Electromagnetic Fields

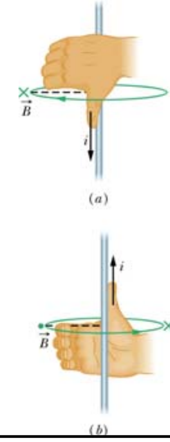
- **Ch.28: The magnetic field: Lorentz Force Law**
- **Ch.29: Electromagnetism:**
  - ***B* field due to a current in a long straight wire**
  - ***B* field due to a current in a short bit of wire**
  - **Ampere's Law: the third of Maxwell's Equations**
- **Ch.30: Induced E Fields: Faraday's Law**

REVIEW:

Field of a long straight wire

1. Direction is given by the right-hand rule!
2. Magnitude is $B = \dfrac{\mu_0 i}{2\pi r}$
3. New universal constant:

$$\mu_0 = 4\pi \times 10^{-7}\ Tm/A$$



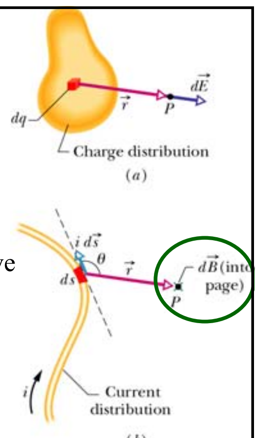
REVIEW: Field due to a *short bit* of wire

Recall Coulomb:
E is **parallel** to ***r.***

But as usual for magnetism, we find ***B*** is **perpendicular** to ***r***!

$$d\vec{B} \propto i\, d\vec{s} \times \vec{r}$$

Another right-hand rule!



REVIEW: Ampere's Law

$$\oint_C \vec{B} \cdot d\vec{s} = \mu_0 i_{enc}$$

C = Any closed path

i_{enc} = Net current linking C (*Right-hand rule)*

***B* = The total magnetic field**

***ds* = A short step along the path**

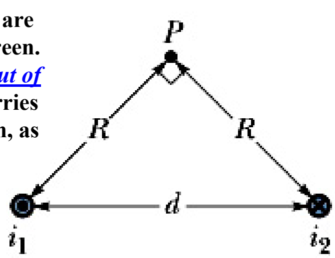
Example: Sample Problem 29-2

Two long parallel wires are perpendicular to the screen. One carries current i_1 *out of* the screen, the other carries current i_2 *into* the screen, as shown.

i_1 = 15 A

i_2 = 32 A

d = 5.3 cm



What is the magnetic field at point P?

(Notice the right angle at P.)

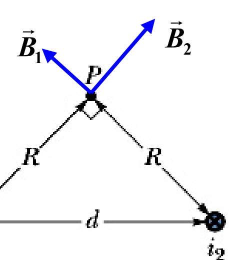
Example continued

What is the magnetic field at point P?

i_1 = 15 A
i_2 = 32 A
d = 5.3 cm

$$R = d\cos 45° = .037\ m$$

$$B_1 = \frac{\mu_0 i_1}{2\pi R} = \frac{4\pi 10^{-7} 15}{2\pi .037} = 8 \times 10^{-5}\ T$$



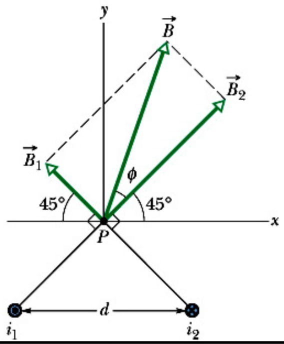
$$B_2 = \frac{\mu_0 i_2}{2\pi R} = \frac{4\pi 10^{-7} 32}{2\pi .037} = 17 \times 10^{-5}\ T$$

Example continued

What is the magnetic field at point P?

$B_1 = 8 \times 10^{-5}\ T$

$B_2 = 17 \times 10^{-5}\ T$



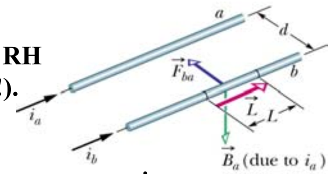
$$B_x = B_{1x} + B_{2x}$$
$$= B_2 \cos 45° - B_1 \cos 45°$$
$$= (17 - 8) \times 10^{-5} / \sqrt{2} = 64\ \mu T$$

$$B_y = B_{1y} + B_{2y}$$
$$= B_1 \sin 45° + B_2 \sin 45°$$
$$= (17 + 8) \times 10^{-5} / \sqrt{2} = 180\ \pi T$$

$$B = \sqrt{B_x^{\ 2} + B_y^{\ 2}}$$
$$= \sqrt{64^2 + 180^2} = 190\ \mu T$$

Force between two wires

Get direction from RH rule (applied twice!).



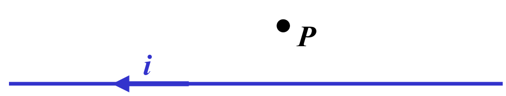
Field at ***b*** due to ***a*** is $B = \dfrac{\mu_0 i_a}{2\pi d}$ $\qquad \vec{F}_{ba} = ?$

Force on ***b*** due to this ***B*** is

$$F_{ba} = i_b L B = \frac{\mu_0 L i_a i_b}{2\pi d}$$

Q.29-1

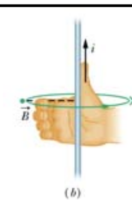
A long straight horizontal wire carries a current ***i*** in the direction shown. What is the direction of the magnetic field at point ***P***, vertically above the wire?



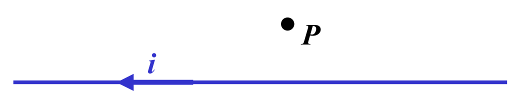
(1) Up (2) Down (3) Right (4) Left
(5) Into the screen (6) Out of the screen

Q.29-1

What is the direction of the magnetic field at point ***P***?



Right-hand rule: thumb with current, field with fingers.

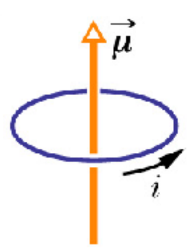


(1) Up (2) Down (3) Right (4) Left
(5) Into the screen (6) Out of the screen

Dipole Moment of a Current Loop

Definition: ***Magnetic dipole moment vector:*** $\vec{\mu}$

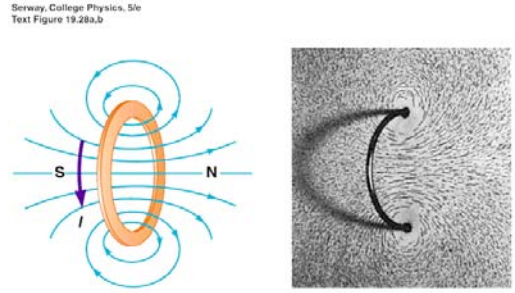
- Direction: ***RH rule***
- Magnitude: $\mu = iA$



Analogous to electric dipole moment vector $\vec{p}$

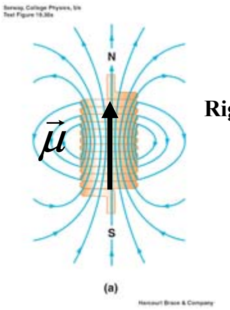
Field Due to a Current Loop

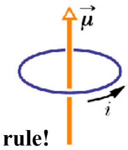
Serway, College Physics, 5/e
Text Figure 19.28a,b



Right-hand rule: fingers with current, thumb gives direction of field on axis.

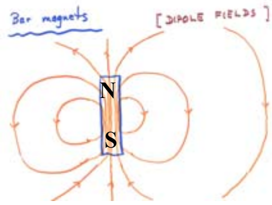
Magnetic Dipole Field





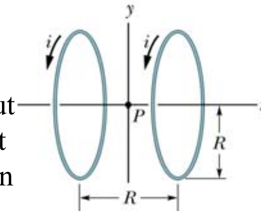
$\vec{\mu}$

Right-hand rule!



Q.29-2

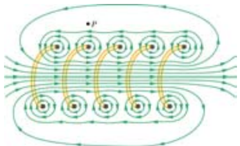
Two wire loops carry currents as shown. If I put a small compass needle at point P, in which direction will it point?

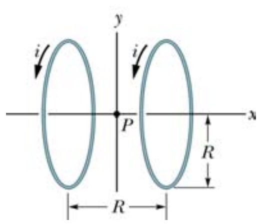


(1) +x (2) –x (3) +y (4) –y (5) +z (6) -z

Q.29-2

This is like a small coil, producing a dipole-type field.

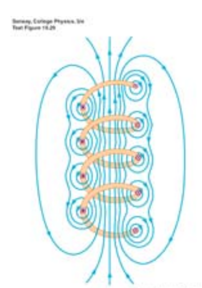


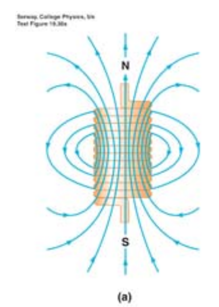


Right-hand rule: fingers with current, thumb gives field inside the loop.

(1) +x (2) –x (3) +y (4) –y (5) +z (6) -z

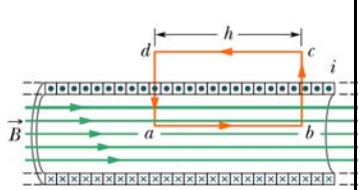
Field Due to a Solenoid





Calculating the Field in a Solenoid

$$\oint_C \vec{B}\cdot d\vec{s} = \mu_0 i_{enc}$$



$$\oint_C \vec{B}\cdot d\vec{s} = Bh + 0 + 0 + 0$$

$$i_{enc} = (nh)i \qquad B = \mu_0 n i$$

Example: Problem 29-40

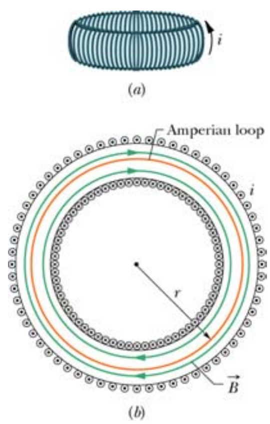
Solenoid of length 1.0 m and diameter 5 cm has 1200 turns and carries current of 4 A. Calculate the magnetic field inside.

$$B = \mu_0 n i$$

$$n = \frac{1200}{0.5} = 2400$$ **turns per meter.**

$$B = \mu_0 n i = 4\pi \times 10^{-7} \times 2400 \times 3 = 9 \times 10^{-3}\ T$$

Field in a Toroid



The textbook derives the field in a solenoid. A toroid is just a solenoid bent into a circle.

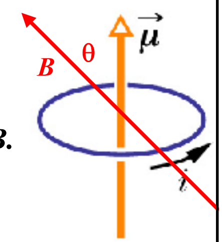
N = total number of turns

$$\oint \vec{B}\cdot d\vec{s} = \mu_0 i_{enc} = \mu_0 iN$$

So $B = \dfrac{\mu_0 iN}{2\pi r}$

Torque on a Current Loop

Given dipole $\vec{\mu}$
placed in magnetic field $\vec{B}$



Torque on loop due to field: $\vec{\tau}$

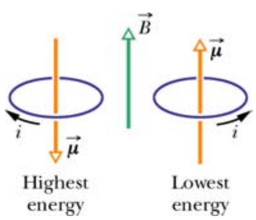
- Direction: ***turns*** μ ***toward B.***
- Magnitude: $\tau = \mu B \sin\theta$

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

Analogous to electric case $\vec{\tau} = \vec{p}\times\vec{E}$

Potential Energy of Current Loop

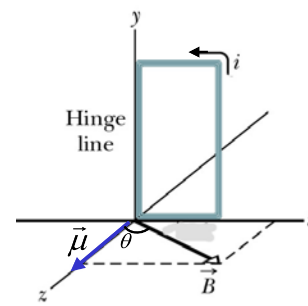
Work required to turn dipole moment ***against*** the field.



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

Example (28-39)

Hinged coil in B field.



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

$\mu = iA$

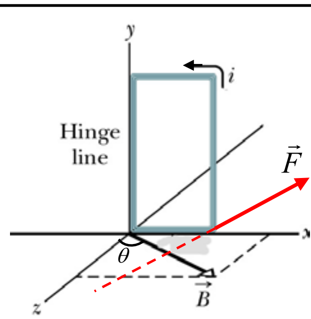
$\tau = \mu B\sin\theta$

So:

$\tau = iAB\sin\theta$

Example (28-39)

Hinged coil in B field.



Check: $\vec{F} = i\vec{L}\times\vec{B}$

$F = iLB$

$\tau = F(w\sin\theta)$

So:

$\tau = iLBw\sin\theta = iAB\sin\theta$

H2

Electromagnetic Fields

- **Ch.28: The magnetic field: Lorentz Force Law**
- **Ch.29: Electromagnetism:**
  - ***B*** **field due to a current in a long straight wire**
  - ***B*** **field due to a current in a short bit of wire**
  - **Ampere's Law: the third of Maxwell's Equations**
- **Ch.30: Induced E Fields: Faraday's Law**