## Phys102 Lecture 13, 14, 15

# Magnetic fields

### Key Points

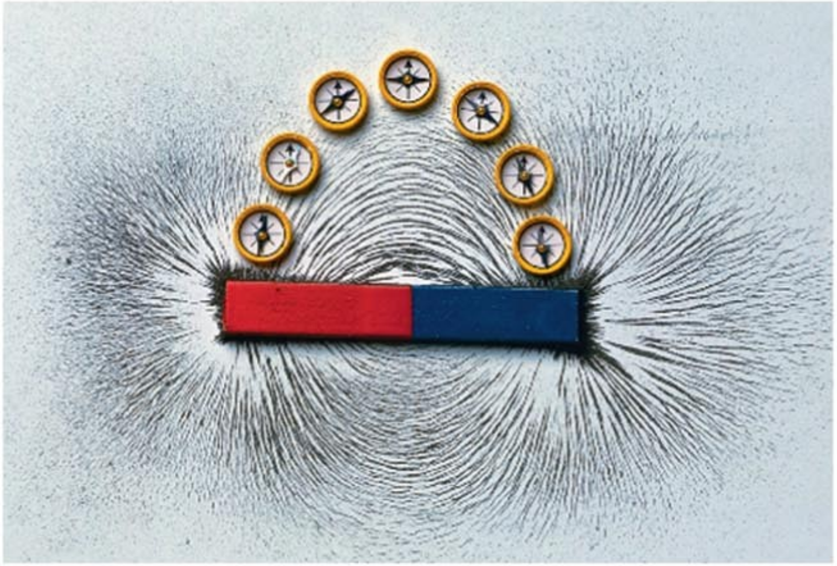
- Electric Currents Produce Magnetic Fields
- Force on an Electric Current in a Magnetic Field
- Force on an Electric Charge Moving in a Magnetic Field
- Torque on a Current Loop; Magnetic Dipole Moment

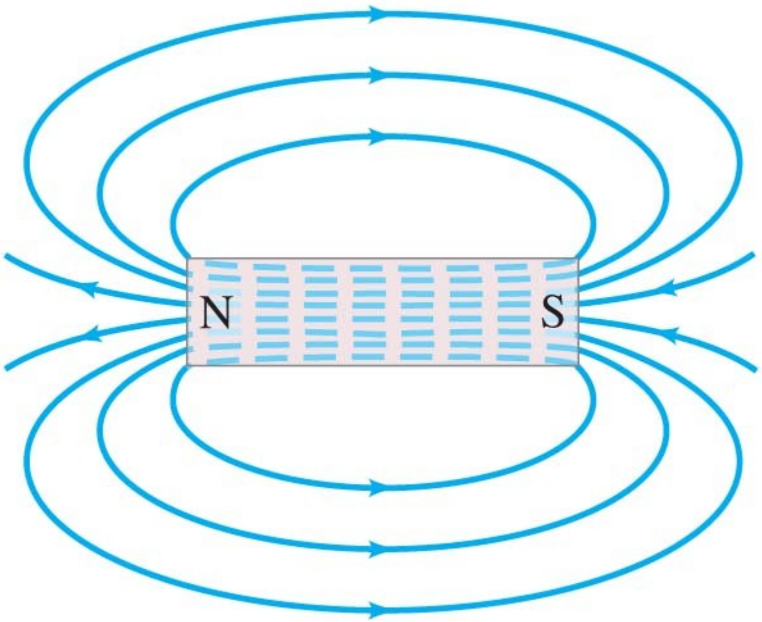
### References

20-1,2,3,4,9,11.

# Magnets and Magnetic Fields

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

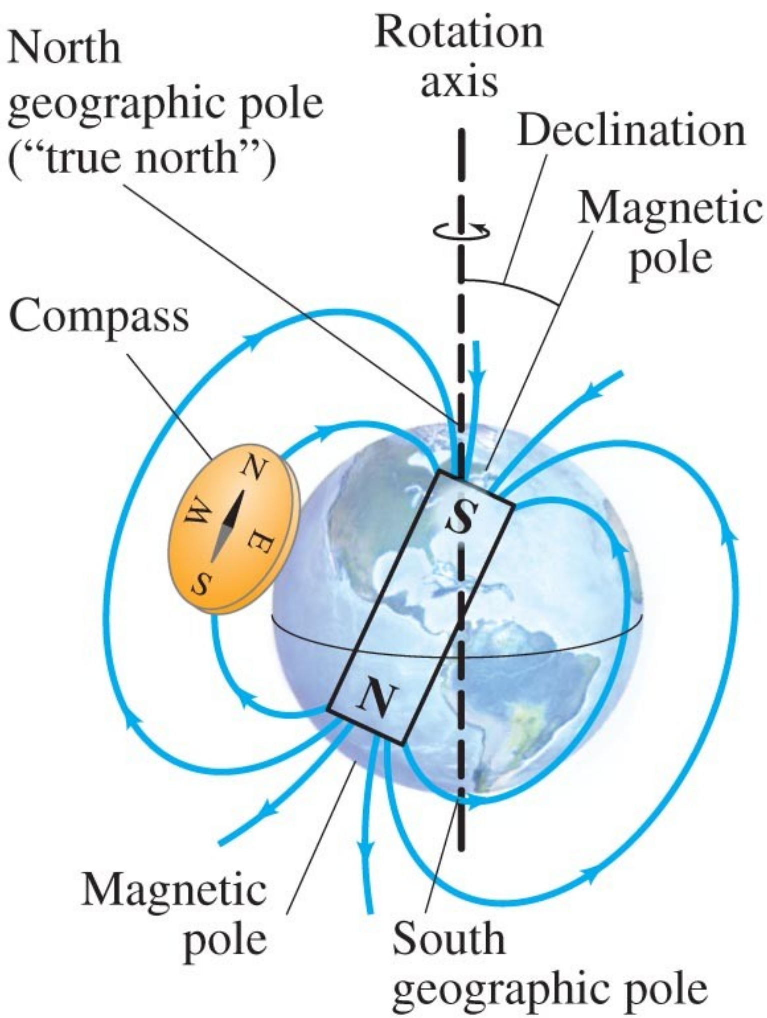




# Magnets and Magnetic Fields

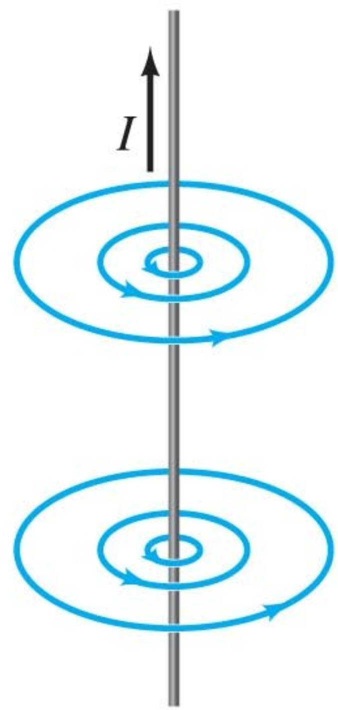
**The Earth's magnetic field is similar to that of a bar magnet.**

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

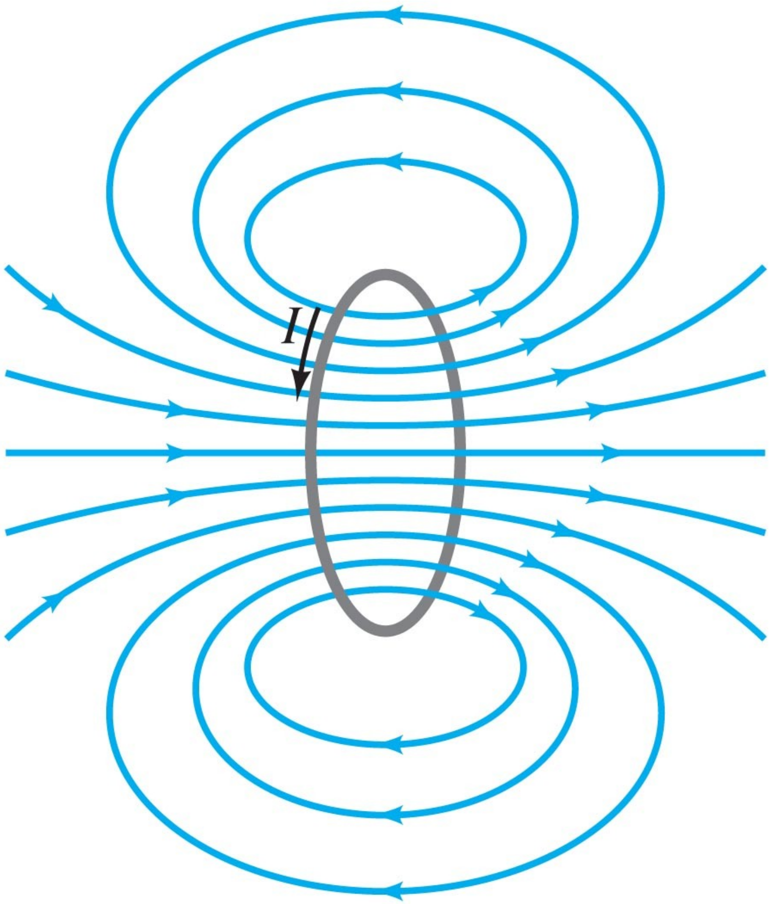


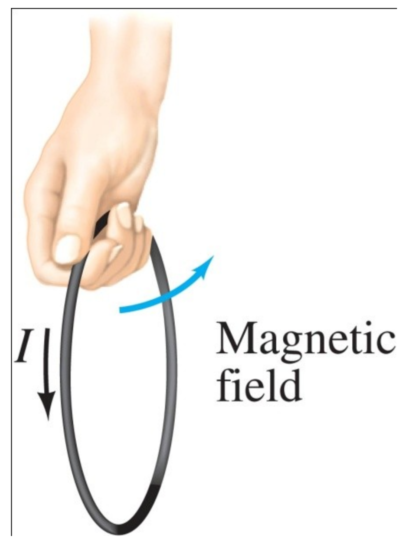
# Electric Currents Produce Magnetic Fields

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




# 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.**

# Force on an Electric Current in a Magnetic Field; Definition of $\vec{\mathbf{B}}$

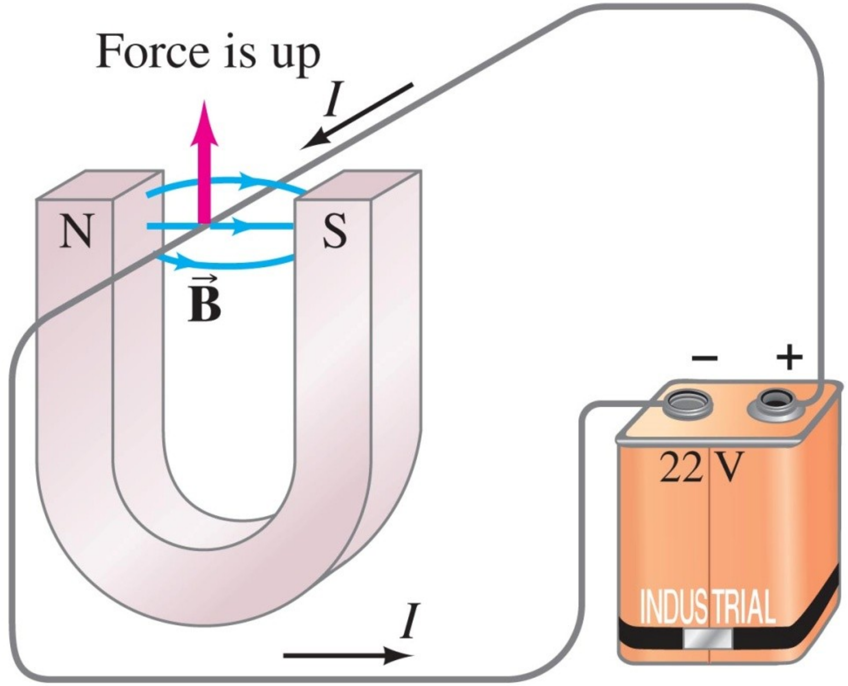
**The force on the wire depends on the current, the length of the wire, the magnetic field, and its orientation:**

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

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

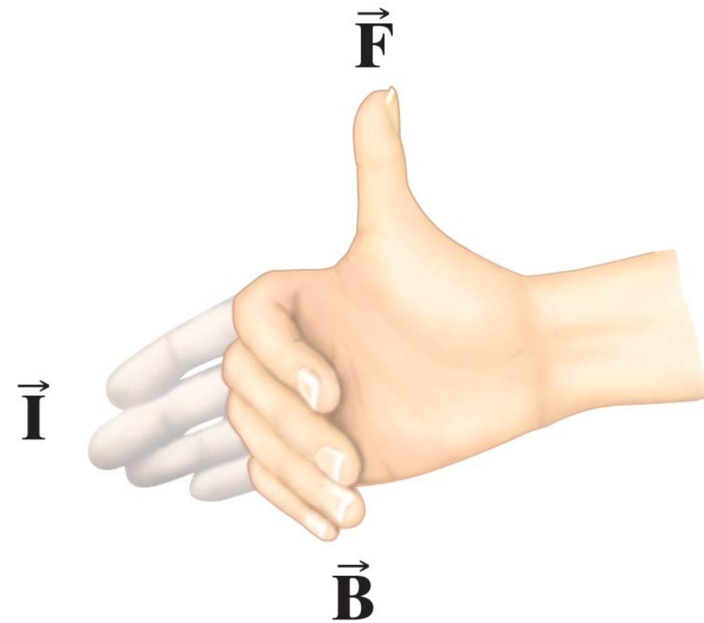
**In vector notation:**

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




(b)






(c) Right-hand rule



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

**Unit of *B*: the tesla, T:**

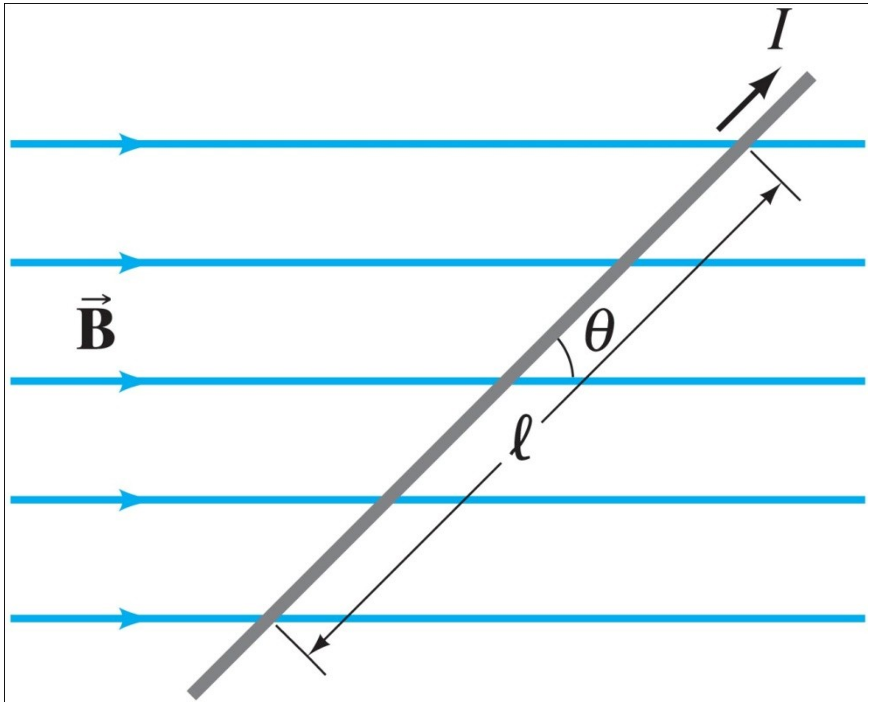
$$1\ \mathrm{T} = 1\ \mathrm{N/A \cdot m}.$$

**Another unit sometimes used: the gauss (G):**

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

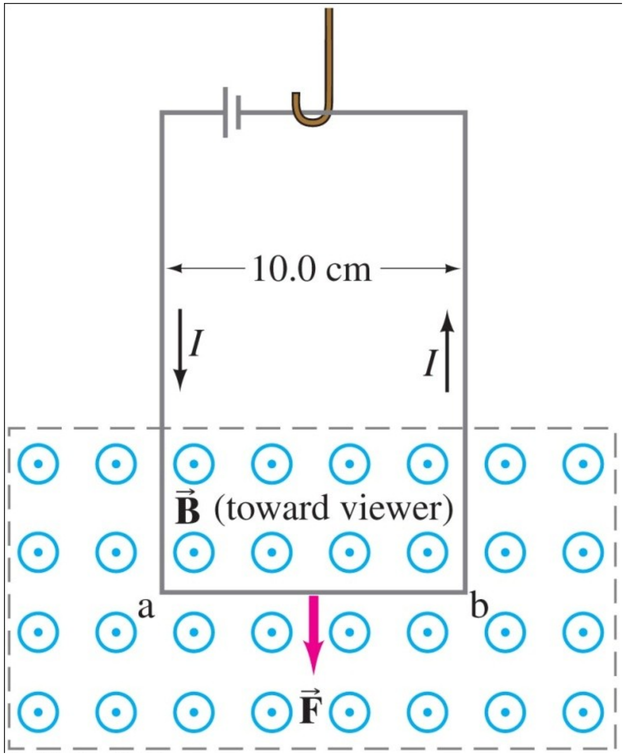
## Example: Magnetic Force on a current-carrying wire.

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 : Measuring a magnetic field.

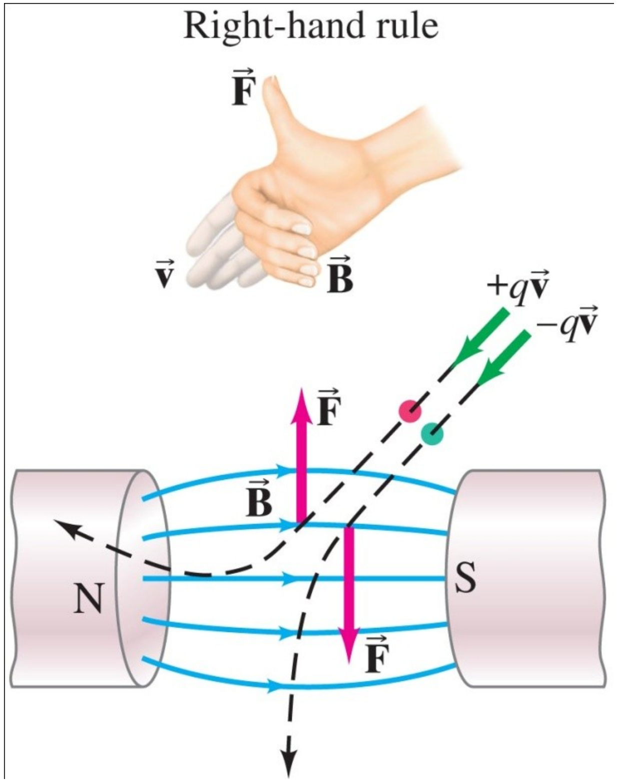
A rectangular loop of wire hangs vertically as shown. A magnetic field $\vec{B}$ is directed horizontally, perpendicular to the wire, and points out of the page at all points. The magnetic field is very nearly uniform along the horizontal portion of wire ab (length $\ell$ = 10.0 cm) which is near the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

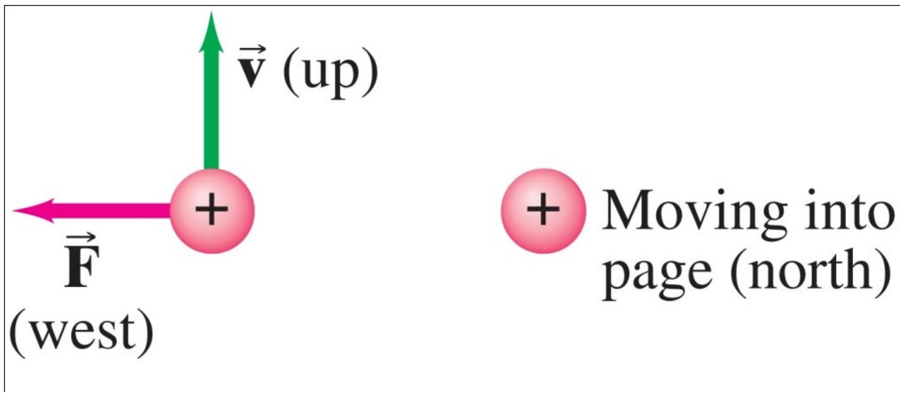


## Conceptual Example: Negative charge near a magnet.

**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, $+Q$?**

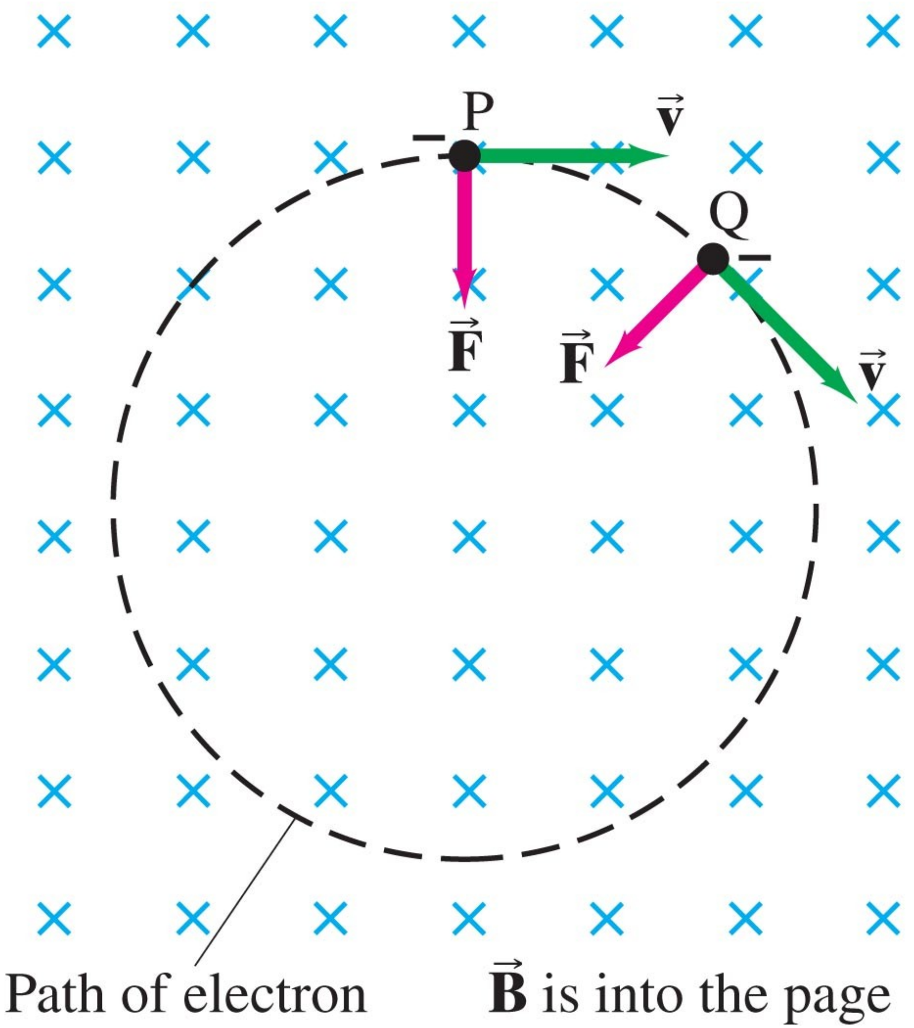
# Example : Magnetic force on a proton.

**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.)**



# 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: Electron's path in a uniform magnetic field.**

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

**Conceptual Example: Stopping charged particles.**

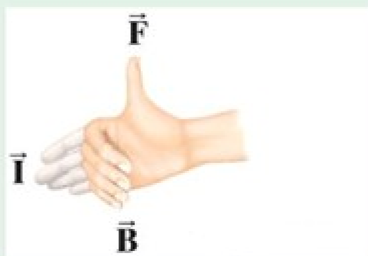
**Can a magnetic field be used to stop a single charged particle, as an electric field can?**

# Force on an Electric Charge Moving in a Magnetic Field

**Problem solving: Magnetic fields – things to remember:**

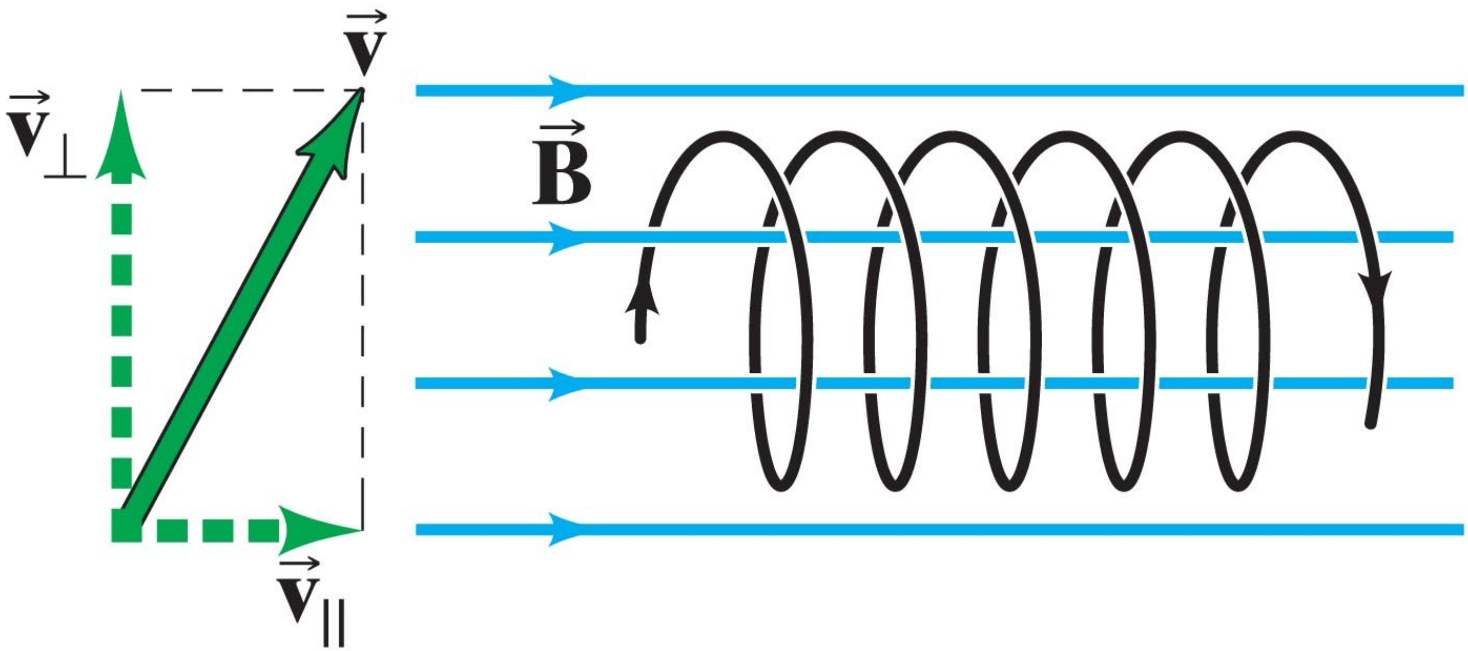
1. **The magnetic force is perpendicular to the magnetic field direction.**
2. **The right-hand rule is useful for determining directions.**
3. **Equations in this chapter give magnitudes only. The right-hand rule gives the direction.**

## TABLE 20-1 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 $\vec{\mathbf{B}}$ |
| **2.** Force on electric current $I$ due to magnetic field (RHR-2) |  | Fingers point straight along current $I$, then bend along magnetic field $\vec{\mathbf{B}}$ | Thumb points in direction of the force $\vec{\mathbf{F}}$ |
| **3.** Force on electric charge $+q$ due to magnetic field (RHR-3) |  | 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: 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?**

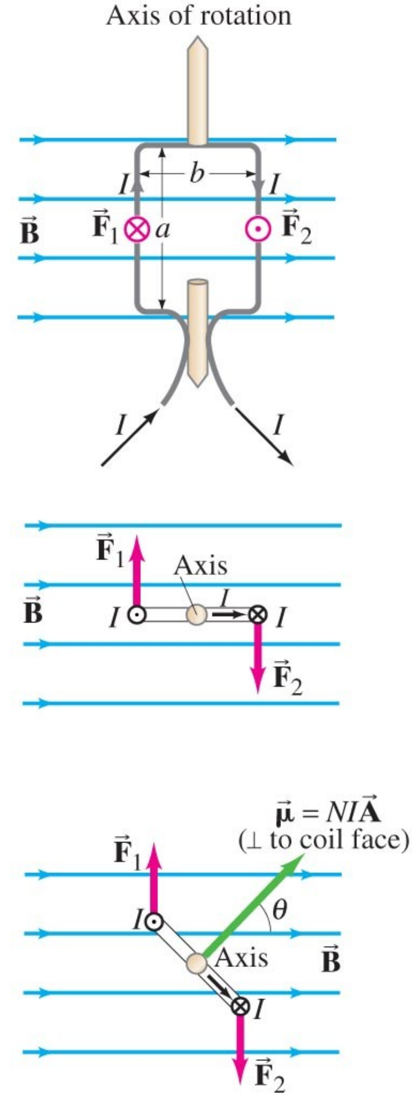


# Torque on a Current Loop; Magnetic Dipole Moment

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

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



# Torque on a Current Loop; Magnetic Dipole Moment

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

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

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

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

## Example: 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: 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.]**

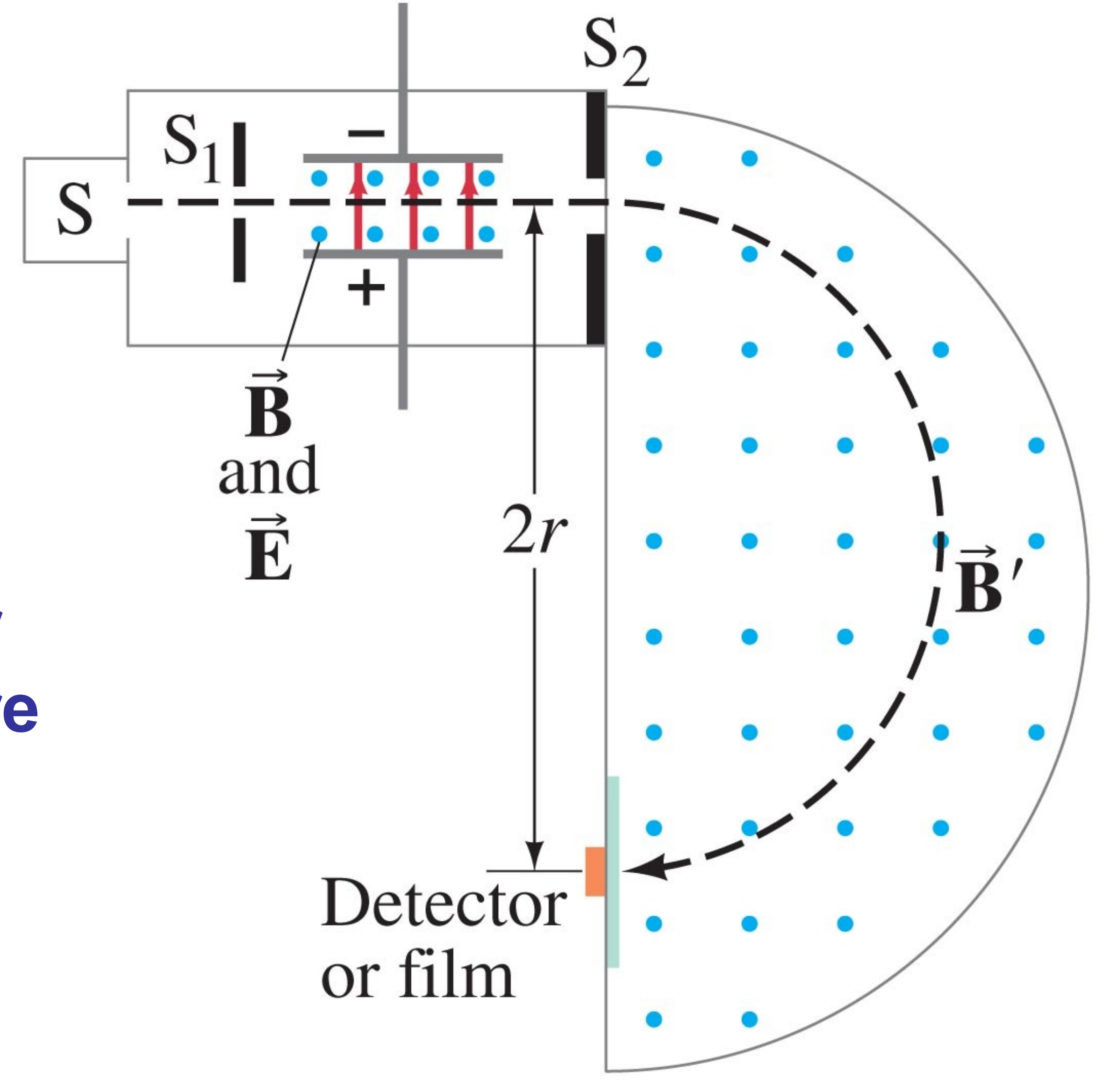
# Mass Spectrometer

**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:**

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

# 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: 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.