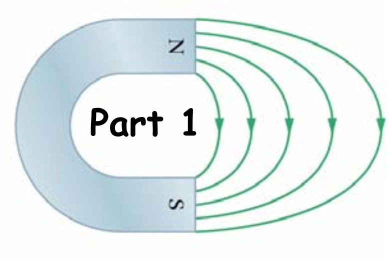
Magnetism

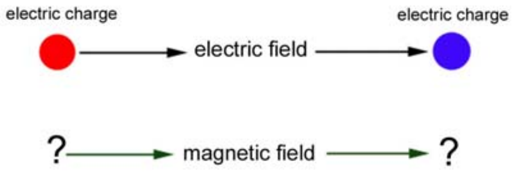
Chapter 20

The Magnetic Field



Part 1

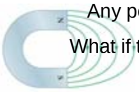
What creates magnetic fields?



There is no magnetic charge!

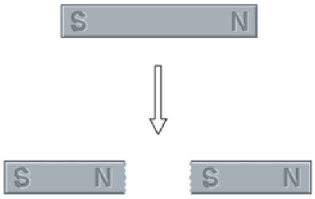
Any permanent magnet has two poles.

What if to cut a permanent magnet in half?



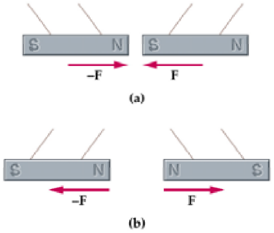

Unlike electrostatics:

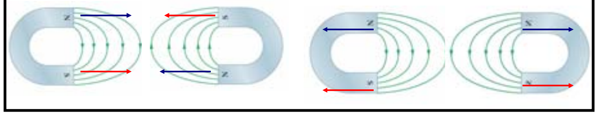
Magnetic monopoles have never been detected.



Interaction between magnetic poles

Opposite magnetic poles attract each other, and like poles repel each other





Magnetic Field Lines

Assume that there is a magnetic field $\vec{B}$ in some area of space

We can represent magnetic fields with field lines, as we did for electric fields

(1) the direction of the tangent to a magnetic field line at any point gives the direction of $\vec{B}$ at that point

(2) the spacing of the lines represents the magnitude of $\vec{B}$

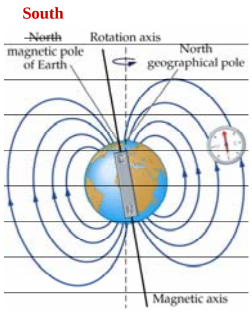
Magnetic Field Lines (cont.)

- ✓ The field lines enter one end of a magnet and exit the other end.
- ✓ The end of a magnet from which the field lines emerge is called the north pole of the magnet
- ✓ the other end, where field lines enter the magnet, is called the south pole

The Earth's Magnetic Field

The spinning iron core of the earth produces a magnetic field.

The magnetic north pole corresponds to the geographic south pole.



Part 2

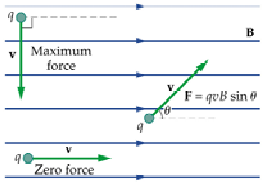
Magnetic Force on a Particle

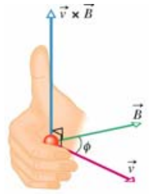
Magnetic force on a charged particle

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

$F_B = |q| vB \sin\phi$

q – electric charge
v – particle velocity
B – magnetic field
the magnitude

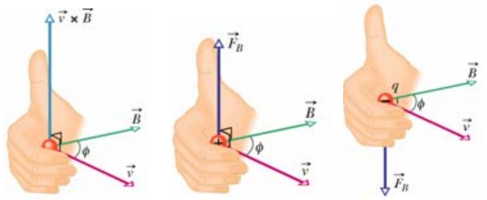




Right Hand Rule / Teddy Bear Rule / Alligator Rule

Right Hand Rule: Positive and negative particle

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



The force acting on a charged particle moving through a magnetic field is **always** perpendicular to the velocity and the field

Magnetic field (definition)

$F_B = |q| vB \sin\phi$

$B = \frac{F_B}{|q|v}$

q – electric charge
v – particle velocity
B – magnetic field

SI unit: Tesla
1 T = newton/(C*m/s) = 1 N/(A*m)
1 tesla = 10^4 gauss (G)

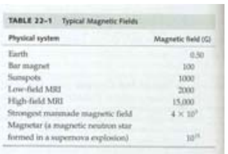


TABLE 22–1 Typical Magnetic Fields

Physical system	Magnetic field (G)
Earth	0.50
Bar magnet	100
Sunspots	1000
Low-field MRI	2000
High-field MRI	15,000
Strongest manmade magnetic field	4×10^5
Magnetar (a magnetic neutron star formed in a supernova explosion)	10^{15}

Notation

To depict a vector oriented **perpendicular** to the page we use crosses and dots.

A **cross** indicates a vector going **into** the page (think of the tail feathers of an arrow disappearing into the page).

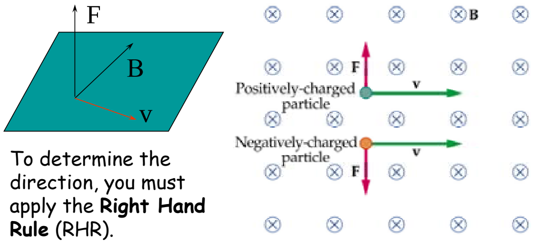
A **dot** indicates a vector coming **out** of the page (think of the tip of an arrow coming at you out of the page).

⊙ B out of the page

⊗ B into the page

Direction of Magnetic Forces (cont.)

The direction of the magnetic force on a moving charge is **perpendicular** to the **plane formed by B and v**.



To determine the direction, you must apply the **Right Hand Rule** (RHR).

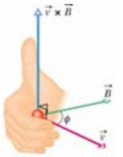
Good to discuss

?

A magnetic field exerts a force on a charged particle:

A) always
B) never
C) if the particle is moving across the field lines
D) if the particle is moving along the field lines
E) if the particle is at rest

$$\boxed{F_B = |q| vB\sin\phi}$$



Example

problem

A charge of 23 mC is moving in the negative *x* direction at 4 m/s. A magnetic field of 30 T is pointing in the positive *y* direction. What is the magnitude and direction of the force on the charge? How does your answer change if the charge is –23 mC?

$$\left|\vec{F}\right| = qvB\sin\theta = 23\times10^{-6}\times4\times30\times\sin 90^\circ$$

$$\boxed{\left|\vec{F}\right| = 2.76\times10^{-3}\ \mathrm{N}}$$

Use the right-hand rule!

$\boxed{\text{Direction is } -\hat{z}\text{, i.e. into the paper}}$

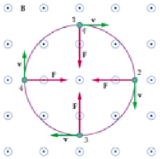
If the charge is negative,

$\boxed{\text{Direction is } \hat{z}.}$

Part 3

The Motion in a Magnetic Field

Motion of Charges in B Fields



If a charged particle is moving in a direction perpendicular to a uniform magnetic field, then its trajectory will be a circle because the force *F=qvB* is always perpendicular to the velocity, and therefore centripetal.

Recall that $F_C = ma = \frac{mv^2}{r}$ so $\boxed{F = qvB = \frac{mv^2}{r}}$

The radius of the circular trajectory $\boxed{r = \frac{mv}{qB}}$

The period (the time for one full revolution) $\boxed{T = \frac{2\pi r}{v} = \frac{2\pi m}{qB}}$

Good to discuss

?

$$F = qvB = \frac{mv^2}{r}$$

An electron and a proton are both initially moving with the same speed and in the same direction at 90^0 to the same uniform magnetic field. They experience magnetic forces, which are initially:

A) identical

[✓ B) equal in magnitude but opposite in direction]

C) in the same direction and differing in magnitude by a factor of 1840

D) in opposite directions and differing in magnitude by a factor of 1840

E) equal in magnitude but perpendicular to each other

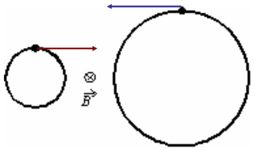
Good to discuss

?

An electron and a proton each travel with equal speeds around circular orbits in the same uniform magnetic field, as shown in the diagram (not to scale). The field is into the page on the diagram.

(a) Where is the electron

(b) What is the direction



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

Good to discuss

?

A uniform magnetic field is directed into the page. A charged particle, moving in the plane of the page, follows a clockwise spiral of decreasing radius as shown. A reasonable explanation is:

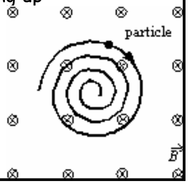
A) the charge is positive and slowing down

[✓ B) the charge is negative and slowing down]

C) the charge is positive and speeding up

D) the charge is negative and speeding up

E) none of the above



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

Good to discuss

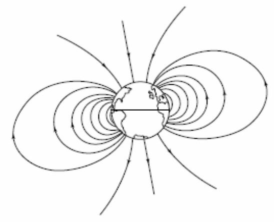
?

Cosmic rays (atomic nuclei stripped bare of their electrons) would continuously bombard Earth's surface if most of them were not **deflected** by Earth's magnetic field. Given that Earth is, to an excellent approximation, a magnetic dipole (a bar magnet), the intensity of cosmic rays bombarding its surface is greatest at the

[✓ 1. poles.]

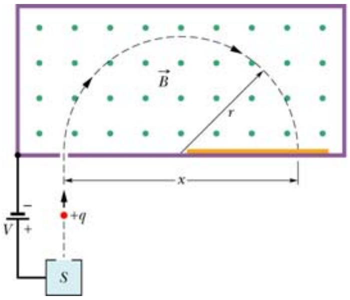
2. mid-latitudes.

3. equator.

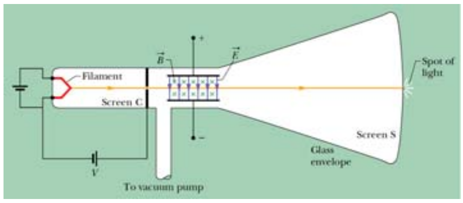


Isotope Separation

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



Crossed E and B fields



Part 4

Magnetic Force on a Current

Force on a Current Carrying Wire

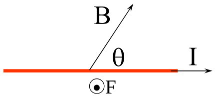
Current in a wire is a collection of moving charges; therefore, a current carrying wire in a magnetic field also experiences a force.

If a wire of length *L*, carrying a current *I*, makes an angle θ with a magnetic field *B*, then the magnitude of the force on the wire is:

$$F = qvB\sin\vartheta = (It)vB\sin\vartheta =$$

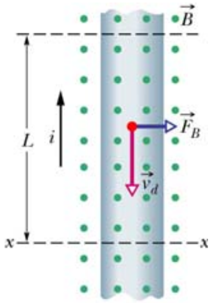
$$= (I\frac{L}{v})vB\sin\vartheta = ILB\sin\theta$$

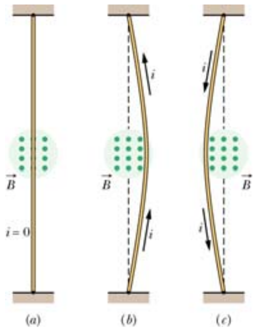
$$\boxed{F = ILB\sin\theta}$$



$$\boxed{F = ILB\sin\theta}$$

Force on a Current Carrying Wire





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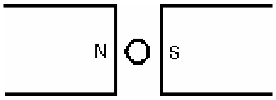
Force on a Current Carrying Wire

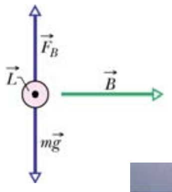
$$\boxed{F = ILB\sin\theta}$$

The diagram shows a straight wire carrying a **flow of electrons into the page**. The wire is between the poles of a permanent magnet. The direction of the magnetic force exerted on the wire is:

A) →
B) ←
C) ↓
[✓ D) ↑]
E) into the page



Magnetic Levitation (Maglev, etc.)



$$\boxed{ILB = mg}$$

Magnetic Torque on current loop

In a uniform magnetic field, the net force on a current loop (independent of geometry) is 0.

However, there can be a torque

$$\tau = F\,r\sin\theta$$

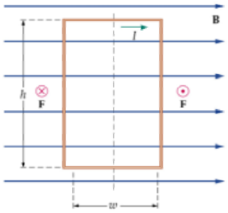
r = distance from axis of rotation to loop segment

F = magnetic force on segment

θ = angle between vector *r* and vector *F*.

$$\tau = IhB\frac{w}{2} + IhB\frac{w}{2} = IB(hw)$$

$$\boxed{\tau = IBA}$$



Only the vertical segments of the loop experience a force. The torque will rotate the loop so that the plane of the loop is perpendicular to the magnetic field.

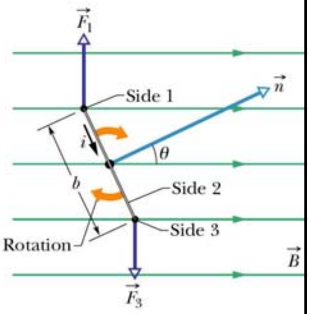
Magnetic Torque on current loop (cont.)

Torque exerted on a rectangular loop of area A

$$\boxed{\tau = IBA\sin\theta}$$

If the loop has N turns, then

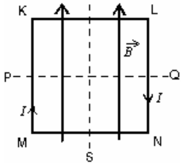
$$\boxed{\tau = NIBA\sin\theta}$$



?

A square loop of wire lies in the plane of the page and carries a current I as shown. There is a uniform magnetic field parallel to the side MK as indicated. The loop will tend to rotate:

[✓ A) about PQ with KL coming out of the page]
B) about PQ with KL going into the page
C) about RS with MK coming out of the page
D) about RS with MK going into the page
E) about an axis perpendicular to the page



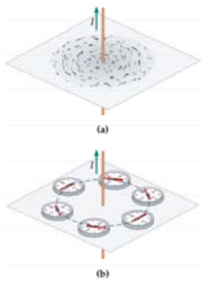
Part 5

Magnetic Fields Due to Currents

Experimental observation in 1820

Hans Oersted:

Electric currents can create magnetic fields

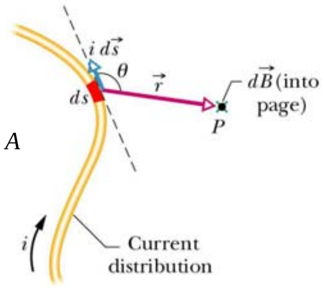


The magnitude of the field produced at point P

A general equation for Physics 232

$$dB = \frac{\mu_0}{4\pi}\frac{i\,ds\sin\vartheta}{r^2}$$

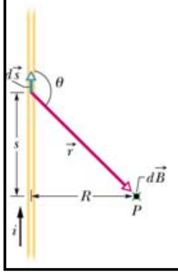
$$\mu_0 = 1.26\times10^{-6}\,T\cdot m/A$$

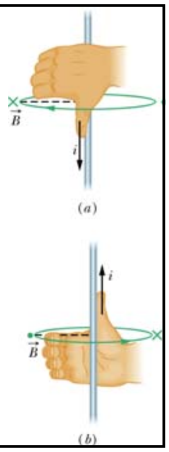


A Long Straight Wire

Proof: integration or Ampere's law

$$\boxed{\begin{gathered}B = \frac{\mu_0 i}{2\pi R}\\ \mu_0 = 1.26\times10^{-6}\,T\cdot m/A\end{gathered}}$$





Conceptual question

?

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

The equation above is true for an infinitely long, straight conductor carrying a current.

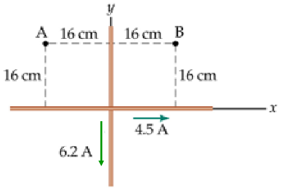
Of course, there is no such thing as an infinitely long *anything*. How would you decide whether a particular wire is long enough to be considered infinite?

---

problem

Problem

Consider the long, straight, current-carrying wires shown in the figure. One wire carries a current of 6.2 A in the negative y direction; the other carries a current of 4.5 A in the positive x direction. Calculate the magnitude and direction of the net magnetic field at points A and B.



Force between two **parallel** currents

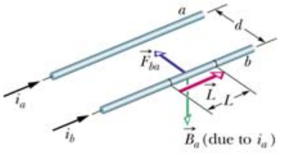
Magnitude of B_a

$$B_a = \frac{\mu_0 i_a}{2\pi d}$$

Force on a length L of wire b

$$F_{ba} = i_b L B_a$$

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



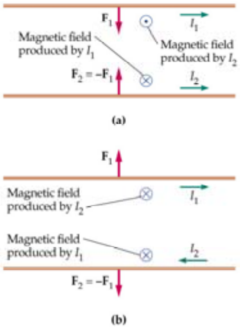
Each of two parallel wires with currents I_1 and I_2, experiences a magnetic force given by

$$F = \frac{\mu_0 I_1 I_2}{2\pi d} L$$

L = length of wire

d = distance between the two wires

If the currents are **parallel**, the force is **attractive**. If the currents are **anti-parallel** the force is **repulsive**.



Good to discuss

?

Two long parallel straight wires carry equal currents in opposite directions. At a point midway between the wires, the magnetic field they produce is:

A) zero

B) non-zero and along a line connecting the wires

C) non-zero and parallel to the wires

[✓ D) non-zero and perpendicular to the plane of the two wires]

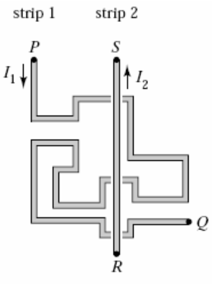
E) none of the above

Good to discuss

?

On a computer chip, two conducting strips carry charge from P to Q and from R to S. If the current direction is reversed in both wires, the net magnetic force of strip 1 on strip 2

1. remains the same.
2. reverses.
3. changes in magnitude, but not in direction.
4. changes to some other direction.
5. other



Conceptual question

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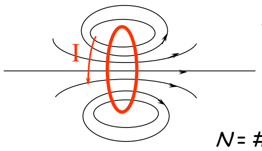
Streams of charged particles emitted from the sun during unusual sunspot activity create a disturbance in the earth's magnetic field (called a magnetic storm).

How can they cause such a disturbance?

B Fields of Current Distributions

By winding wires in various geometries, we can produce different magnetic fields.

For example, a **current loop** (perpendicular to plane, radius R, current emerging from plane at top of loop):



Magnitude of magnetic field at the center of loop:

$$\boxed{B = \frac{N\mu_0 I}{2R}}$$

N = # of loops of wire (i.e. # turns)

Direction of magnetic field from the RHR.

Solenoids

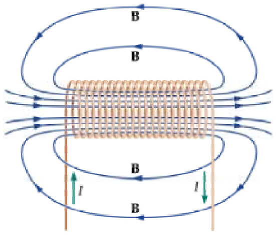
If we stack several current loops together we end up with a **solenoid**.

In the limit of a very long solenoid, the magnetic field inside is very uniform:

$$\boxed{B = \mu_0 n I}$$

n = number of windings per unit length,

I = current in windings



Magnetic Materials

On atomic level – moving electrons (microscopic current loops) create magnetic fields.

In many materials, these currents are randomly oriented (net magnetic field is zero).

In some materials, the presence of an external magnetic field can cause the loops to become oriented

Paramagnetism – orientation with an external field

Diamagnetism – orientation against an external field

Ferromagnetism – line up loops (magnetic domains) without an external field