

Phys102 Lecture 16/17

Magnetic fields

Key Points

- Electric Currents Produce Magnetic Fields
- Force on an Electric Current in a Magnetic Field;
Definition of
- Force on an Electric Charge Moving in a Magnetic Field
- Torque on a Current Loop; Magnetic Dipole Moment

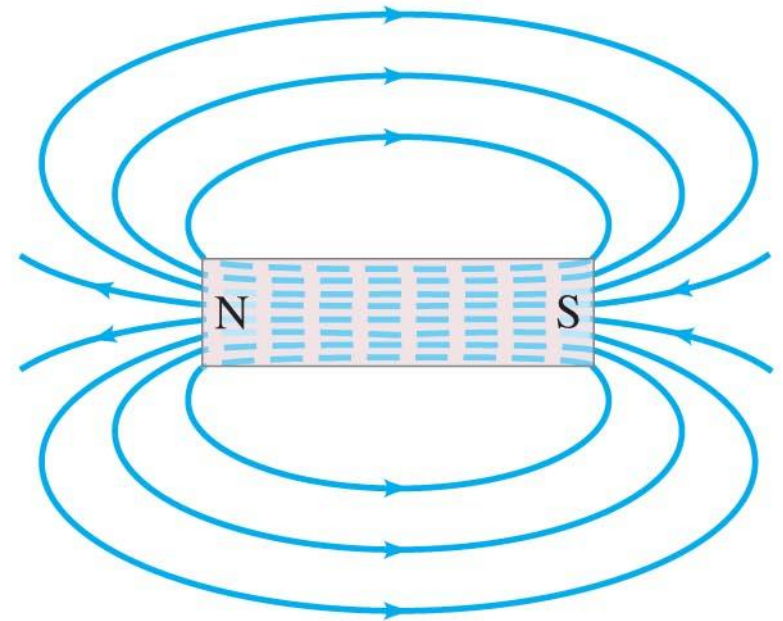
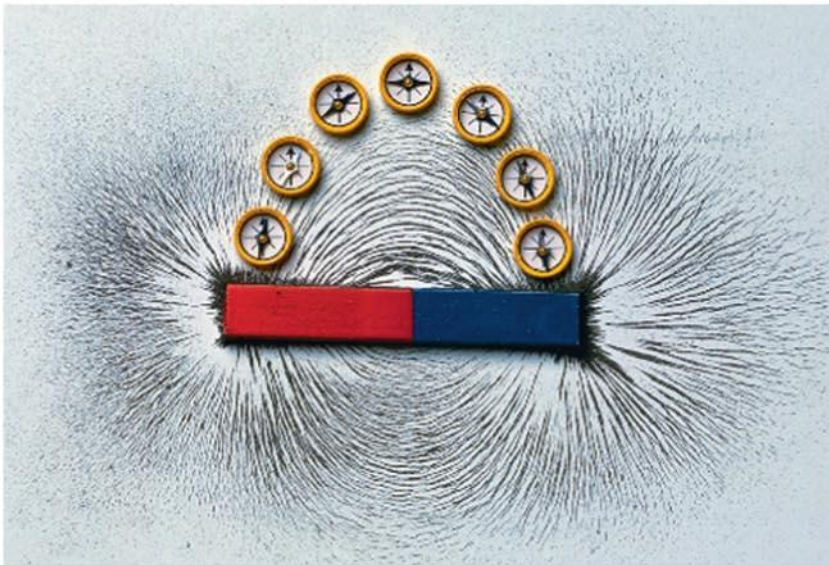
References

SFU Ed: 27-1,2,3,4,5,9.

6th Ed: 20-1,2,3,4,9,11.

27-1 Magnets and Magnetic Fields

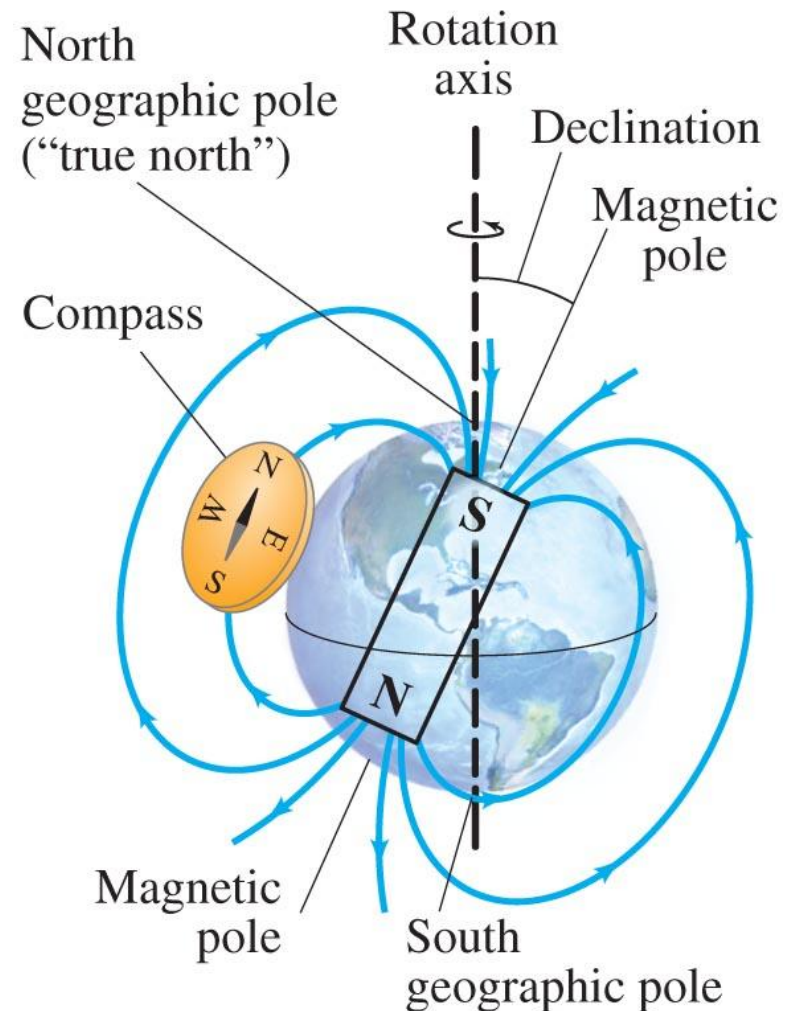
Magnetic fields can be visualized using magnetic field lines, which are always closed loops.



27-1 Magnets and Magnetic Fields

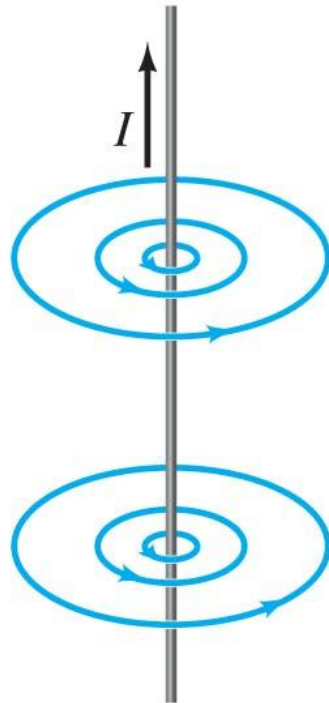
The Earth's magnetic field is similar to that of a bar magnet.

Note that the Earth's "North Pole" is really a south magnetic pole, as the north ends of magnets are attracted to it.

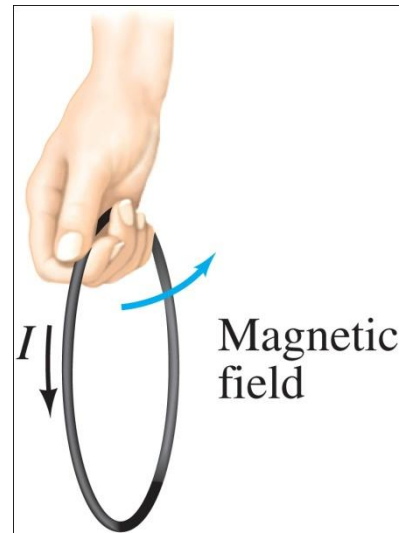
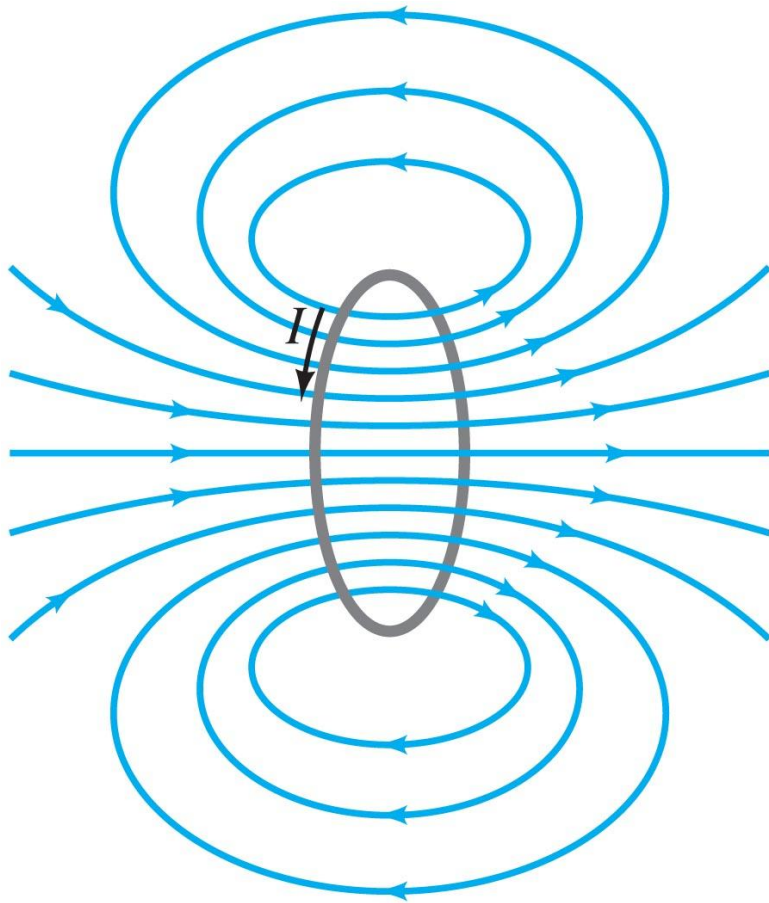


27-2 Electric Currents Produce Magnetic Fields

Experiment shows that an electric current produces a magnetic field. The direction of the field is given by a right-hand rule.



27-2 Electric Currents Produce Magnetic Fields



Here we see the field due to a current loop; the direction is again given by a right-hand rule.

27-3 Force on an Electric Current in a Magnetic Field; Definition of \vec{B}

The force on the wire depends on the current, the length of the wire, the magnetic field, and its orientation:

$$F = I\ell B \sin \theta.$$

This equation defines the magnetic field \vec{B} .

In vector notation:

$$\vec{F} = I\vec{\ell} \times \vec{B}.$$

The direction can be determined by the right-hand-rule.

Unit of B : the tesla, T:

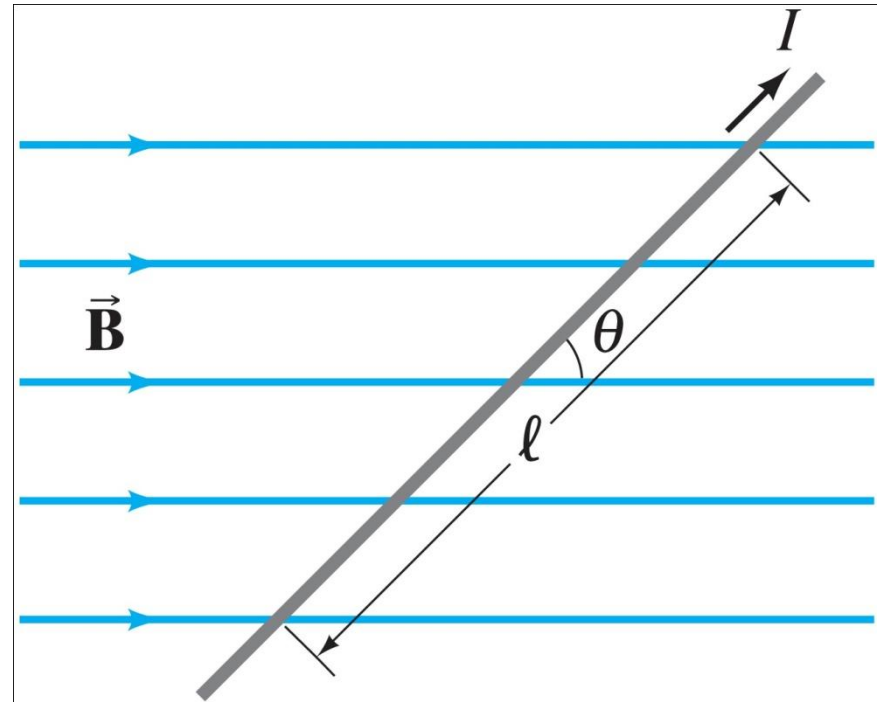
$$1 \text{ T} = 1 \text{ N/A m.}$$

Another unit sometimes used: the gauss (G):

$$1 \text{ G} = 10^{-4} \text{ T.}$$

Example 27-1: Magnetic Force on a current-carrying wire.

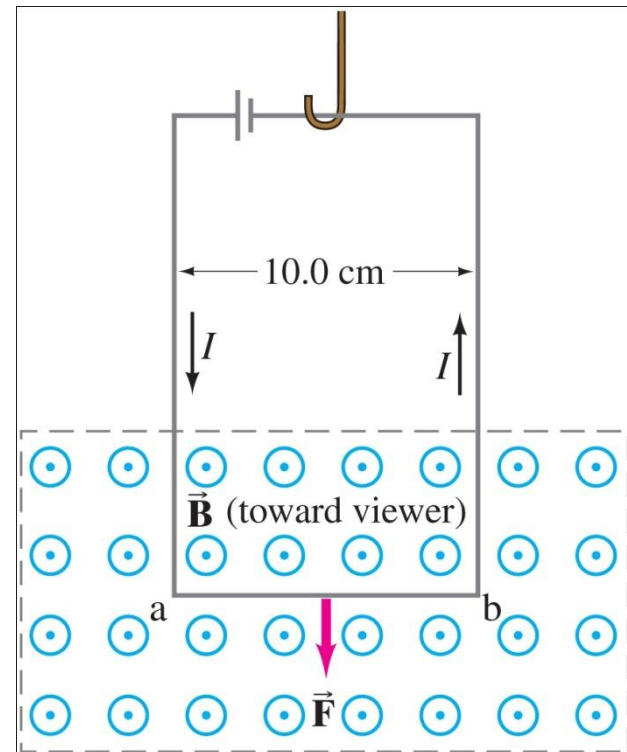
A wire carrying a 30-A current has a length $\ell = 12$ cm between the pole faces of a magnet at an angle $\theta = 60^\circ$, as shown. The magnetic field is approximately uniform at 0.90 T. We ignore the field beyond the pole pieces. What is the magnitude of the force on the wire?



$$\vec{F} = I\vec{\ell} \times \vec{B}.$$

Example 27-2: Measuring a magnetic field.

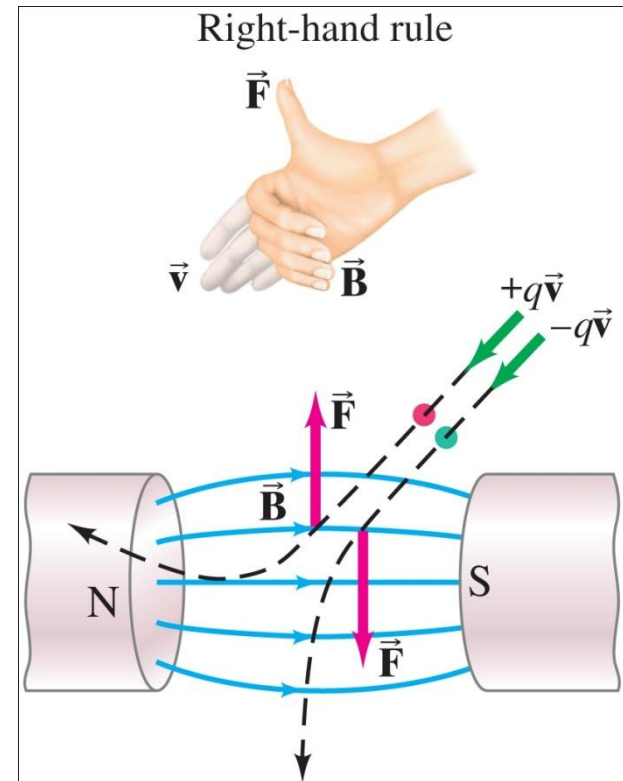
A rectangular loop of wire hangs vertically as shown. A magnetic field \vec{B} is directed horizontally, perpendicular to the wire, and points out of the page at all points. The magnetic field is very nearly uniform along the horizontal portion of wire ab (length $\ell = 10.0$ cm) which is near the center of the gap of a large magnet producing the field. The top portion of the wire loop is free of the field. The loop hangs from a balance which measures a downward magnetic force (in addition to the gravitational force) of $F = 3.48 \times 10^{-2}$ N when the wire carries a current $I = 0.245$ A. What is the magnitude of the magnetic field B ?



The force on a moving charge is related to the force on a current:

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

Once again, the direction is given by a right-hand rule.



Conceptual Example 27-4: Negative charge near a magnet (i-clicker 16-1).

A negative charge $-Q$ is placed at rest near a magnet. Will the charge begin to move? Will it feel a force? What if the charge were positive, $+Q$?

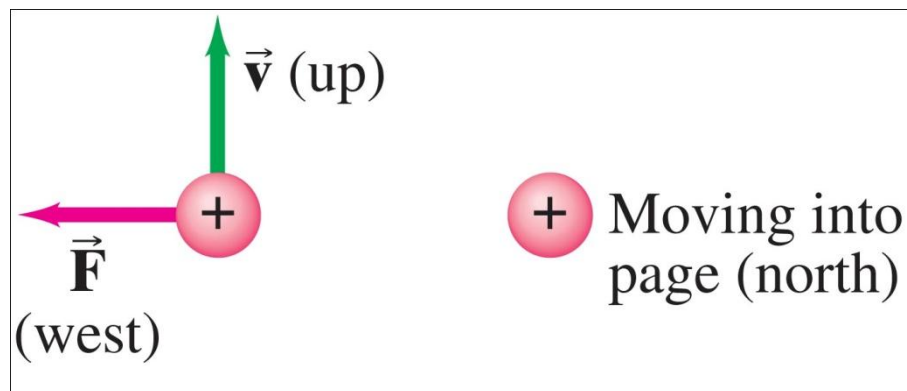
A) Yes.

B) No.

C) Depends on the strength of the magnetic field.

Example 27-5: Magnetic force on a proton.

A magnetic field exerts a force of 8.0×10^{-14} N toward the west on a proton moving vertically upward at a speed of 5.0×10^6 m/s. When moving horizontally in a northerly direction, the force on the proton is zero. Determine the magnitude and direction of the magnetic field in this region. (The charge on a proton is $q = +e = 1.6 \times 10^{-19}$ C.)

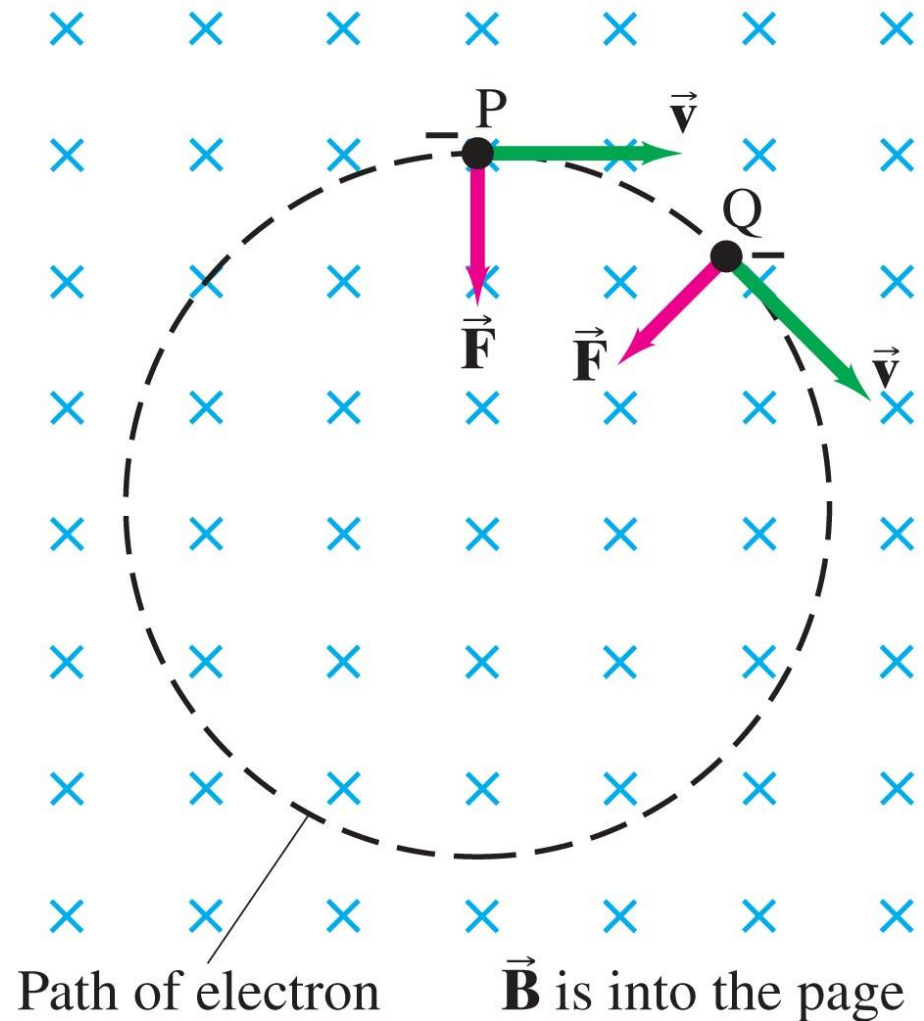


$$\vec{F} = q\vec{v} \times \vec{B}.$$

(The page is vertical.)

27-4 Force on an Electric Charge Moving in a Magnetic Field

If a charged particle is moving perpendicular to a uniform magnetic field, its path will be a circle.



Example 27-7: Electron's path in a uniform magnetic field.

An electron travels at 2.0×10^7 m/s in a plane perpendicular to a uniform 0.010-T magnetic field. Describe its path quantitatively.

Conceptual Example 27-8: Stopping charged particles (i-clicker 16-2).

Can a magnetic field be used to stop a single charged particle, as an electric field can?


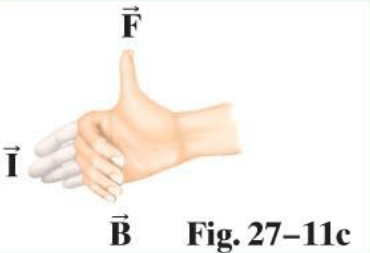
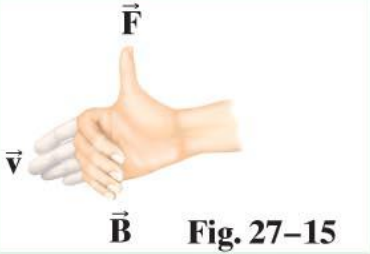
- A) Yes, because the magnetic field exerts a force on the particle.**
- B) No, because the magnetic force on the particle is zero.**
- C) No, even though the magnetic force on the charge particle is not zero.**

27-4 Force on an Electric Charge Moving in a Magnetic Field

Problem solving: Magnetic fields – things to remember:

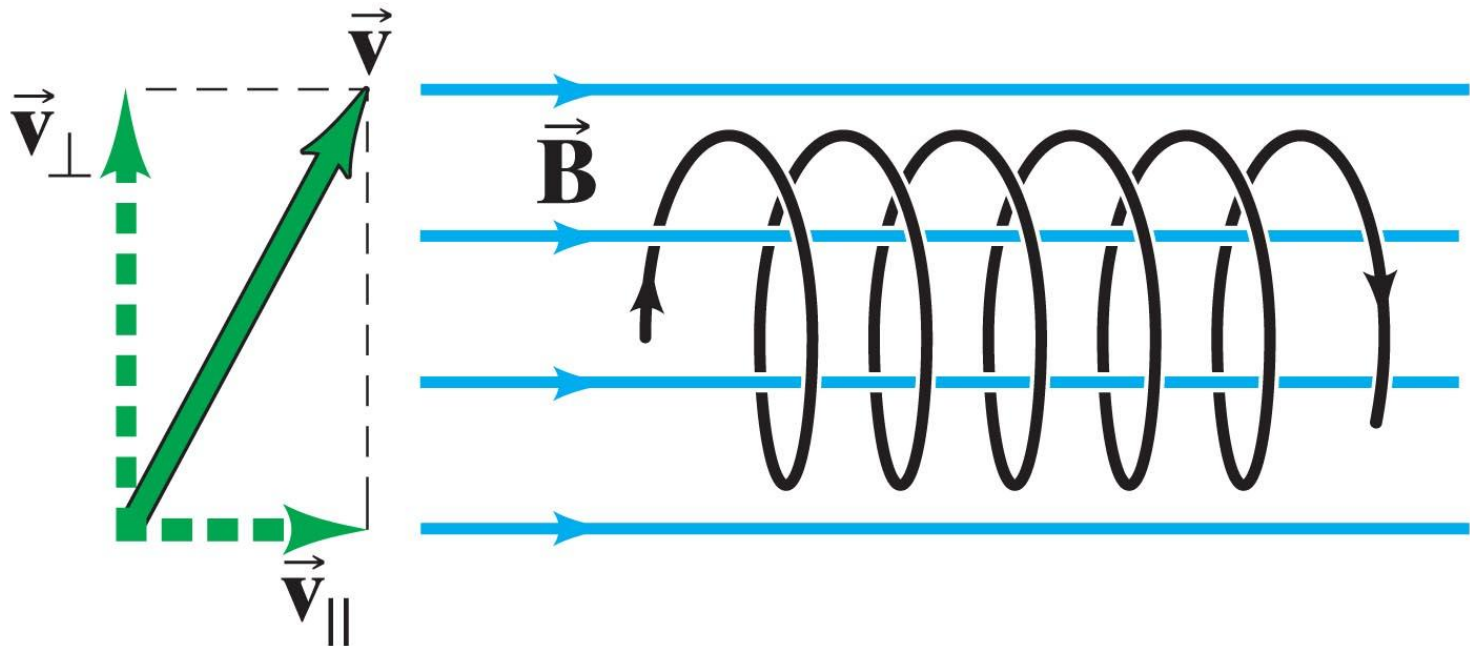
- 1. The magnetic force is perpendicular to the magnetic field direction.**
- 2. The right-hand rule is useful for determining directions.**
- 3. Equations in this chapter give magnitudes only. The right-hand rule gives the direction.**

TABLE 27-1 Summary of Right-hand Rules (= RHR)

Physical Situation	Example	How to Orient Right Hand	Result
1. Magnetic field produced by current (RHR-1)		Wrap fingers around wire with thumb pointing in direction of current I	Fingers point in direction of \vec{B}
2. Force on electric current I due to magnetic field (RHR-2)		Fingers point straight along current I , then bend along magnetic field \vec{B}	Thumb points in direction of the force \vec{F}
3. Force on electric charge $+q$ due to magnetic field (RHR-3)		Fingers point along particle's velocity \vec{v} , then along \vec{B}	Thumb points in direction of the force \vec{F}

Conceptual Example 27-9: A helical path.

What is the path of a charged particle in a uniform magnetic field if its velocity is not perpendicular to the magnetic field?



27-5 Torque on a Current Loop; Magnetic Dipole Moment

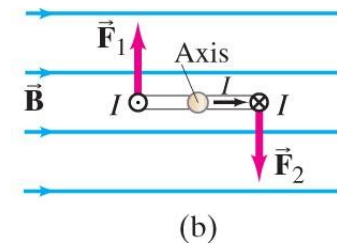
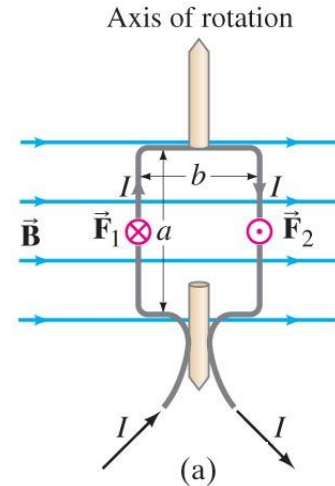
The forces on opposite sides of a current loop will be equal and opposite (if the field is uniform and the loop is symmetric), but there may be a torque.

The magnitude of the torque is given by

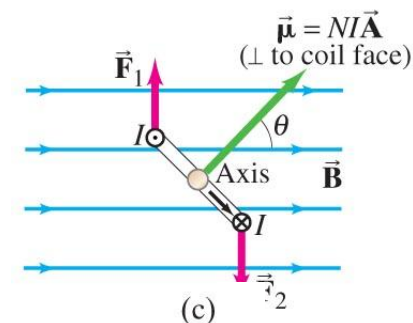
$$\tau = NIAB \sin \theta.$$

$NI\vec{A}$ – Magnetic dipole moment

θ – Angle between the field and the normal of the loop.



Top view



Torque on a Current Loop; Magnetic Dipole Moment

The quantity NIA is called the magnetic dipole moment, μ :

$$\vec{\mu} = NIA\vec{\mathbf{A}}.$$

The potential energy of the loop depends on its orientation in the field:

$$U = -\mu B \cos \theta = -\vec{\mu} \cdot \vec{\mathbf{B}}.$$

The torque on a magnetic dipole:

$$\tau = \mu B \sin \theta \quad (\text{magnitude})$$

Example 27-11: Torque on a coil.

A circular coil of wire has a diameter of 20.0 cm and contains 10 loops. The current in each loop is 3.00 A, and the coil is placed in a 2.00-T external magnetic field. Determine the maximum and minimum torque exerted on the coil by the field.

Example 27-12: Magnetic moment of a hydrogen atom.

Determine the magnetic dipole moment of the electron orbiting the proton of a hydrogen atom at a given instant, assuming (in the Bohr model) it is in its ground state with a circular orbit of radius $r = 0.529 \times 10^{-10}$ m. [This is a very rough picture of atomic structure, but nonetheless gives an accurate result.]

27-9* Mass Spectrometer

A mass spectrometer measures the masses of atoms. If a charged particle is moving through perpendicular electric and magnetic fields, there is a particular speed at which it will not be deflected, which then allows the measurement of its mass:

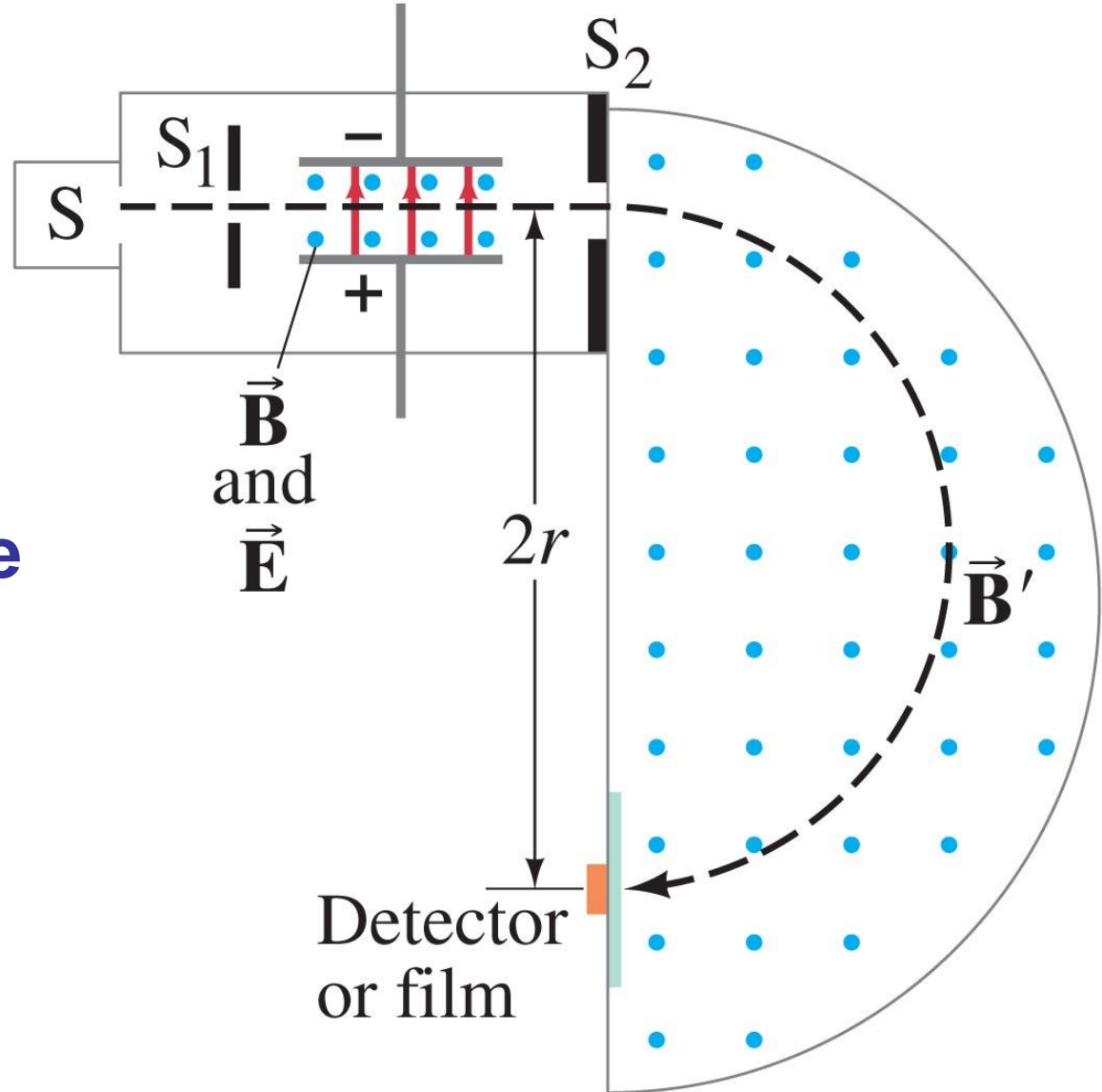
$$m = \frac{qB'r}{v} = \frac{qBB'r}{E}.$$

27-9 Mass Spectrometer

All the atoms reaching the second magnetic field will have the same speed; their radius of curvature will depend on their mass.

Lorentz equation:

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



Example 27-14: Mass spectrometry.

Carbon atoms of atomic mass 12.0 u are found to be mixed with another, unknown, element. In a mass spectrometer with fixed B' , the carbon traverses a path of radius 22.4 cm and the unknown's path has a 26.2-cm radius. What is the unknown element? Assume the ions of both elements have the same charge.

Summary of Chapter 27

- Magnets have north and south poles.
- Like poles repel, unlike attract.
- Unit of magnetic field: tesla.
- Electric currents produce magnetic fields.
- A magnetic field exerts a force on an electric current:

$$d\vec{\mathbf{F}} = I d\vec{\ell} \times \vec{\mathbf{B}}.$$

Summary of Chapter 27

- A magnetic field exerts a force on a moving charge:

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

- Torque on a current loop:

$$\vec{\boldsymbol{\tau}} = \vec{\boldsymbol{\mu}} \times \vec{\mathbf{B}}.$$

- Magnetic dipole moment:

$$\vec{\boldsymbol{\mu}} = NI\vec{\mathbf{A}}.$$