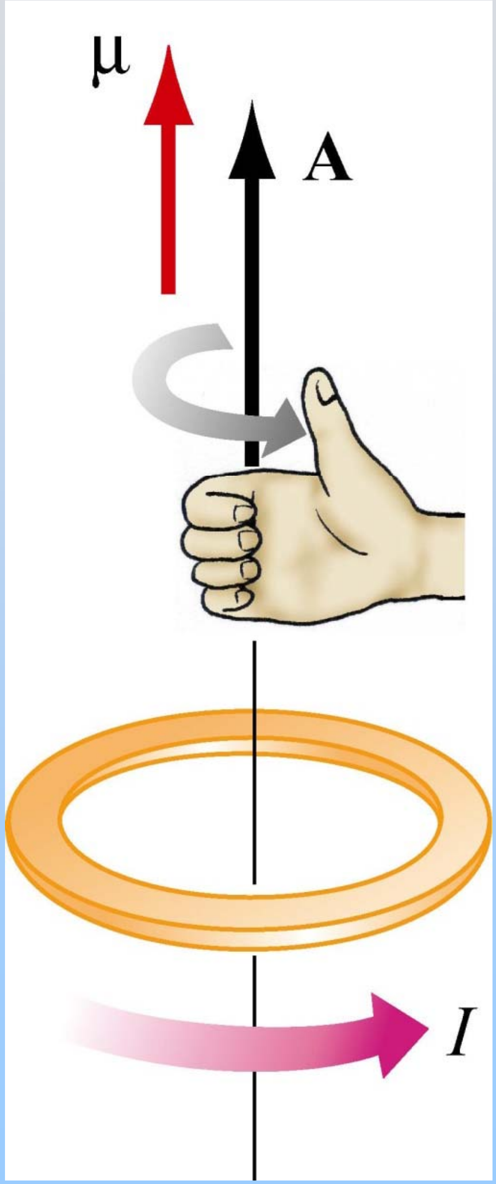
Module 18: Outline

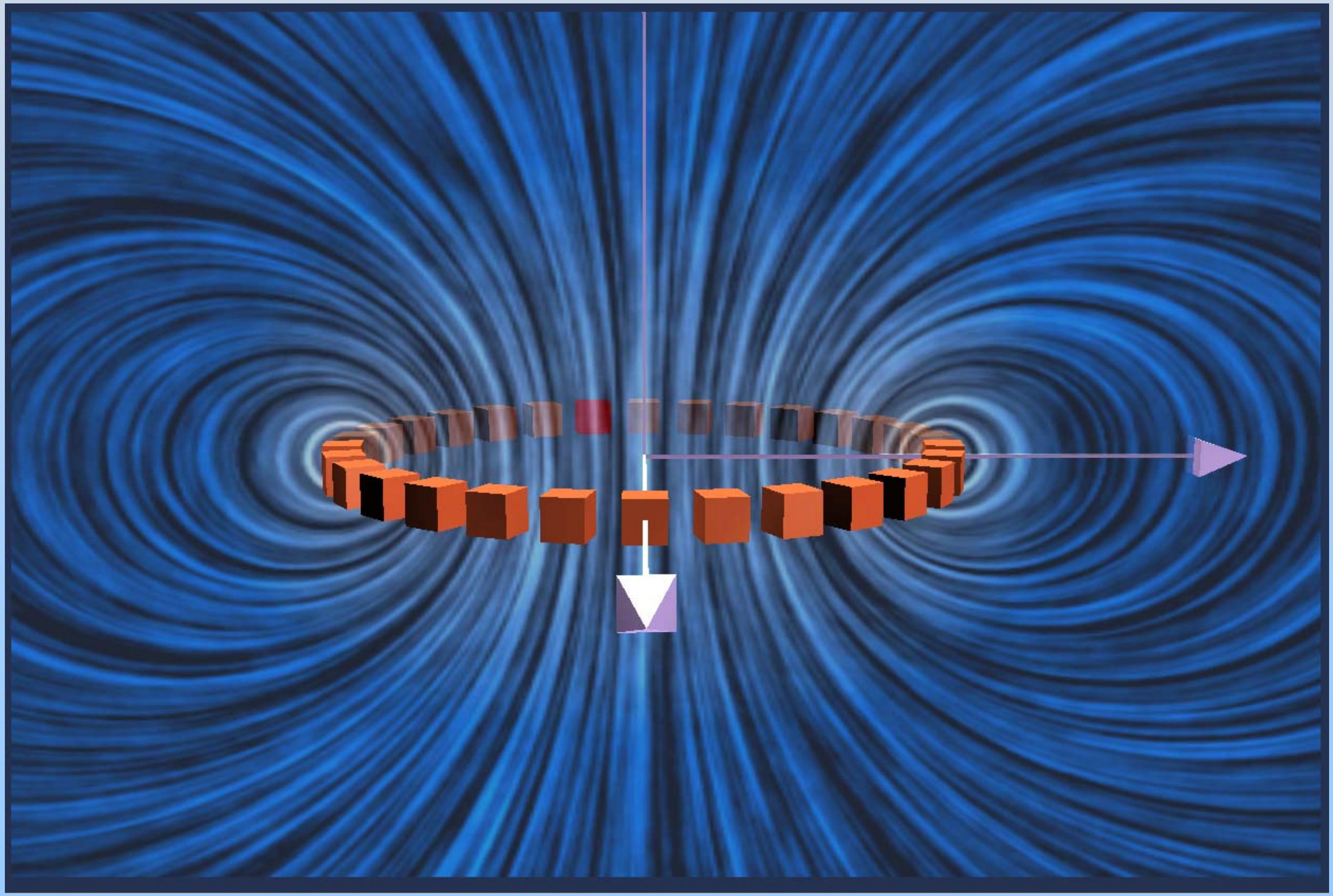
Magnetic Dipoles

Magnetic Torques

Magnetic Dipole Moment

$$\vec{\boldsymbol{\mu}} \equiv IA\hat{\mathbf{n}} \equiv I\vec{\mathbf{A}}$$

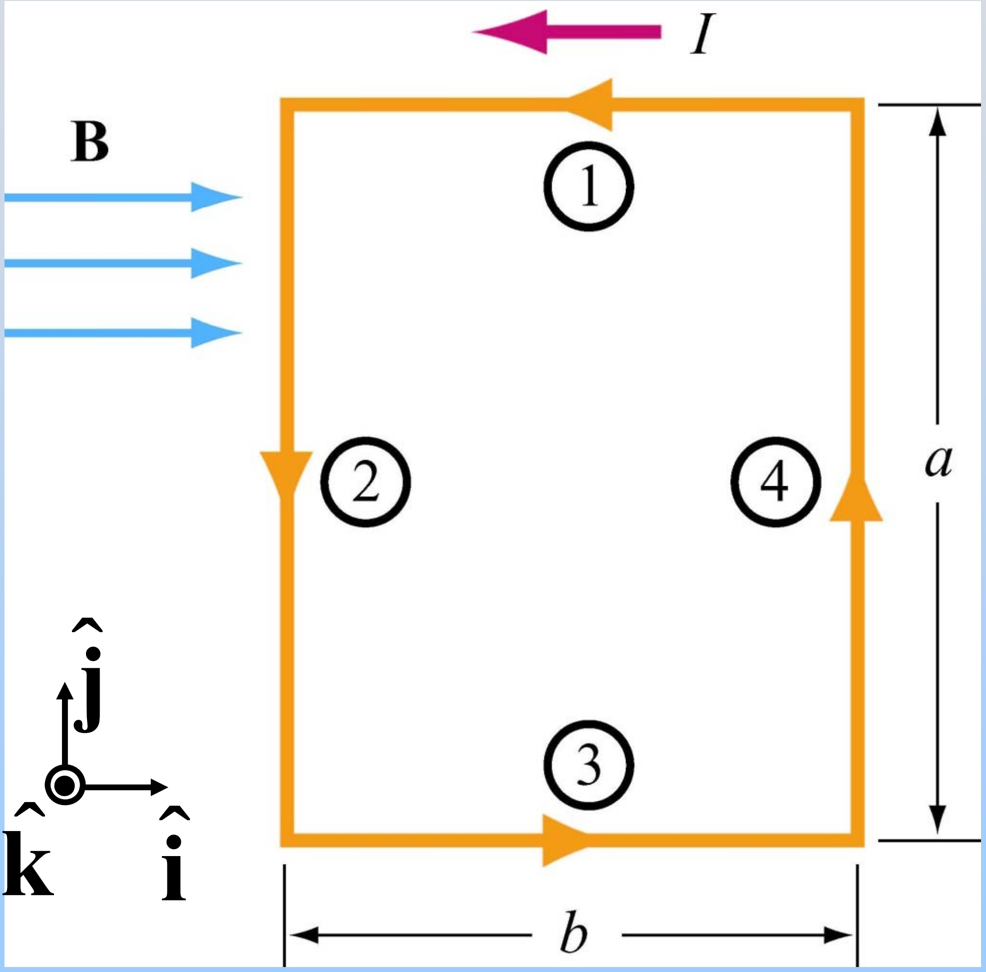




Torque on a Current Loop in a Uniform Magnetic Field

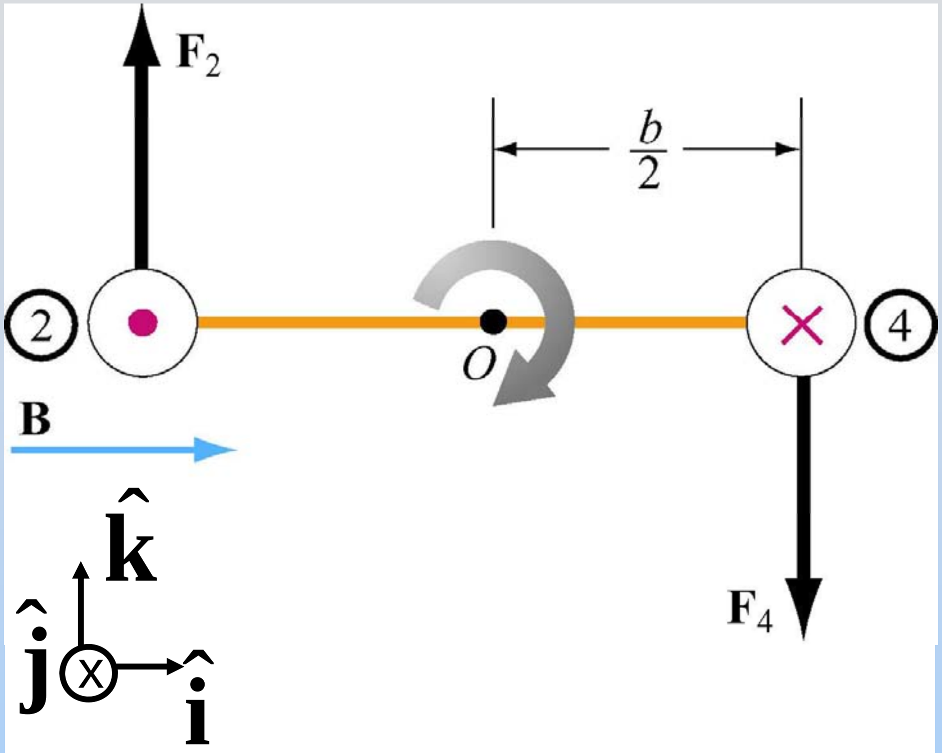
Problem: Current Loop

Place rectangular current loop in uniform B field



1) What is the net force on this loop?
2) What is the net torque on this loop?
3) Describe the motion the loop makes

Torque on Rectangular Loop



$$\vec{\boldsymbol{\tau}} = IAB\hat{\mathbf{j}}$$

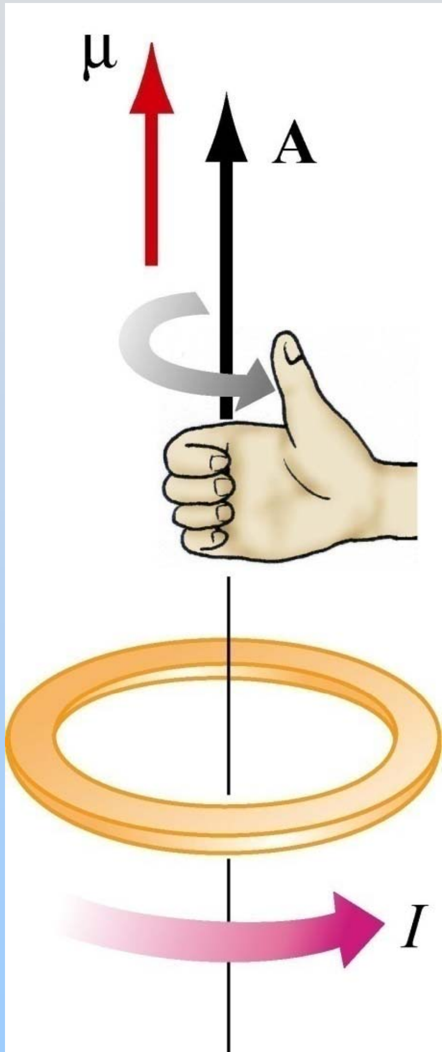
$\vec{\mathbf{A}} = A\hat{\mathbf{n}} = ab\hat{\mathbf{n}}$: area vector

$$\hat{\mathbf{n}} = +\hat{\mathbf{k}}, \quad \vec{\mathbf{B}} = B\hat{\mathbf{i}}$$

$$\boxed{\vec{\boldsymbol{\tau}} = I\vec{\mathbf{A}} \times \vec{\mathbf{B}}}$$

Familiar? No net force but there is a torque

Magnetic Dipole Moment



Define Magnetic Dipole Moment:

$$\boxed{\vec{\boldsymbol{\tau}} \equiv IA\hat{\mathbf{n}} \equiv I\vec{\mathbf{A}}}$$

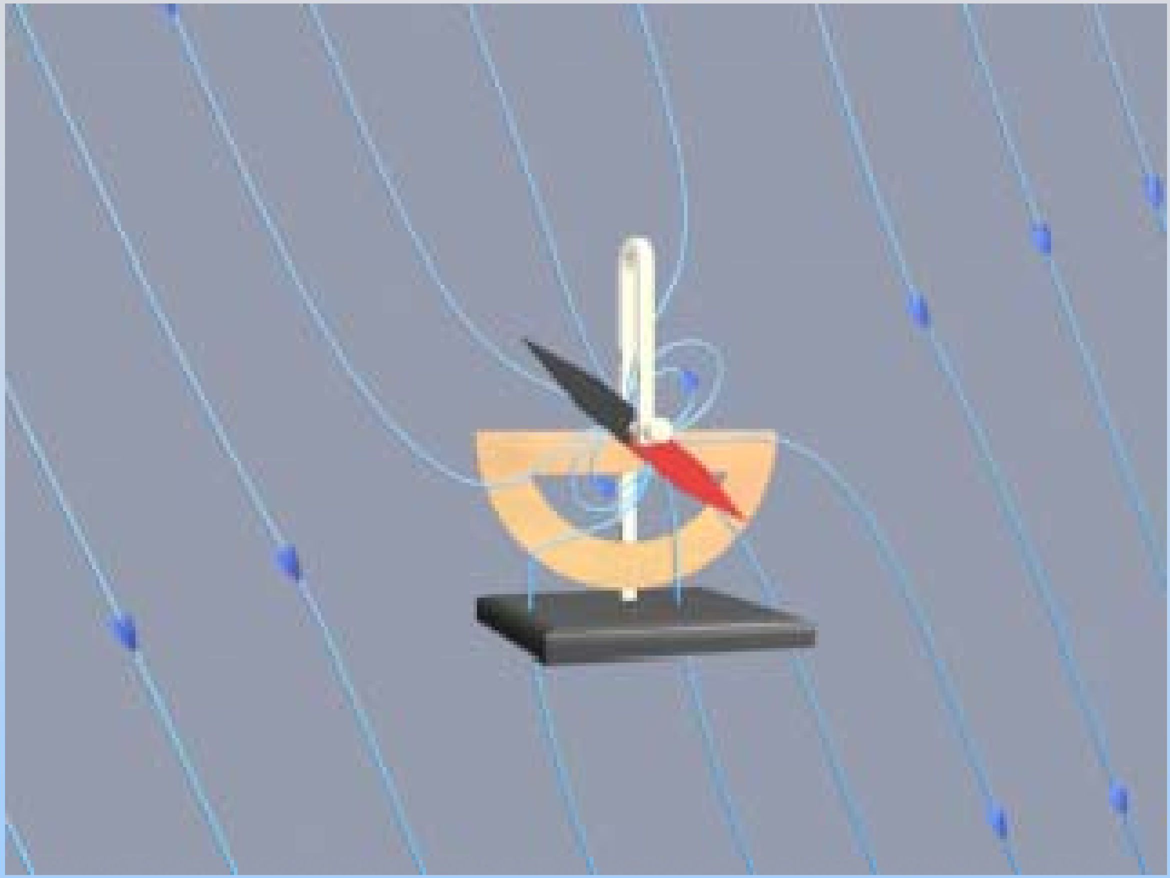
Then:

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

Analogous to $\vec{\boldsymbol{\tau}} = \vec{\mathbf{p}} \times \vec{\mathbf{E}}$

$\boldsymbol{\tau}$ tends to align $\boldsymbol{\mu}$ with B

Animation: Another Way To Look At Torque



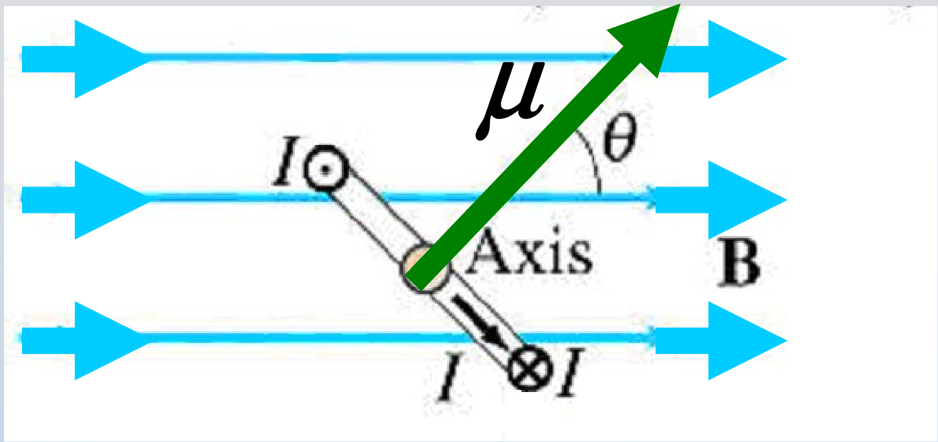
Link to animation

External field connects to field of magnet and “pulls” the dipole into alignment

Demonstration: Galvanometer

Concept Question Question: Force on Magnetic Dipole

Concept Question: Dipole in Field



From rest, the coil above will:

1. rotate clockwise, not move
2. rotate counterclockwise, not move
3. move to the right, not rotate
4. move to the left, not rotate
5. move in another direction, without rotating
6. both move and rotate
7. neither rotate nor move
8. I don’t know

Energy of Magnetic Dipole

$$\boxed{U_{Dipole} = -\vec{\mu} \cdot \vec{\mathbf{B}}}$$

This equation gives you a general way to think about what dipoles will do in B fields

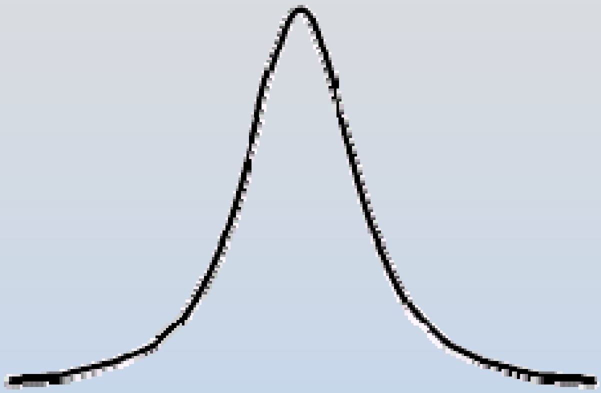
Experiment 6:
Magnetic Forces on Dipoles

This is a little tricky. We will lead you through with lots of Concept Question questions

First: Set up current supply

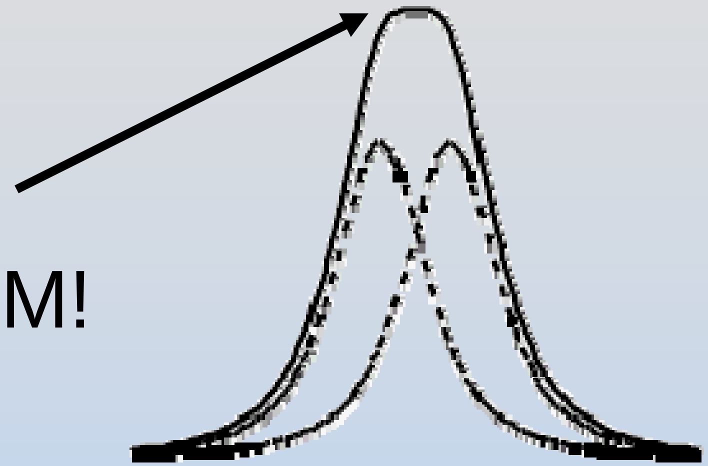
- Open circuit (disconnect a lead)
- Turn current knob full CCW (off)
- Increase voltage to ~12 V
  - This will act as a protection: V<12 V
- Reconnect leads in Helmholtz mode
- Increase current to ~1 A

Field Profiles: B vs. Height

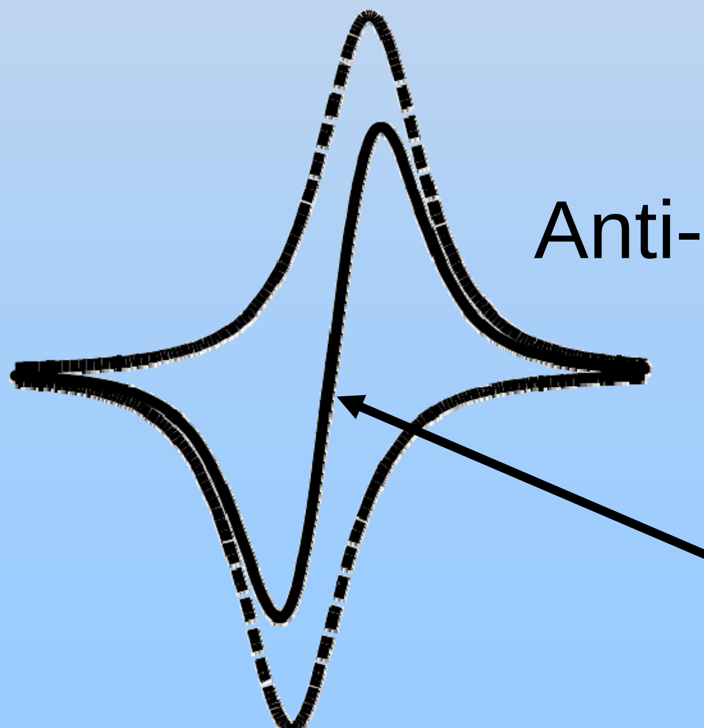


Single Coil

VERY
UNIFORM!



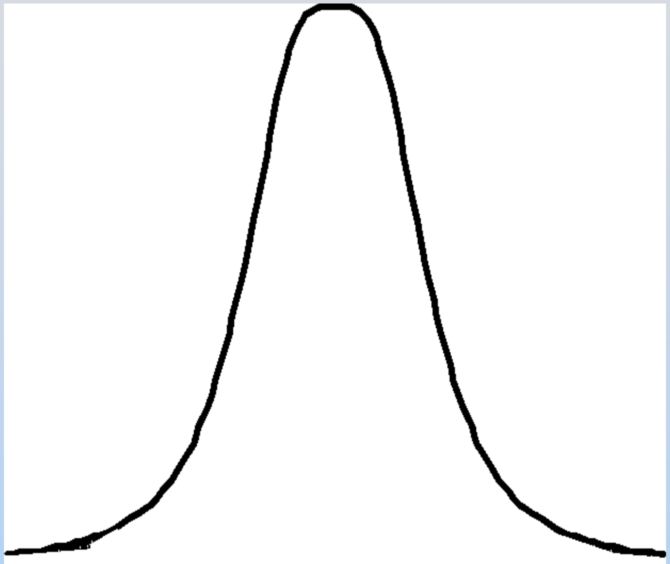
Helmholtz



Anti-Helmholtz

ZERO
FIELD!

Concept Question: Dipole in Helmholtz



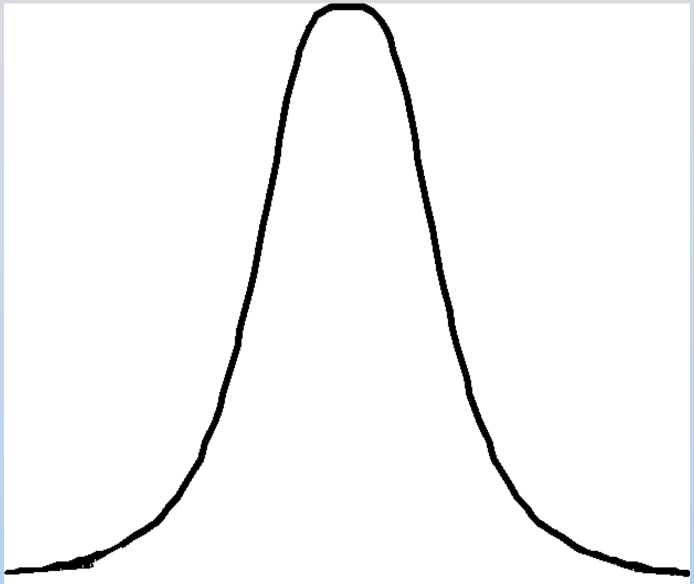
A randomly aligned dipole at the center of a Helmholtz coil will feel:

1. a force but not a torque
2. a torque but not a force
3. both a torque and a force
4. neither force nor torque

Next: Dipole in Helmholtz (Q1-2)

- Set in Helmholtz Mode (~1 A)
- Turn off current
- Put dipole in center (0 on scale)
- Randomly align using bar magnet
- Turn on current
- What happens?

Concept Question: Moving in Helmholtz



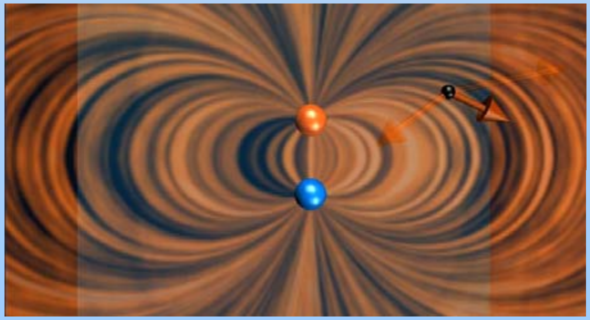
When moving through the above field profile, a dipole will:

1. Never rotate
2. Rotate once
3. Rotate twice

Fields: Grav., Electric, Magnetic

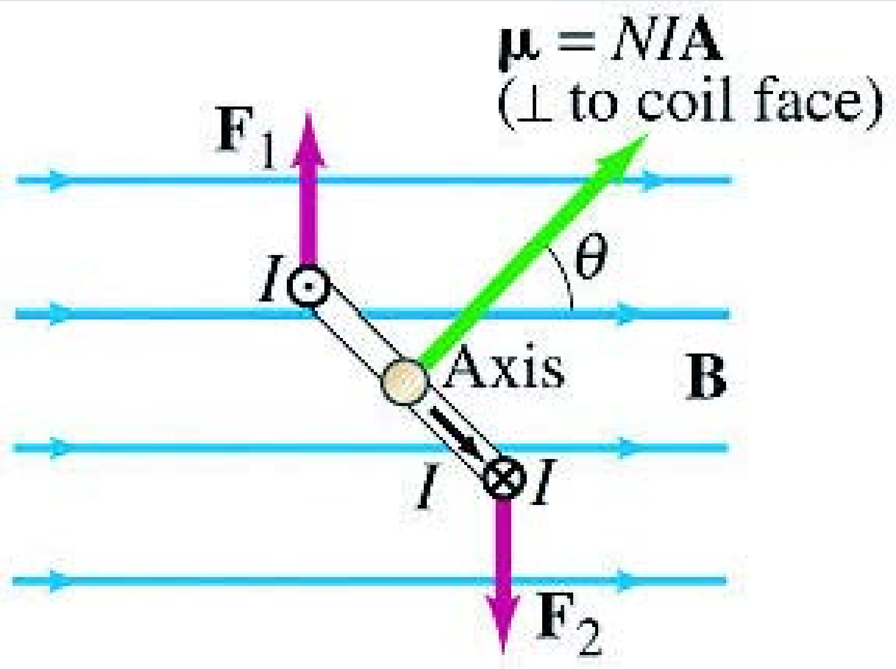
	Mass *m*	Charge *q* (±)	No Magnetic Monopoles!
Create:	$\vec{\mathbf{g}} = -G\dfrac{m}{r^2}\hat{\mathbf{r}}$	$\vec{\mathbf{E}} = k_e \dfrac{q}{r^2}\hat{\mathbf{r}}$	
Feel:	$\vec{\mathbf{F}}_g = m\vec{\mathbf{g}}$	$\vec{\mathbf{F}}_E = q\vec{\mathbf{E}}$	

	Dipole **p**	Dipole **μ**
Create:	$\vec{\mathbf{E}} \rightarrow$	$\leftarrow \vec{\mathbf{B}}$
Feel:	$\vec{\boldsymbol{\tau}} = \vec{\mathbf{p}} \times \vec{\mathbf{E}}$	$\vec{\boldsymbol{\tau}} = \vec{\boldsymbol{\mu}} \times \vec{\mathbf{B}}$

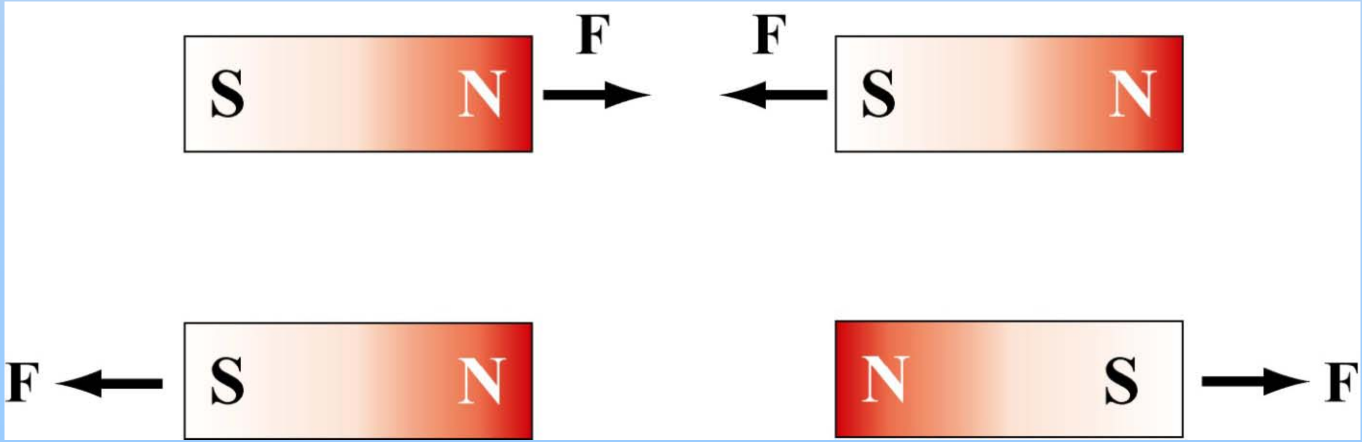


Appendix: Force on a Dipole in a Non-Uniform Field

Dipoles don't move???



This dipole rotates but doesn't feel a net force

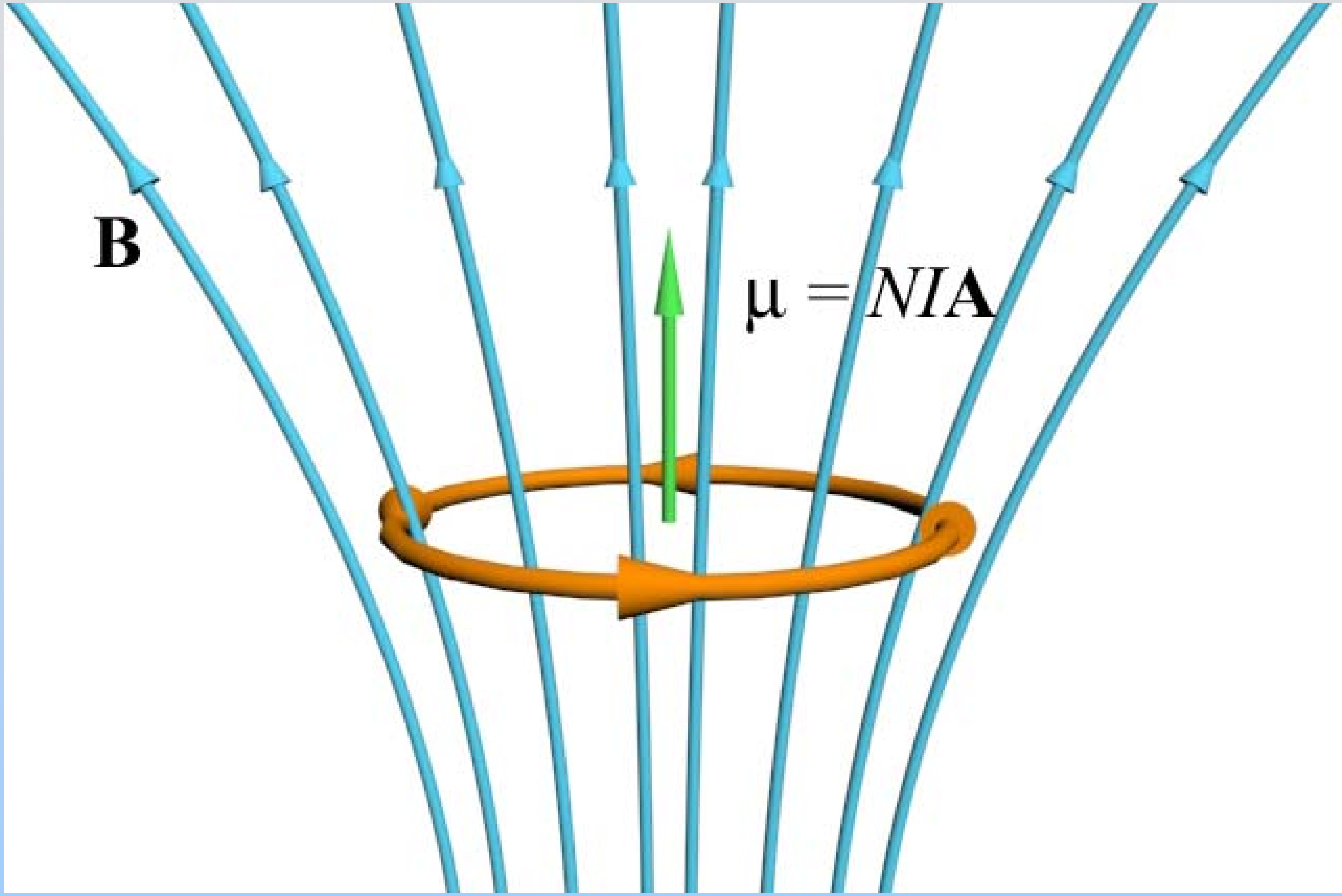


But dipoles CAN feel force due to **B**. What's up?

Something New

Dipoles in Non-Uniform Fields: Force

Force on Magnetic Dipole?

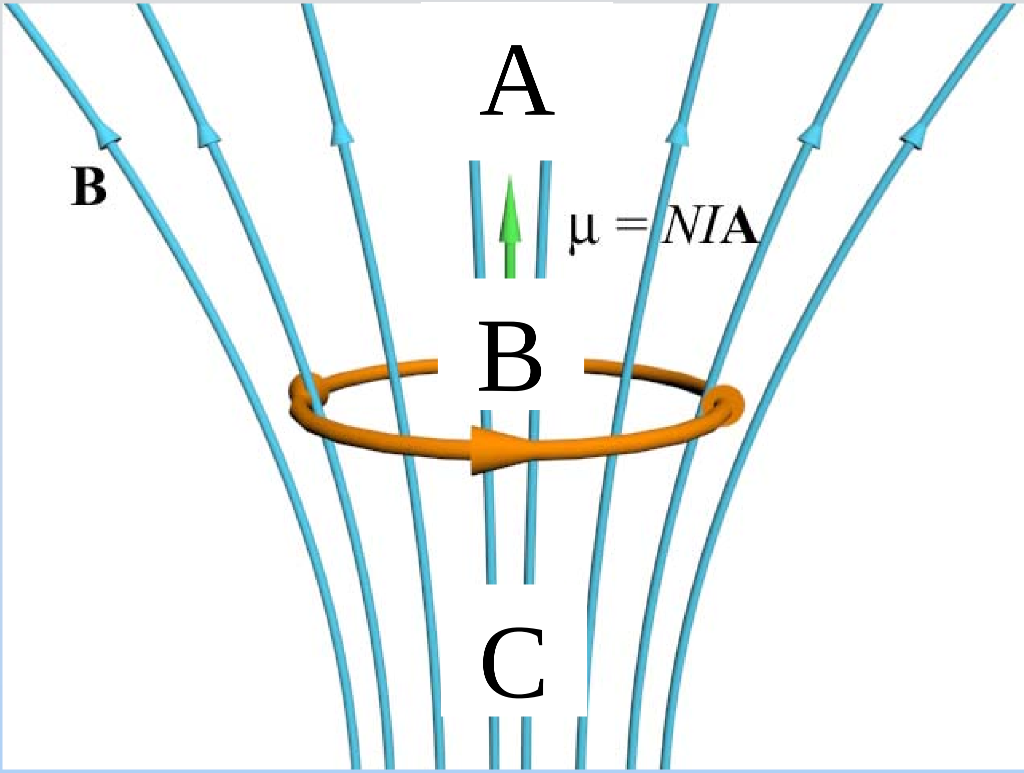


We Want to Know:

What is the force on this dipole?

Concept Question Question: Force on Magnetic Dipole

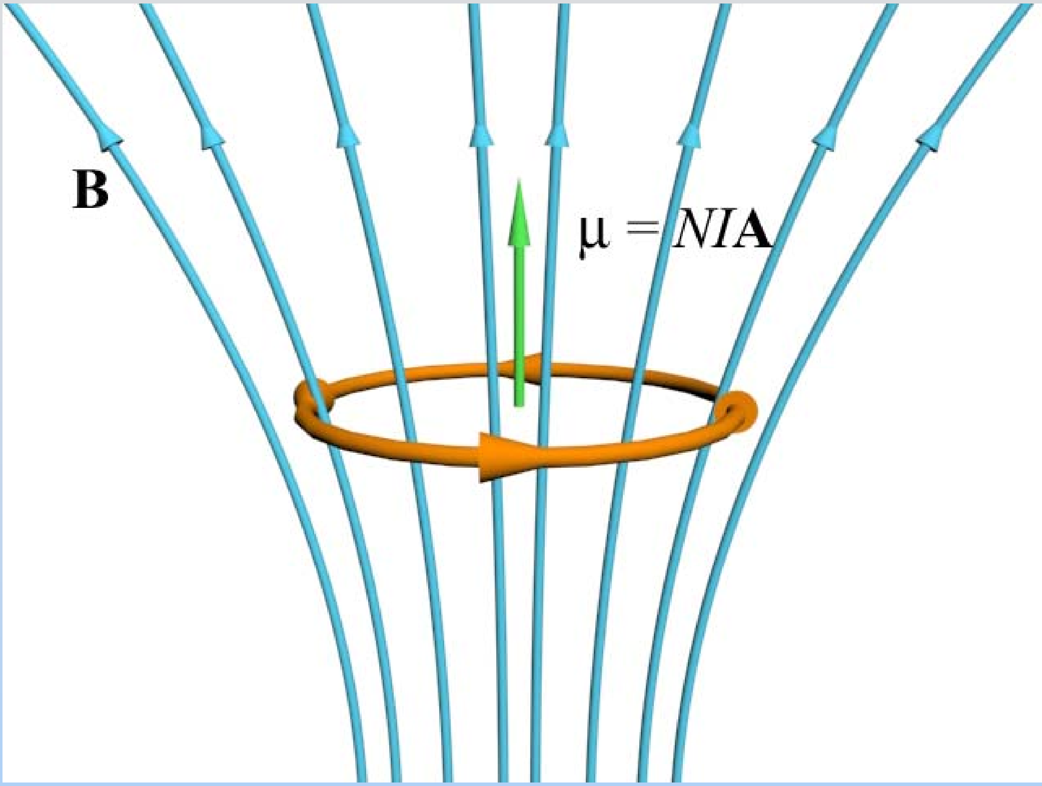
Concept Question: Field Strength



Where is the pictured field the strongest?

1. A
2. B
3. C
4. I don't know

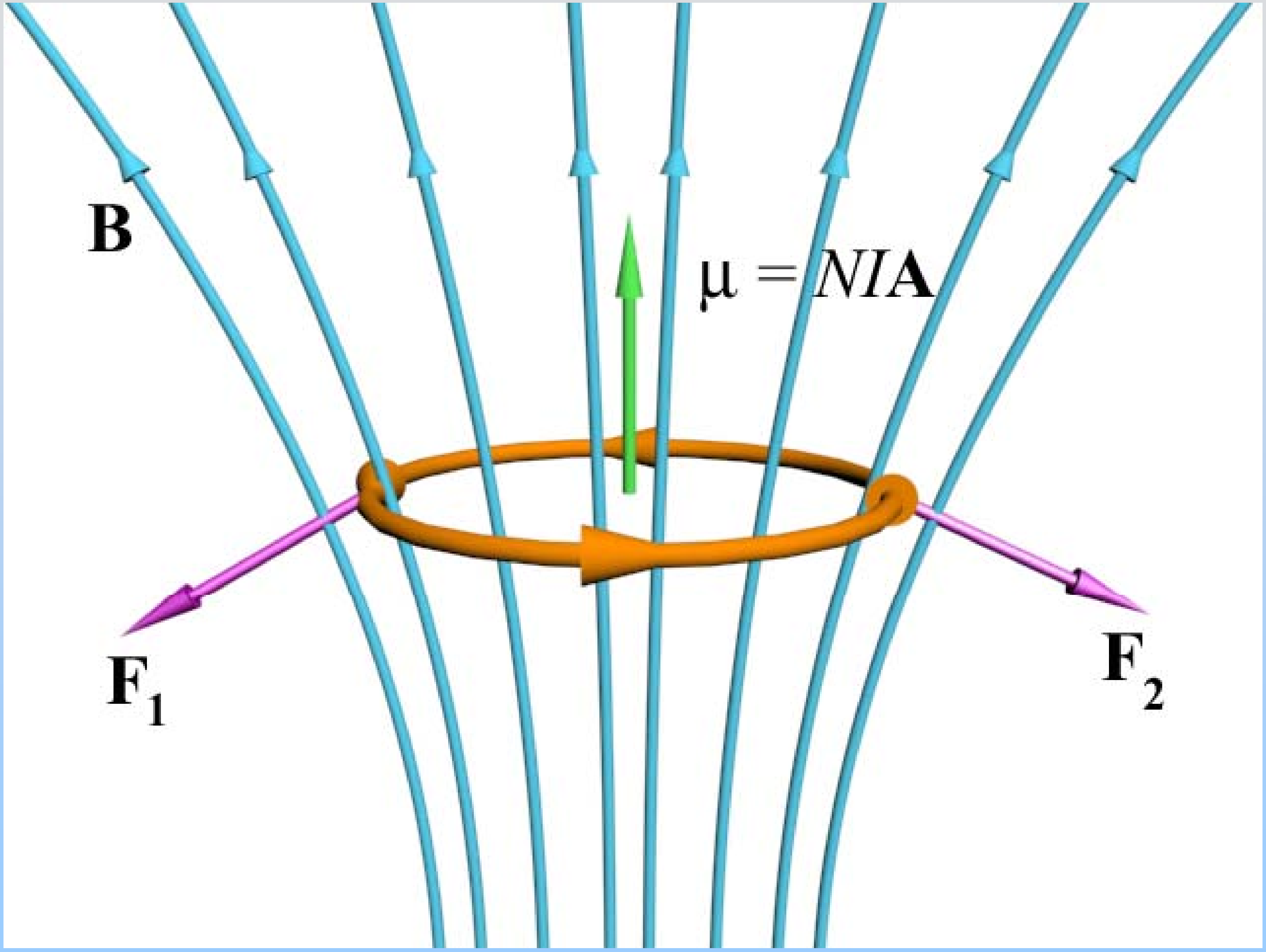
Concept Question: Dipole in Field



The current carrying coil above will feel a net force

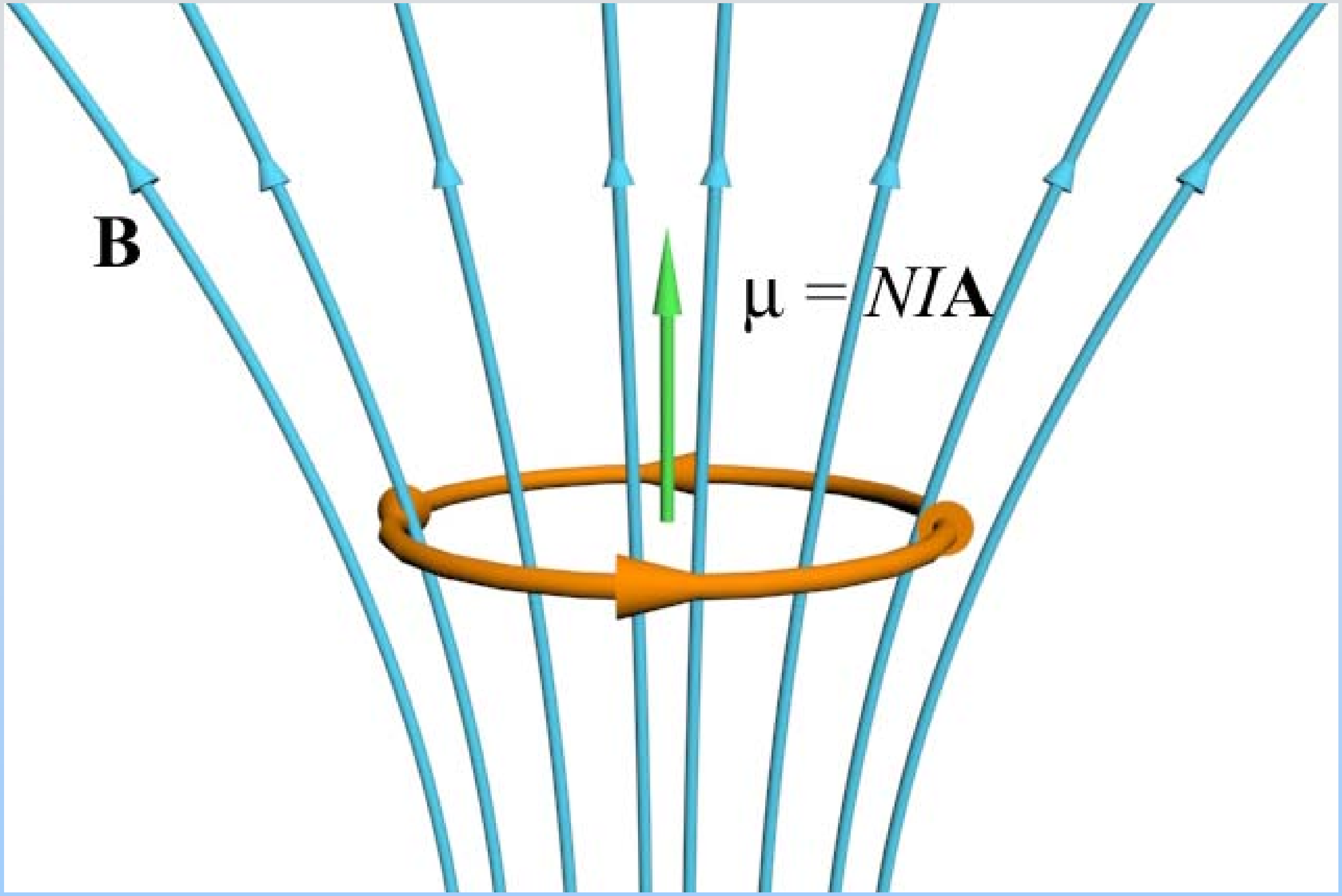
1. upwards
2. downwards
3. of zero
4. I don't know

Can just sum I ds x B forces



Is there another way?

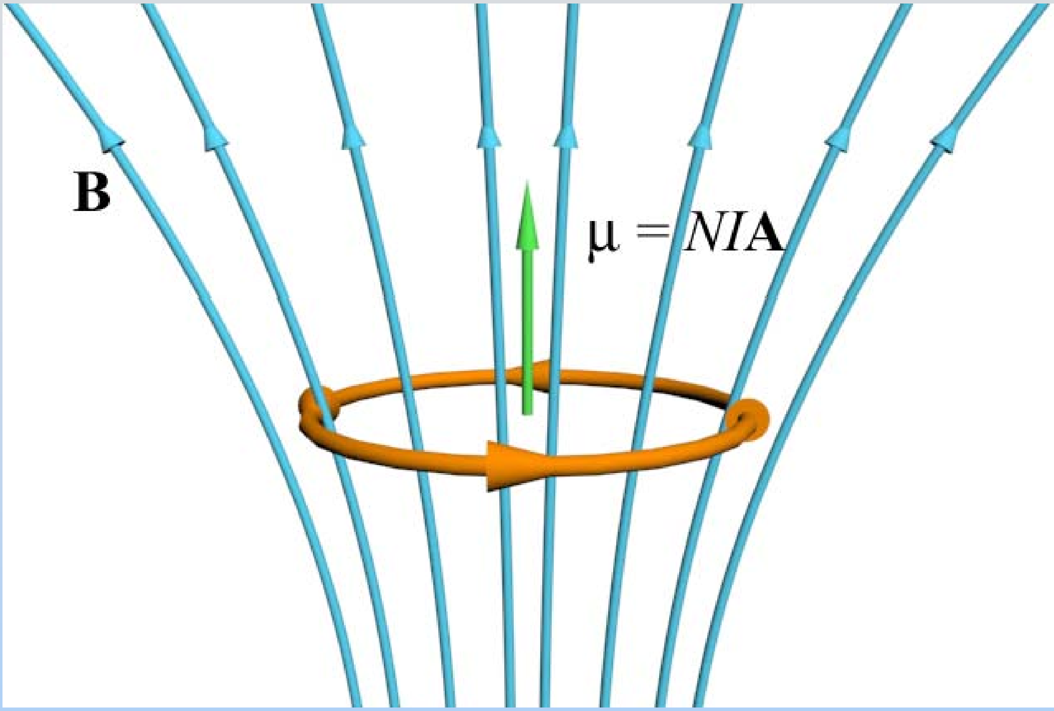
Force on Magnetic Dipole



Alternate Thought #1

Where does the dipole want to be?

Think Using Energy



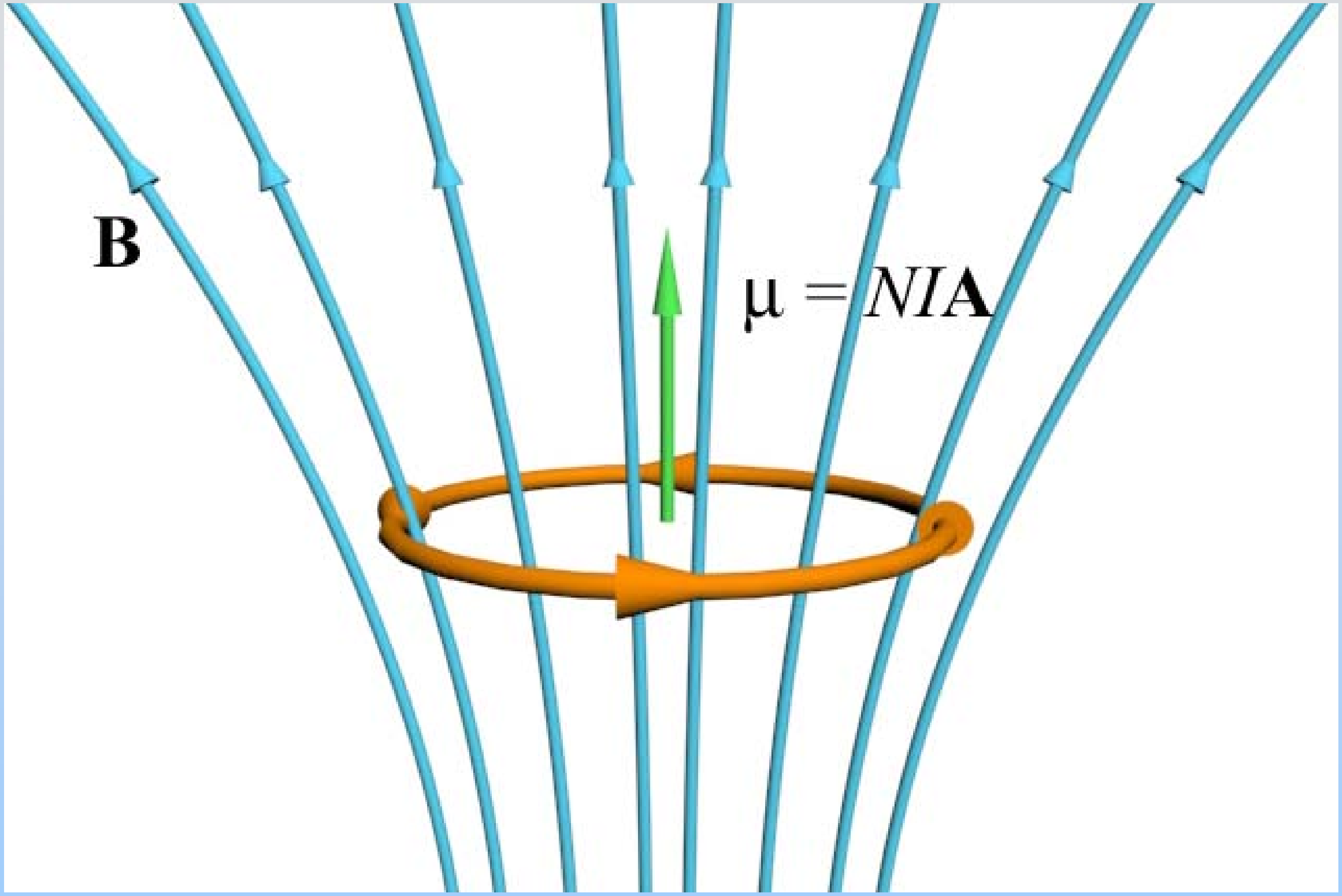
$$U_{Dipole} = -\vec{\mu} \cdot \mathbf{B}$$

Where does dipole go to reduce its energy?

Aligned dipoles seek high fields!

→ Force here is down

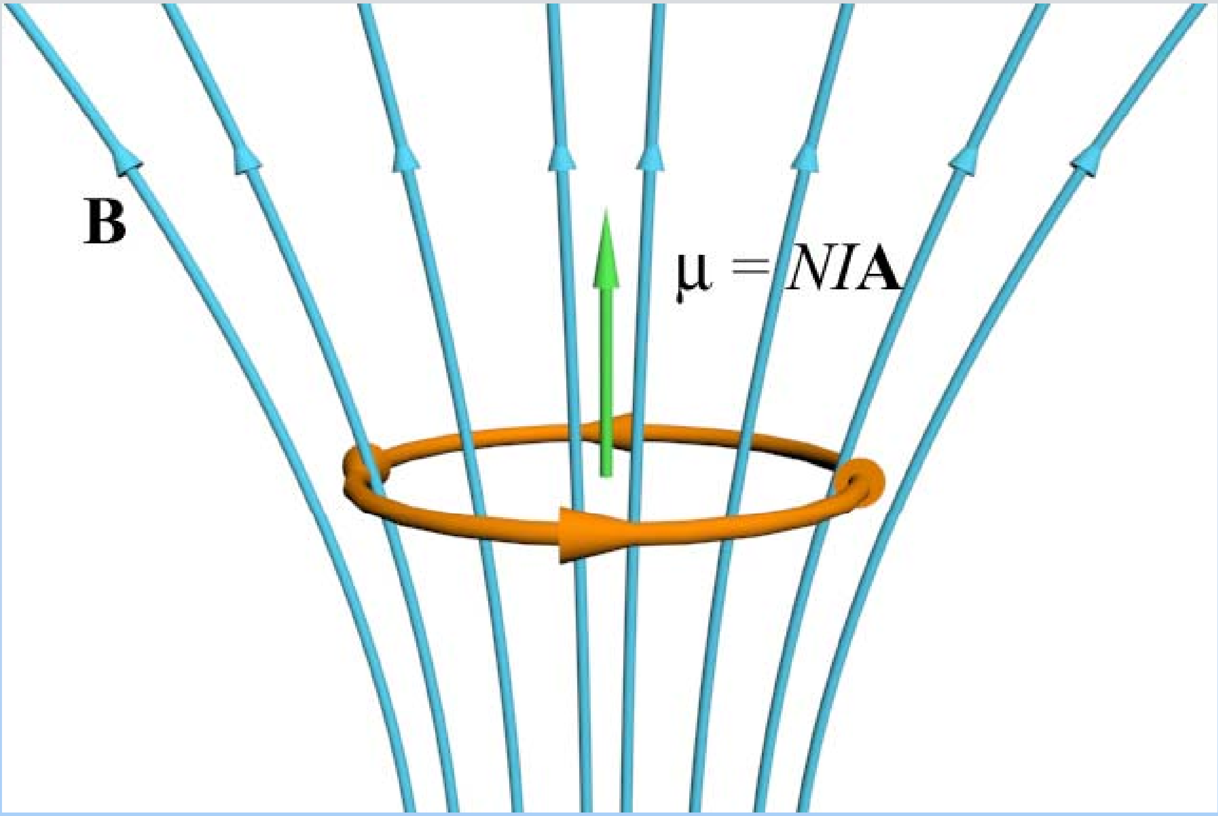
Force on Magnetic Dipole

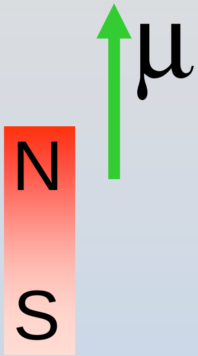


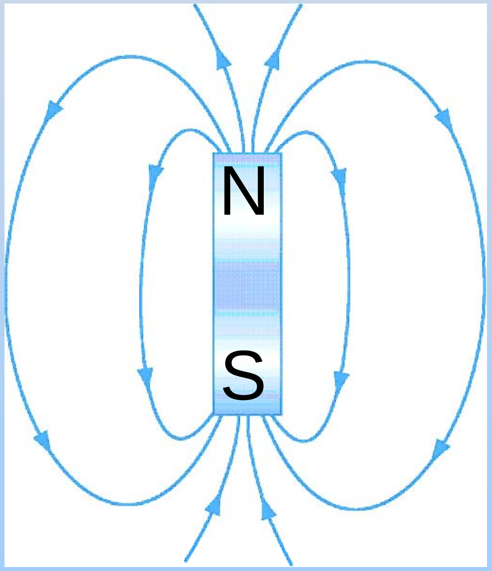
Alternate Thought #2

What makes the field pictured?

Force on Magnetic Dipole



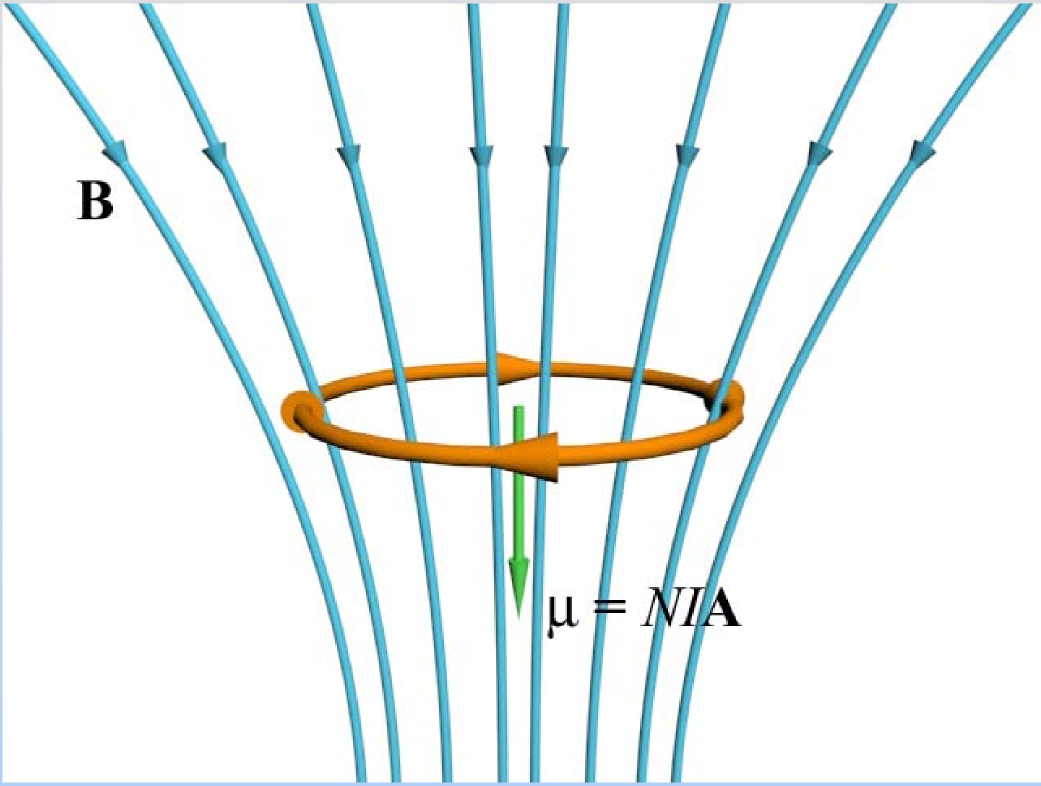




Bar magnet below dipole, with N pole on top
It is aligned with the dipole pictured, they attract!

Concept Question Questions: Force on Dipole

Concept Question: Dipole in Field



The current carrying coil above will feel a net force

1. upwards
2. downwards
3. of zero
4. I don’t know

Concept Question: Free Dipoles

If a number of dipoles are randomly scattered through space, after a while they

1. Attract (move together)
2. Repel (move apart)
3. Basically stay put
4. I don't know