Magnetic Fields (II)

Text sections 29.4, 29.5

- Force on a current-carrying wire
- Torque on a current loop

For practice: Chapter 29,
Objective Questions 7, 11
Conceptual Questions 2, 6
Problems 13, 15, 16, 27, 73

Magnetic Forces

Charged Particle: $$\vec{F} = q\vec{v} \times \vec{B}$$

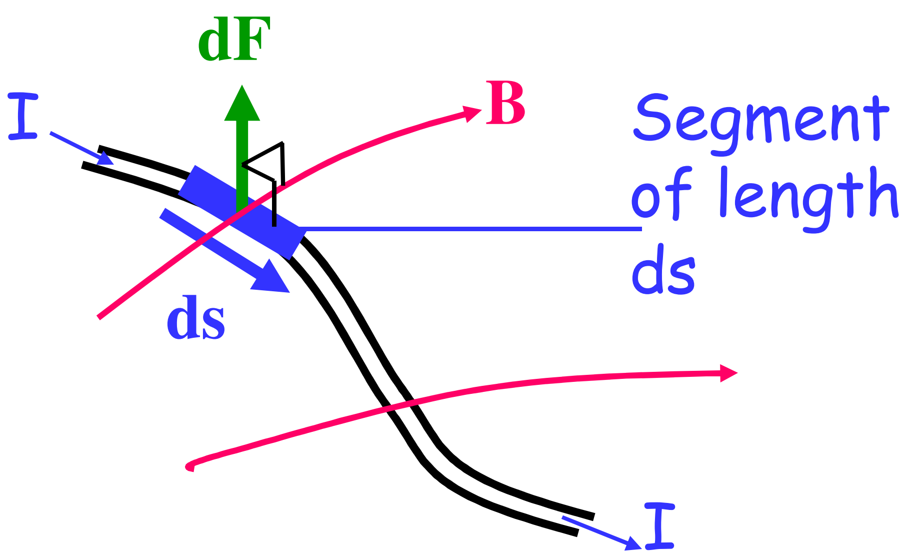
Straight wire, Uniform B: $$\vec{F} = I\vec{L} \times \vec{B}$$

B *not uniform, and/or wire not straight: the force* **dF** *on a short segment of vector length* **ds** *is*

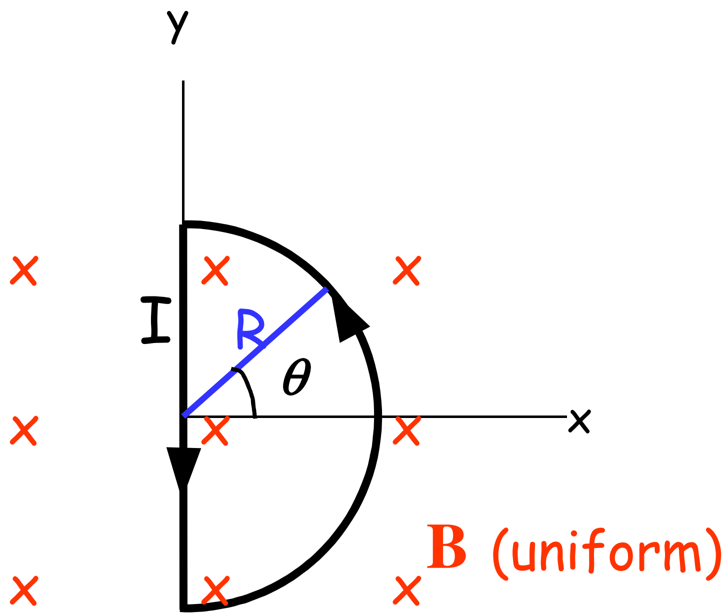
$$\mathbf{dF} = I\mathbf{ds} \times \mathbf{B}$$

*The **total** force on the wire is*

$$\mathbf{F} = \int_{\substack{along \\ wire}} I\mathbf{ds}\times\mathbf{B}$$



Example



Find the force on:

a) The straight wire
b) The semicircular wire
c) The whole circuit

For (b): start with force **dF** due to an infinitesimal piece, and do the integral.

Quiz

The magnetic force **on the straight wire** is:

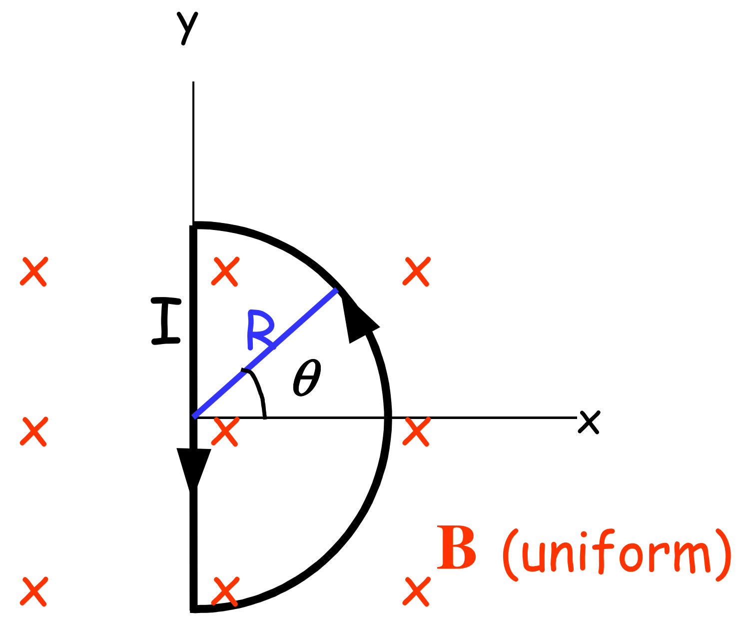
A) Into the page

B) Out of the page

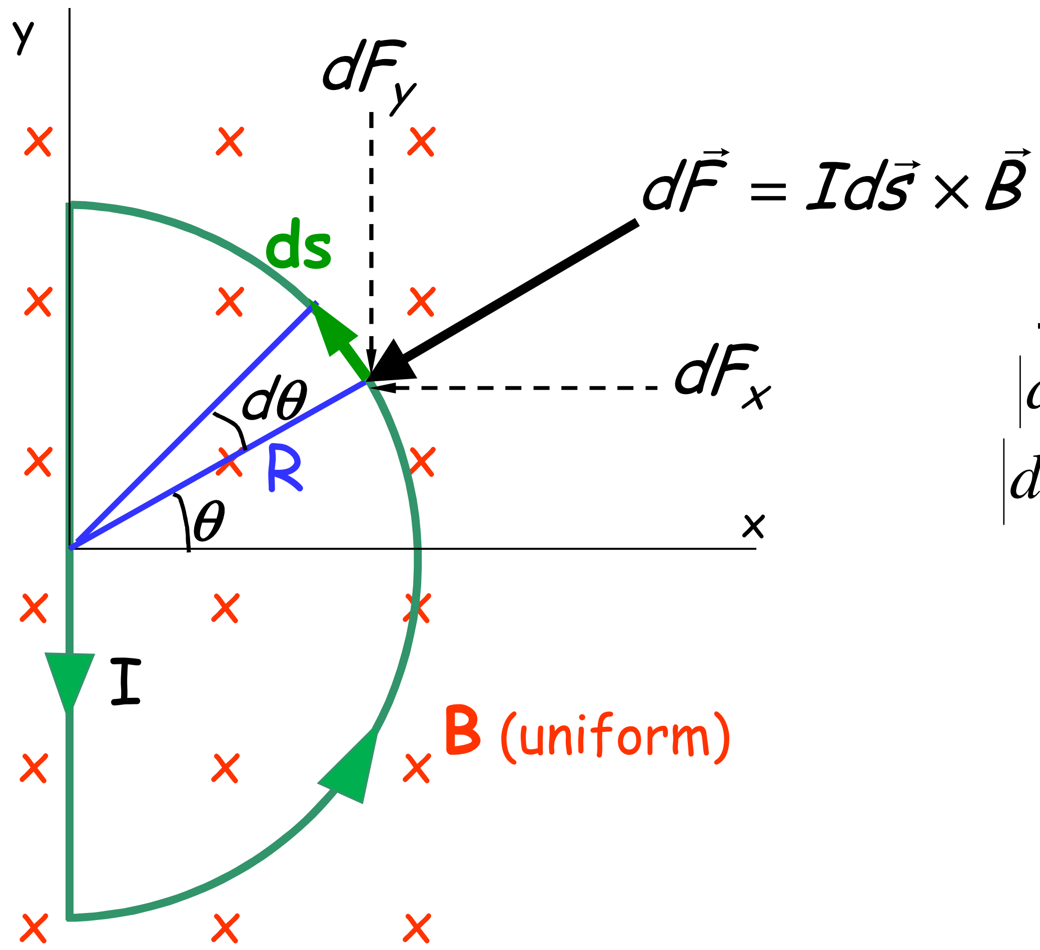
C) Left ←

D) Right →

E) Zero



Part b)



where:

$$|d\vec{s}| = R d\theta$$

$$|d\vec{F}| = I |d\vec{s}| \cdot |\vec{B}|$$

$$= I\, R\, B\, d\theta$$

Exercise: set up the integrals and find F_x, F_y.

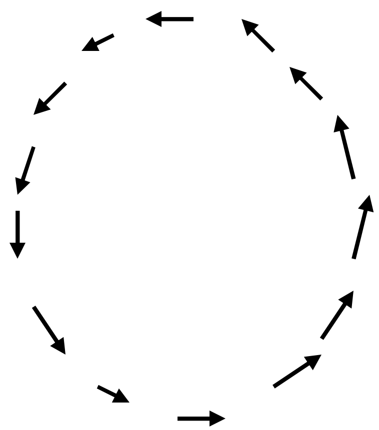
Theorem: *For a* ***closed*** *current loop, in a* ***uniform*** *magnetic field,*

Total magnetic force = 0

Proof: $\vec{F} = \int I d\vec{s} \times \vec{B}$

$= I\left\{\int d\vec{s}\right\} \times \vec{B}$ *(if* **B** *is a constant vector)*

BUT: $\int d\vec{s} = \mathbf{0}$ for a closed loop!

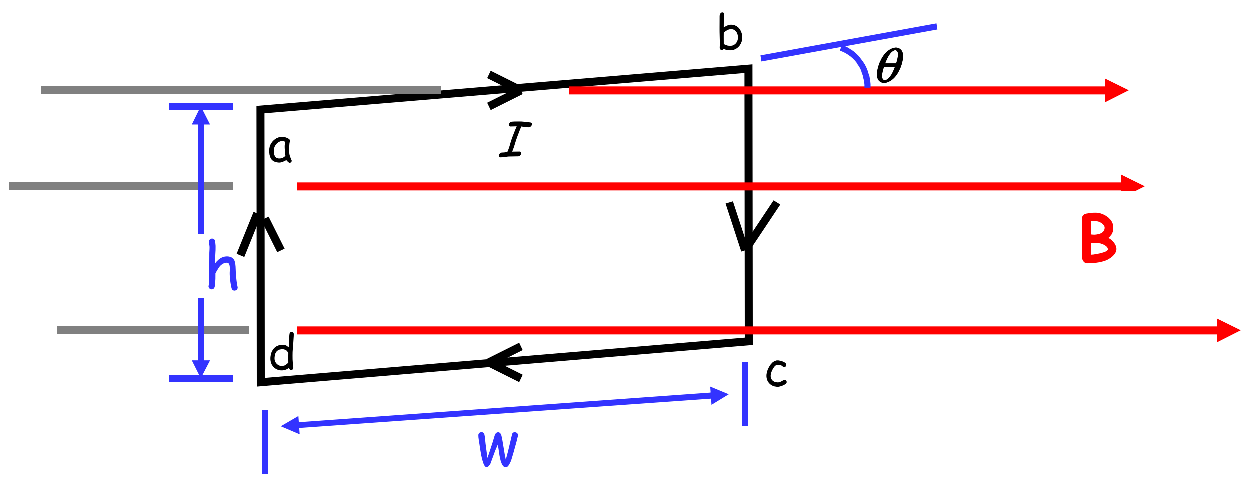


Although there is no net force on a circuit in a uniform field, there may be a net torque. The torques due to equal and opposite forces applied at different locations do not necessarily cancel.

We can calculate the torque directly for a rectangular loop. There is also a simple rule, which applies to a loop of any shape. First we need to define the "magnetic dipole moment" (a vector) for a current loop.

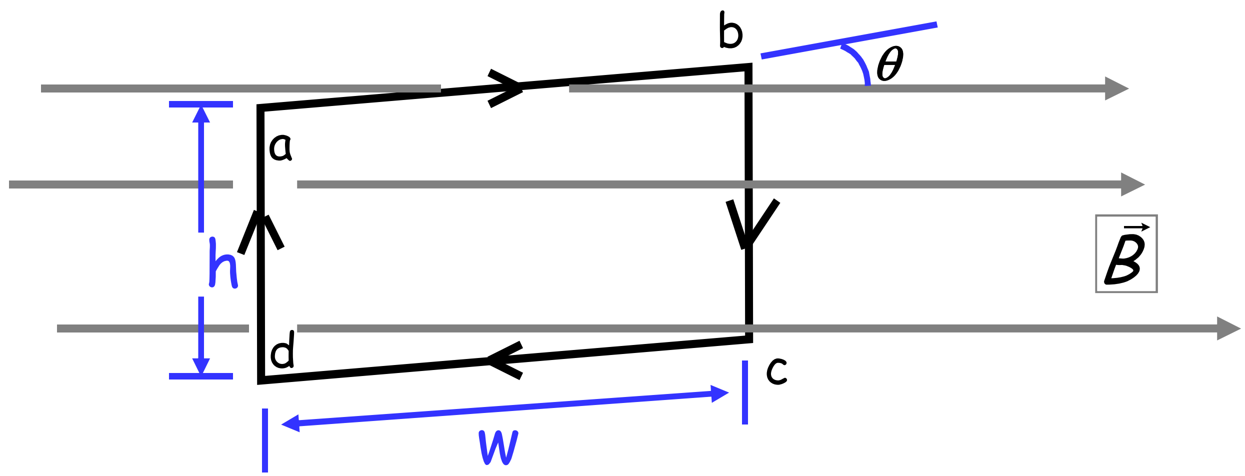
Torque on a Current Loop (Uniform B)

Example: a rectangular loop

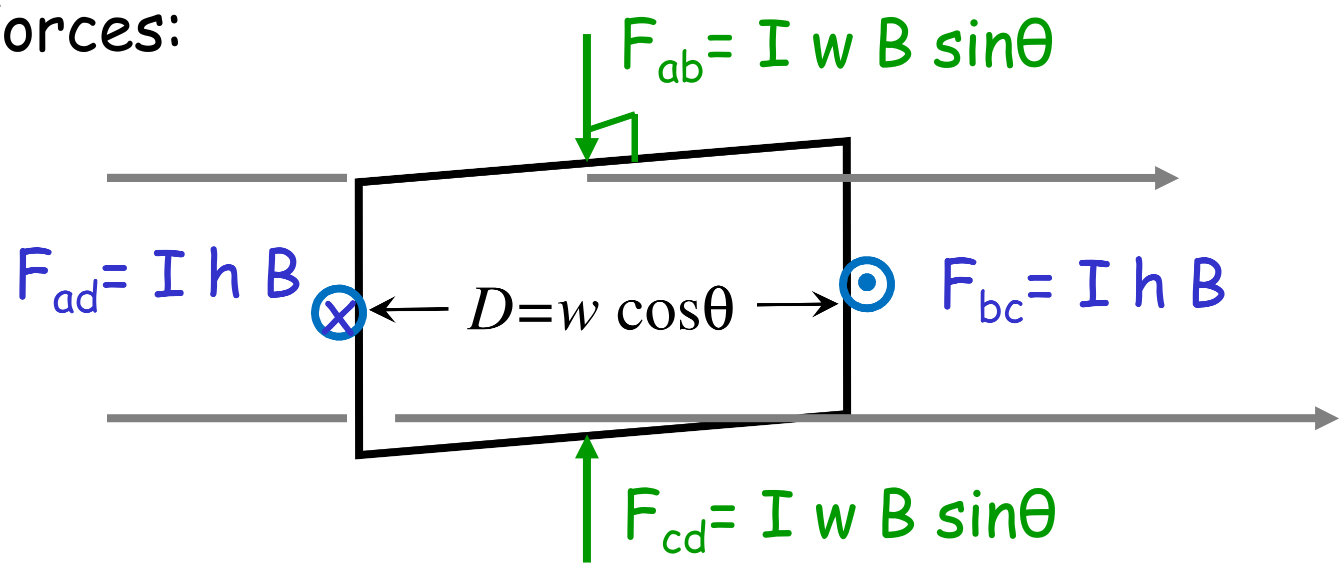


Exercise: Find the 4 forces on the 4 sides of the rectangle, and show that they produce a net torque equal to $(Iwh)B\cos\theta$.

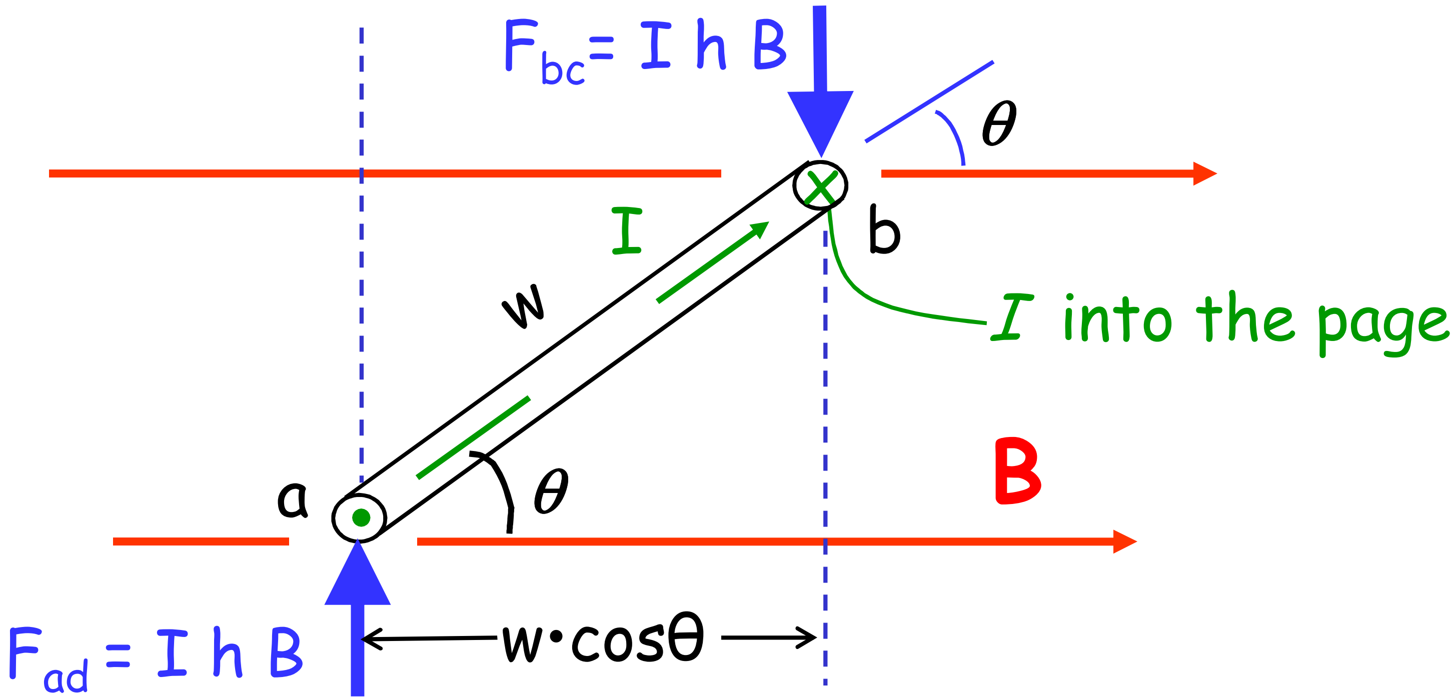
rectangular loop



Forces:



Top view:



➔**Torque** (about *any* pivot; *e.g.*, at a)

$$= IhB \times w\cos\theta$$

$$= (Ihw)B \cdot \cos\theta$$

$$= (I \times area) \times B \times \cos\theta$$

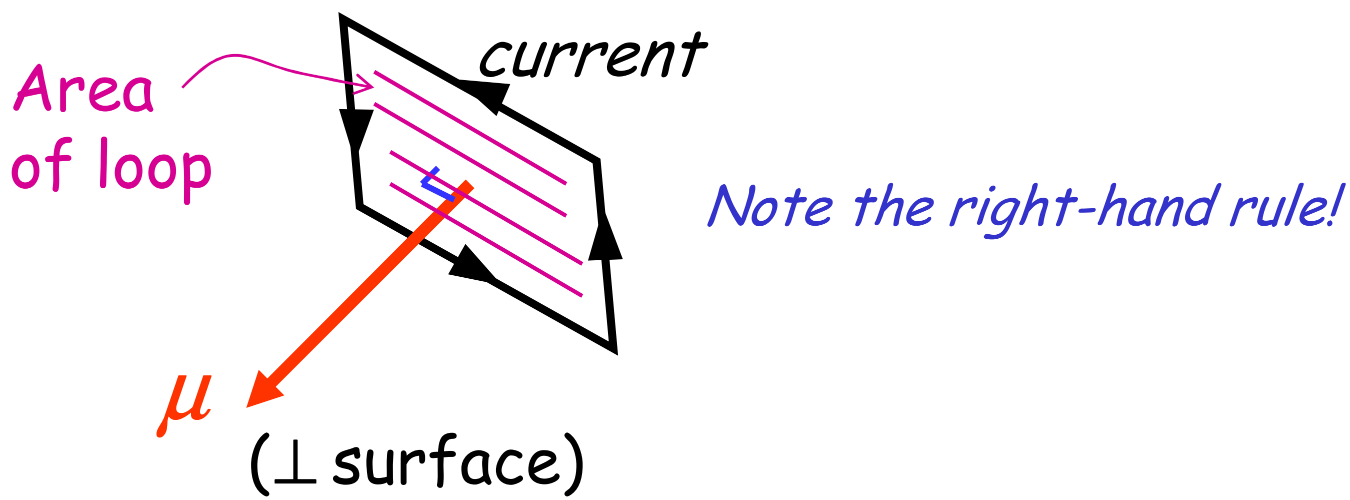
Magnetic Moment $\vec{\mu}$

(or "magnetic dipole moment")

Define the magnetic moment of a current loop by

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

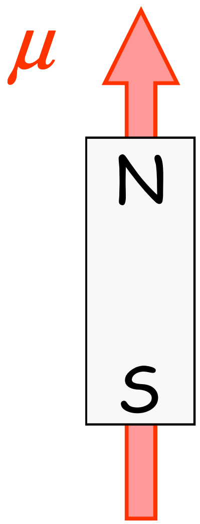
$(\vec{A} = \text{"vector area" of loop})$



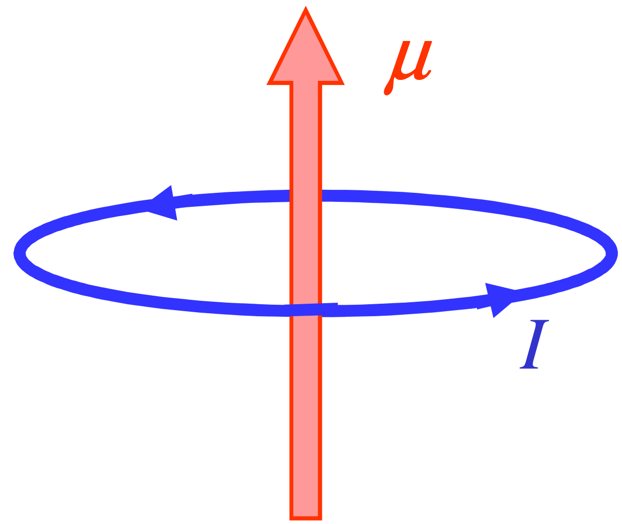
Then the **torque** on a circuit in a <u>uniform</u> field $\vec{B}$ is

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

The magnetic dipole moment is a measure of the "magnetic strength" of a current loop or magnet.



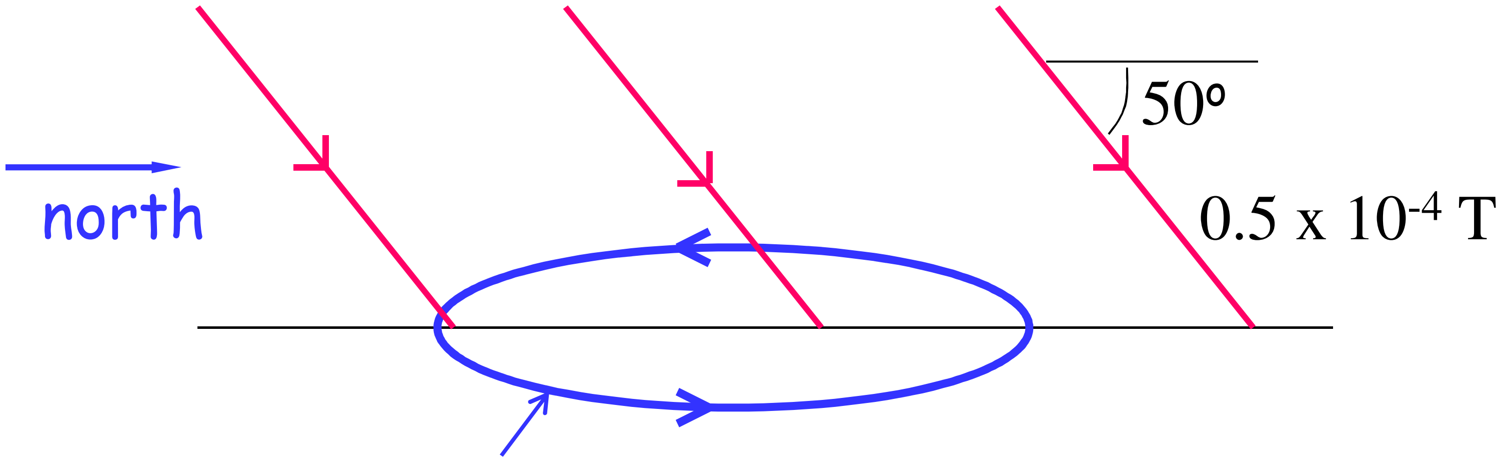
bar magnet



current loop

Example

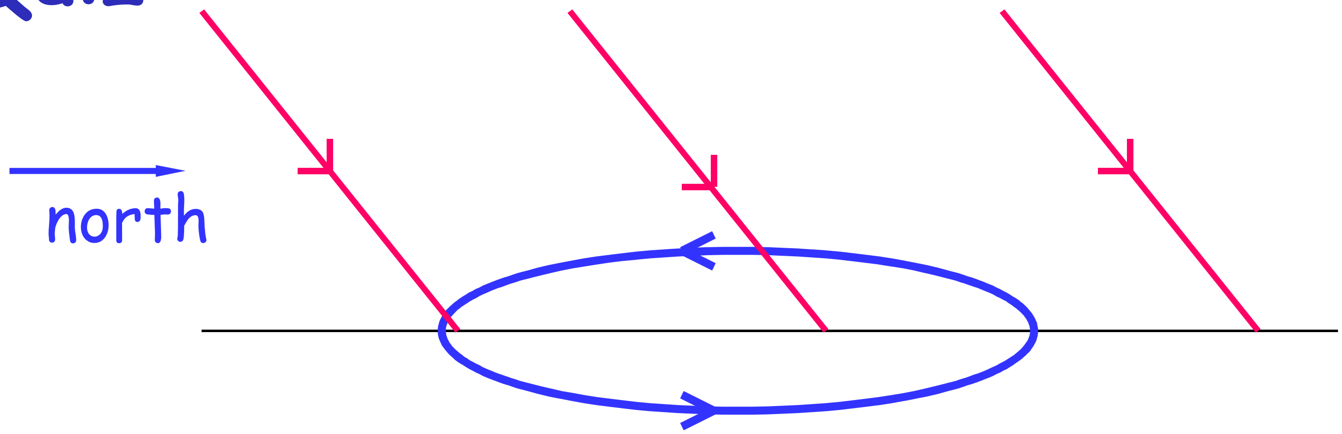
Find the torque on a flat, horizontal, circular coil due to the magnetic field of the Earth.



Circular loop, 200 turns, R = 1 m, I = 20 A, CCW (from above)

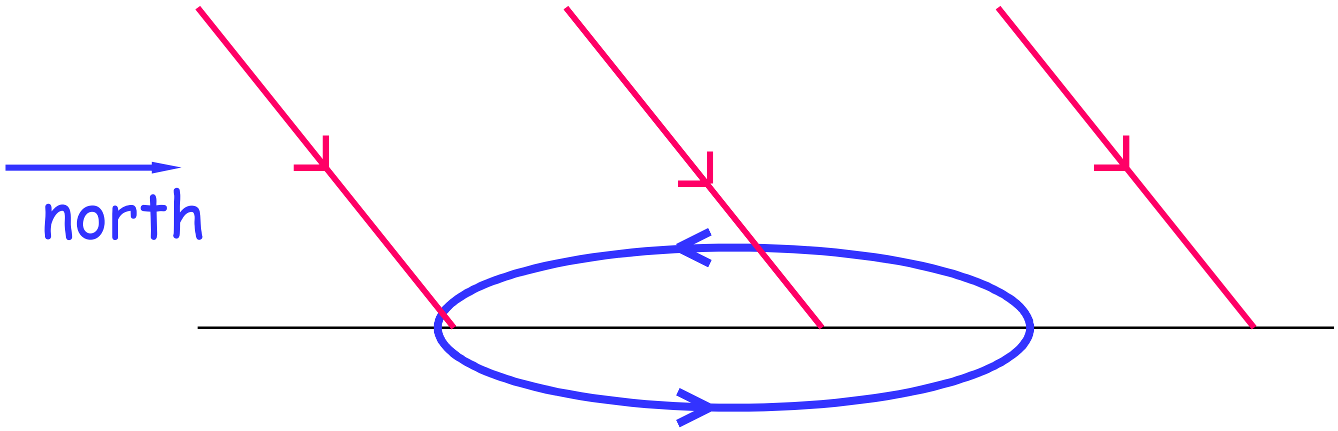
Find: Torque (magnitude and direction)

Quiz



First step: What is the direction of the magnetic moment of the circuit?

A) North
B) South
C) East
D) West
E) Up



What is the direction of the *torque vector*?

A) North
B) South
C) East
D) West
E) Up