

Electromagnetic Fields

- Ch.28: The magnetic field: Lorentz Force Law
- Ch.29: Electromagnetism: Ampere's Law

HOMEWORK for TODAY

- Chapter 28 Questions 1, 7
- Chapter 28 Problems 3, 15, 33, 47

HOMEWORK for TOMORROW

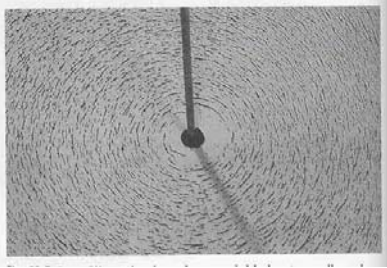
- Chapter 29 Questions 4, 5
- Chapter 29 Problems 7, 9, 37, 49
- WileyPlus assignment: chapters 28, 29

TODAY: Electromagnetism

Production of magnetic field by a current

- 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

Field Due to a Long Straight Wire



Lines of B make circles around wire!

BUT FIRST REVIEW: The Lorentz Force

If a particle with electric charge q moves with velocity v through a magnetic field B , then the force by the field on the particle is

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

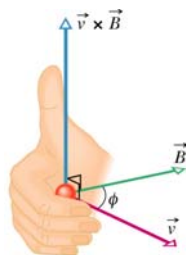
If a wire of length L carries a current i through a field B , the force by the field on the wire is

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

REVIEW: The cross product

Given vectors v and B , and θ the angle between them, we define the vector product (cross product) $\vec{v} \times \vec{B}$

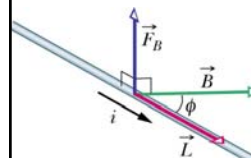
1. Magnitude is $vB\sin\theta$.
2. Right-hand rule gives direction, perpendicular to both v , B .



Example

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

Given wire in field with angle $\phi = 37^\circ$. $B = 0.3T$, $i = 20 \text{ mA}$. Find force per unit length on wire.



(1) Direction of force: By right-hand rule, force is upward as shown.

(2) Magnitude of force:
 $F = i|\vec{L} \times \vec{B}| = iLB \sin \phi$

$$F / L = iB \sin \phi = .02 \times .3 \times .6 = \underline{3.6 \times 10^{-3} \text{ N / m}}$$

Q.28-3

An electron with speed v enters a magnetic field B as shown. What is the direction of the *force* on the electron?

- 1) Out of the screen
- 2) Into the screen
- 3) In the direction of B
- 4) In the direction of v

20

Q.28-3

What is the direction of the *force* on the electron?

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

$\vec{v} \times \vec{B}$ is out of screen by RH rule.
But q is negative, so F is into the screen.

(1) Out of the screen. **(2) Into the screen.**
(3) In the direction of B . (4) In the direction of v .

REVIEW: Charge in Uniform Field

B is *out of* screen so F is *toward center* so ion moves in circle with *constant speed*.

Centripetal acceleration is $a = v^2 / r$
 $\therefore F = qvB = ma = mv^2 / r$

So solving for r gives the radius of curvature of the path: $r = \frac{mv}{qB}$

Q.28-4

An ion with charge $+e$ and mass M_1 follows the dashed path in given B field.

Another ion with charge $+e$, but a different mass M_2 enters the field with the same velocity as the first, and follows the **blue path**. How do the masses compare?

(1) $M_1 > M_2$ (2) $M_2 > M_1$ (3) Can't say.

Q.28-4

- 1) $M_1 > M_2$
- 2) $M_2 > M_1$
- 3) Not enough information

20

Two ions, same q , v .
 M_1 follows dashed path.
 M_2 follows blue path.
How do their masses compare?

Q.28-4

Two ions with equal charges and velocities follow the two curves shown.

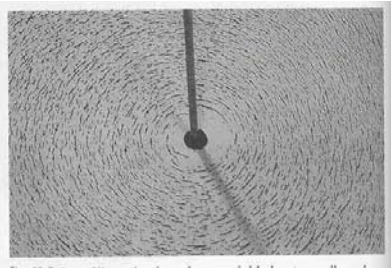
$r = \frac{mv}{qB}$

M_1 follows the dashed, M_2 the **blue** path. How do the masses compare?

Blue radius is smaller so blue mass is smaller.

(1) $M_1 > M_2$ (2) $M_2 > M_1$ (3) Can't say.

Field Due to a Long Straight Wire



Lines of B make circles around wire!

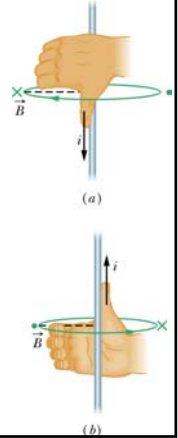
Field of a long straight wire

1. Direction is given by the right-hand rule!

2. Magnitude is $B = \frac{\mu_0 i}{2\pi r}$

3. New universal constant:

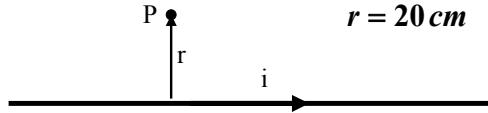
$$\mu_0 = 4\pi \times 10^{-7} \text{ Tm} / \text{A}$$



Example

$$i = 3.0 \text{ A}$$

$$r = 20 \text{ cm}$$



What is the magnetic field at point P?

Direction: **Out of the screen by right-hand rule.**

Magnitude:

$$B = \frac{\mu_0 i}{2\pi r} = \frac{4\pi \times 10^{-7} \times 3.0}{2\pi \times 0.20} = 3.0 \times 10^{-6} \text{ T}$$

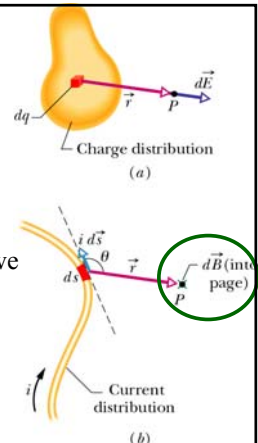
Field Due to a Short Bit of Wire

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!



The Biot-Savart Law

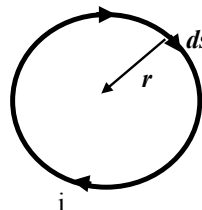
$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{i d\vec{s} \times \vec{r}}{r^3}$$

- Field dB is perpendicular to both ds and r .
- Inverse square law like Coulomb's Law.
- Universal constant:

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

Example

Field at the center of a circular loop of wire.



Direction: **Into the screen,** by the right-hand rule.

Magnitude: Must add up (integrate) all the little dB from all the little ds .

$$B = \int dB = \frac{\mu_0}{4\pi} \frac{i}{r^2} \int ds = \frac{\mu_0}{4\pi} \frac{i}{r^2} 2\pi r = \frac{\mu_0 i}{2r}$$

Ampere's Law

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

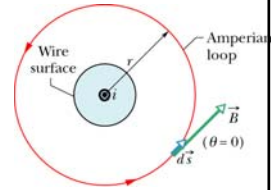
- C = Any closed path
- i_{enc} = Net current linking C (*Right-hand rule*)
- B = The total magnetic field
- ds = A short step along the path

This is the third of Maxwell's equations.

Field Due to a Long Straight Wire

1. Direction is given by the right-hand rule!

2. Magnitude is found by applying Ampere's Law to a circular path of radius r :



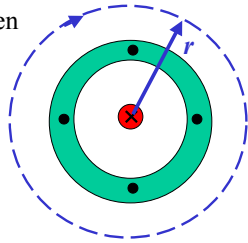
$$\oint \vec{B} \cdot d\vec{s} = \mu_0 i$$

$$B \cdot \oint ds = B \cdot 2\pi r = \mu_0 i$$

$$B = \frac{\mu_0 i}{2\pi r}$$

Example: Field in Coaxial Cable

Cable perpendicular to screen
 Central wire: i inward
 Outer cylinder: i outward



(b) Field outside the cable?

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

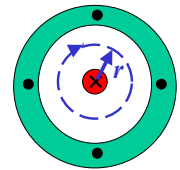
$$B \cdot \oint ds = B \cdot 2\pi r = \mu_0 (i - i)$$

$$B = 0$$

Outer conductor prevents field from escaping!

Example: Field in Coaxial Cable

Cable perpendicular to screen
 Central wire: i inward
 Outer cylinder: i outward



(a) Field between conductors?

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

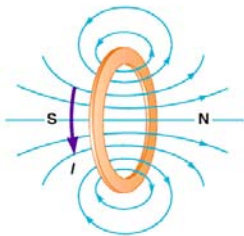
$$B \cdot \oint ds = B \cdot 2\pi r = \mu_0 i$$

$$B = \frac{\mu_0 i}{2\pi r}$$

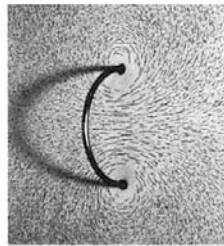
Just as if outer conductor did not exist!

Field Due to a Current Loop

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



(a)

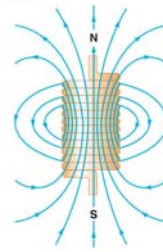


(b)

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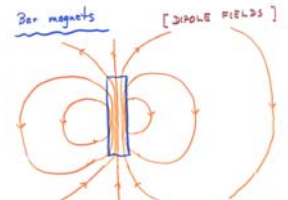
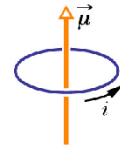
Magnetic Dipole Field

Serway, College Physics, 5/e
Text Figure 19.29a



(a)

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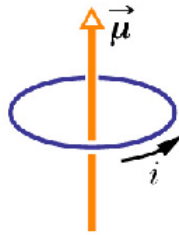


Dipole Moment of a Current Loop

Definition: *Magnetic dipole moment vector:*

$$\vec{\mu}$$

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



Analogous to electric dipole moment vector \vec{p}

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