



Phys 102 – Lecture 11

Magnetic dipoles & current loops

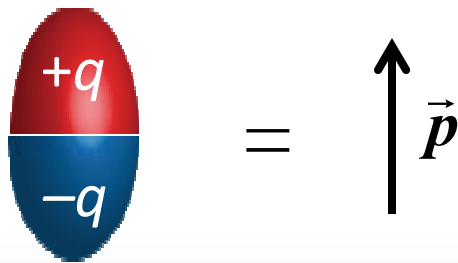
Today we will...

- Learn how magnetic fields act on
 - Magnetic dipoles
 - Current loops
- Apply these concepts!
 - Magnetotactic bacteria
 - Principles behind NMR/MRI, EPR/ESR
 - Magnetic materials (paramagnets and ferromagnets)

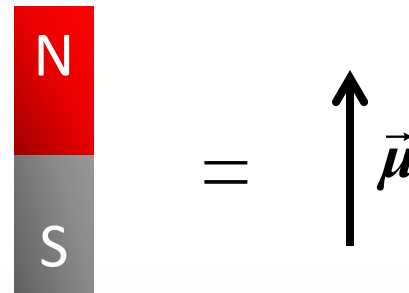
Magnetic dipole & dipole moment

A magnetic N and S pole make up a *magnetic dipole*

Recall: electric dipole



Magnetic dipole



Magnetic dipole moment is analogous to electric dipole moment

Direction

Vector from S to N pole (by convention)

Dipole in uniform field

Electric & magnetic dipole moments align parallel to field

Torque: $\tau = pE \sin \theta$

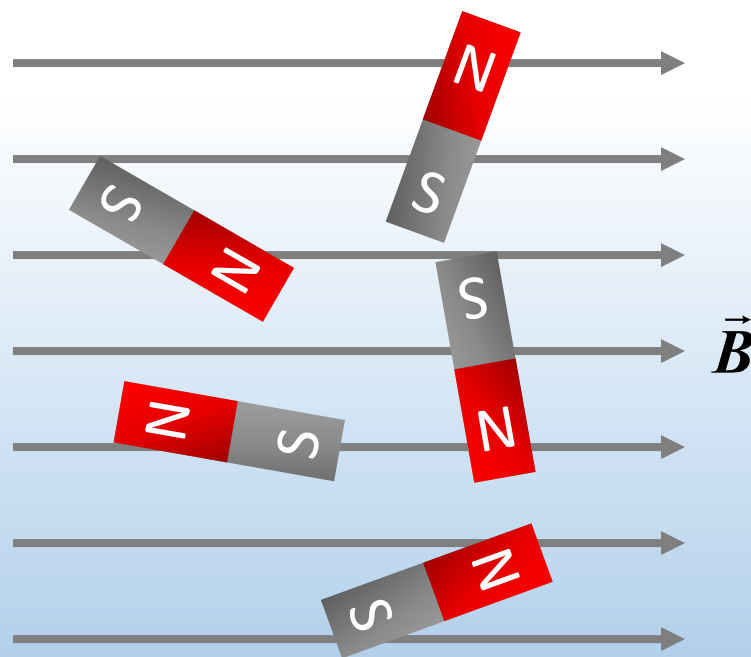
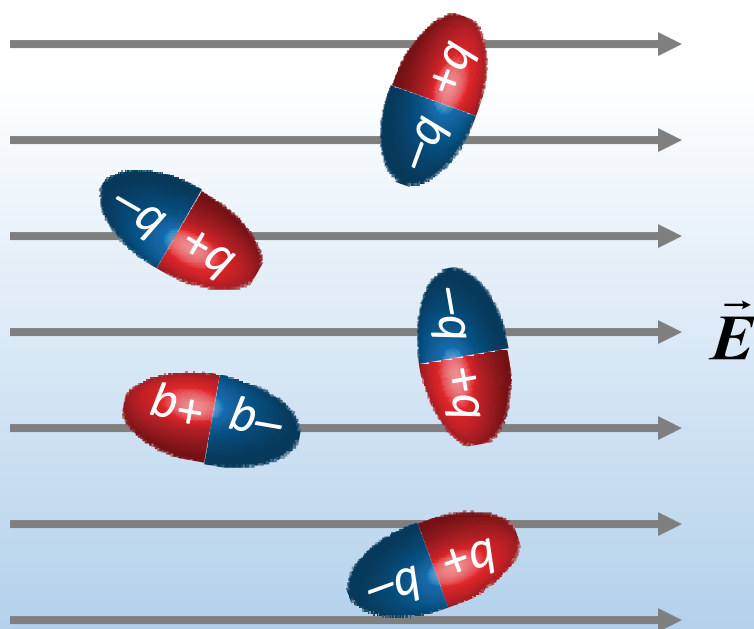
Lect. 3

$$\tau = \mu B \sin \theta$$

Energy: $U_{dip} = -pE \cos \theta$

Lect. 4

$$U_{dip} = -\mu B \cos \theta$$



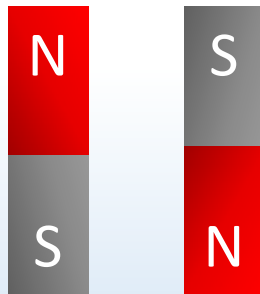
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ACT: CheckPoint 1.1

Which of the three configurations of magnetic dipoles show below has the highest potential energy?

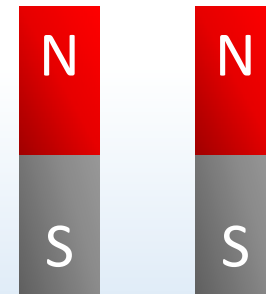
A.



B.



C.



Calculation: magnetic bacteria

Magnetotactic bacteria grow a chain of magnets to align to the Earth's B field



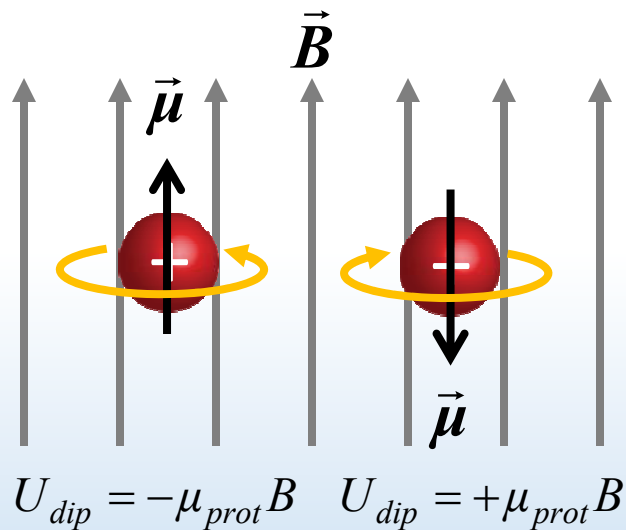
Magnetospirillum magnetotacticum

Room temperature kinetic energy tends to randomizes orientation

Find minimum value of μ such that cells align to the Earth's field

Spin & magnetic fields

Electrons, protons, & neutrons (and many others) have an intrinsic property called “spin” which gives them a *magnetic dipole moment*



Nuclear magnetic resonance (NMR) / magnetic resonance imaging (MRI)

Detects energy difference between nuclear spins (ex: ^1H) parallel and anti-parallel to B field

$$\mu_{prot} = 1.4 \times 10^{-26} \text{ J/T}$$

Electron paramagnetic resonance (EPR) / electron spin resonance (ESR) applies same principle with electron spin

$$\mu_{elec} = 9.3 \times 10^{-24} \text{ J/T}$$

Magnetic force on current

Recall: B field exerts a force on a moving charge q

Current I is flow of + charge

Magnitude

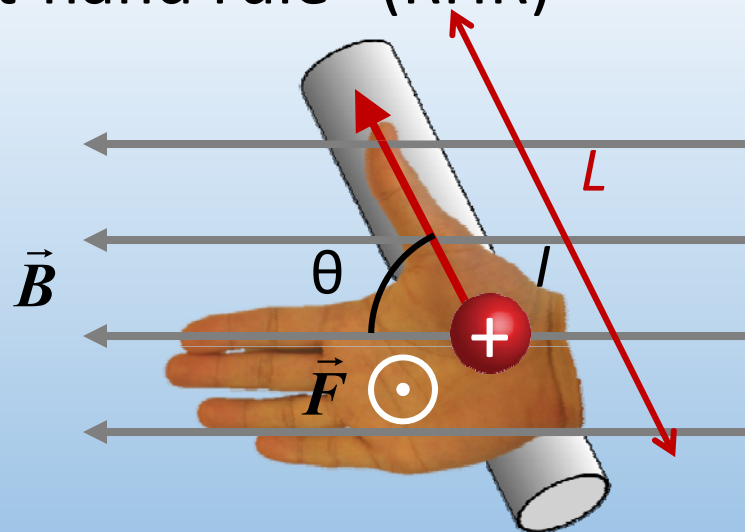
$$F = |q| v B \sin \theta = ILB \sin \theta$$

← Angle between I and B

Current Length of wire B field strength

Direction

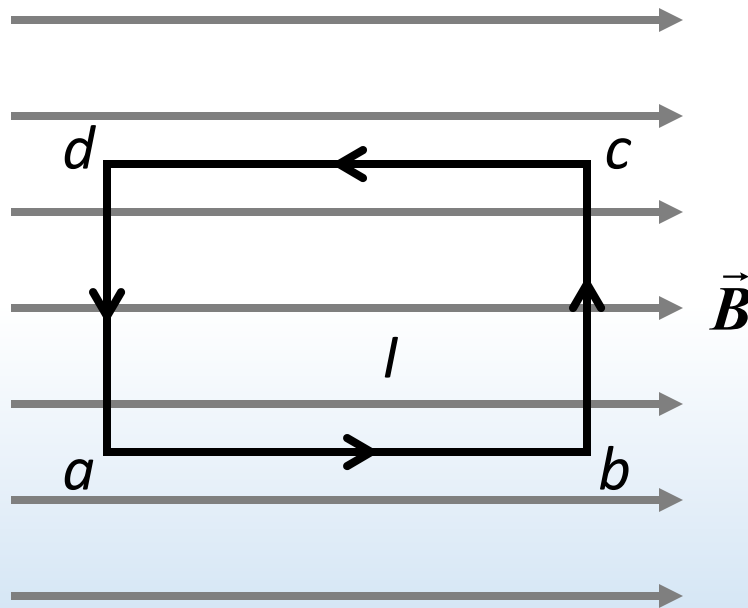
“Right-hand rule” (RHR)



Thumb along I
Fingers along \vec{B}
 \vec{F} on I is out of palm

Checkpoint 2.1

A rectangular loop of wire is carrying current I 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?

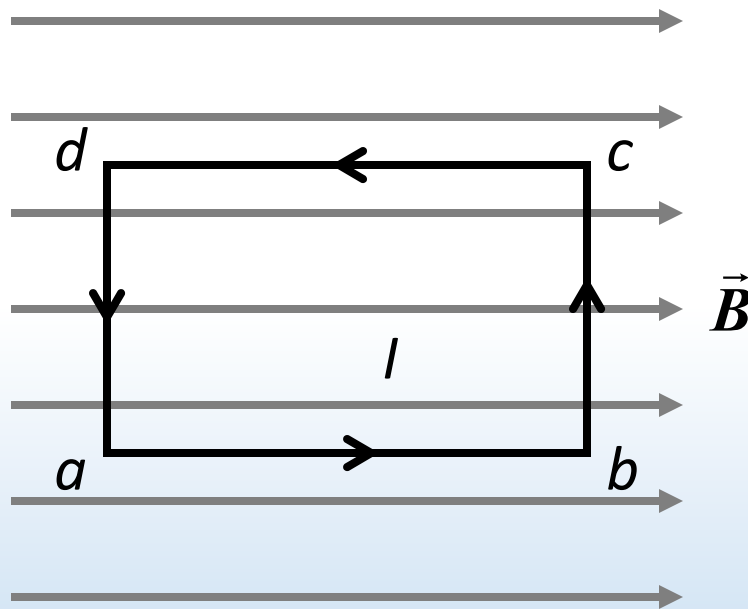
- A. force is zero
- B. out of the page
- C. into the page

...on section $c-d$ of the wire?



ACT: CheckPoint 2.2

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



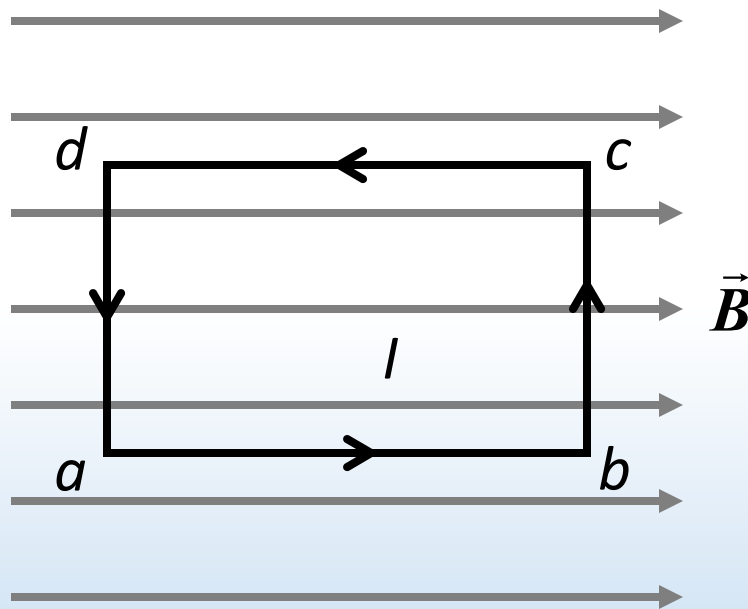
What is the direction of the force on section $b-c$ of the wire?

- A. force is zero
- B. out of the page
- C. into the page



ACT: Force on loop

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

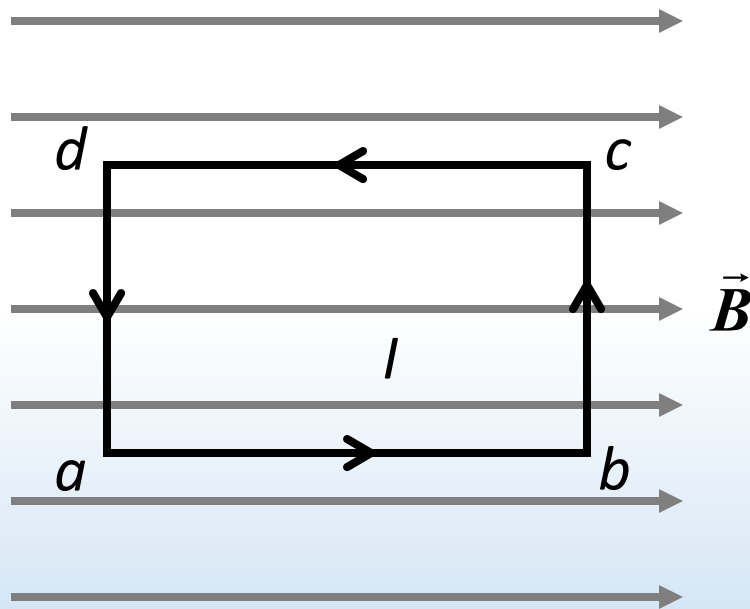


What is the direction of the force on section $d-a$ of the wire?

- A. force is zero
- B. out of the page
- C. into the page

CheckPoints 2.3 & 2.4

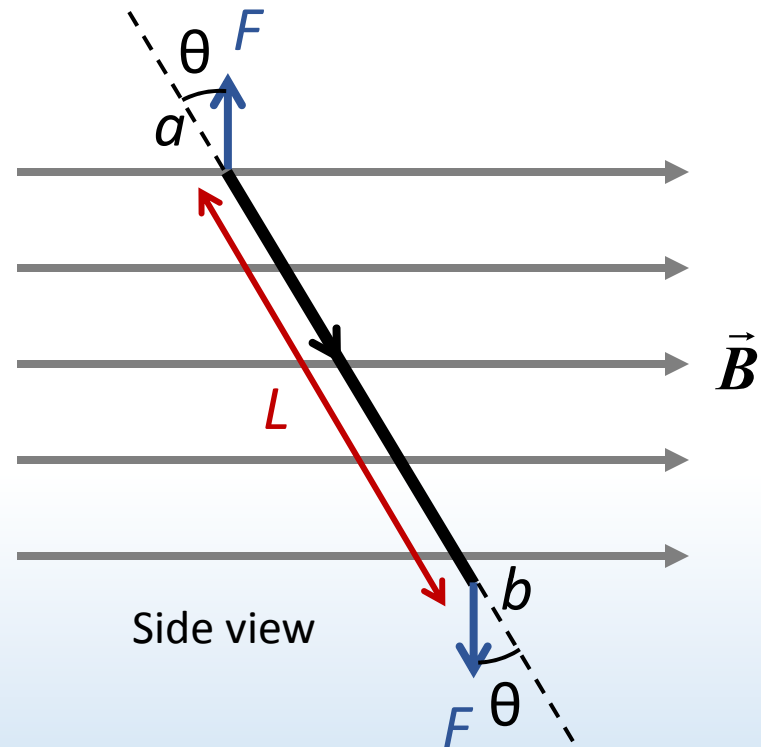
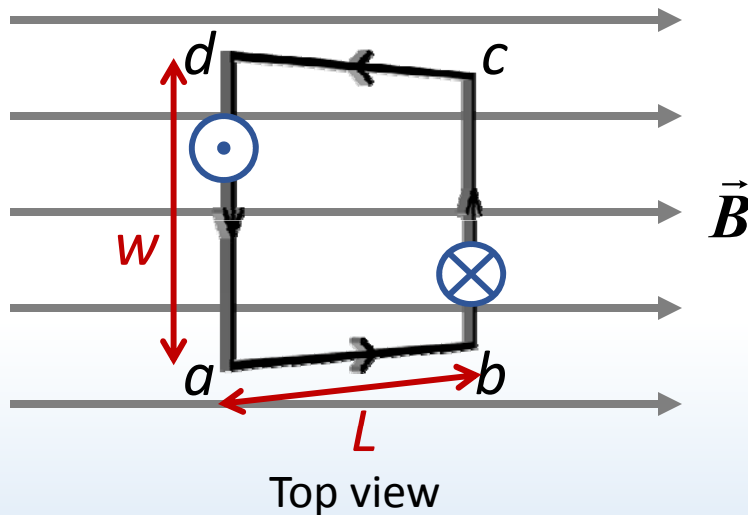
So, does the loop move?



DEMO

Torque on current loop

Loop spins in B field



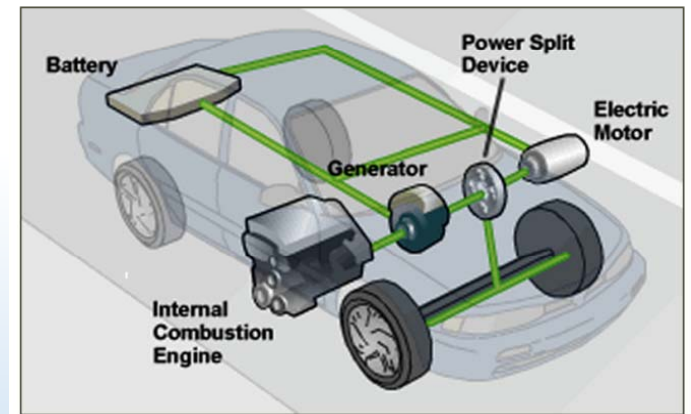
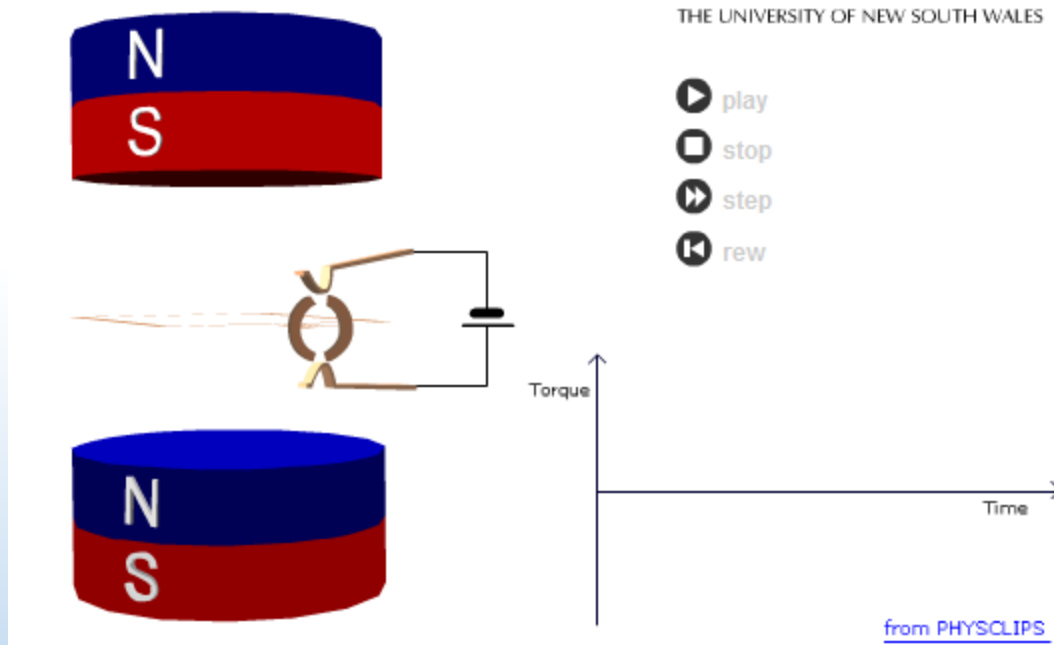
B field generates a torque on the loop

$$\tau_{loop} = FL \sin \theta = IBwL \sin \theta$$

$$\tau_{loop} = IAB \sin \theta$$

Electric motors

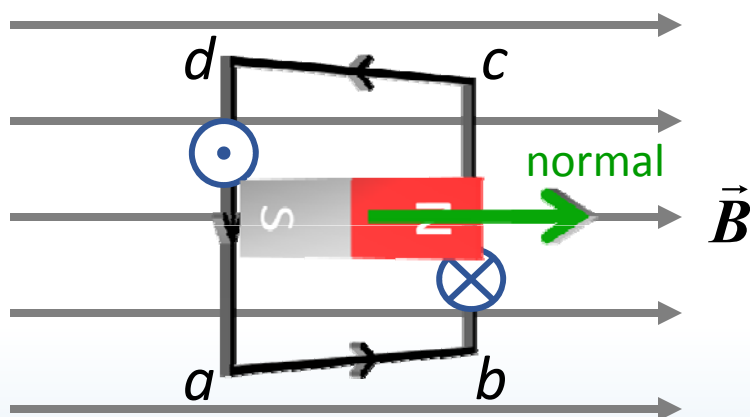
DC motors use a clever arrangement of current carrying coils and permanent magnets to turn a shaft:



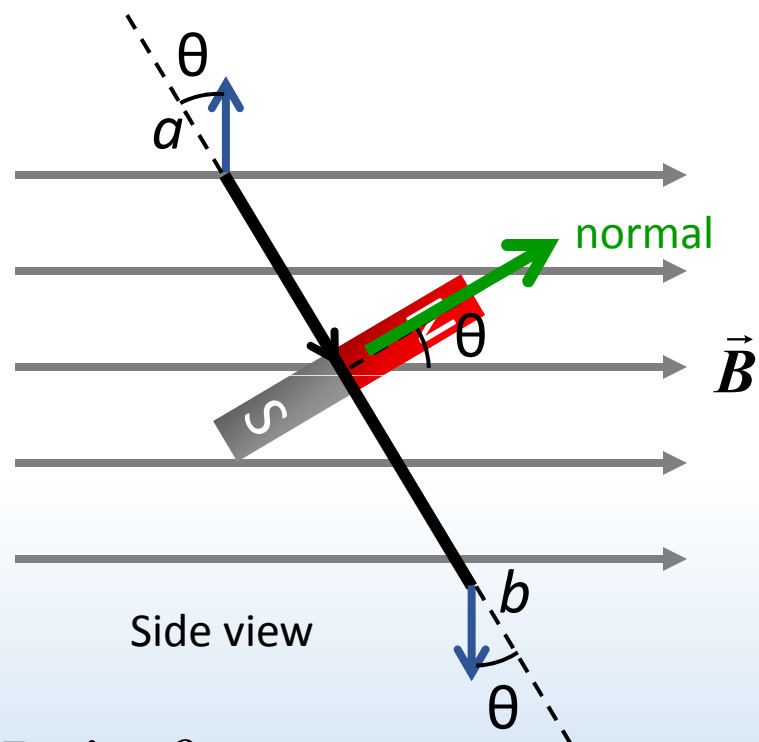
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Current loop & magnetic dipole

B field exerts torque on loop



Top view



Side view

$$\tau_{loop} = IAB \sin \theta = \mu B \sin \theta$$

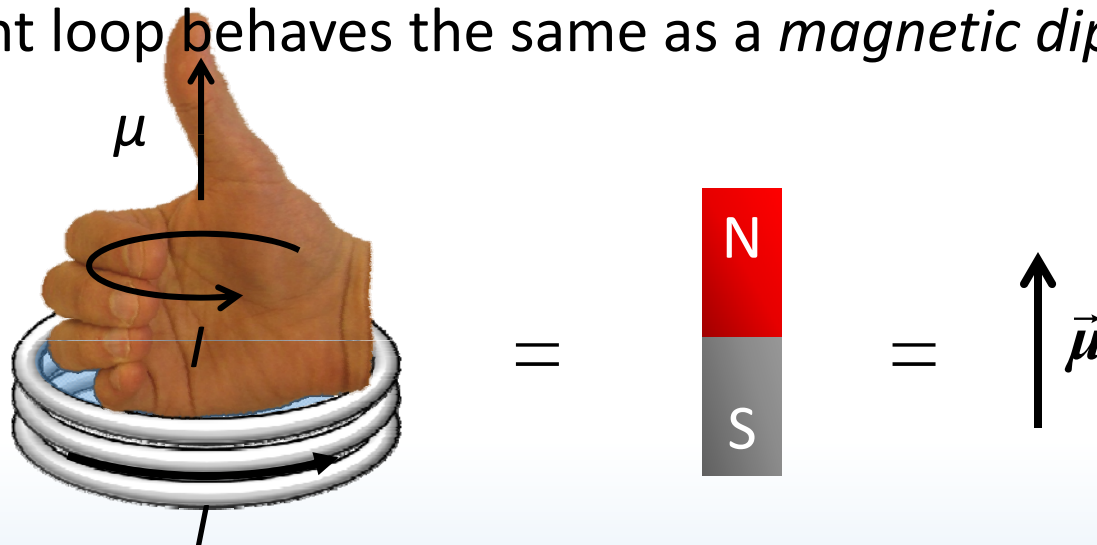
Current loop behaves the same as magnetic dipole \perp to loop plane

Convenient to define a normal vector \perp to loop plane, $||$ to dipole moment

Torque aligns normal vector $||$ to B field

Magnetic dipole & current loop

A current loop behaves the same as a *magnetic dipole*



Equivalent magnetic dipole moment:

Magnitude

$$\mu = NIA$$

True for *flat* loop of *any* shape

For a loop with N turns of wire

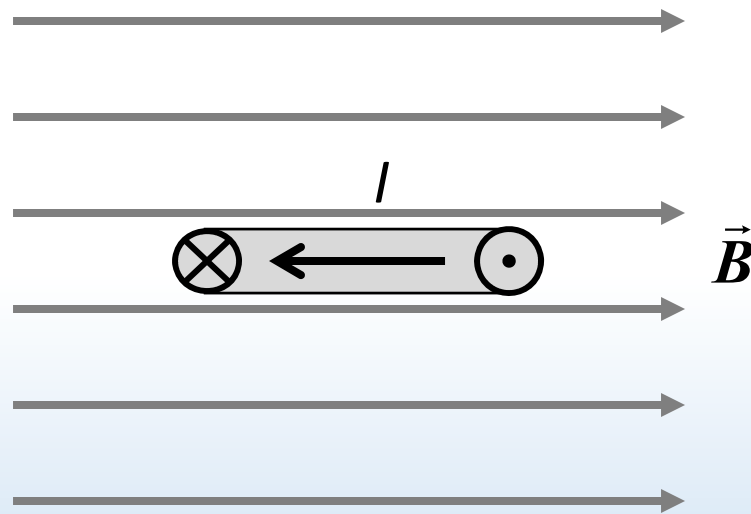
Direction

Another “right hand rule”: Curl fingers along I
 $\vec{\mu}$ along thumb



ACT: Current loop practice

A loop is placed in a uniform B field. A current I flows around the loop as shown.



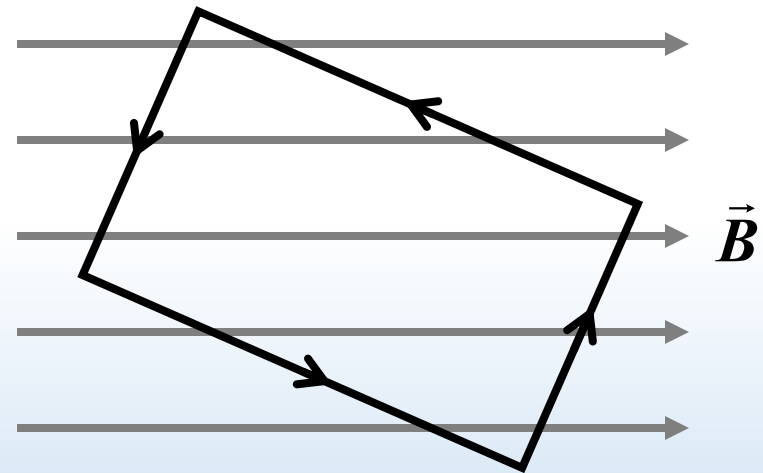
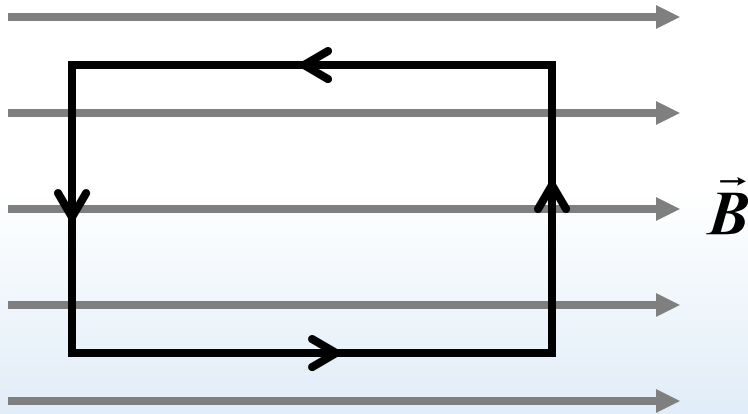
Which way does loop rotate?

- A. Clockwise
- B. Counterclockwise
- C. The loop does not rotate



ACT: Torque on a loop

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

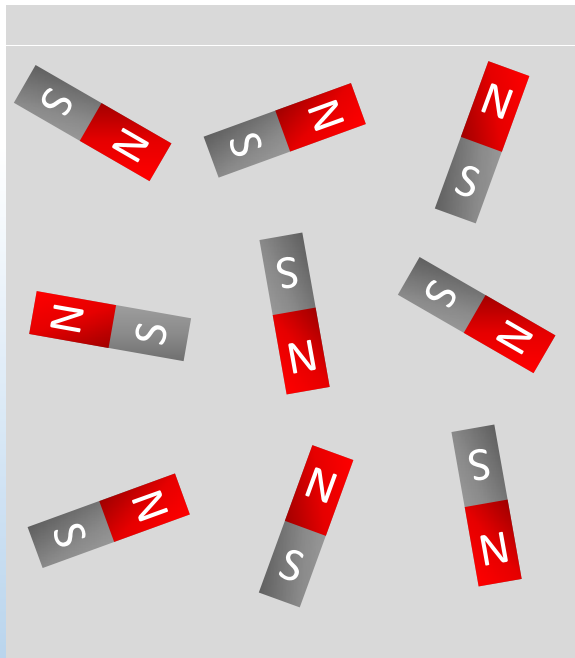


- A. $\tau_1 > \tau_2$
- B. $\tau_1 = \tau_2$
- C. $\tau_1 < \tau_2$

Para- & ferromagnetism

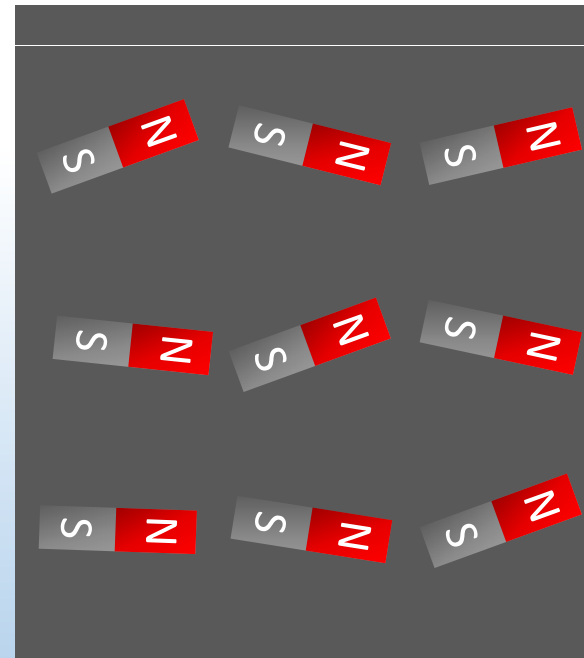
In some materials, unpaired electron (spin & orbit) give atoms net magnetic moment

In paramagnets, atomic dipoles are randomly oriented



Apply a B field and dipoles align!
Material now behaves as a magnet

In ferromagnets, atomic dipoles interact and align together



Material is a permanent magnet



ACT: Magnetic materials

The N pole of a permanent magnet is brought near a *paramagnetic* ball bearing. What happens next?



- A. The ball moves toward the magnet
- B. The ball moves away from the magnet
- C. The ball does not move

DEMO

Summary of today's lecture

- B fields exert torque on magnetic dipoles

$$\tau_{dip} = \mu B \sin \theta \quad U_{dip} = -\mu B \cos \theta$$

- B fields exert force on current-carrying wire

$$F_{wire} = ILB \sin \theta$$

- Current loops are equivalent to magnetic dipole

$$\mu = NIA$$

