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

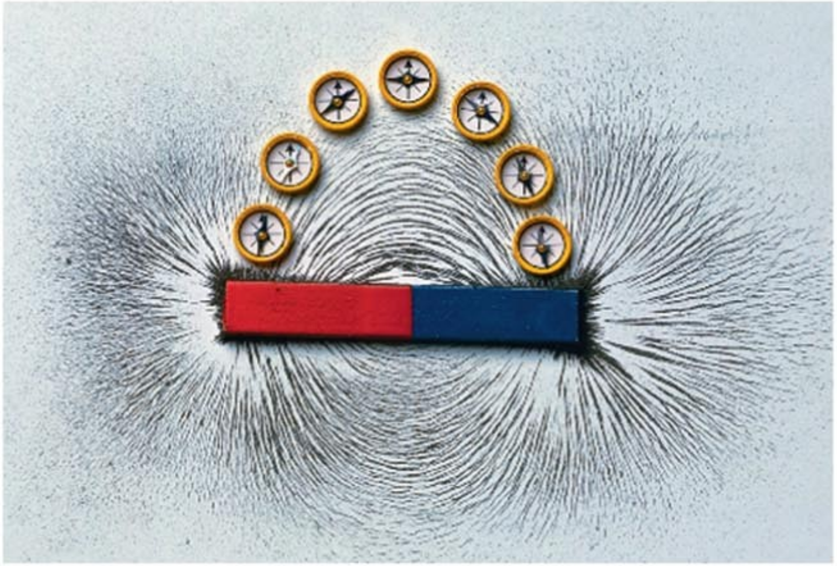
References

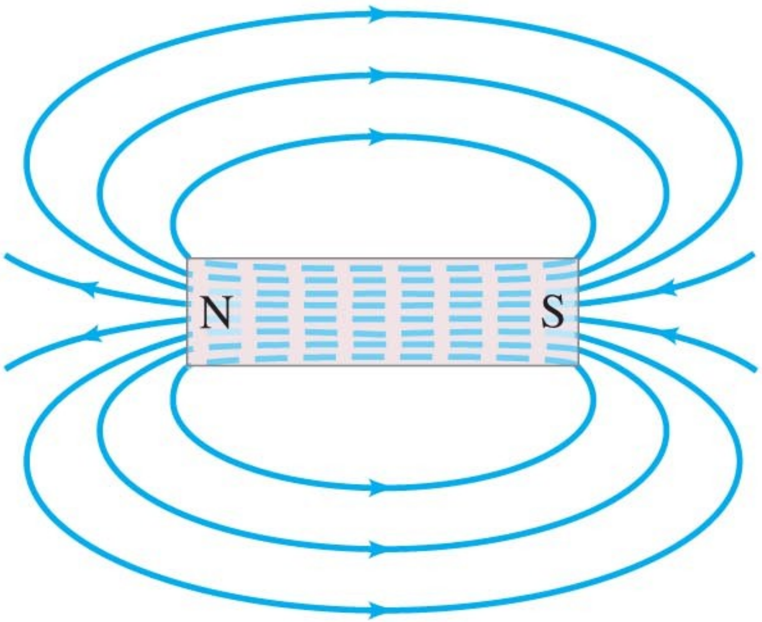
SFU Ed: 27-1,2,3,4,5,9.

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.

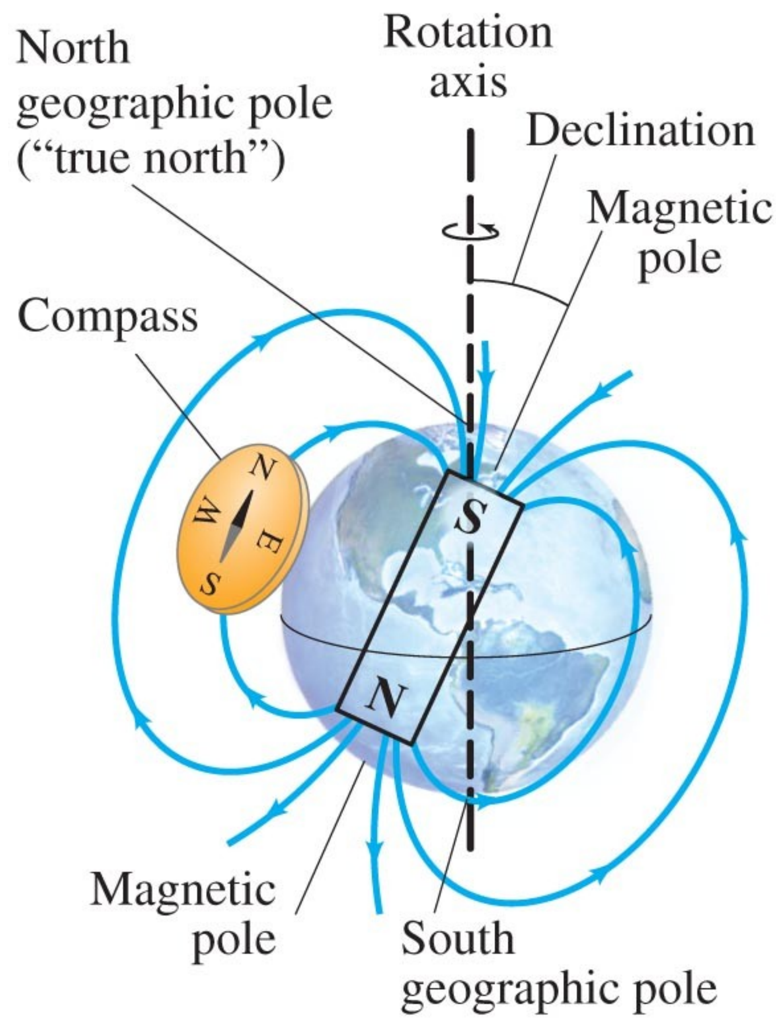




27-1 Magnets and Magnetic Fields

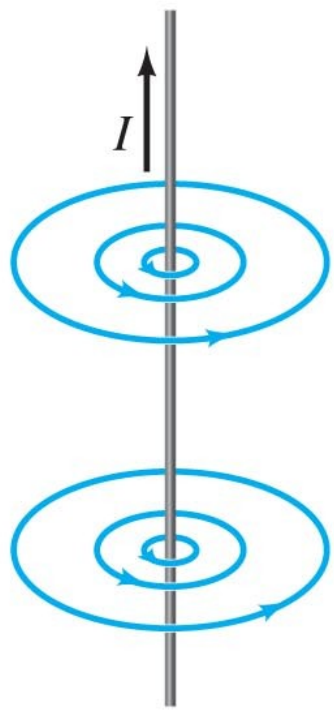
The Earth's magnetic field is similar to that of a bar magnet.

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

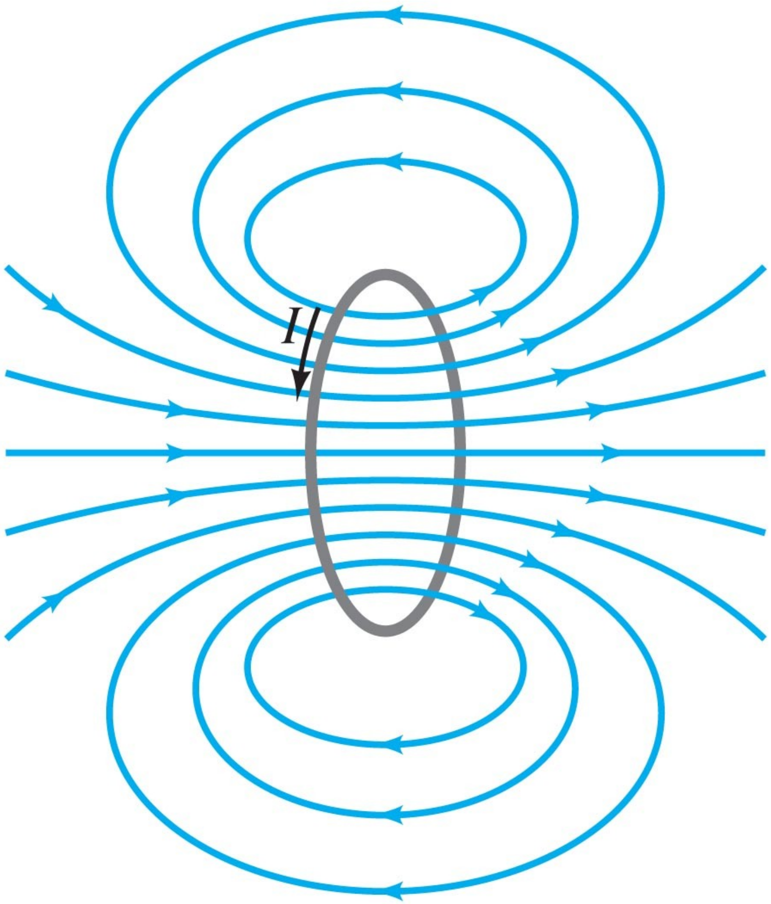


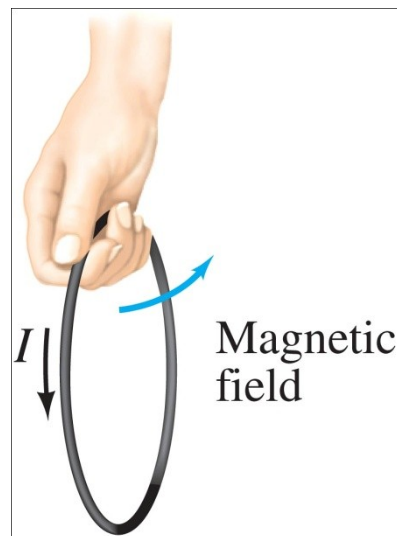
27-2 Electric Currents Produce Magnetic Fields

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 $\vec{\mathbf{B}}$

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 $\vec{\mathbf{B}}$.

In vector notation:

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

Unit of B: the tesla, T:

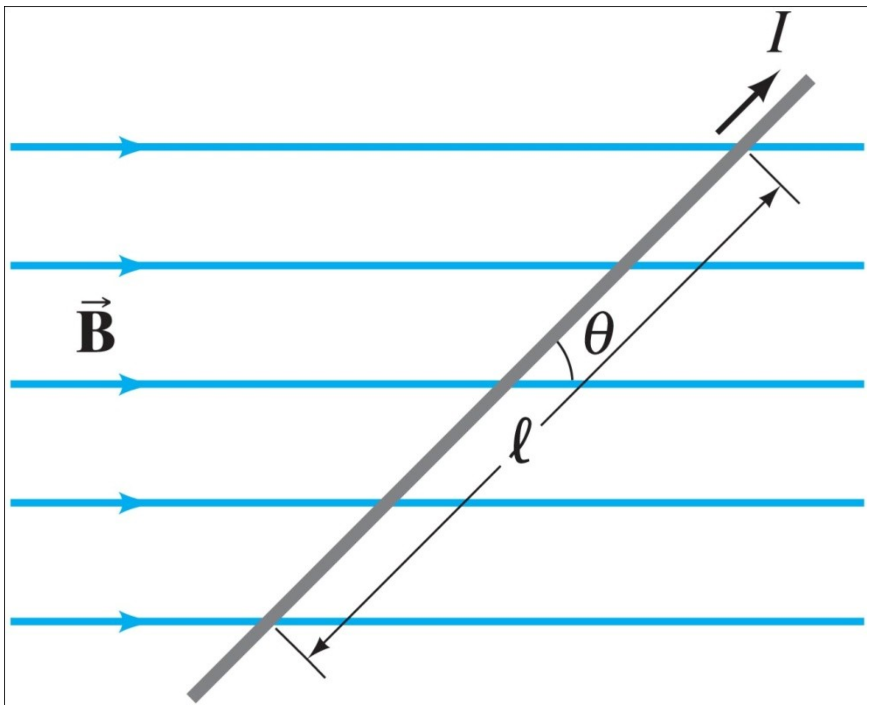
$$1\ \mathrm{T} = 1\ \mathrm{N/A \cdot m}.$$

Another unit sometimes used: the gauss (G):

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

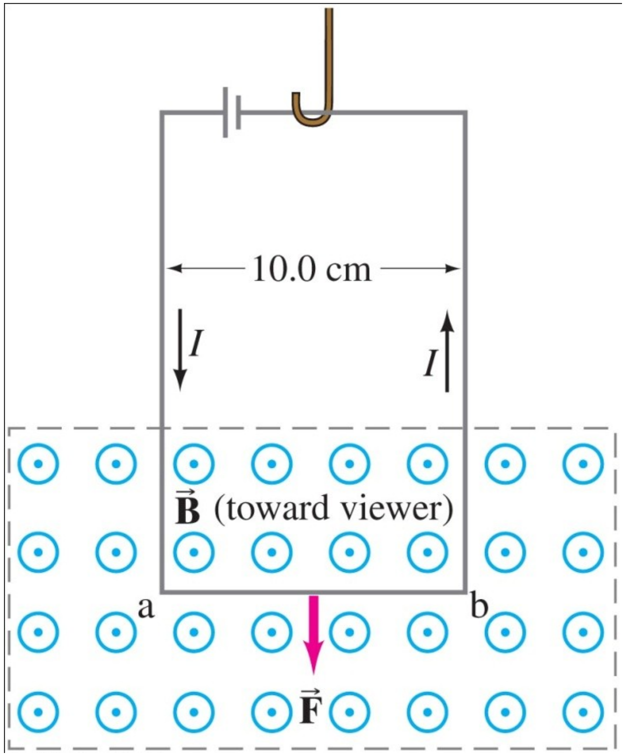
Example 27-1: Magnetic Force on a current-carrying wire.

A wire carrying a 30-A current has a length $\ell = 12$ cm between the pole faces of a magnet at an angle $\theta = 60°$, 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?



Example 27-2: Measuring a magnetic field.

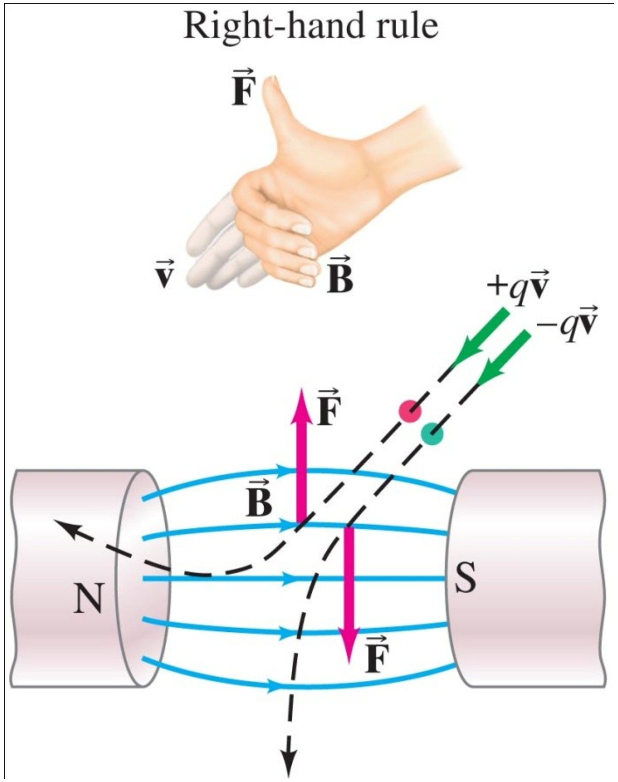
A rectangular loop of wire hangs vertically as shown. A magnetic field $\vec{B}$ is directed horizontally, perpendicular to the wire, and points out of the page at all points. The magnetic field is very nearly uniform along the horizontal portion of wire ab (length ℓ = 10.0 cm) which is near the center 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 x 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.

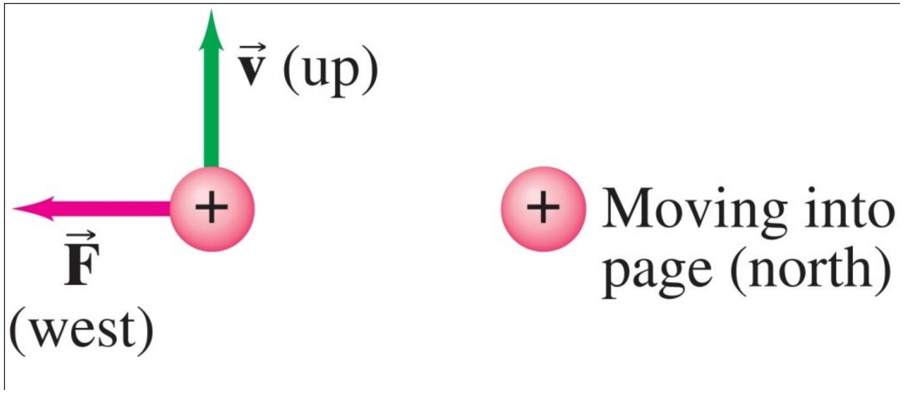


Conceptual Example 27-4: Negative charge near a magnet.

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*?

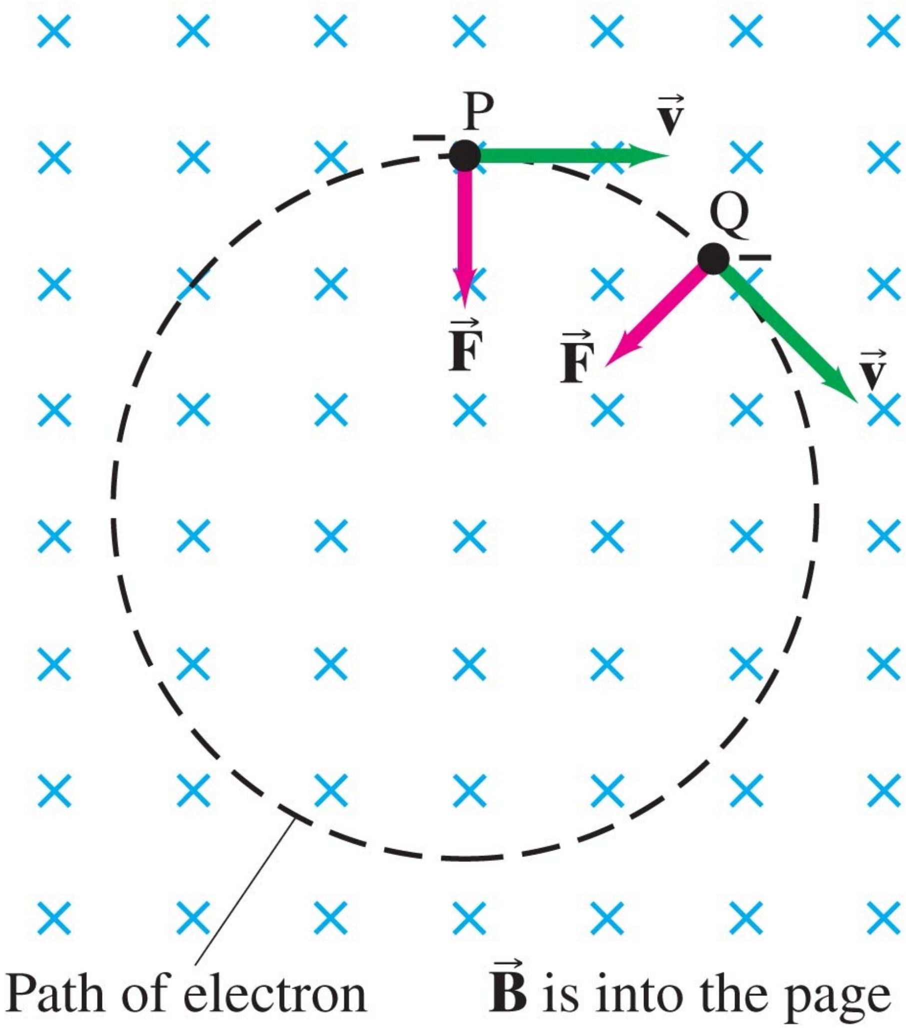
Example 27-5: Magnetic force on a proton.

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



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 x 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.

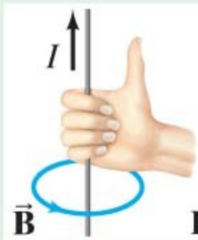
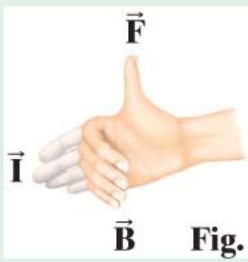
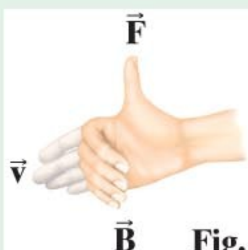
Can a magnetic field be used to stop a single charged particle, as an electric field can?

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

Problem solving: Magnetic fields – things to remember:

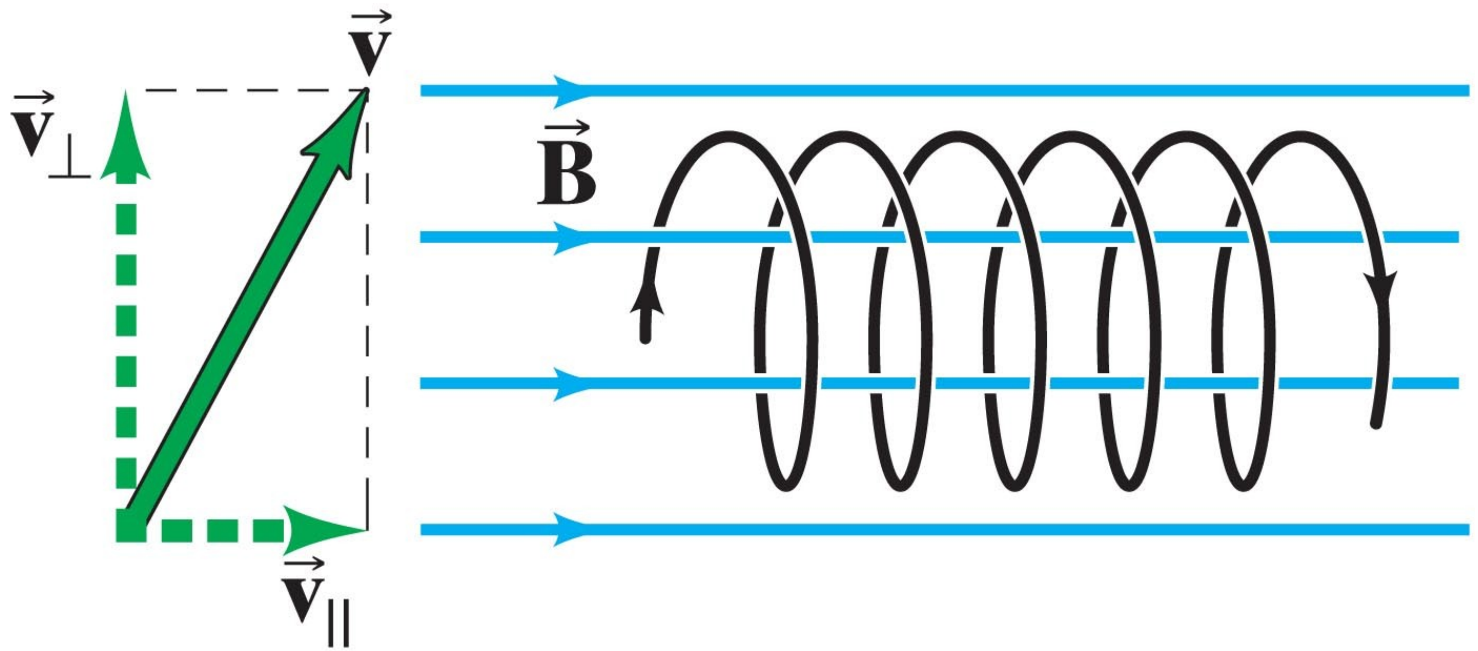
1. **The magnetic force is perpendicular to the magnetic field direction.**
2. **The right-hand rule is useful for determining directions.**
3. **Equations in this chapter give magnitudes only. The right-hand rule gives the direction.**

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)	 **Fig. 27–8c**	Wrap fingers around wire with thumb pointing in direction of current I	Fingers point in direction of $\vec{\mathbf{B}}$
2. Force on electric current I due to magnetic field (RHR-2)	 **Fig. 27–11c**	Fingers point straight along current I, then bend along magnetic field $\vec{\mathbf{B}}$	Thumb points in direction of the force $\vec{\mathbf{F}}$
3. Force on electric charge $+q$ due to magnetic field (RHR-3)	 **Fig. 27–15**	Fingers point along particle's velocity $\vec{\mathbf{v}}$, then along $\vec{\mathbf{B}}$	Thumb points in direction of the force $\vec{\mathbf{F}}$

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?

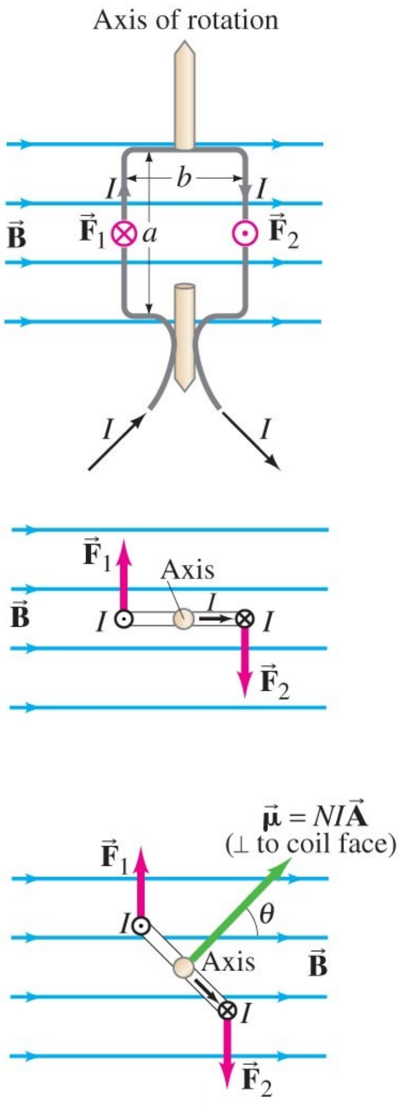


27-5 Torque on a Current Loop; Magnetic Dipole Moment

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

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



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

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

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

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

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

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.]

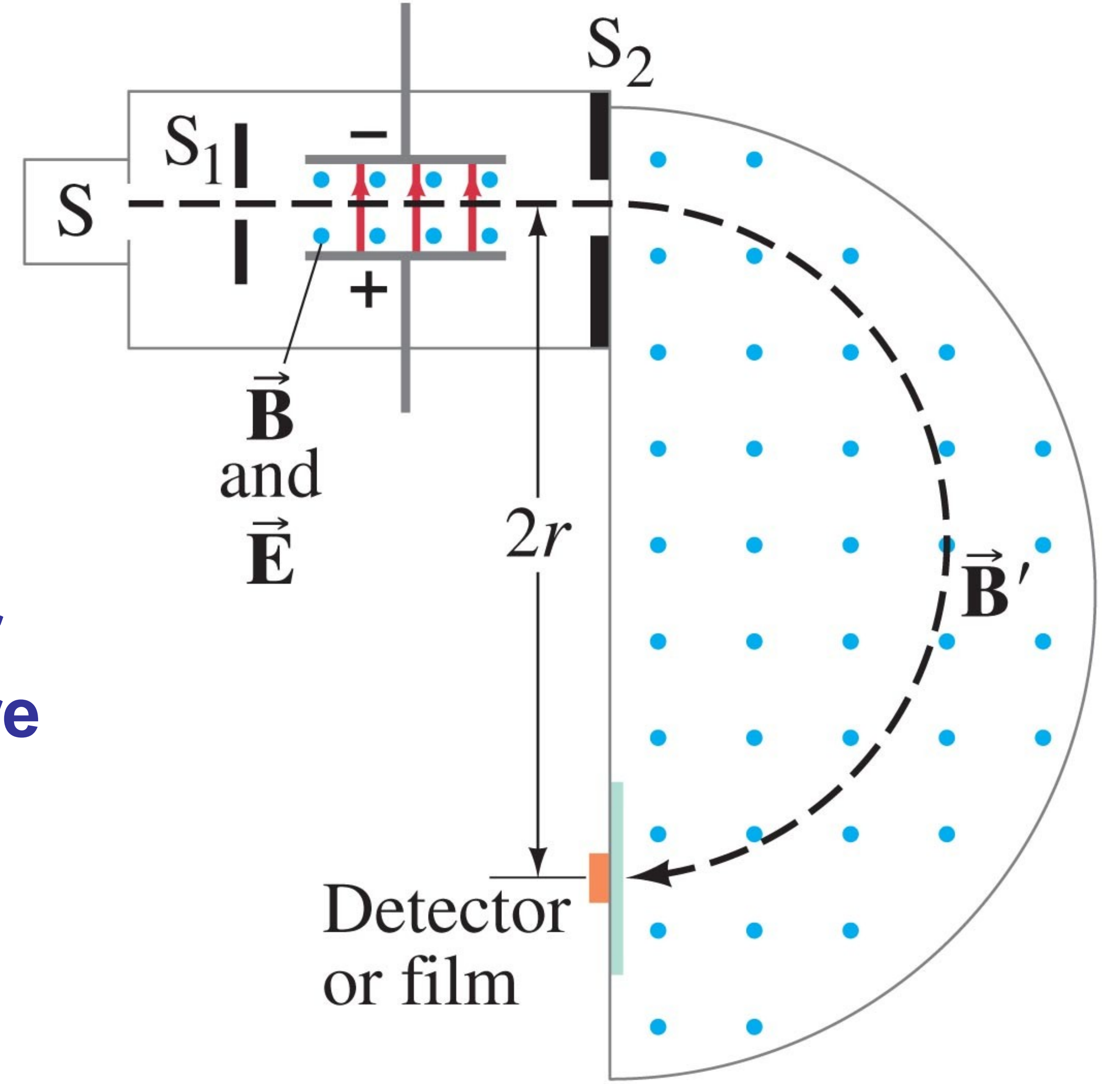
27-9 Mass Spectrometer

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.



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:**

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

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:**

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