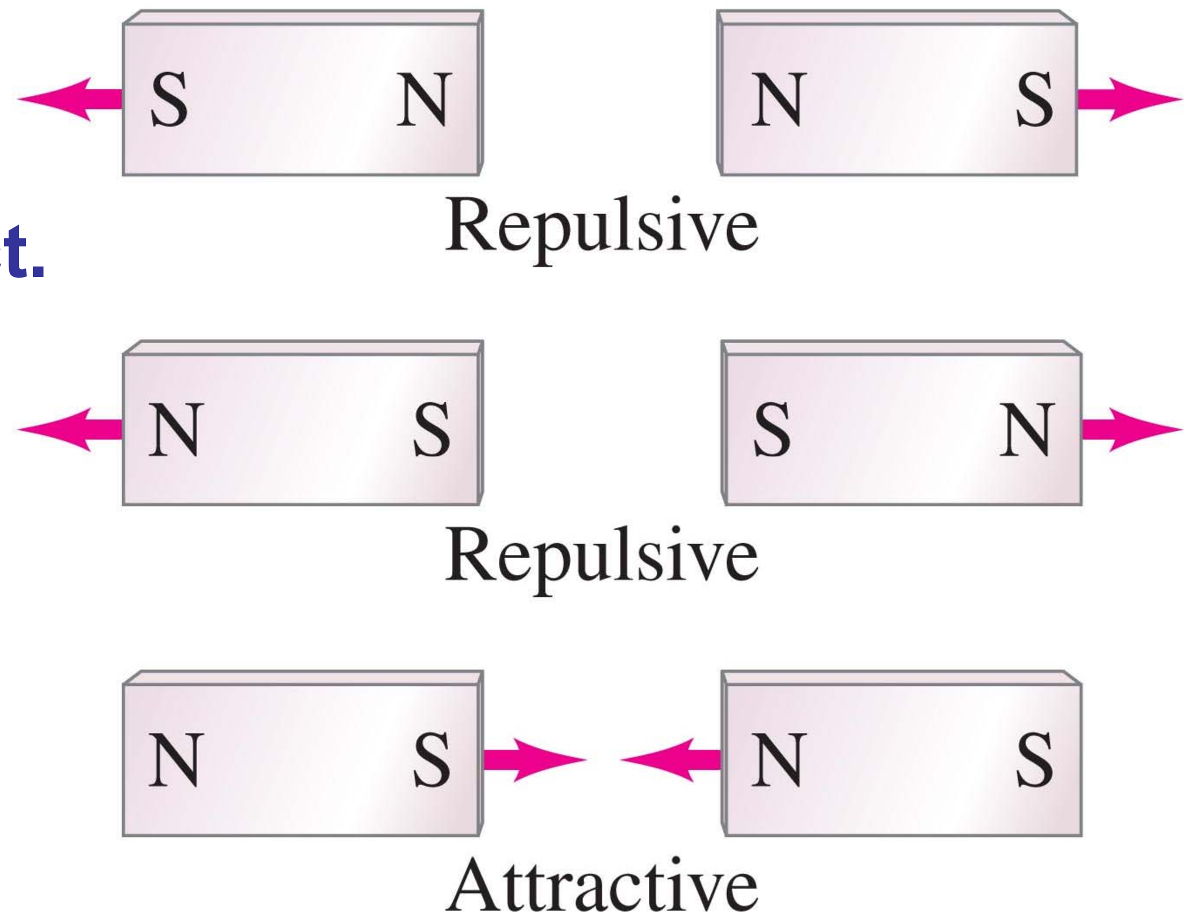
Chapter 27
Magnetism

27-1 Magnets and Magnetic Fields

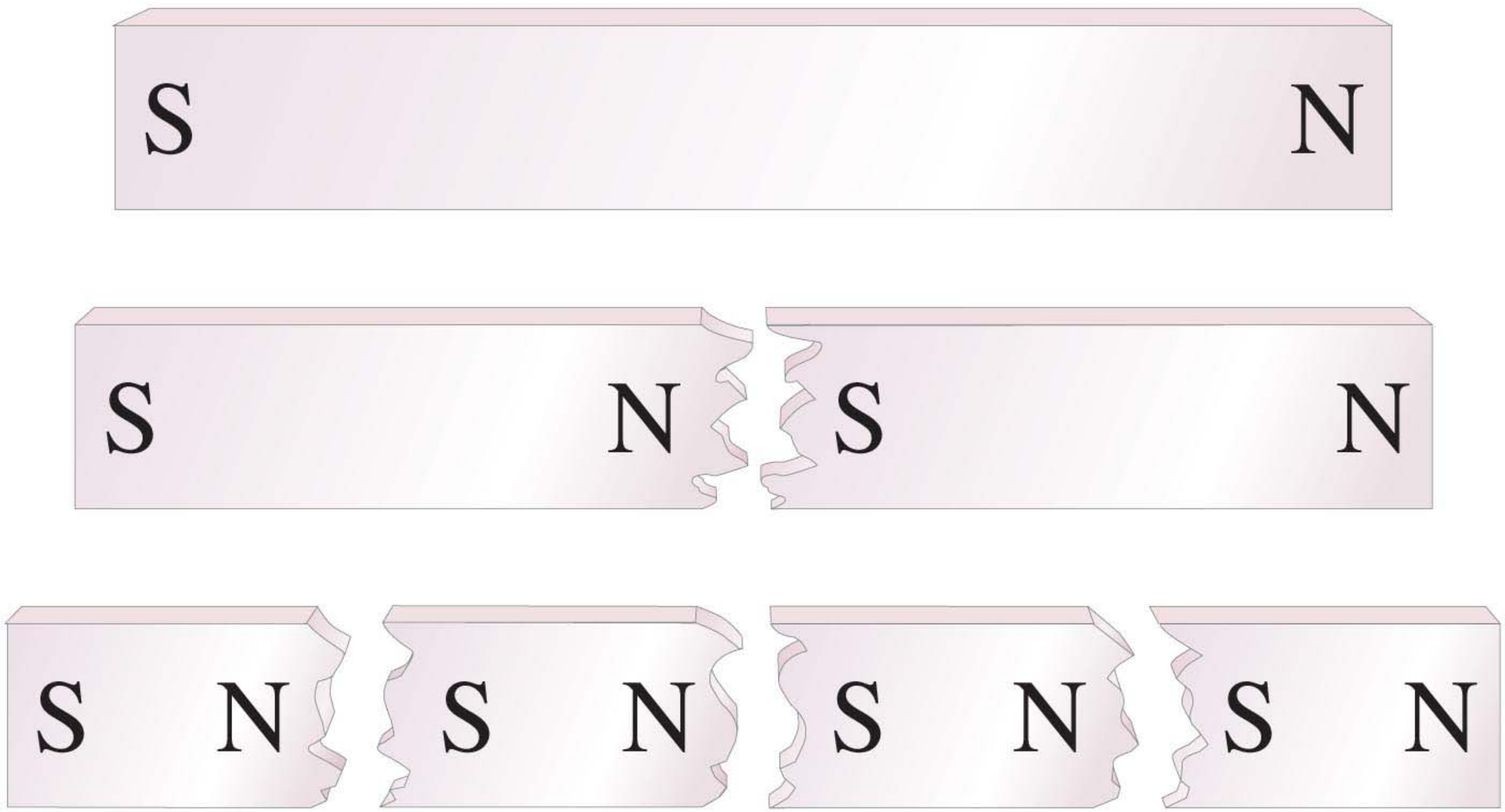
Magnets have two ends – poles – called north and south.

Like poles repel; unlike poles attract.



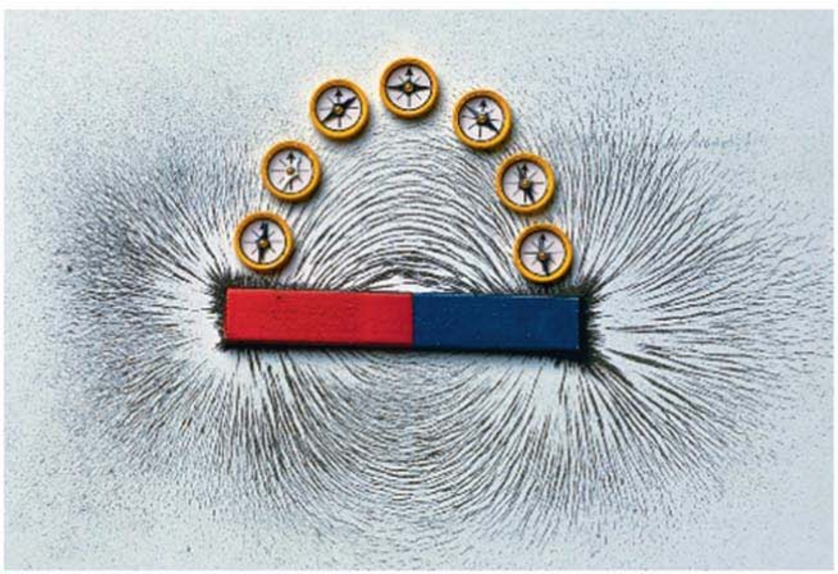
27-1 Magnets and Magnetic Fields

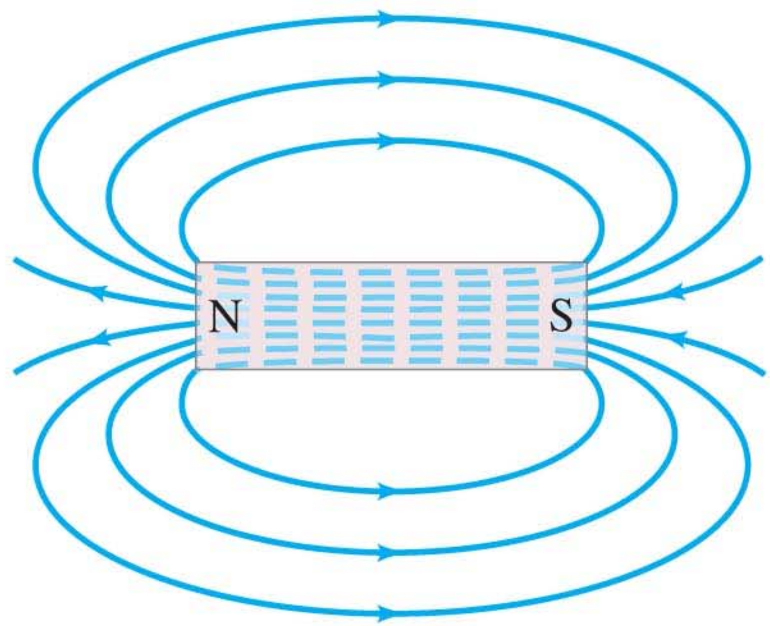
However, if you cut a magnet in half, you don't get a north pole and a south pole – you get two smaller magnets.



27-1 Magnets and Magnetic Fields

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

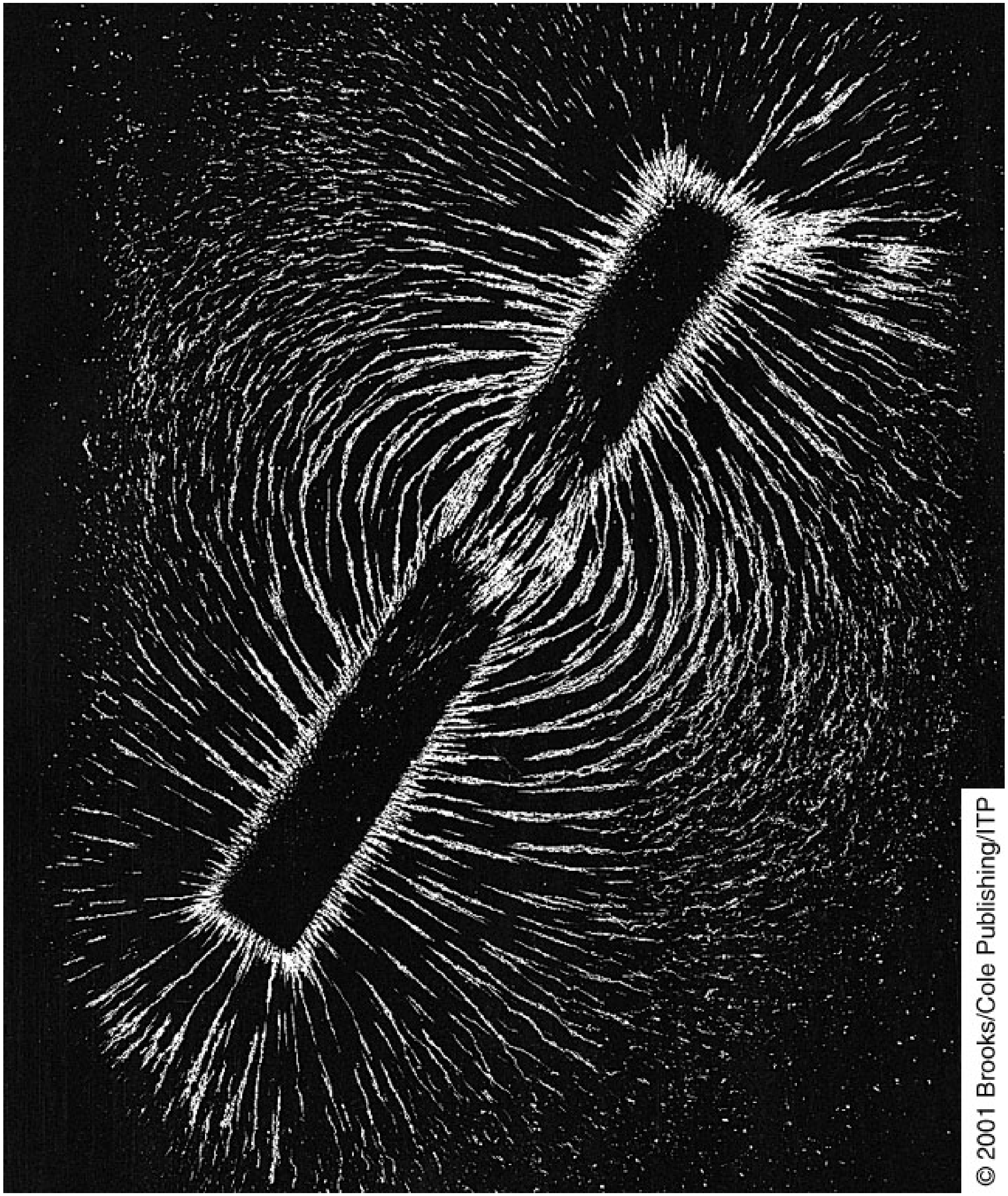




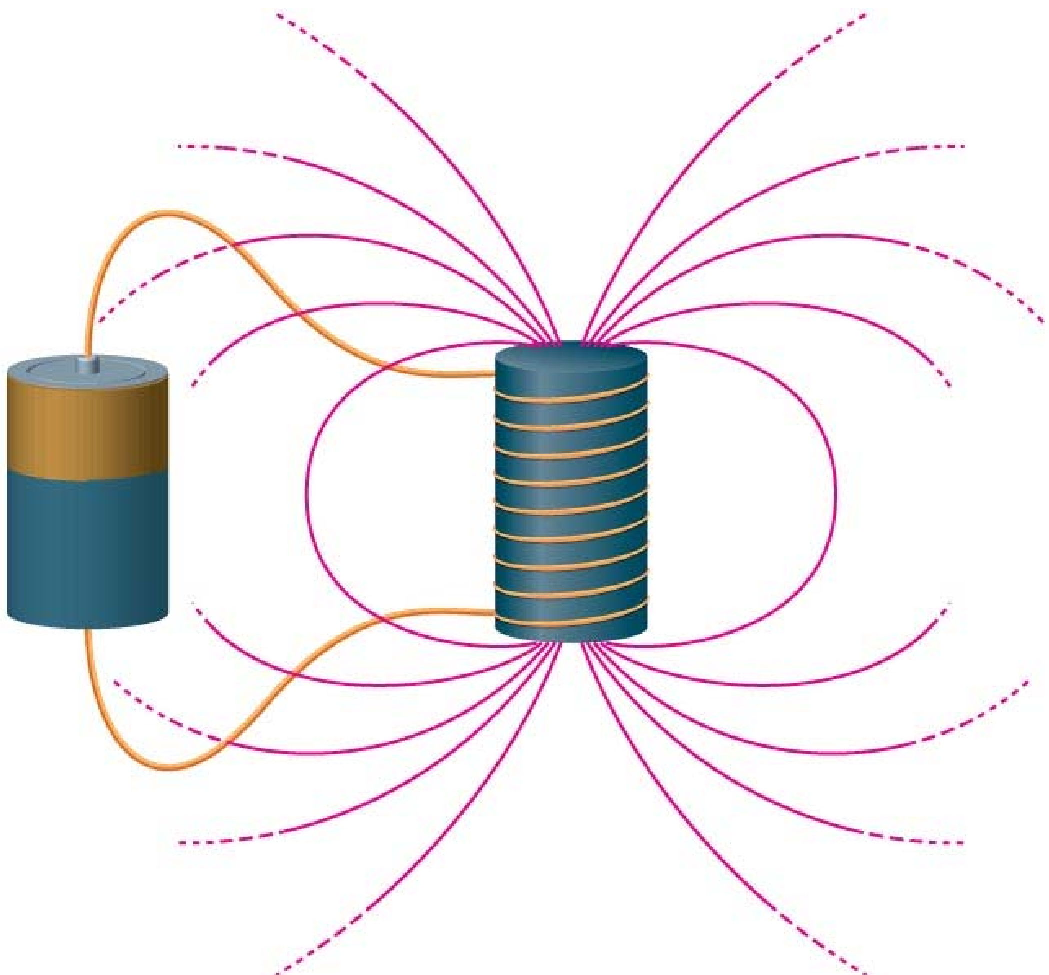
Magnetism
Plays a Major Role
On the structure of the Sun
and important on Earth
Here Iron filings are
Sprinkled about a
Magnet and
We get a sense of what
Is happening
Around the space of
The magnet

FILM: MAGNET AND IRON FILINGS

FILM 3D FIELD



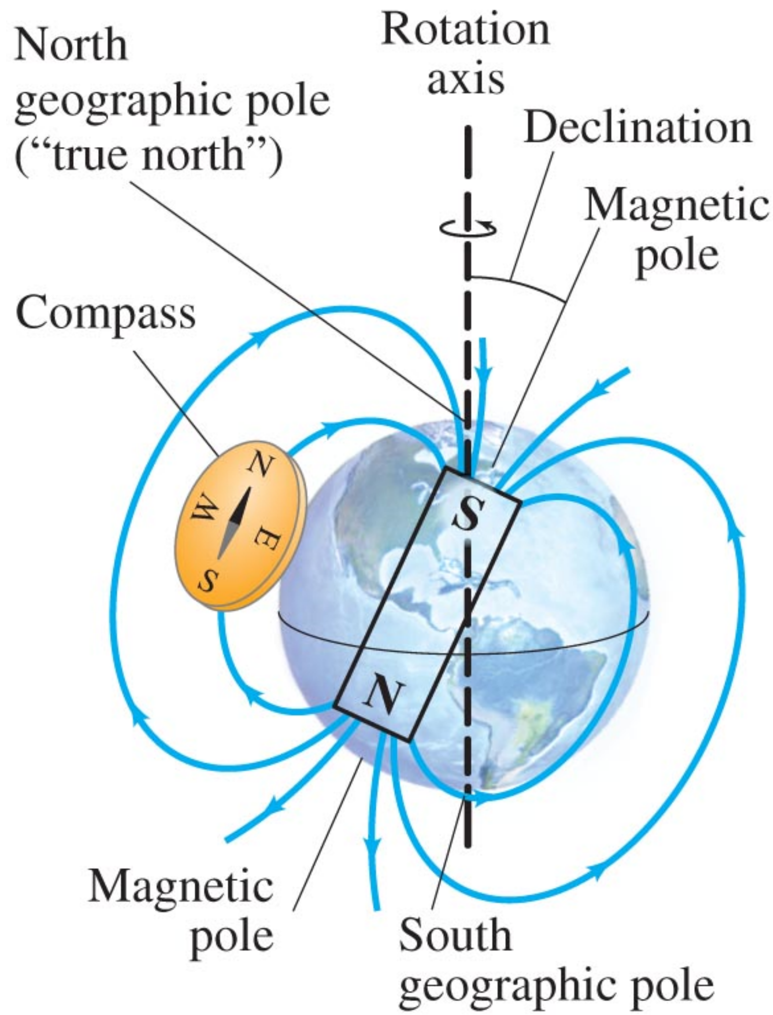
Sources of Magnetic Fields



- Motions of charged particles are what create magnetic fields
- In Planets and the Sun and in devices!
- We use this for many applications

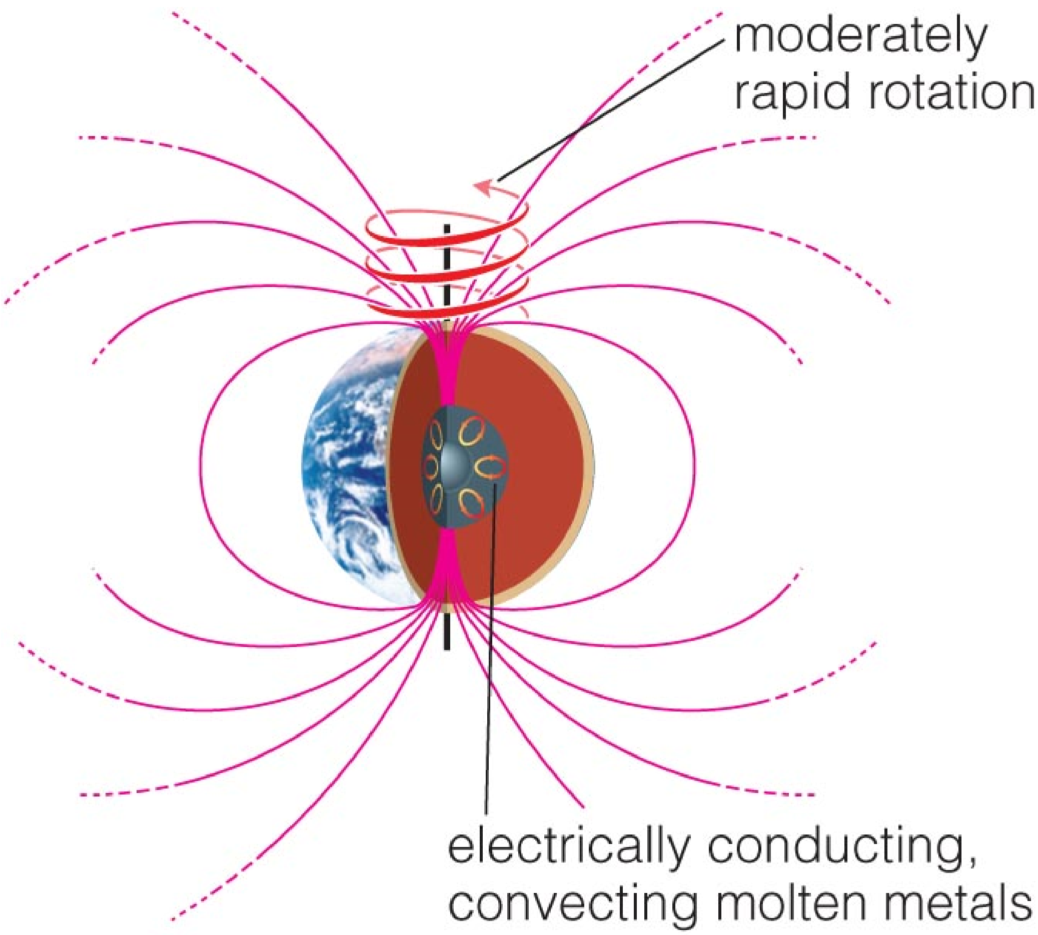
27-1 Magnets and Magnetic Fields

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.

Sources of Magnetic Fields



- A planet can have a magnetic field if charged particles are moving inside
- 3 requirements:
  - Molten interior
  - Convection
  - Moderately rapid rotation

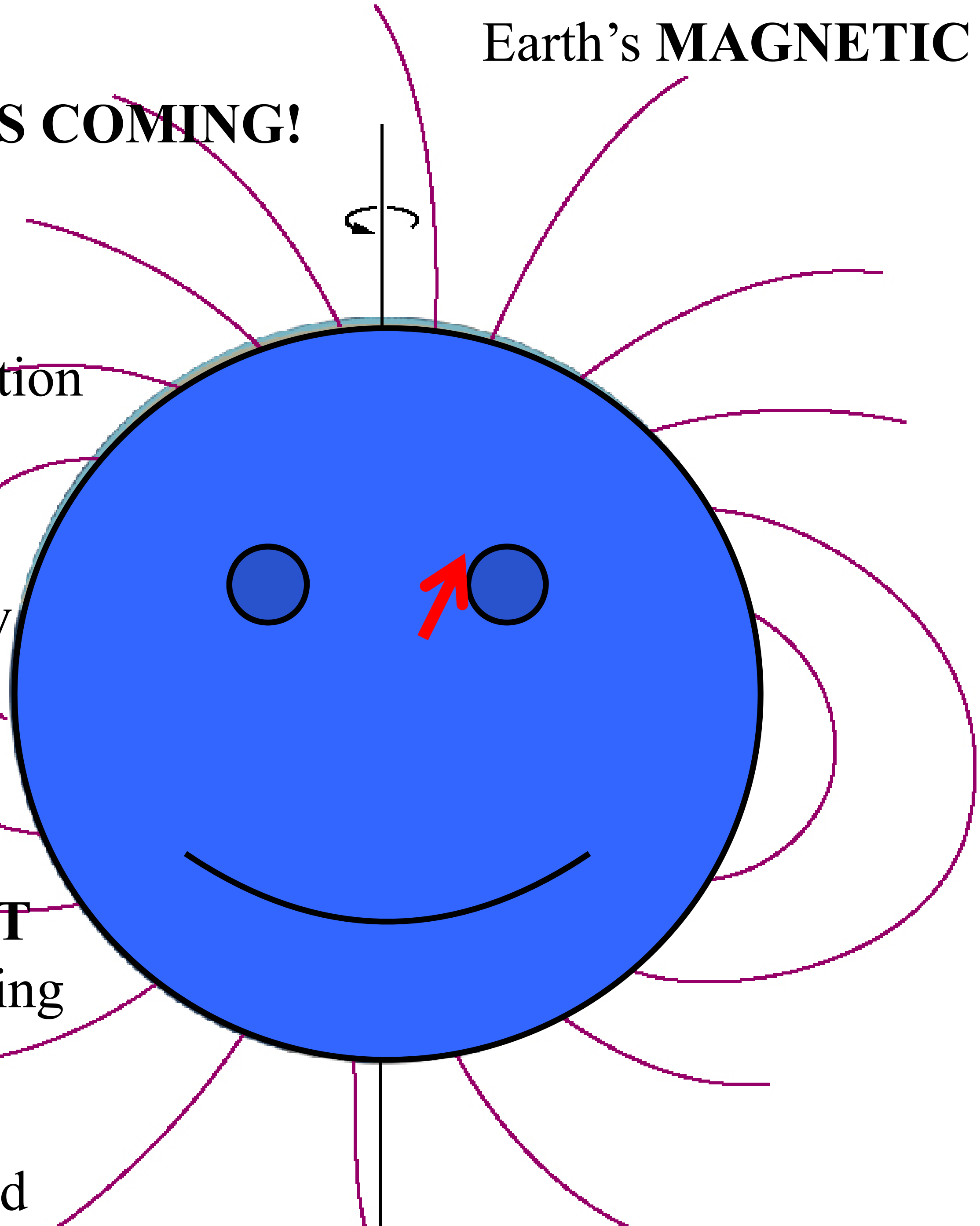
Earth's **MAGNETIC FIELD**

SHIELDS UP!
SOLAR WIND IS COMING!

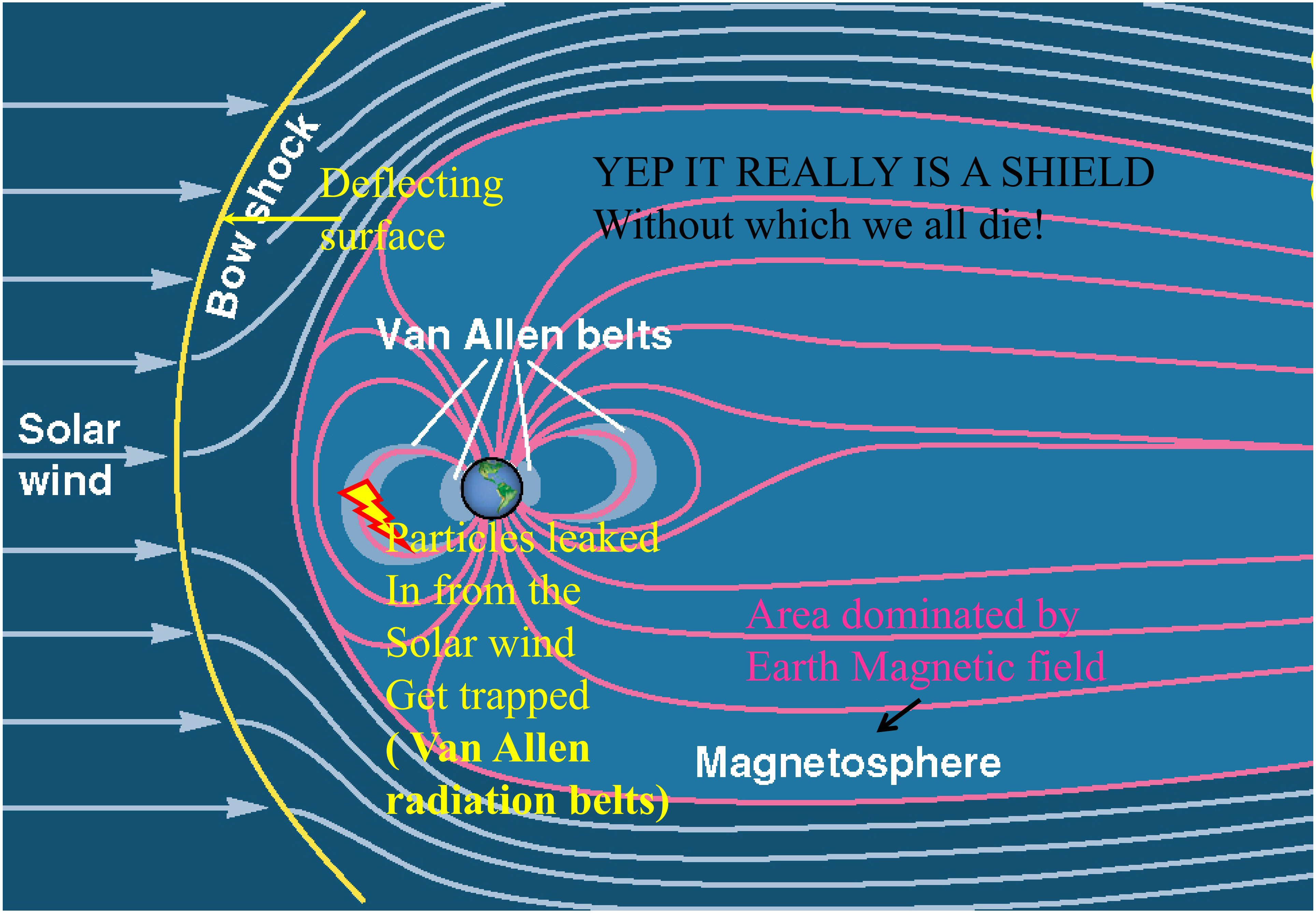
Earth rotates

Rising heat
Causes convection
In liquid core.

Which is a
Highly electrically
conductive
Iron-nickel alloy



DYNAMO EFFECT
=rotation of convecting
conducting liquid
generates the
dipole magnetic field


YEP IT REALLY IS A SHIELD
Without which we all die!
Deflecting
surface
Bow shock
Van Allen belts
Solar
wind
Particles leaked
In from the
Solar wind
Get trapped
(Van Allen
radiation belts)
Area dominated by
Earth Magnetic field
Magnetosphere

AURORA

Solar wind particles
That leak into the
Earth's upper
Atmosphere
Ionize gas atoms that
Capture electrons
Resulting in
An
EMISSION
SPECTRUM
Of rays
& beautiful
curtains

Another Aurora (Polar Light)

As high-energy particles leak into the lower magnetosphere, they excite molecules near the Earth's magnetic poles, causing the **aurora**

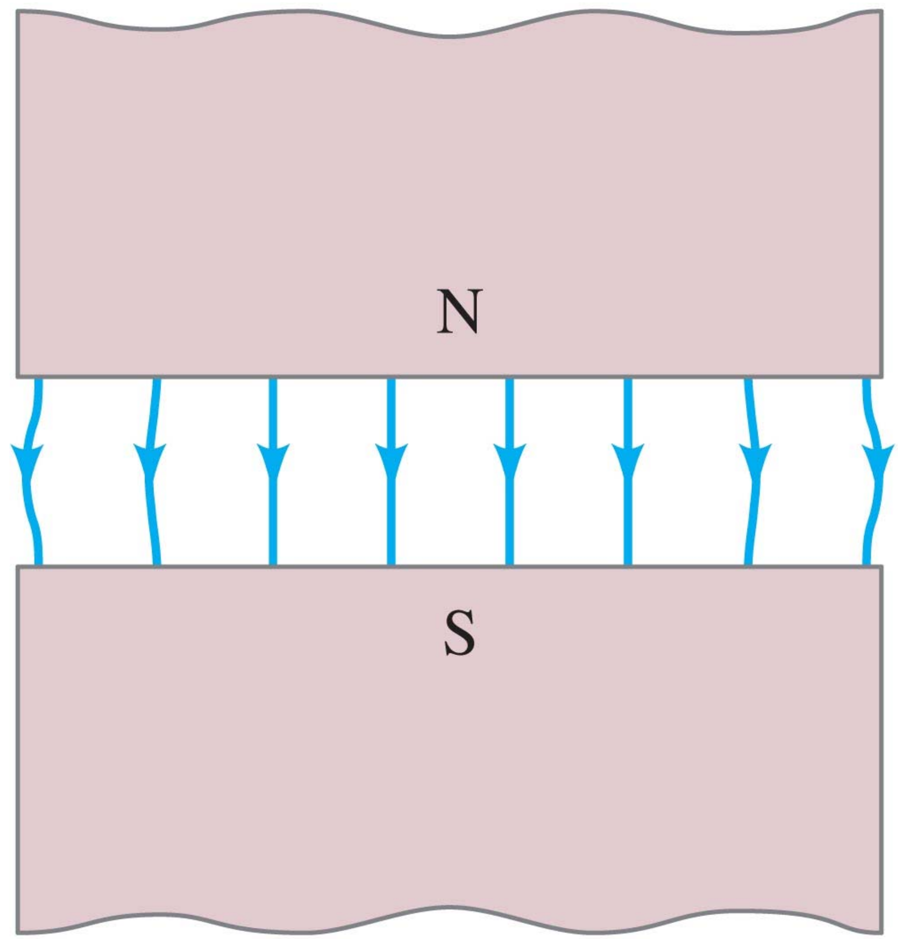
Aurora are dynamic!

- Aurora Australis From McMurdo station Antarctica

27-1 Magnets and Magnetic Fields

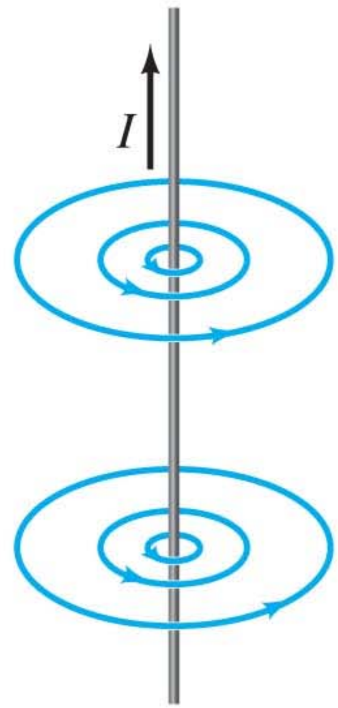
A uniform magnetic field is constant in magnitude and direction.

The field between these two wide poles is nearly uniform.

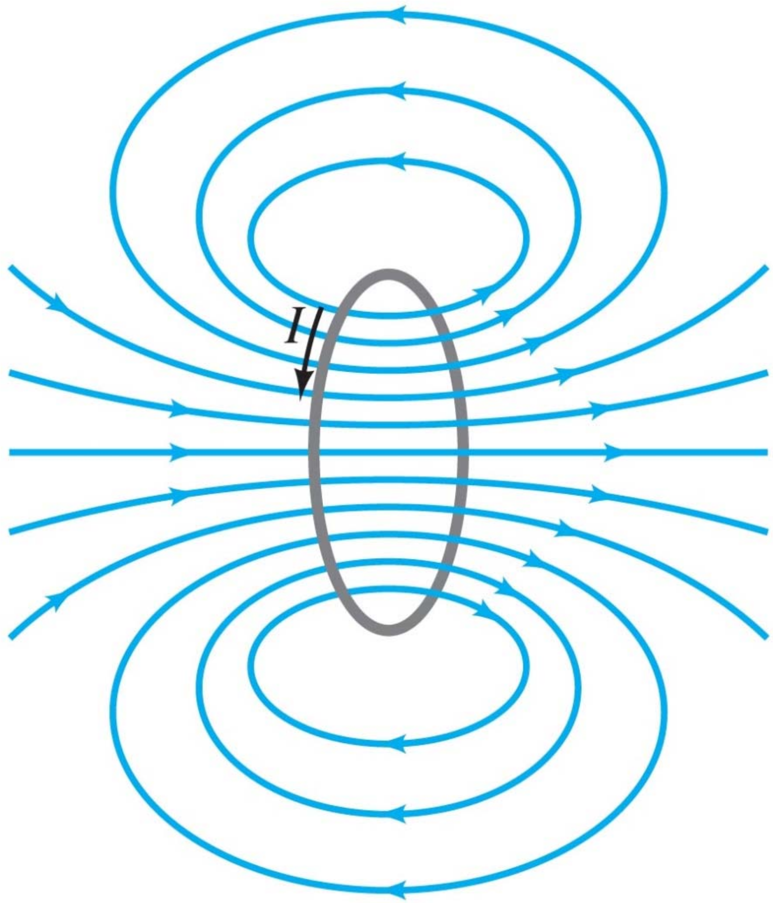


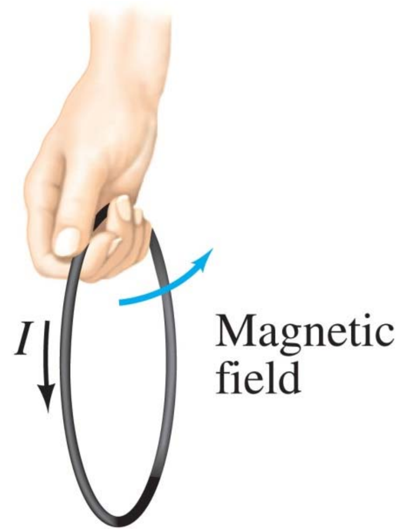
27-2 Electric Currents Produce Magnetic Fields

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

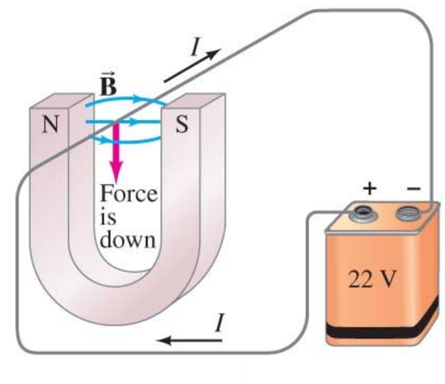




Here we see the field due to a current loop; the direction is again given by a right-hand rule.

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

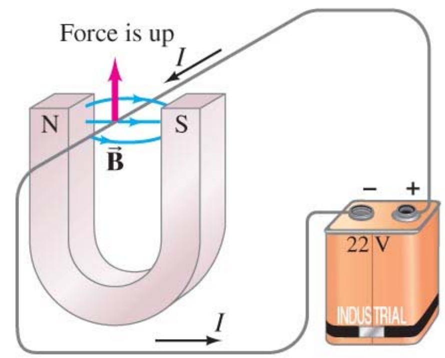
A magnet exerts a force on a current-carrying wire. The direction of the force is given by a right-hand rule.



The force on the wire depends on

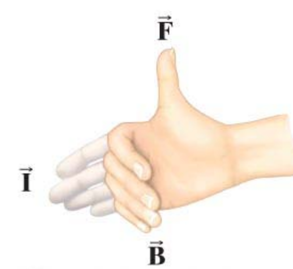
the current, the length of the wire,

the magnetic field, and its orientation:



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

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



This last equation defines the magnetic field In vector notation:

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

Unit of *B*: the tesla, T:

1 T = 1 N/A·m. Ie from F=ilB-> B=F/il

Another unit sometimes used: the gauss (G):

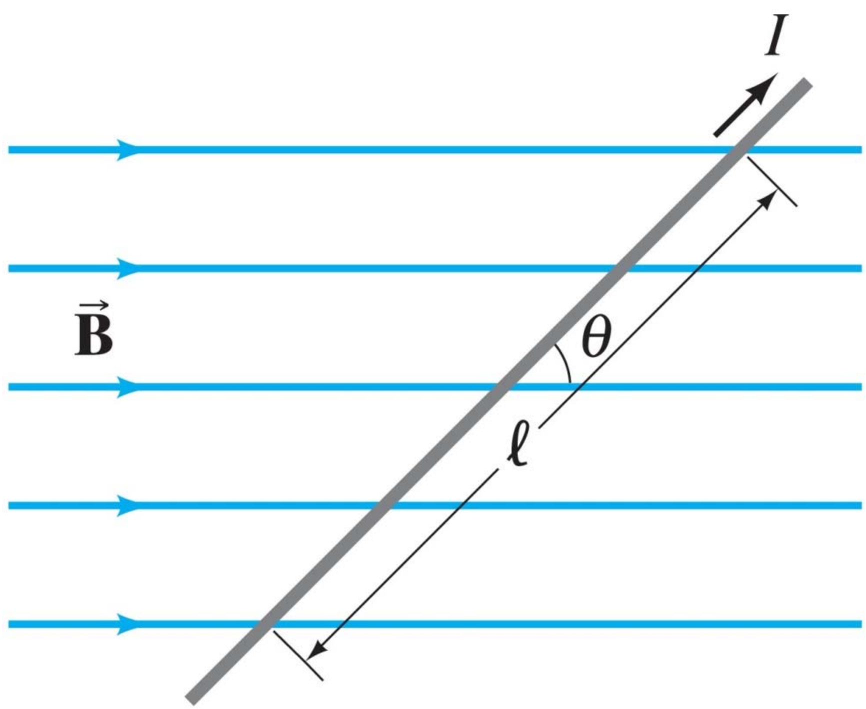
1 G = 10^{-4} T.

Earth's field is ~0.5G

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

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?



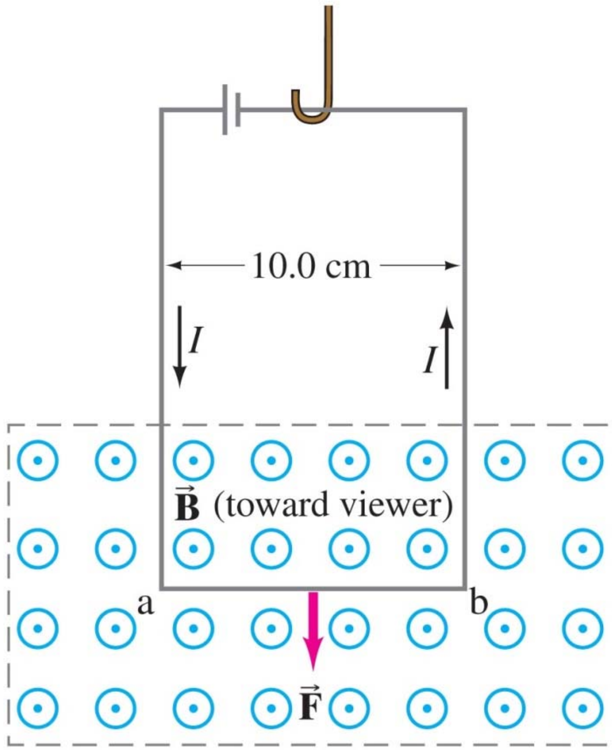
CLASS

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

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

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 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 $F = 3.48 \times 10^{-2}$ N when the wire carries a current I = 0.245 A. What is the magnitude of the magnetic field B?



class

Θ=90 **F=ilB or**

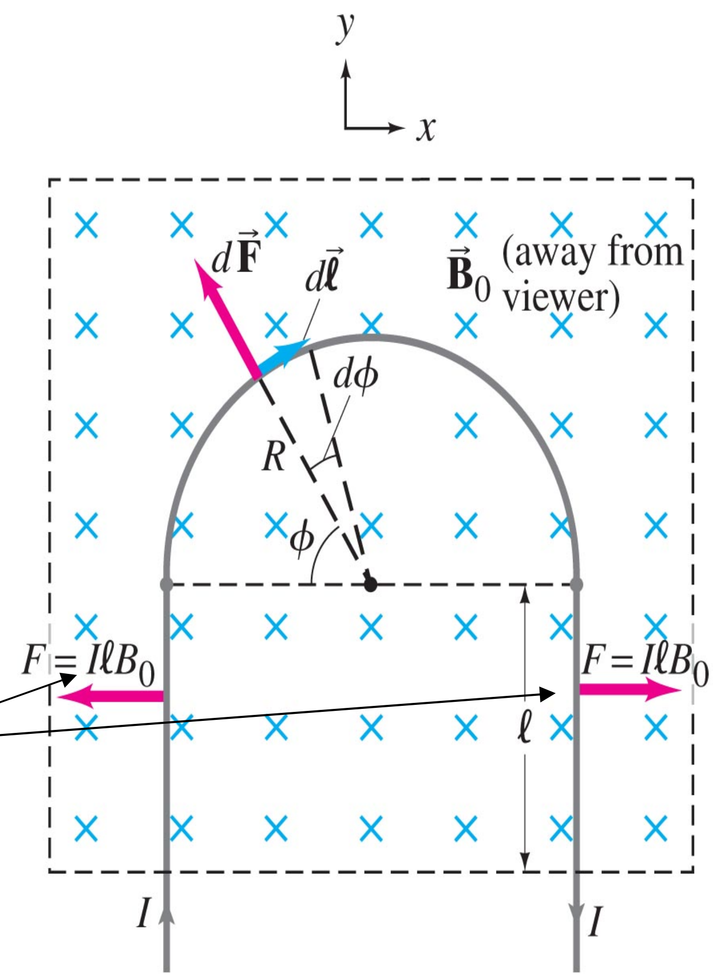
B=F/il =1.42T

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

Example 27-3: Magnetic Force on a semicircular wire.

A rigid wire, carrying a current I, consists of a semicircle of radius R and two straight portions as shown. The wire lies in a plane perpendicular to a uniform magnetic field B_0 Note choice x and y axis. The straight portions each have length ℓ within the field. Determine the net force on the wire due to the magnetic field.

Note symmetry cancellations all x Components of dF and these



Only y component of dF, dFsinϕ

Also dl=Rdϕ –> ΣdFsinϕ & dF=iB$_0$Rdϕ

$$F = \int_0^{\pi} dF \sin\varphi = IB_0 R \int_0^{\pi} \sin\varphi \, d\varphi = 2 IB_0 R$$

HAND IN HW. Recall by first Sketch, set up equations, solve algebraically then plug in numbers. All answers in Scientific notation.

These problems are from the textbook and please I do not want to see online solutions(they will have no value). Do them in your own way.

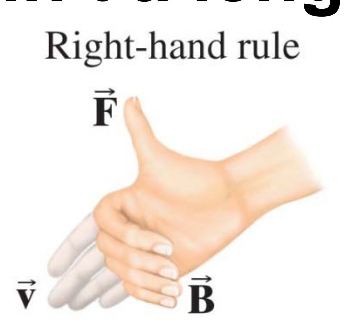
85: 27-2
86: 27-6
87: 27-7
88: 27-10

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

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

Ie. Assume i=Q/t=Nq/t N **number of charges**

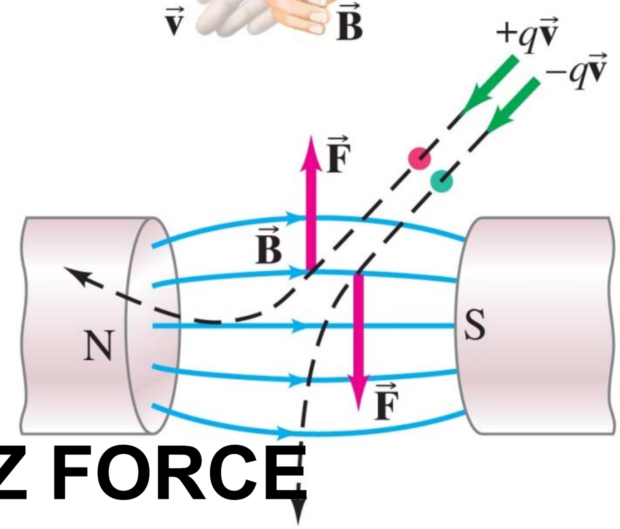
And v velocity so they travel in t **a length l=vt**



Thus F=ilxB=N(q/t)**vt xB =**Nq**vxB**

So for one charge.

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



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

part of: THE LORENTZ FORCE

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

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, $+Q$?

CLASS?

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

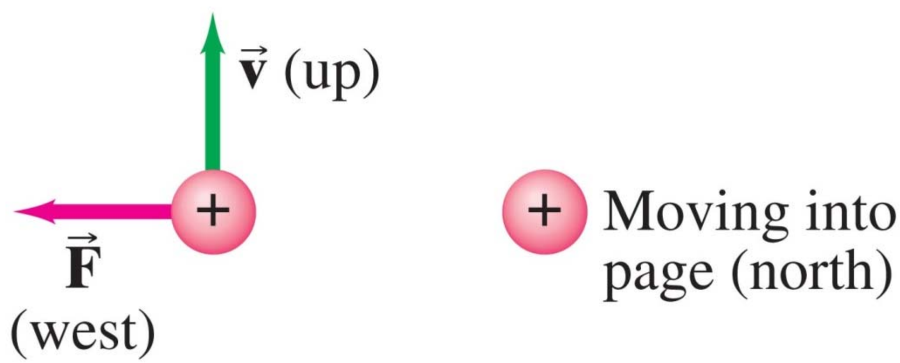
Example 27-5: Magnetic force on a proton.

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.)

Direction of B?

Angle θ ?

$B = F/qv = 0.1T$



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

Example 27-6: Magnetic force on ions during a nerve pulse.

Estimate the magnetic force due to the Earth's magnetic field on ions crossing a cell membrane during an action potential. Assume the speed of the ions is 10^{-2} m/s. **$B \sim 0.5$ G $\sim 10^{-4}$ T**

$F \sim qvB \sim 10^{-19}\,\text{C}\ 10^{-2}\ \text{m/s} \times 10^{-4}\,\text{T} = 10^{-25}\,\text{N}$

HAND IN HW. Recall by first Sketch, set up equations, solve algebraically then plug in numbers. All answers in Scientific notation.

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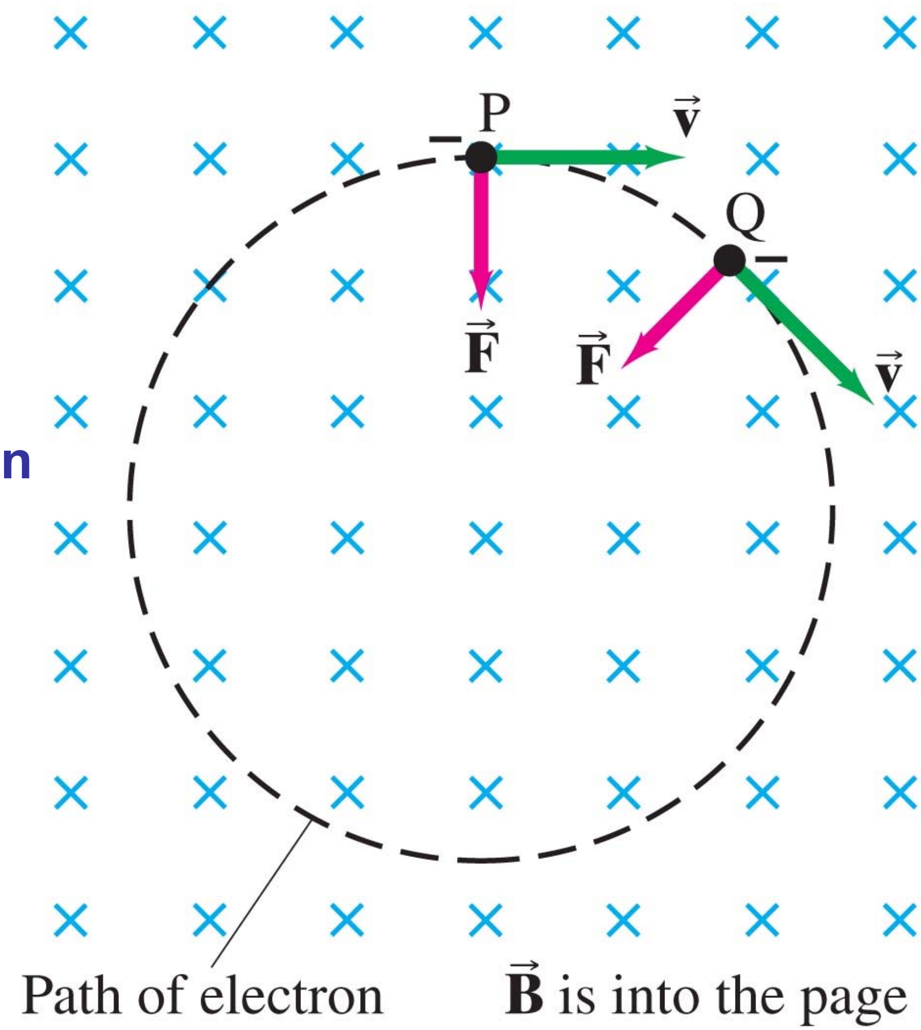
89: 27- 13
90: 27- 14
91: 27- 16

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. NOTE Perpendicular!!!

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.
Ie radius of path, period and Frequency of orbit

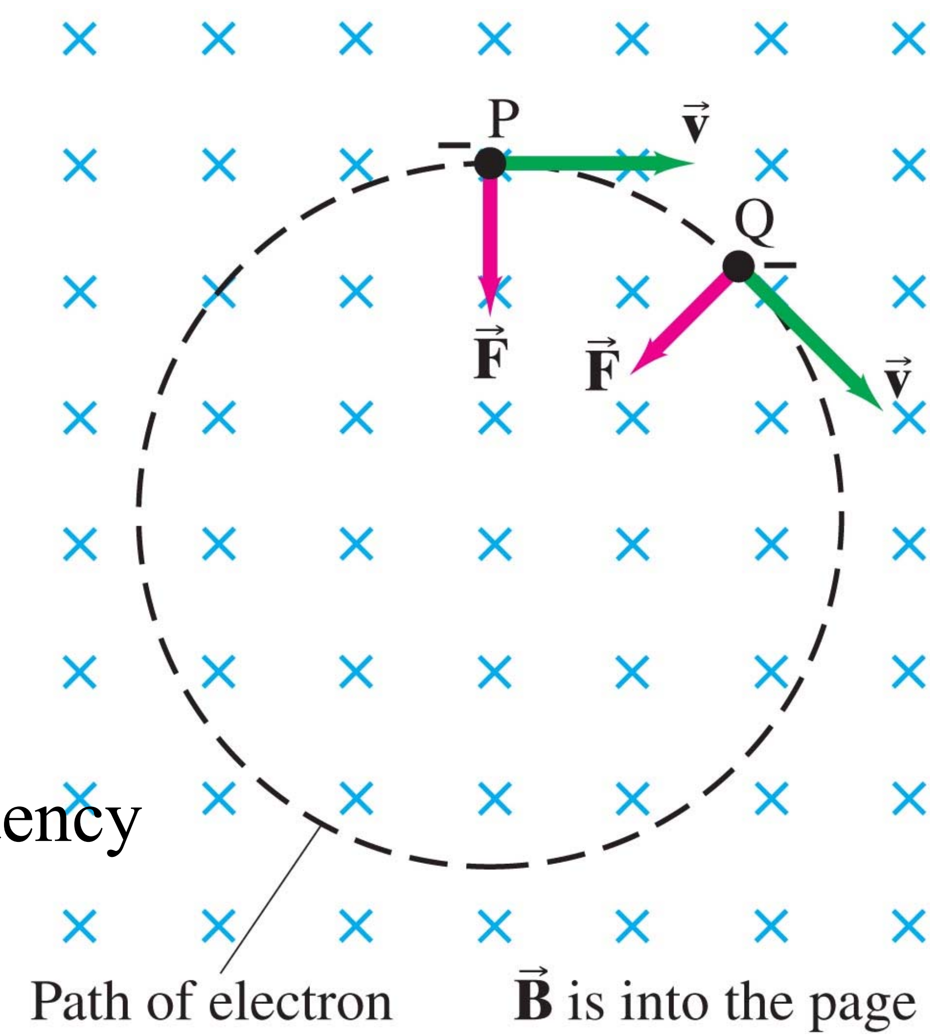


CLASS?

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

Given:v=2.0 x 107 m/s B=0.010T

radius of path, period and frequency of orbit ?



$\Sigma F=ma$-> so $qvB=mv^2/r$

$r=mv/qB$ (v, B, & r constant!)

$T=2\pi r/v=2\pi r/qBr/m=$
$2\pi m/qB$

$f=qB/2\pi m$ -> Cyclotron frequency

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

Conceptual Example 27-8: Stopping charged particles.

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

CLASS

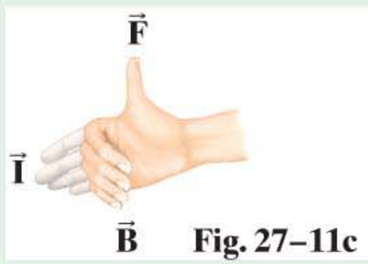
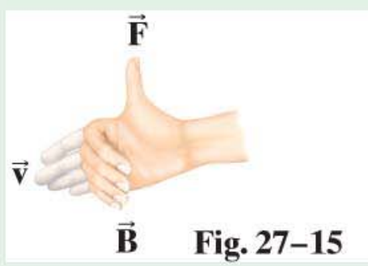
27-4 Force on an Electric Charge Moving in a Magnetic Field

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.

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

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 $\vec{\mathbf{F}}$

HAND IN HW. Recall by first Sketch, set up equations, solve algebraically then plug in numbers. All answers in Scientific notation.

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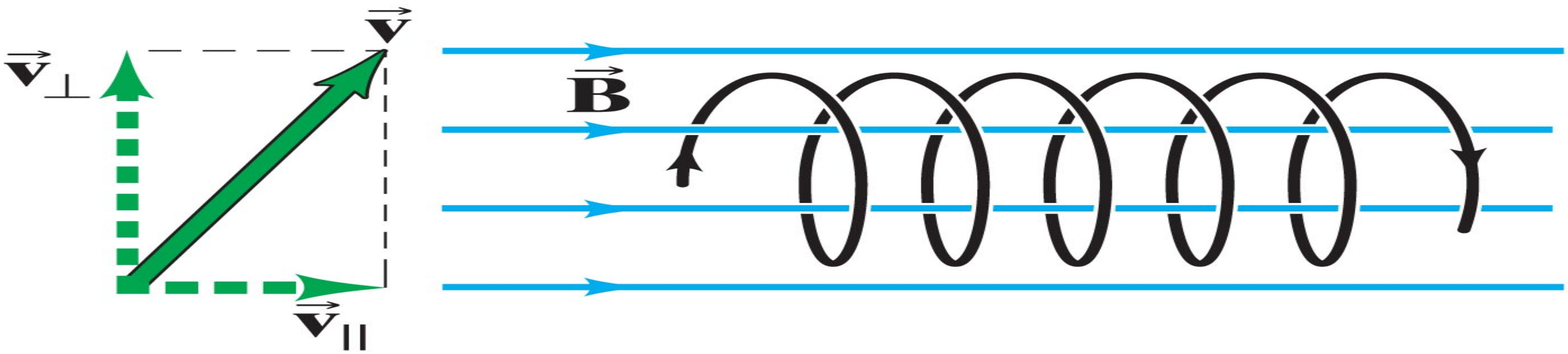
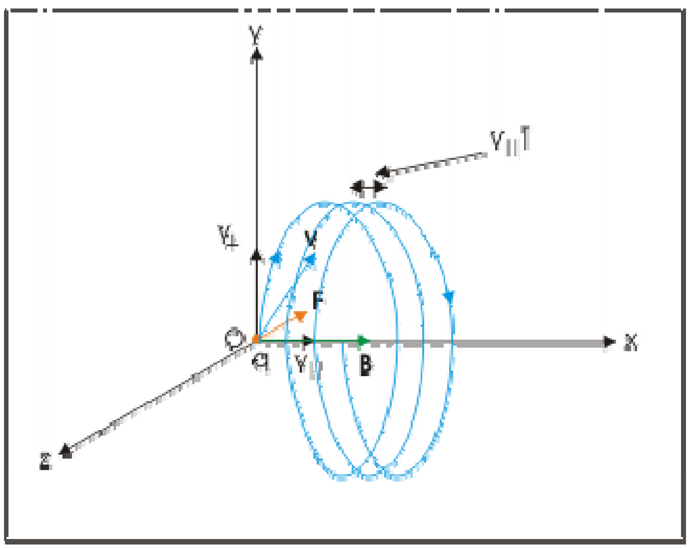
92: 27 - 15
93: 27 - 18
94: 27- 19
95: 27- 22

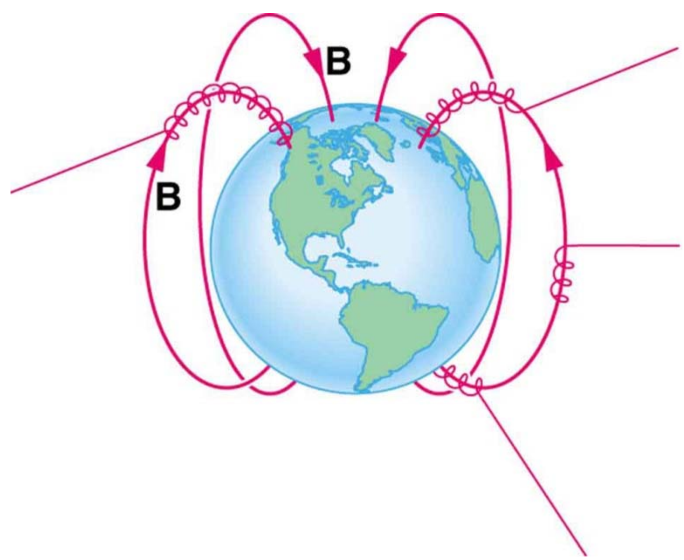
27-4 Force on an Electric Charge Moving in a Magnetic Field

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?

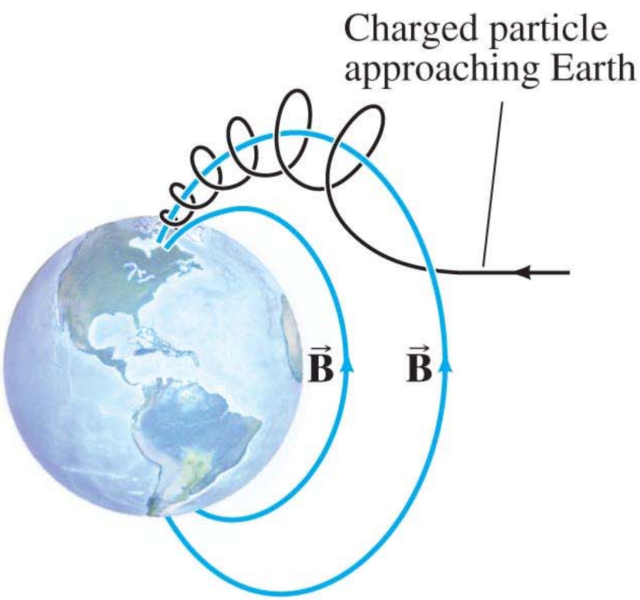






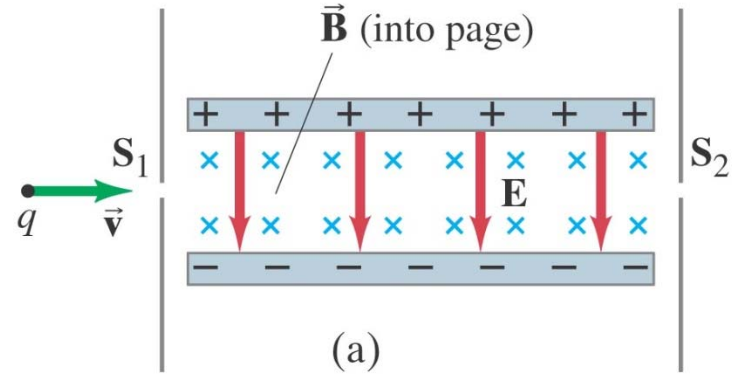
27-4 Force on an Electric Charge Moving in a Magnetic Field

The aurora borealis (northern lights) is caused by charged particles from the solar wind spiraling along the Earth's magnetic field, and colliding with air molecules.

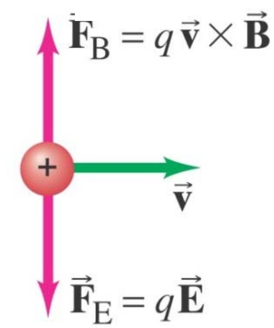


27-4 Force on an Electric Charge Moving in a Magnetic Field

Conceptual Example 27-10: Velocity selector, or filter: crossed $\vec{E}$ and $\vec{B}$ fields.



Some electronic devices and experiments need a beam of charged particles all moving at nearly the same velocity. This can be achieved using both a uniform electric field and a uniform magnetic field, arranged so they are at right angles to each other. Particles of charge q pass through slit S_1 and enter the region where $\vec{B}$ points into the page and $\vec{E}$ points down from the positive plate toward the negative plate. If the particles enter with different velocities, show how this device "selects" a particular velocity, and determine what this velocity is.



CLASS?

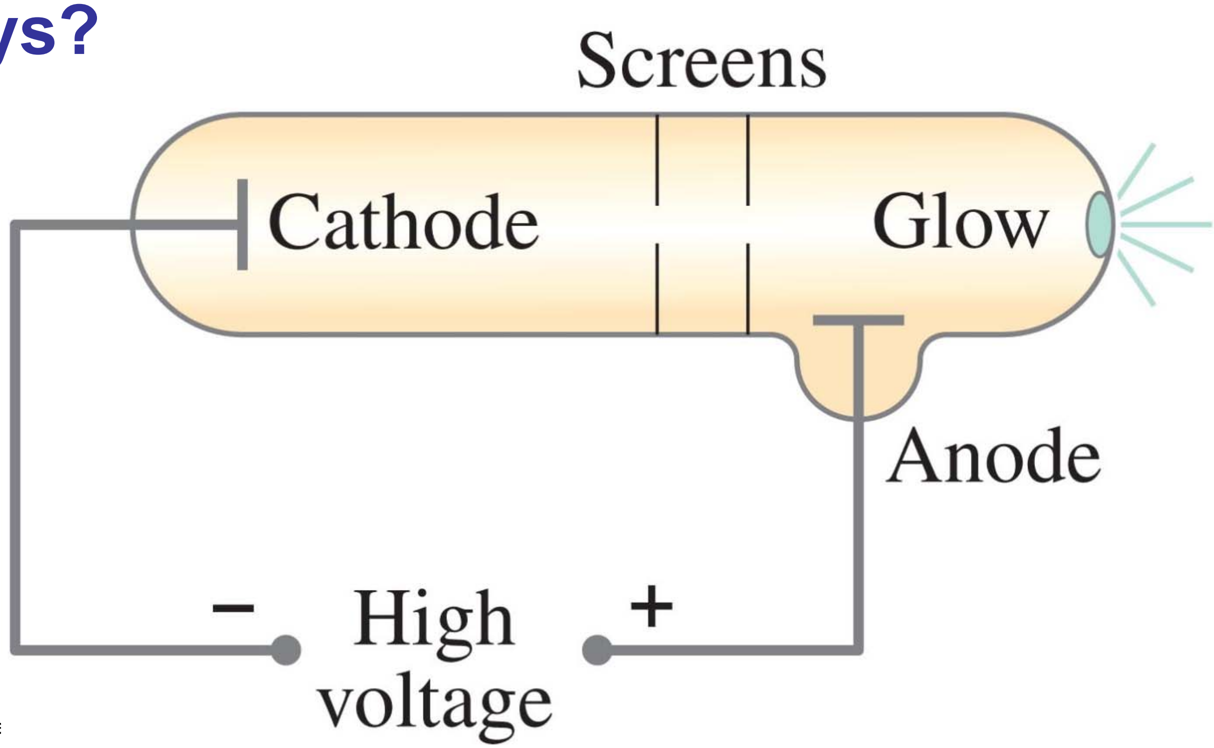
$\Sigma F=0$

$qvB=qE$ get thru!

Only! $v=E/B$!

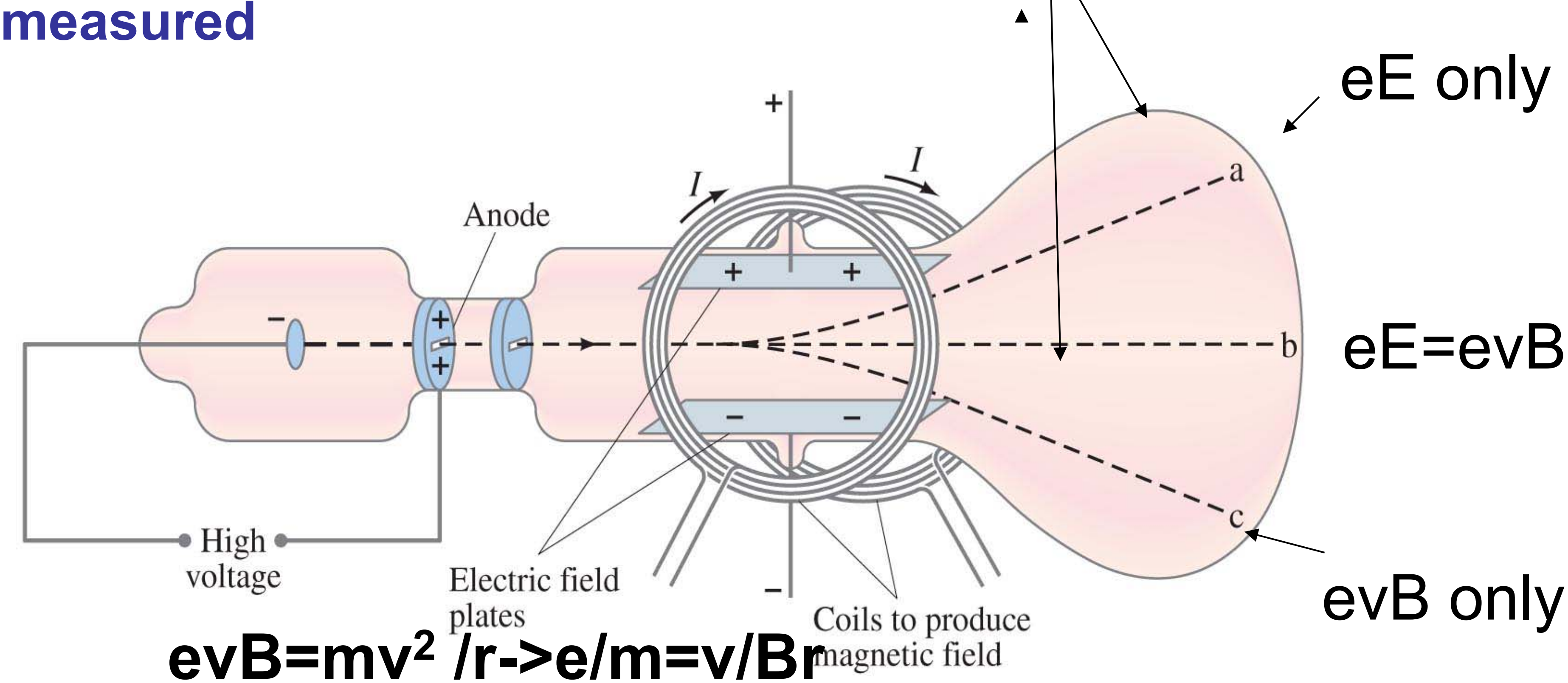
27-7 Discovery and Properties of the Electron

Electrons were first observed in cathode ray tubes. These tubes had a very small amount of gas inside, and when a high voltage was applied to the cathode, some "cathode rays" appeared to travel from the cathode to the anode. What are these mysterious rays?



27-7 Discovery and Properties of the Electron

The value of *e/m* for the cathode rays was measured in 1897 using the apparatus below; it was then that the rays began to be called electrons(negative!). Circular arcs r can be measured

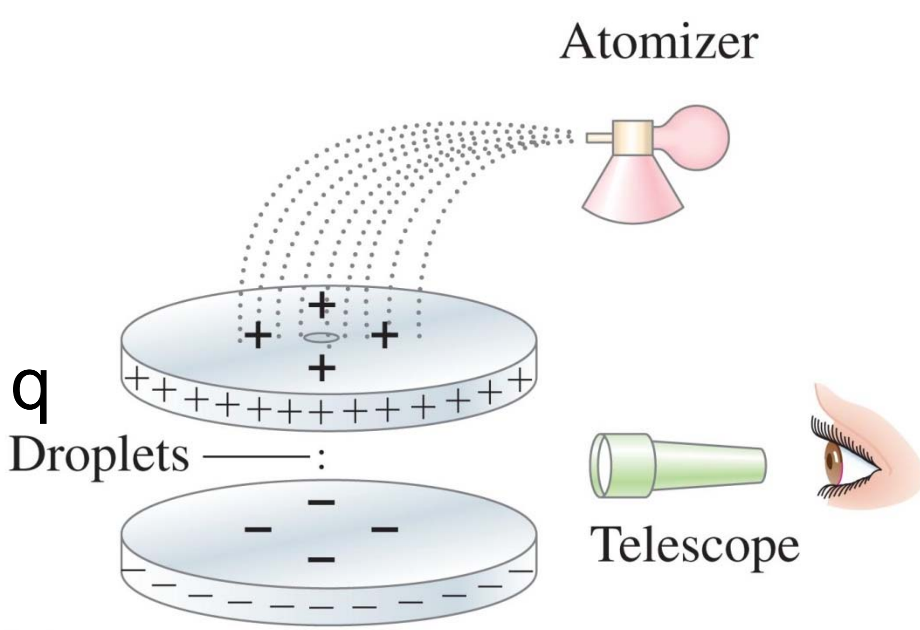


$evB=mv^2/r \rightarrow e/m=v/Br$

Find v? with point b $v=E/B$ so $e/m=E/B^2r$

27-7 Discovery and Properties of the Electron

Millikan measured the electron charge directly shortly thereafter, using the oil-drop apparatus diagrammed below, and showed that the electron was a constituent of the atom (and not an atom itself, as its mass is far too small).



qE=mg balance drops
q=mg/E m is found by
A different technique

Experiment yields
Q=Ne!

The currently accepted values of the electron mass and charge are

$$m = 9.1 \times 10^{-31}\ \text{kg}$$

$$e = 1.6 \times 10^{-19}\ \text{C}$$

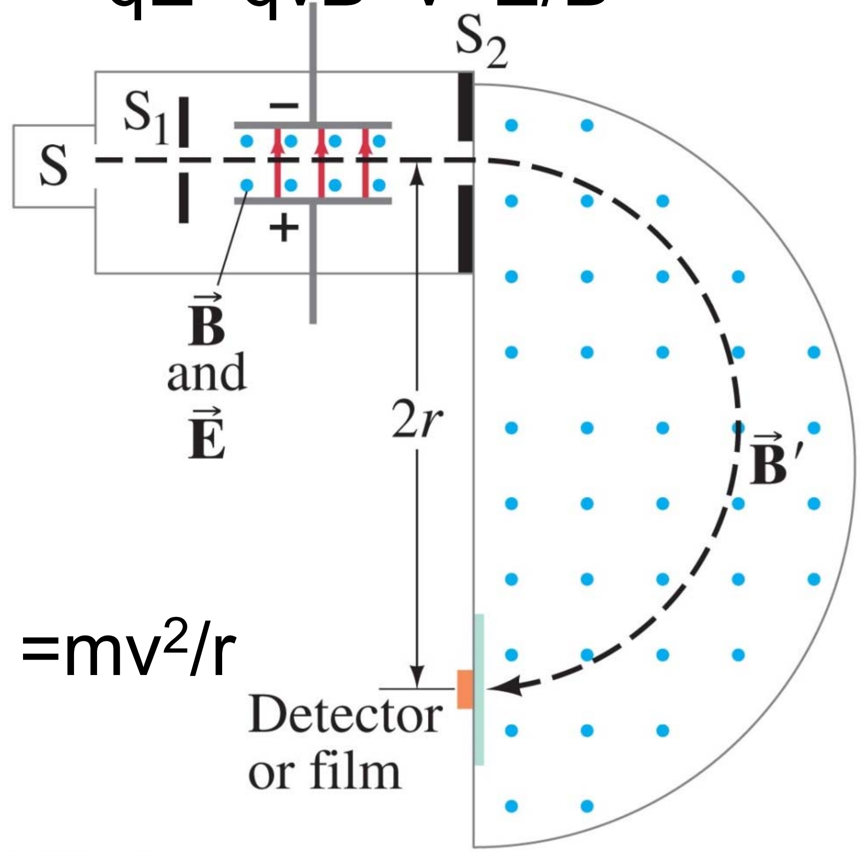
27-9 Mass Spectrometer

Vel. select

$qE = qvB \quad v = E/B$

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:

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



$qvB' = mv^2/r$

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

If all fields are known we measure r and get m two or more r's from sample S =isotopes

27-9 Mass Spectrometer

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.

CLASS?

$m_x / m_C = r_x / r_C = 1.17 \quad m_x = 1.17 m_C = 14.0 u$

$^{14}C_6$ or $^{14}N_7$

HAND IN HW. Recall by first Sketch, set up equations, solve algebraically then plug in numbers. All answers in Scientific notation.

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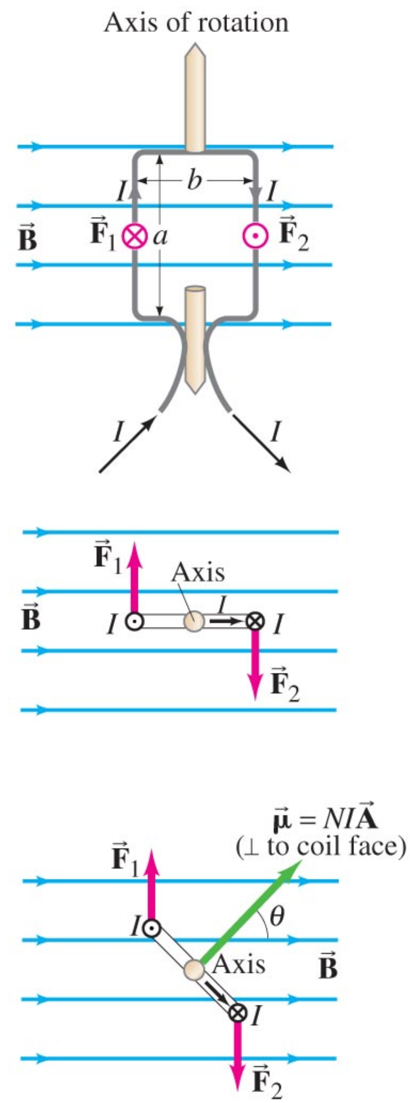
96: 27-20
97: 27- 22
98: 27-25

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:

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

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

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

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

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.

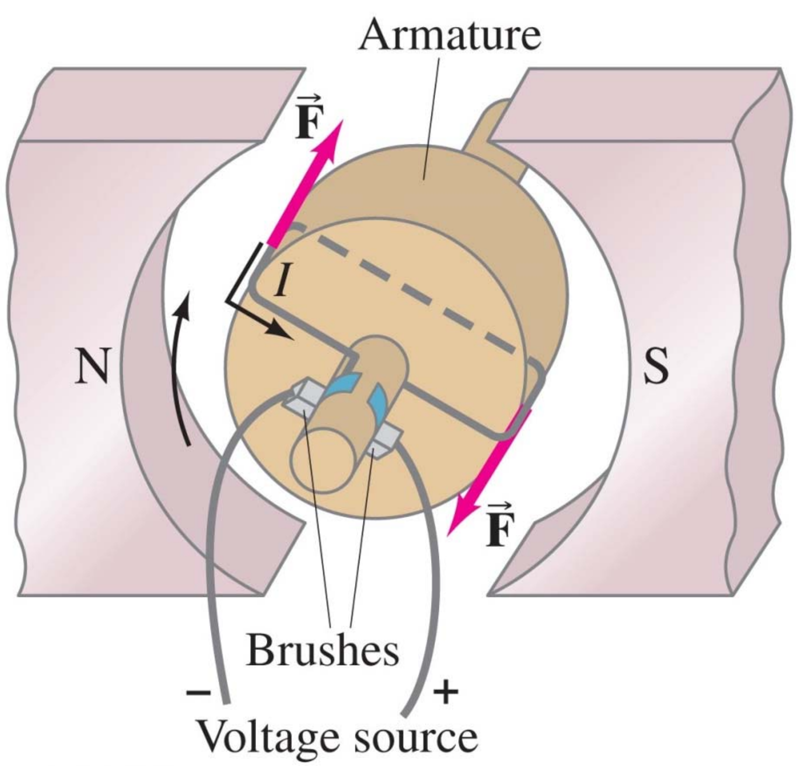
27-5 Torque on a Current Loop; Magnetic Dipole Moment

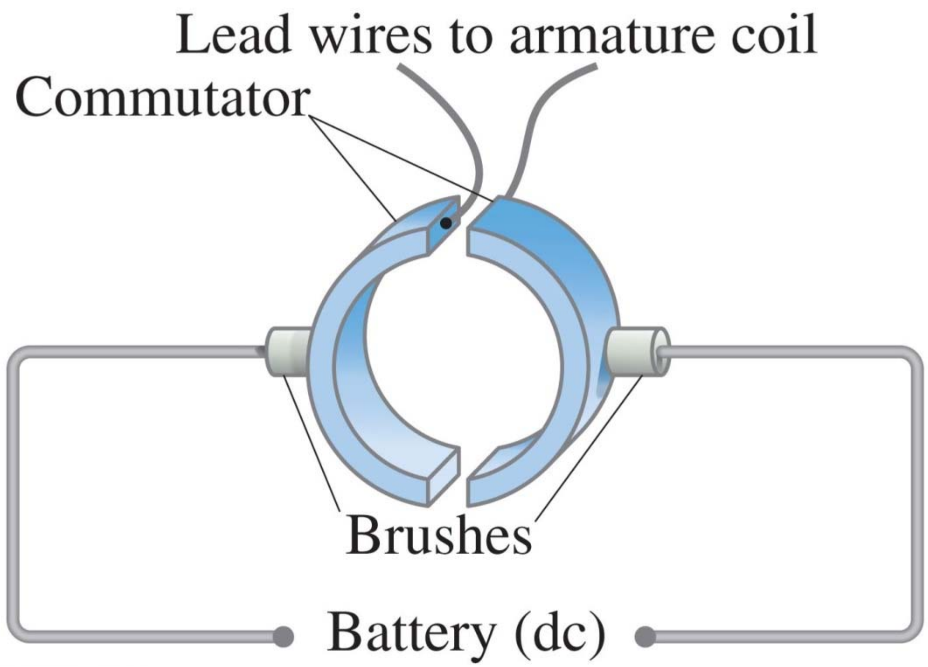
Example 27-12: Magnetic moment of a hydrogen atom.

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.]

27-6 Applications: Motors, Loudspeakers, Galvanometers

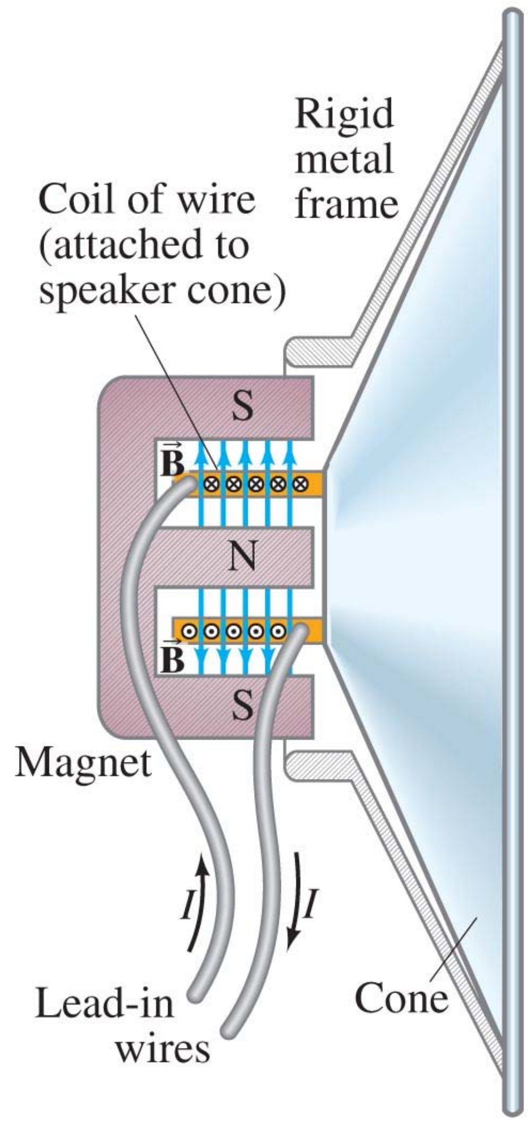
An electric motor uses the torque on a current loop in a magnetic field to turn magnetic energy into kinetic energy.





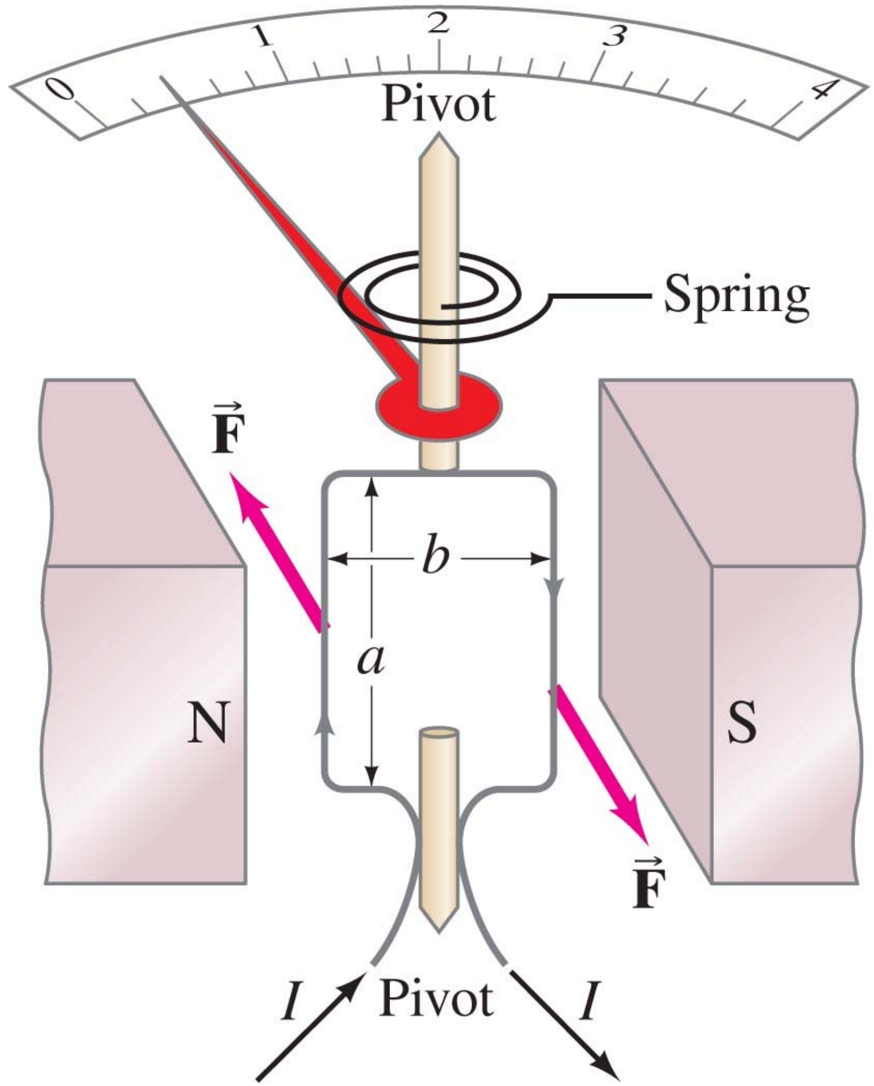
27-6 Applications: Motors, Loudspeakers, Galvanometers

Loudspeakers use the principle that a magnet exerts a force on a current-carrying wire to convert electrical signals into mechanical vibrations, producing sound.



27-6 Applications: Motors, Loudspeakers, Galvanometers

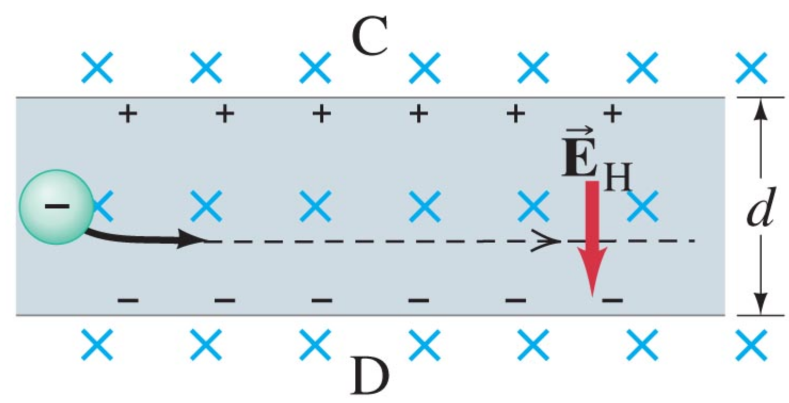
A galvanometer takes advantage of the torque on a current loop to measure current; the spring constant is calibrated so the scale reads in amperes.



SKIP WHAT FOLLOWS SPR 16

27-8 The Hall Effect->Hall Probe to measure magnetic fields

When a current-carrying wire is placed in a magnetic field, there is a sideways force on the electrons in the wire. This tends to push them to one side and results in a potential difference from one side of the wire to the other; this is called the Hall effect. The emf differs in sign depending on the sign of the charge carriers; this is how it was first determined that the charge carriers in ordinary conductors are negatively charged.



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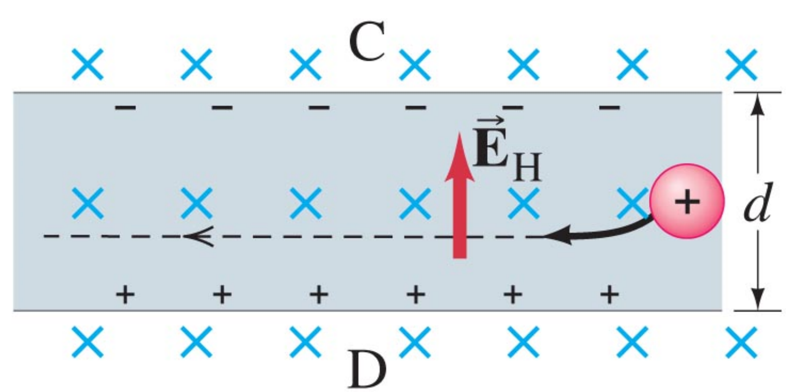

$$\Sigma F = 0 \rightarrow \; eE_H = ev_d B$$

$$EMF(V) = E_H d = v_d B d$$

27-8 The Hall Effect

Example 27-13: Drift velocity using the Hall effect.

A long copper strip 1.8 cm wide and 1.0 mm thick is placed in a 1.2-T magnetic field. When a steady current of 15 A passes through it, the Hall emf is measured to be 1.02 μV. Determine the drift velocity of the electrons and the density of free (conducting) electrons (number per unit volume) in the copper.