Chp 27: Magnetic Field and Magnetic Forces - I

Goals for Chapter 27

- To study magnets and the forces they exert on each other
- To calculate the force that a magnetic field exerts on a
- moving charge
- To contrast magnetic field lines with electric field lines
- To analyze the motion of a charged particle in a magnetic field
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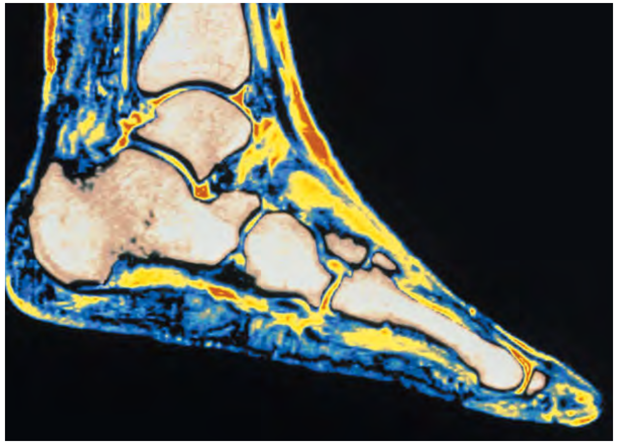
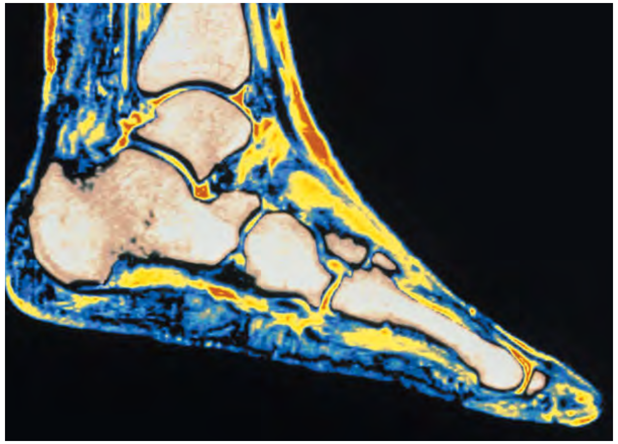
- To see applications of magnetism in physics and chemistry
-
- To analyze magnetic forces on current-carrying conductors
- To study the behavior of current loops in a magnetic field

Magnetism



Magnetic phenomena were first observed at least 2500 years ago in fragments of magnetized iron ore found near the ancient city of Magnesia (now Manisa, in west- ern Turkey). These fragments were examples of what are now called **permanent magnets;**

Magnetism



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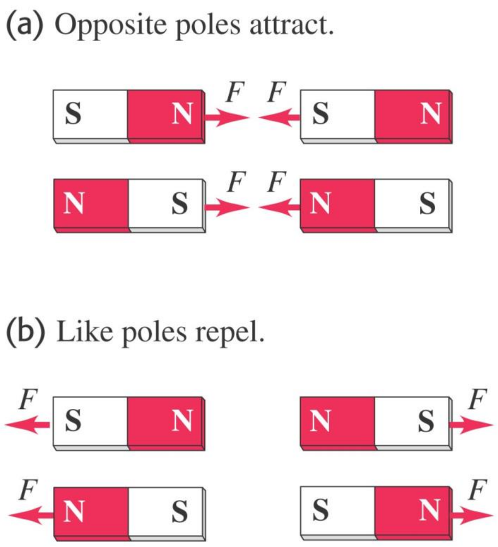
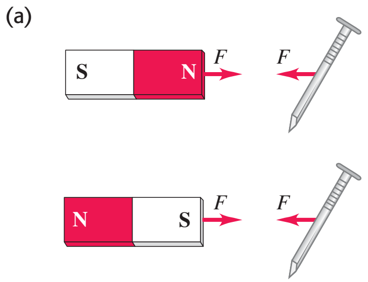
- How does magnetic resonance imaging (MRI) allow us to see details in soft nonmagnetic tissue?
- How can magnetic forces, which act only on moving charges, explain the behavior of a compass needle?
- In this chapter, we will look at how magnetic fields affect charges.

Magnetic poles

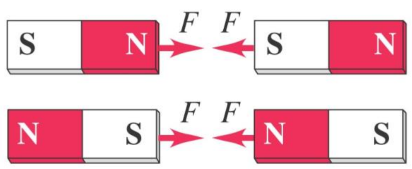




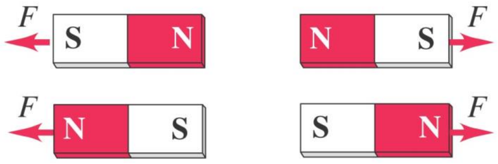
Either pole of a bar magnet attracts an unmagnetized object that contains iron, such as a nail.

Magnetic poles

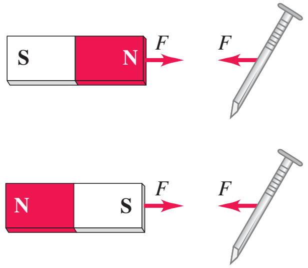
(a) Opposite poles attract.



(b) Like poles repel.



(a)



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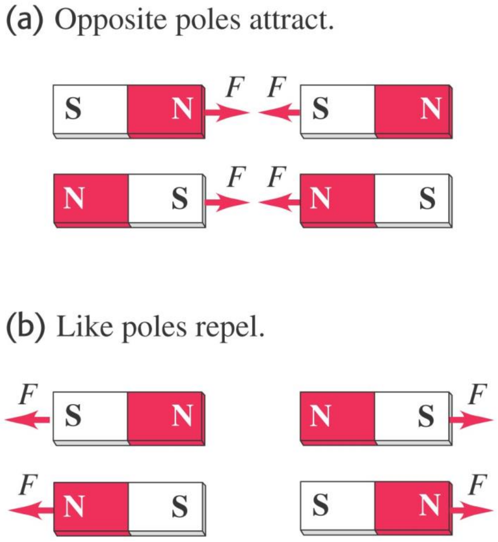

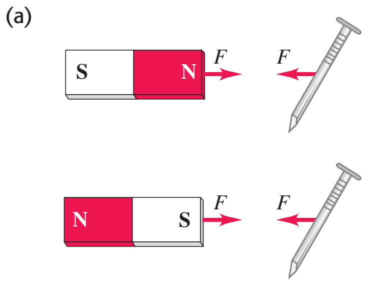

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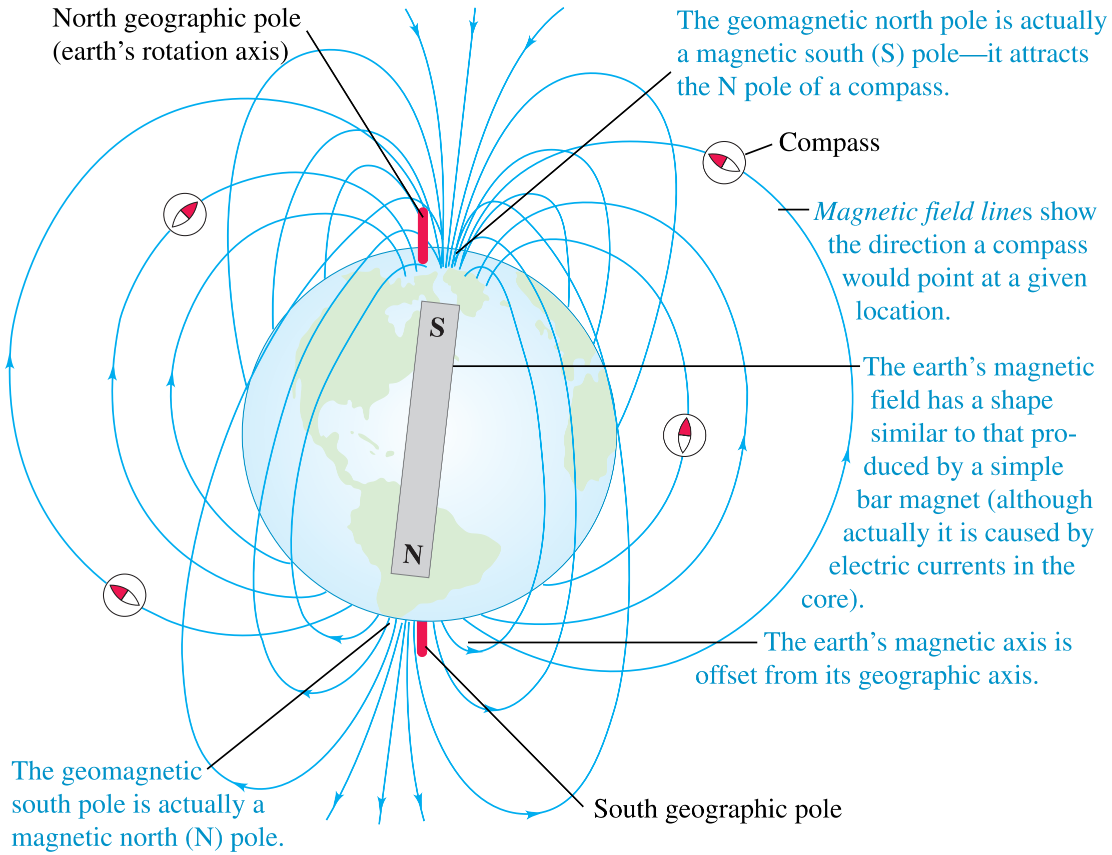

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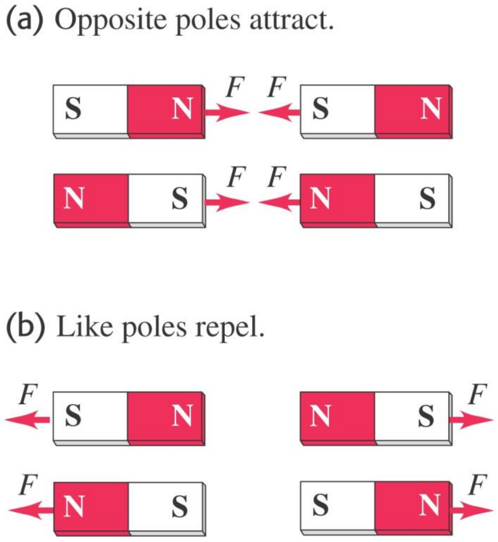

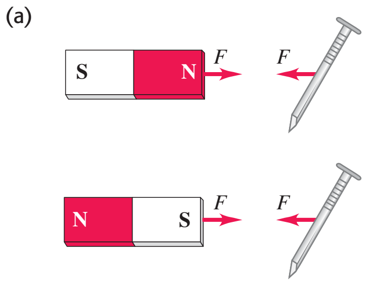

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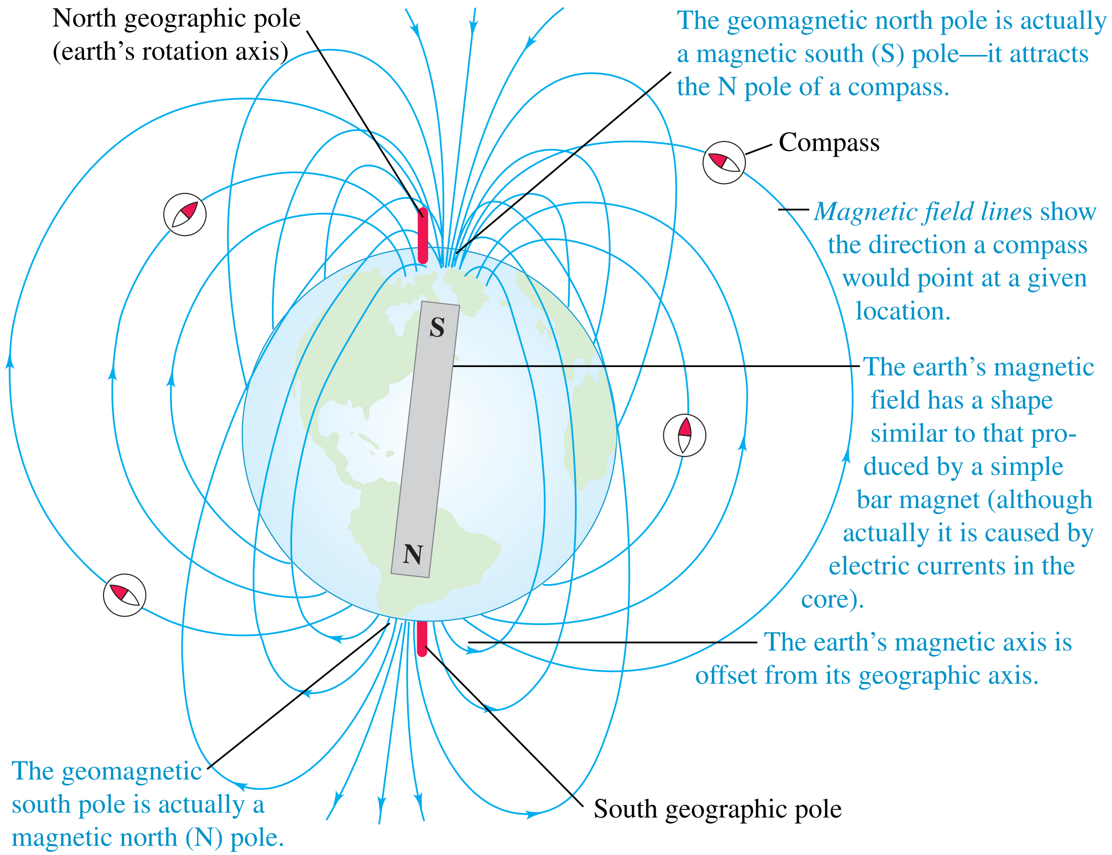
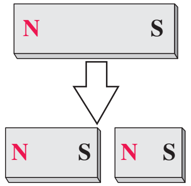


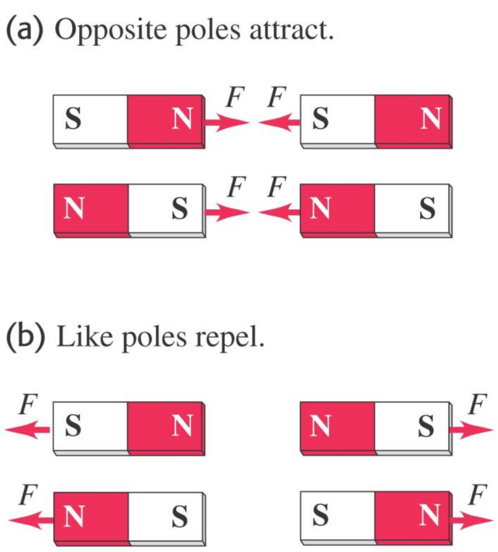
In contrast to electric charges, magnetic pol
always come in pairs and can't be isolated.

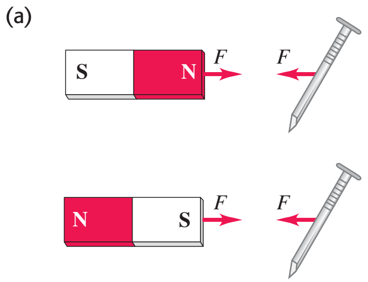
Breaking a magnet in two ...



... yields two magnets,
not two isolated poles.

Magnetic poles





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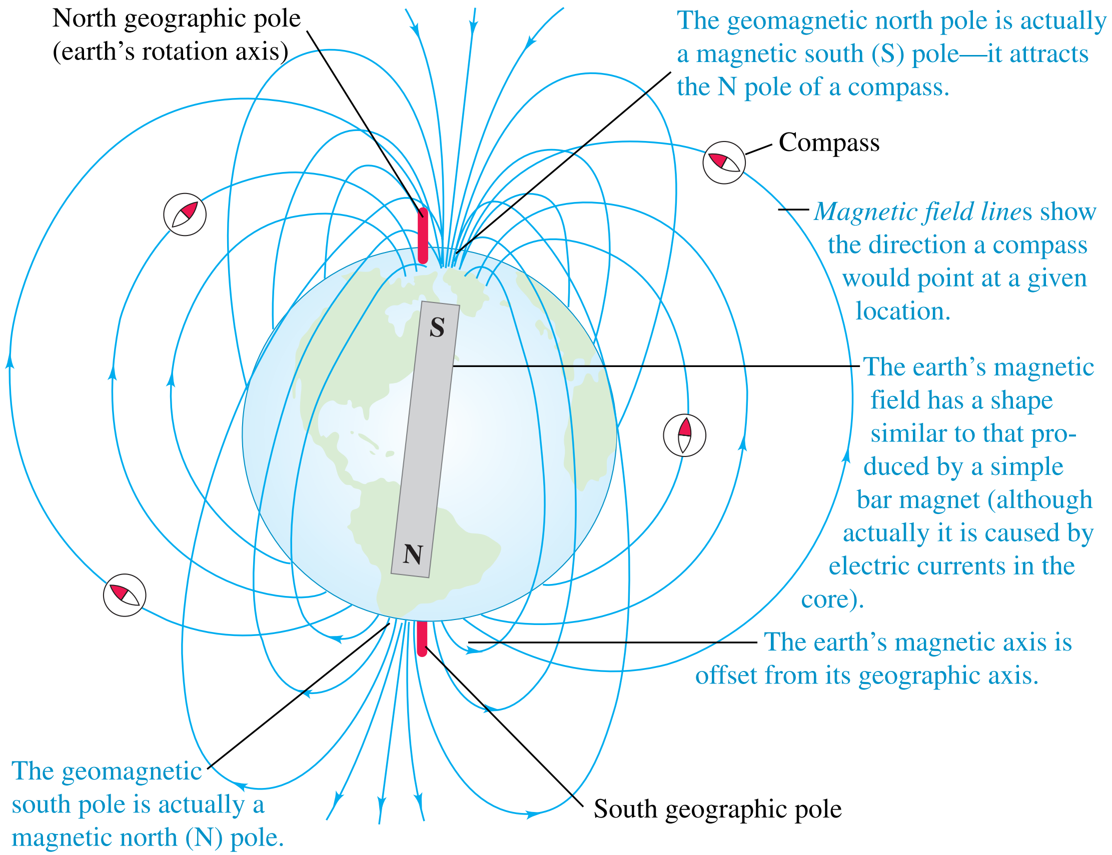
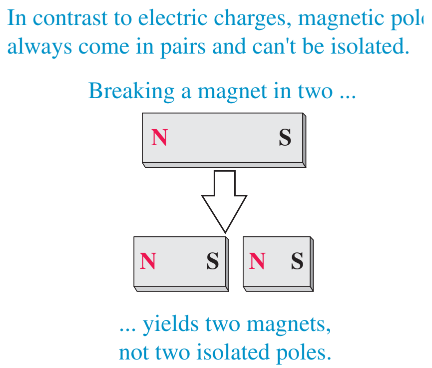




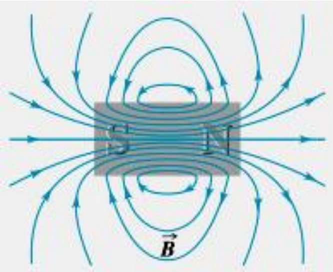
There are no magnetic monopoles

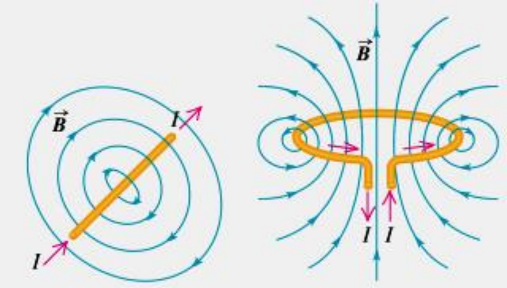
Magnetic Units and Field Line Examples

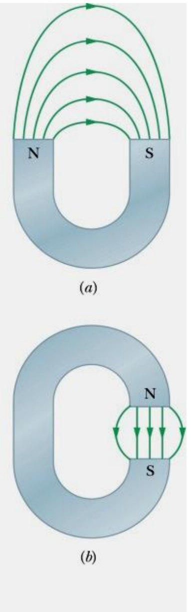
- SI unit of magnetic field: tesla (T)
  - 1T = 1 N/[Cm/s] = 1 N/[Am] = 10^4 gauss

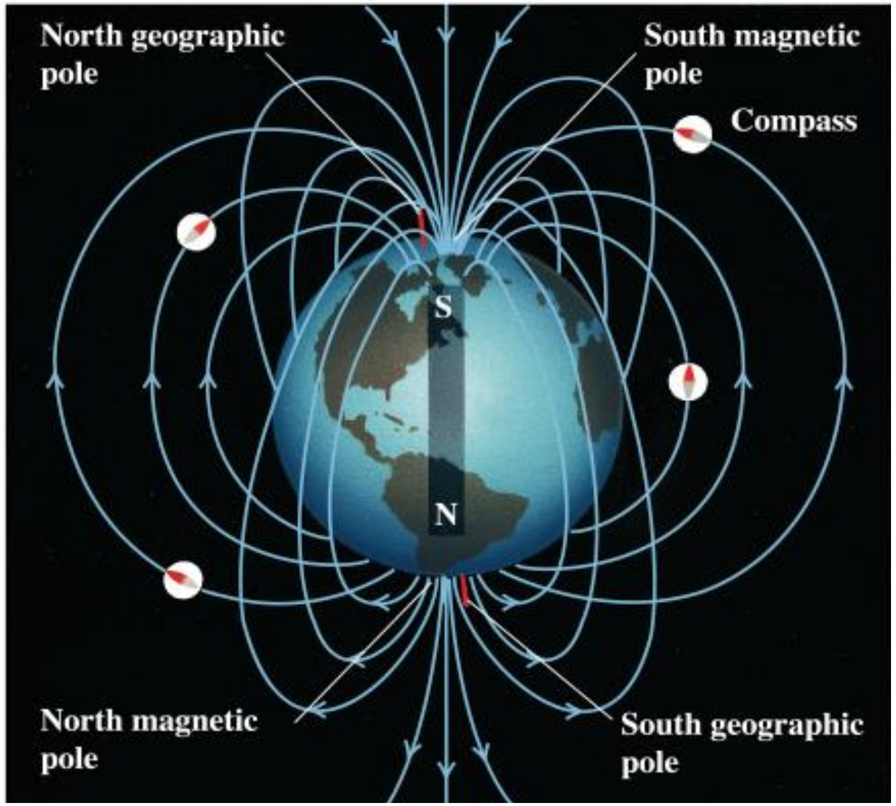
- Magnetic field lines – interpret similarly to <u>E</u>
  - The tangent to a magnetic field line at any point gives the direction of B at that point;
  - The spacing of the lines represents the magnitude of B – the magnetic field is stronger where the lines are closer together, and conversely.

At surface of neutron star	10^8 T
Near big electromagnet	1.5 T
Inside sunspot	10^{-1} T
Near small bar magnet	10^{-2} T
At Earth's surface	10^{-4} T
In interstellar space	10^{-10} T



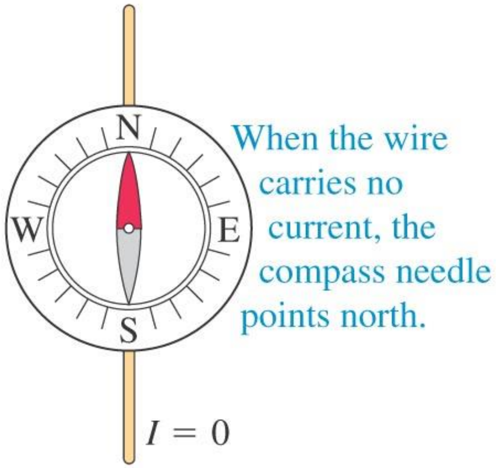






Electric current and magnets

(a)



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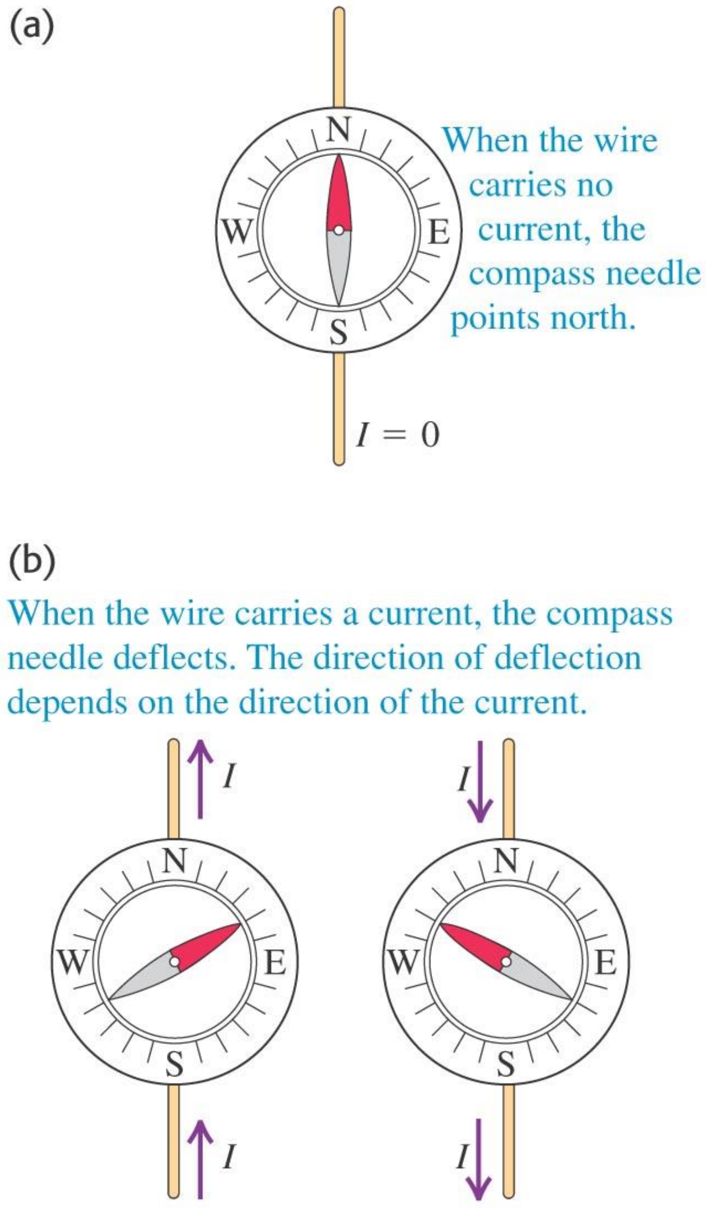

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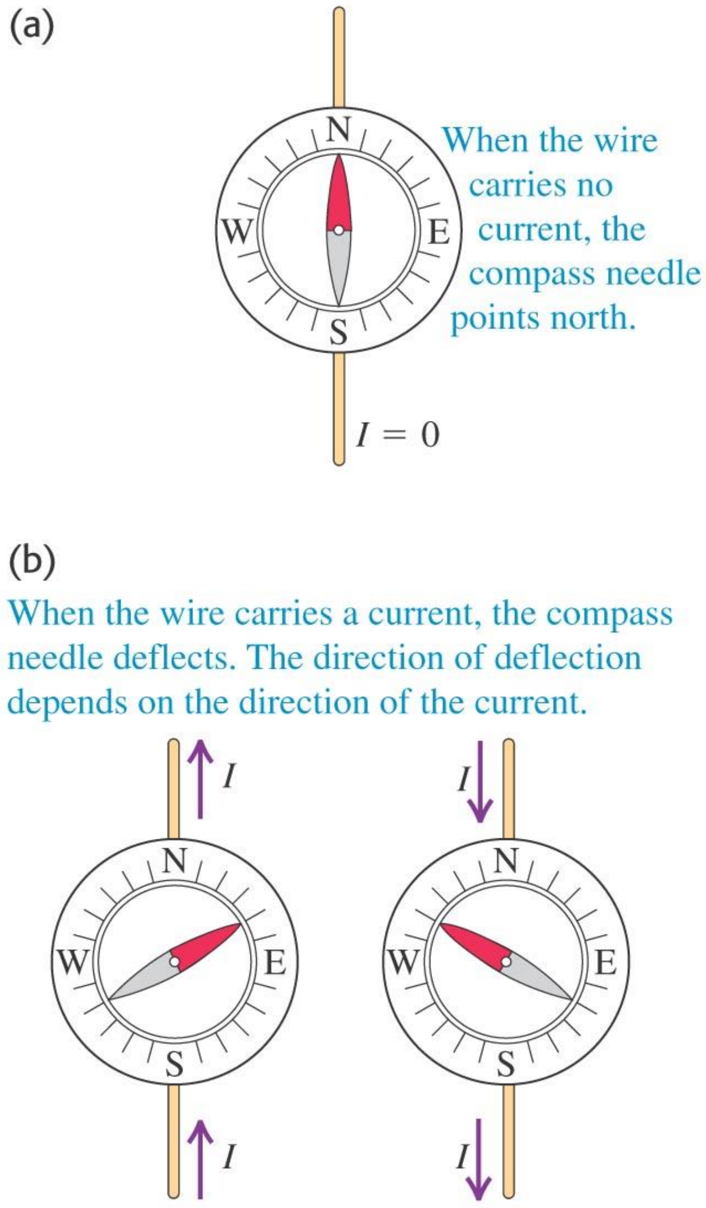


- In 1820, Hans Oersted discovered that a current- carrying wire causes a compass to deflect

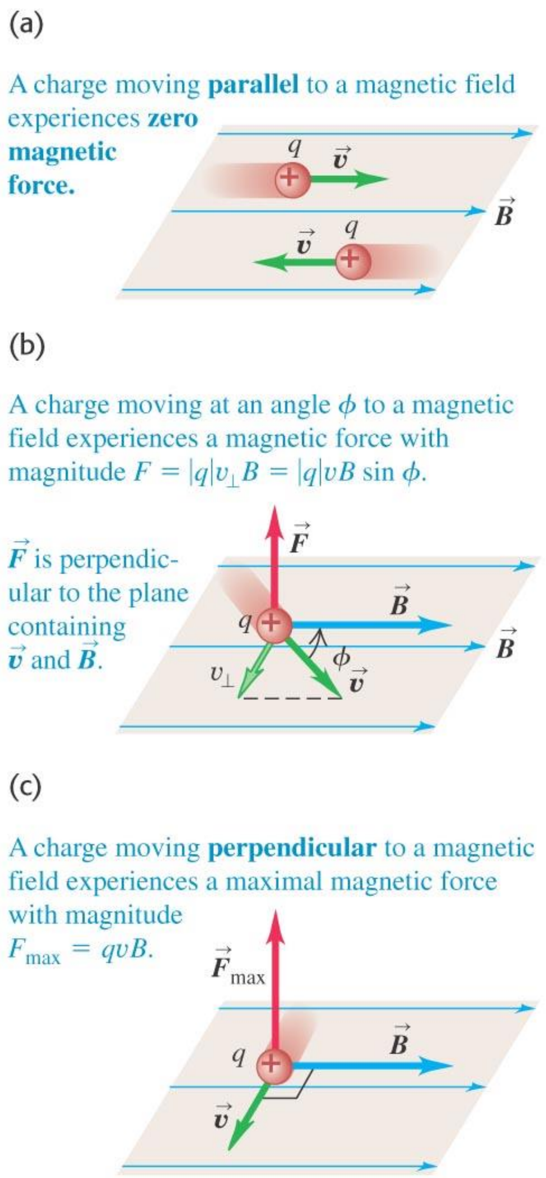
- This discovery revealed a connection between moving charge and magnetism.

The magnetic field

- A moving charge (or current) creates a magnetic field in the surrounding space.

- The magnetic field exerts a force on any other moving charge (or current) that is present in the field.

The magnetic force on a moving charge



- The force exerted by the magnetic field on a moving charge that is present in the field is:

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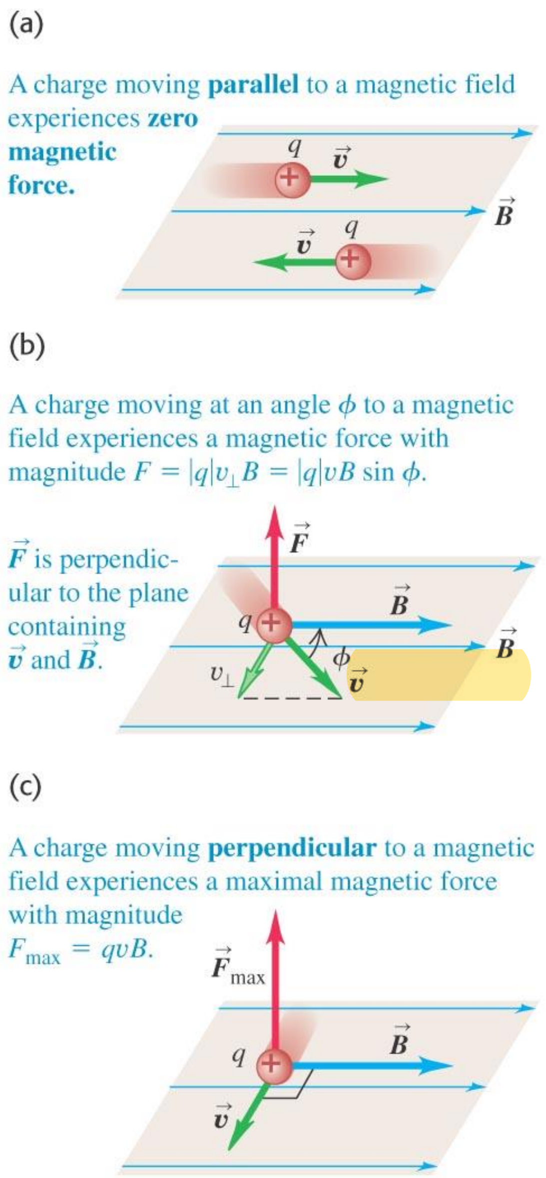

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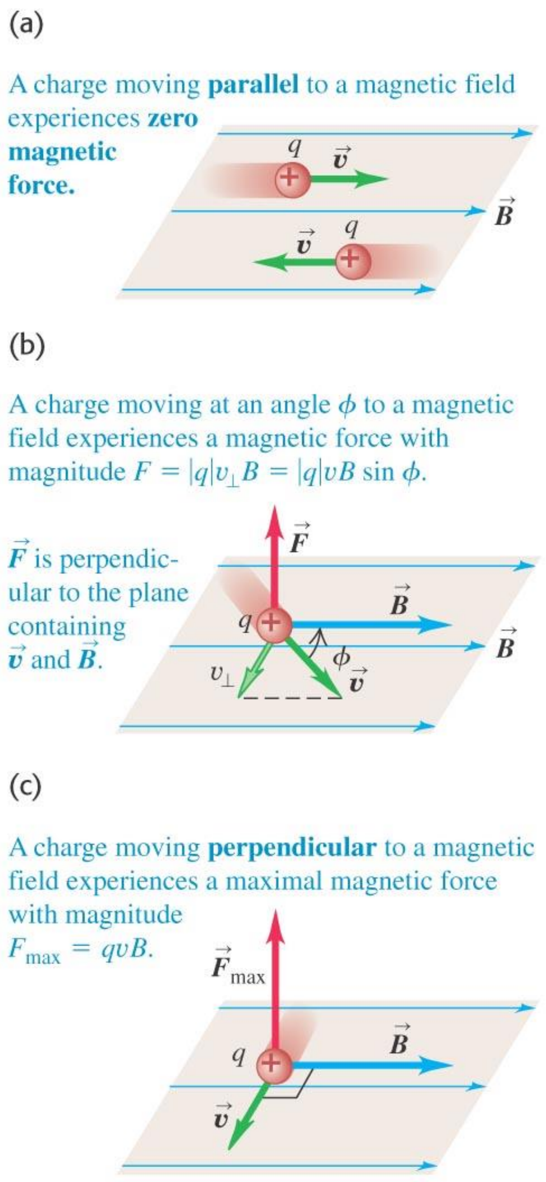

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$$\vec{F} = q\vec{v} \times \vec{B} \qquad \text{(magnetic force on a moving charged particle)}$$

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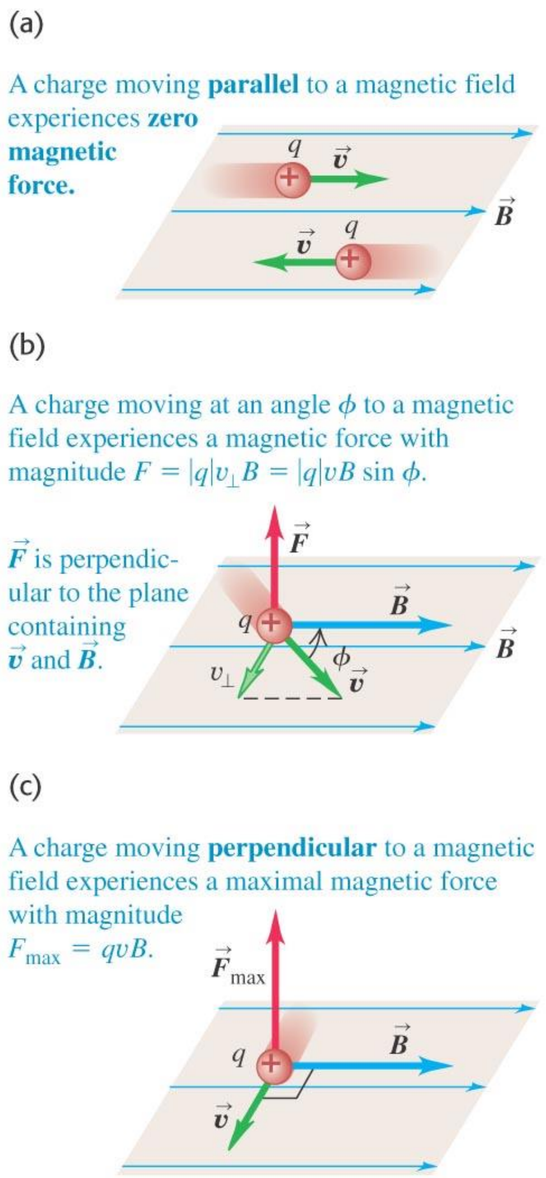

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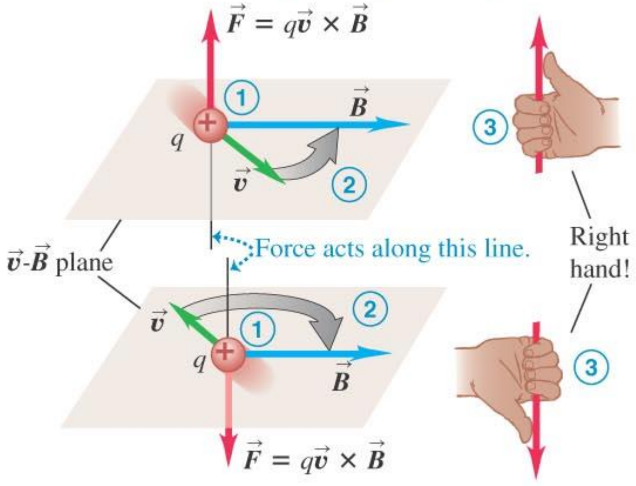

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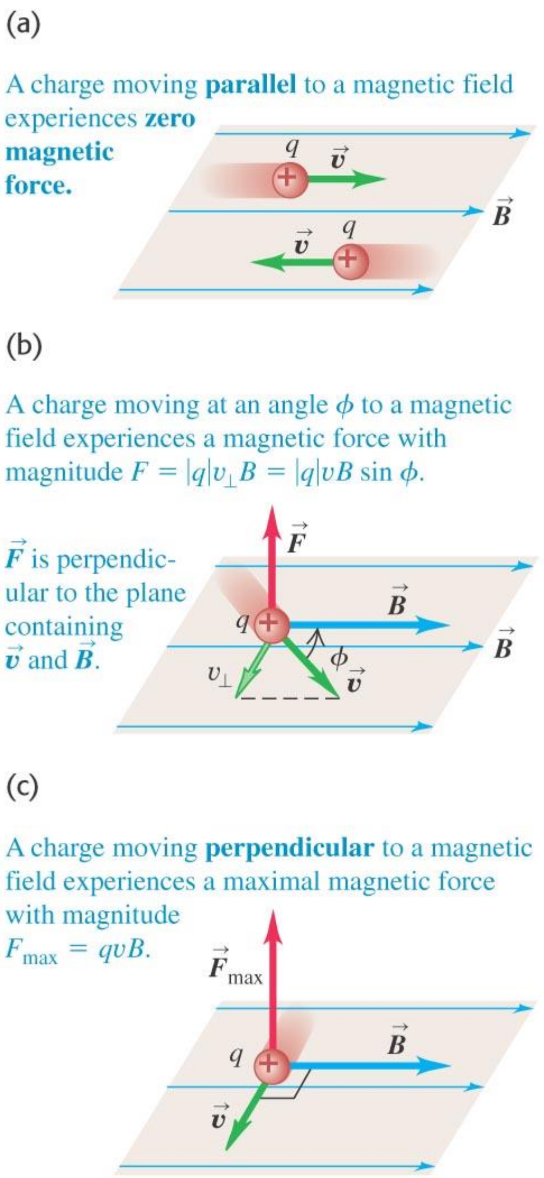

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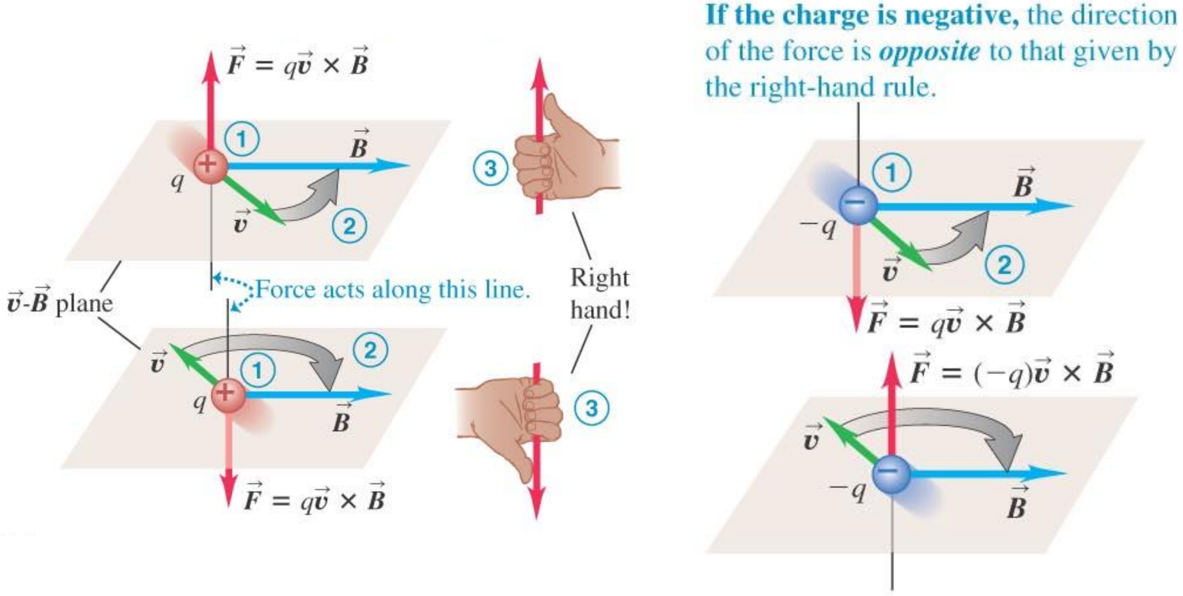
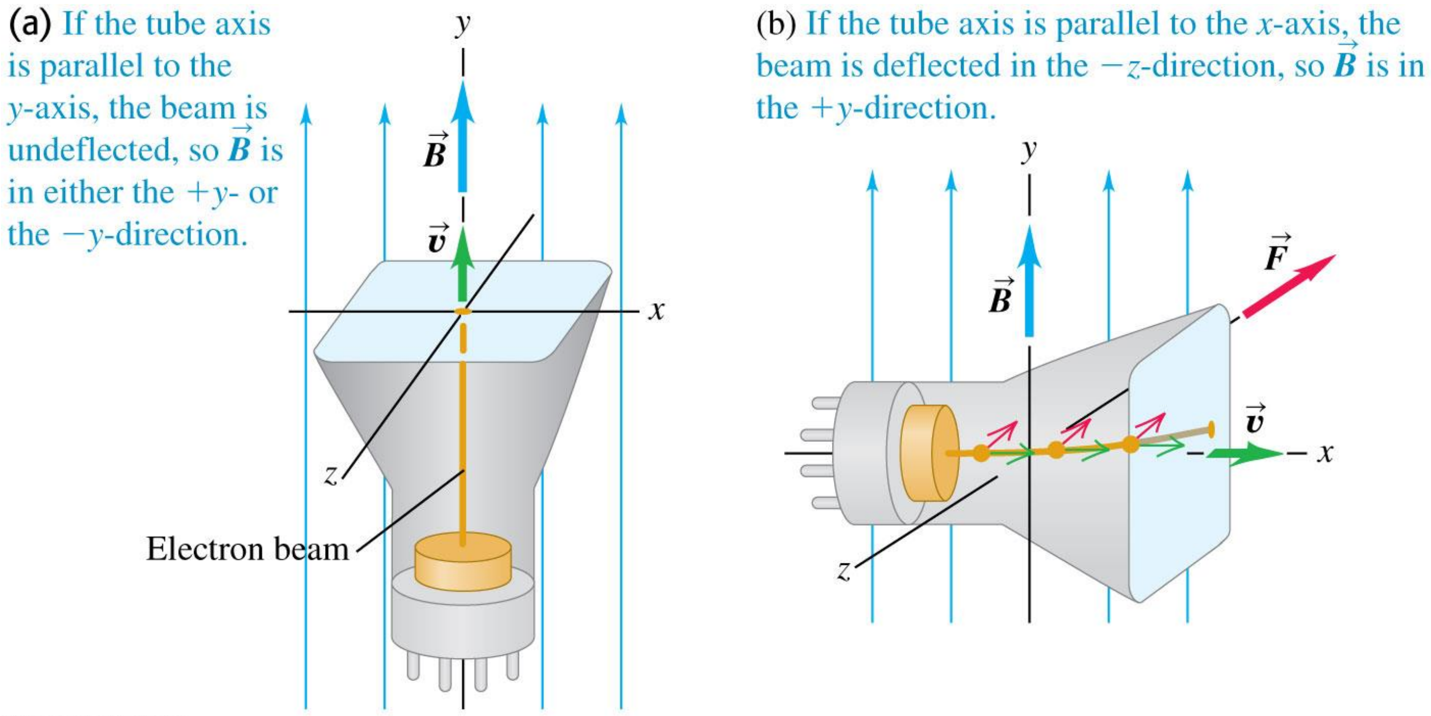


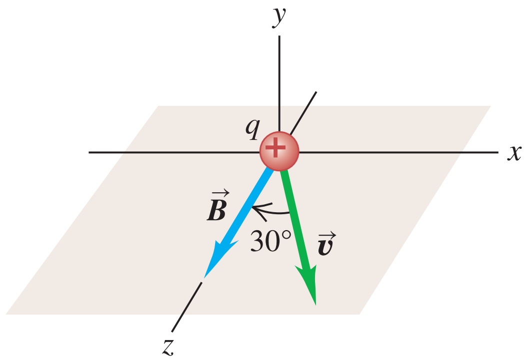
Measuring Magnetic Fields with Test Charges

When a charged particle moves through a region of space where *both* electric and magnetic fields are present, both fields exert forces on the particle. The total force *F* is the vector sum of the electric and magnetic forces:

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



Ex: Magnetic force on a proton



A beam of protons (q = 1.6 x 10^{-19} C) moves at 3.0x10^5 m/s through a uniform 2.0-T magnetic field directed along the positive *z*-axis. The velocity of each proton lies in the *xz*-plane and is directed at 30° to the +*z*-axis. Find the force on a proton.

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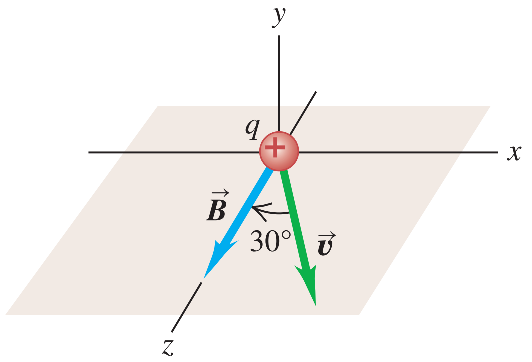

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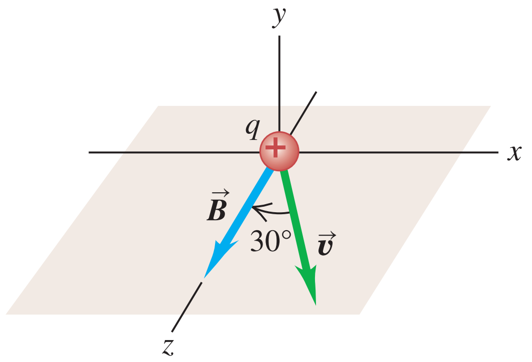

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$$\vec{v} = (3.0 \times 10^5\ \text{m/s})(\sin 30°)\hat{\imath} + (3.0 \times 10^5\ \text{m/s})(\cos 30°)\hat{k}$$
$$\vec{B} = (2.0\ \text{T})\hat{k}$$
$$\vec{F} = q\vec{v} \times \vec{B} = (1.6 \times 10^{-19}\ \text{C})(3.0 \times 10^5\ \text{m/s})(2.0\ \text{T}) \times (\sin 30°\hat{\imath} + \cos 30°\hat{k}) \times \hat{k}$$
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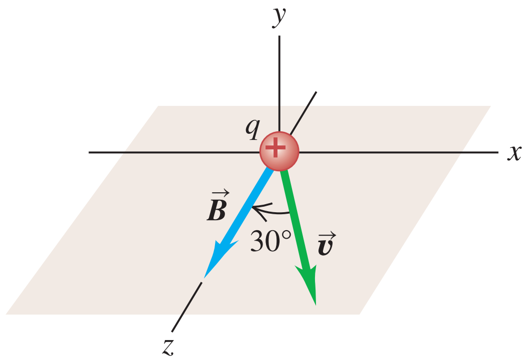

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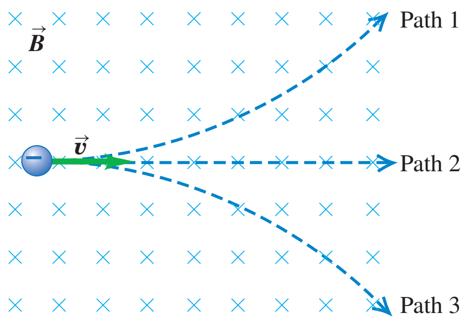

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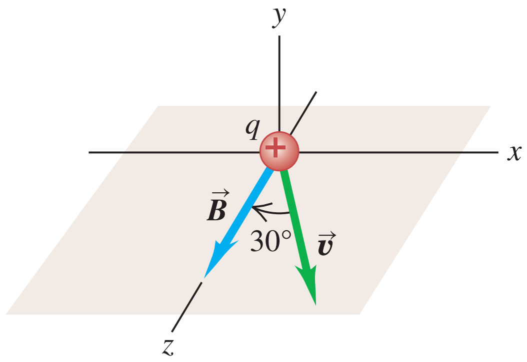

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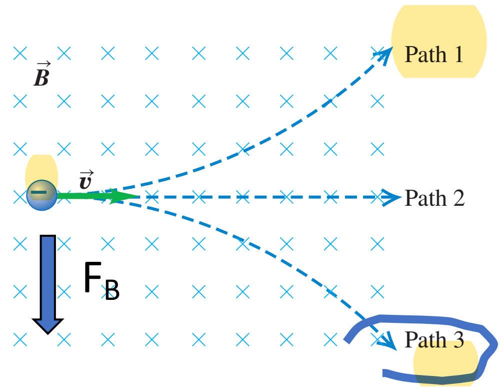

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Magnetic Field Lines and Magnetic Flux

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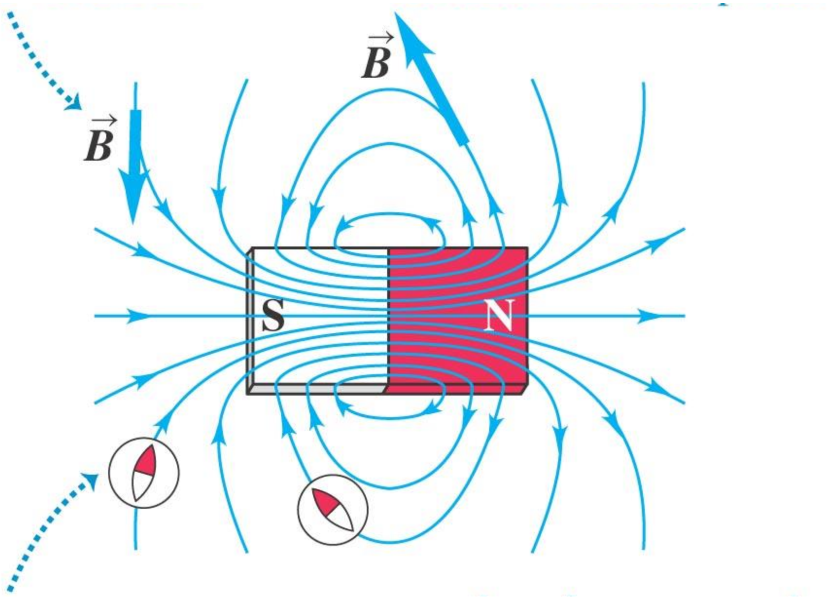

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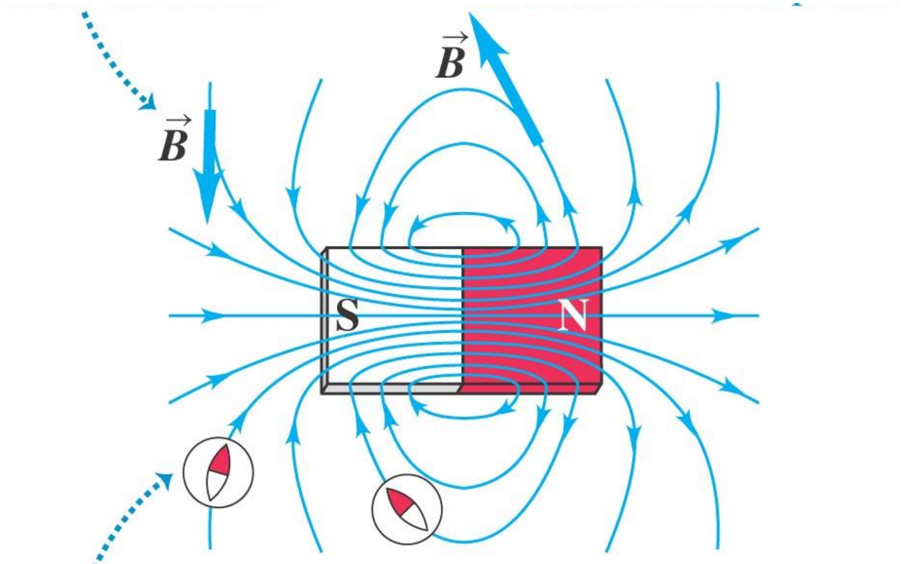
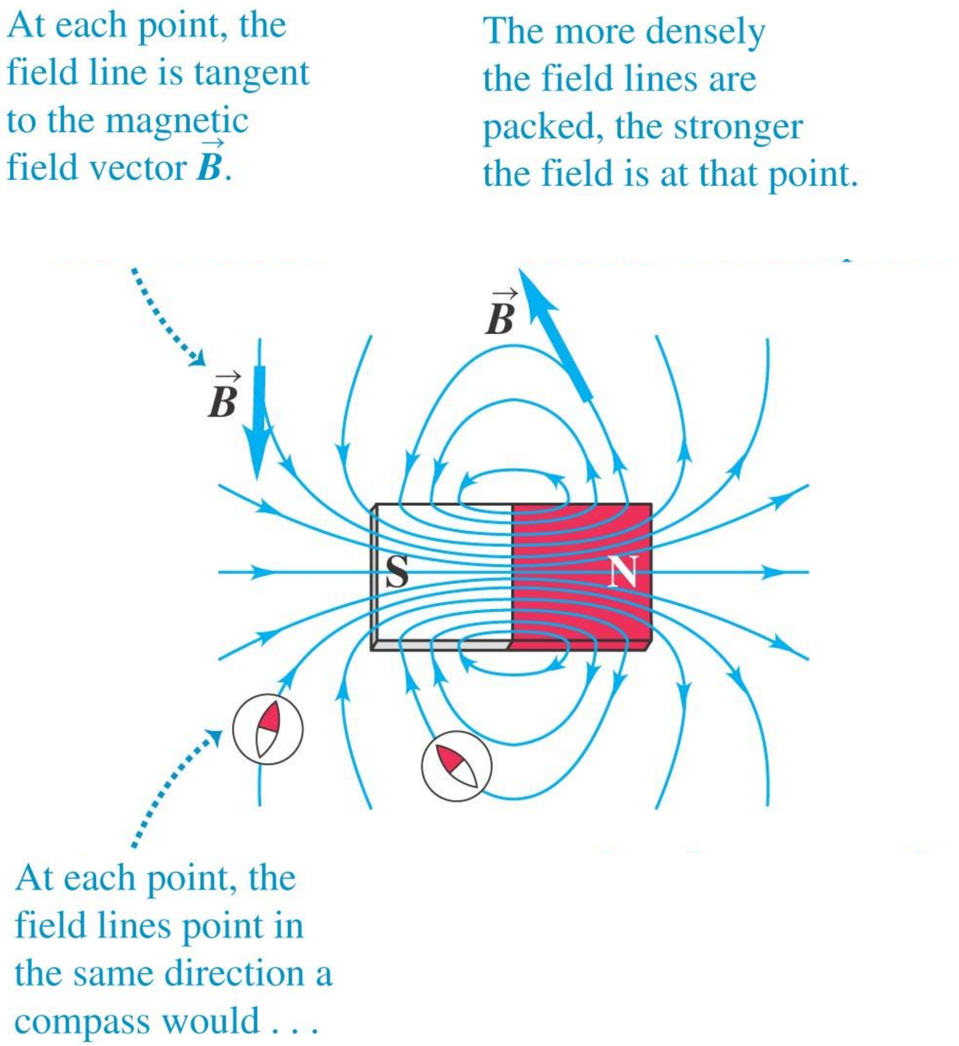


At each point, the field lines point in the same direction a compass would . . .

. . . therefore, magnetic field lines point *away from* N poles and *toward* S poles.

Magnetic Field Lines and Magnetic Flux



Magnetic Field Lines and Magnetic Flux

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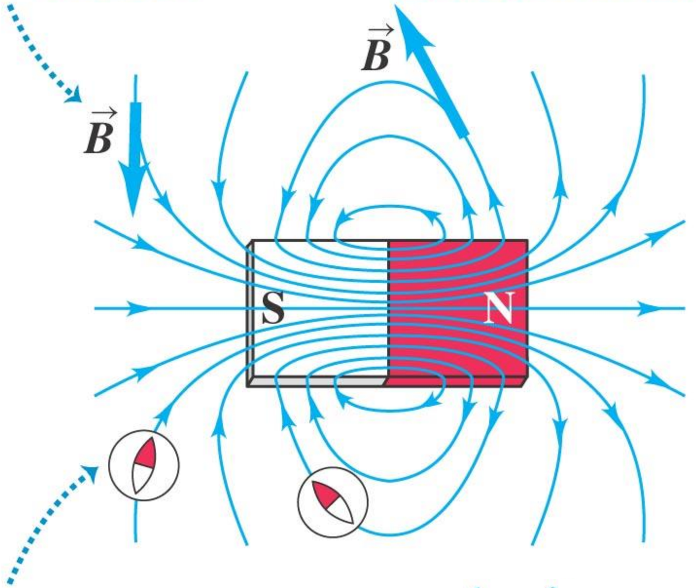
The more densely the field lines are packed, the stronger the field is at that point.



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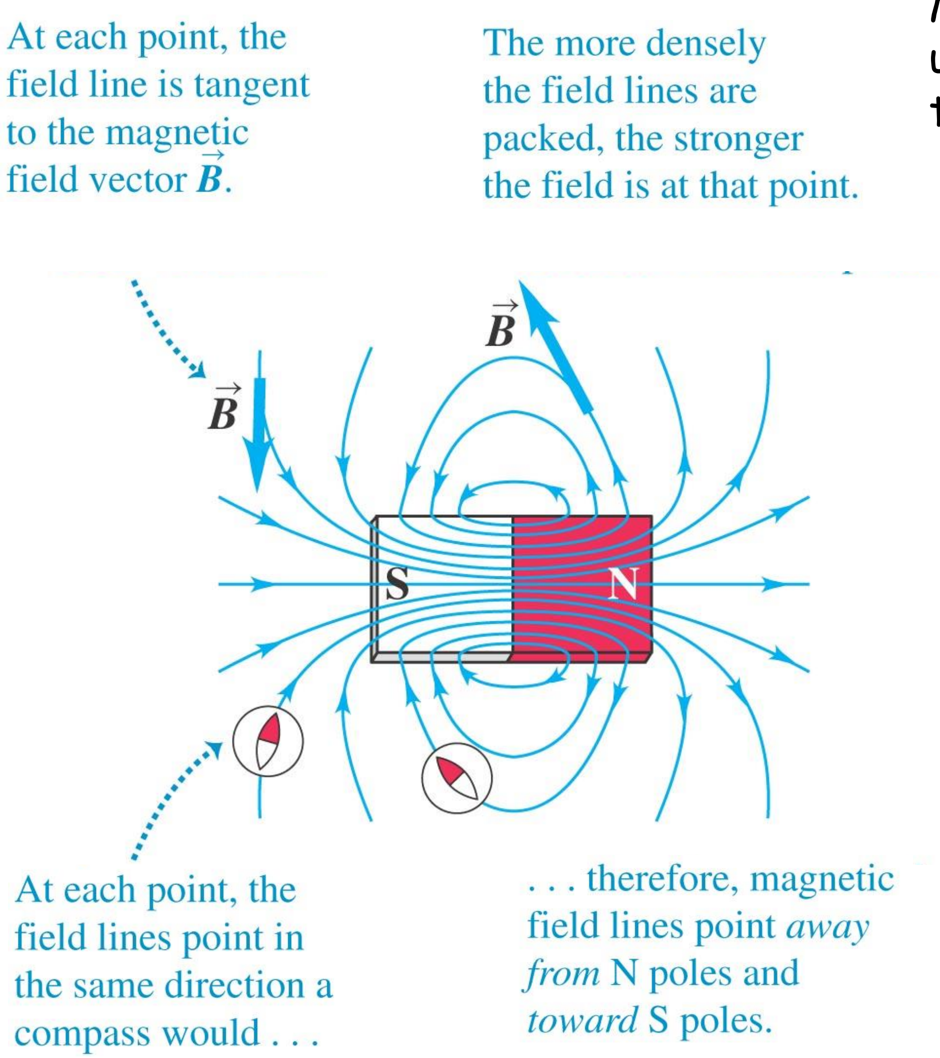

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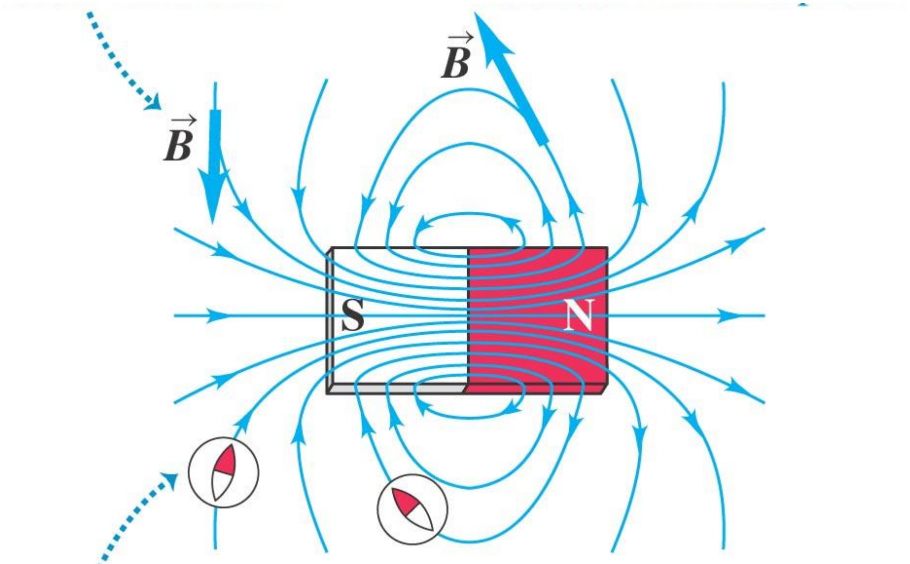

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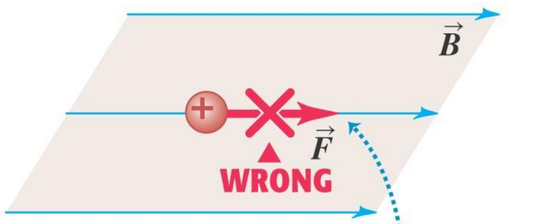
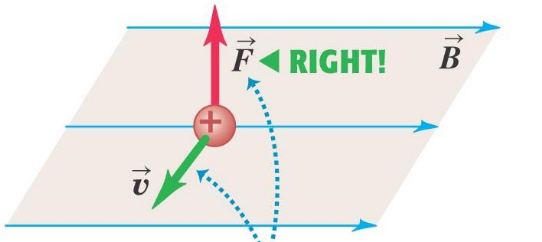
Magnetic field lines are not "lines of force" unlike electric field lines, they *do not* point in the direction of the force on a charge



Magnetic field lines are *not* "lines of force." The force on a charged particle is not along the direction of a field line.

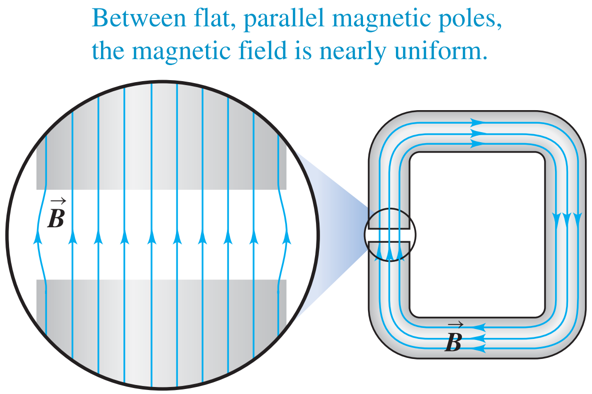


The direction of the magnetic force depends on the velocity $\vec{v}$, as expressed by the magnetic force law $\vec{F} = q\vec{v} \times \vec{B}$.

Magnetic flux Φ_B

We define the magnetic flux through a surface just as we defined electric flux

(a) Magnetic field of a C-shaped magnet



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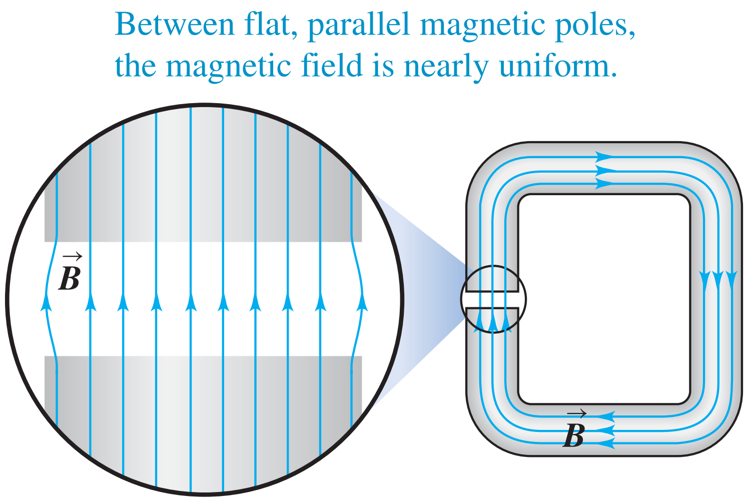
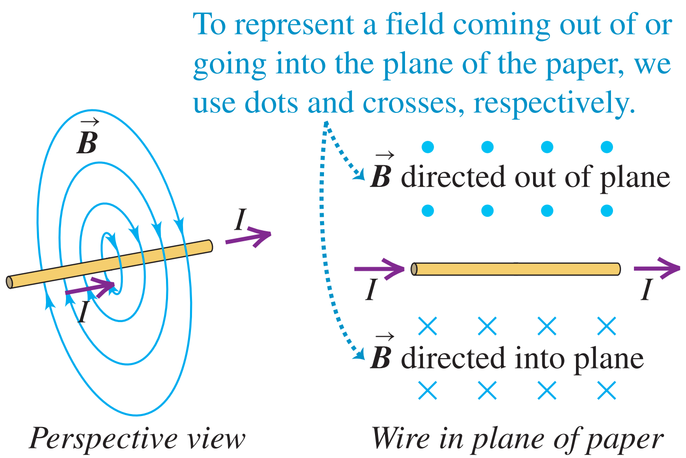


(b) Magnetic field of a straight current-carrying wire



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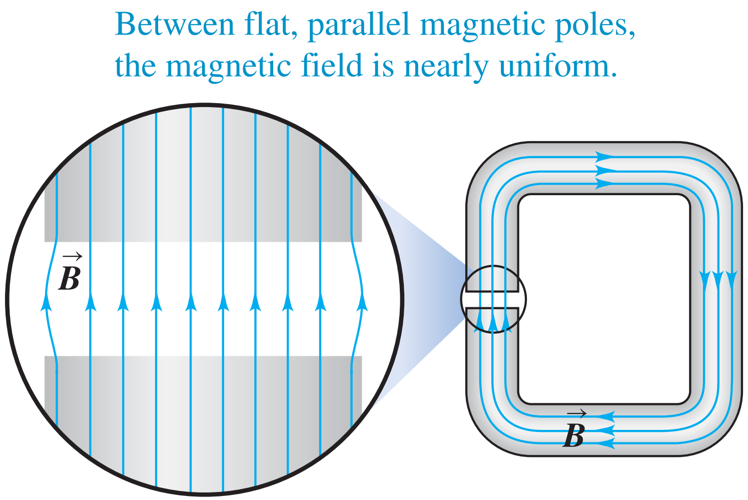

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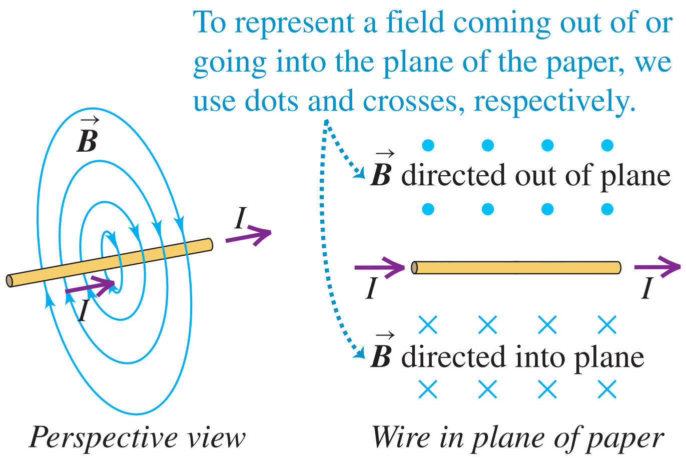
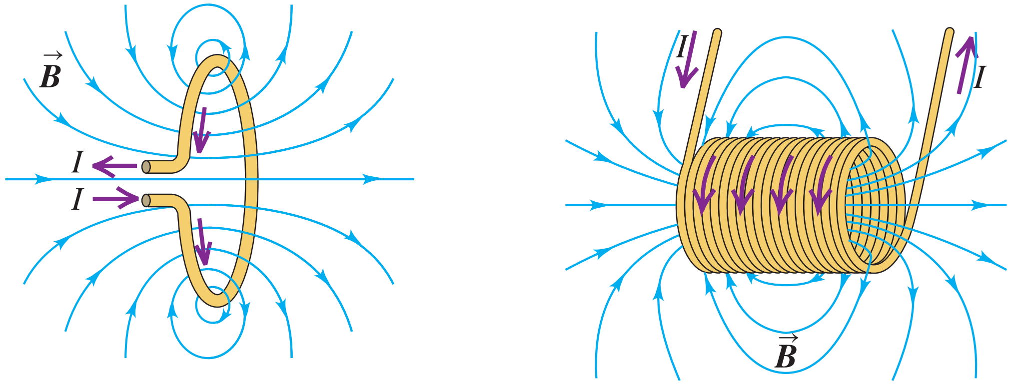


(c) Magnetic fields of a current-carrying loop and a current-carrying coil (solenoid)



Magnetic flux Φ_B

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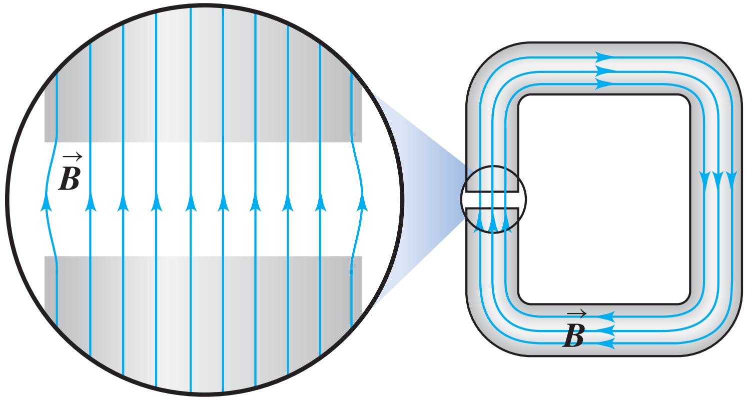
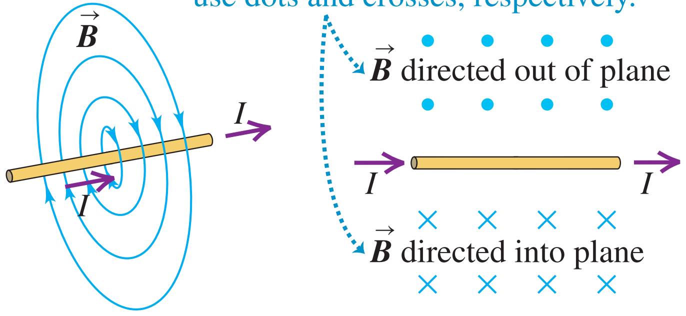
(a) Magnetic field of a C-shaped magnet

Between flat, parallel magnetic poles, the magnetic field is nearly uniform.



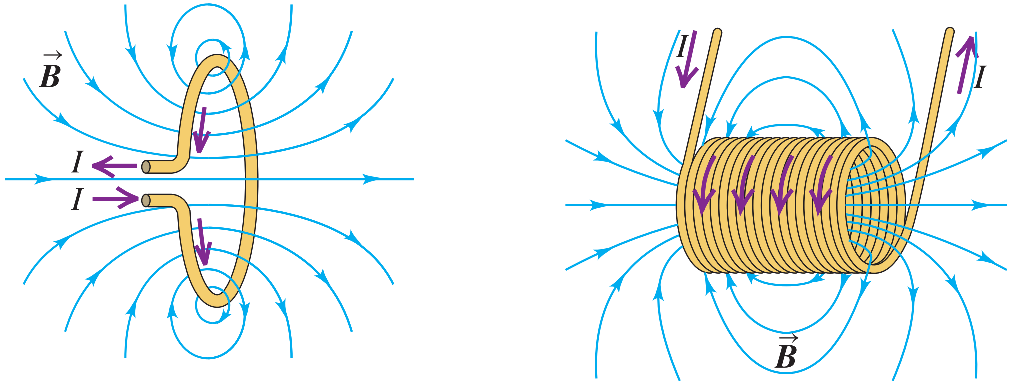
(b) Magnetic field of a straight current-carrying wire

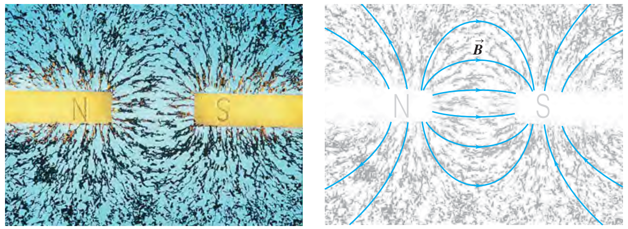
To represent a field coming out of or going into the plane of the paper, we use dots and crosses, respectively.



Perspective view *Wire in plane of paper*

(c) Magnetic fields of a current-carrying loop and a current-carrying coil (solenoid)

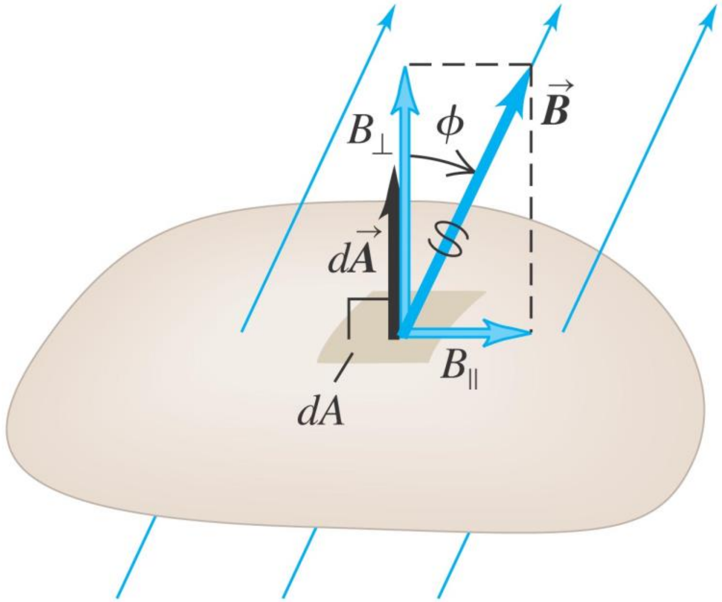




Like little compass needles, iron filings line up tangent to magnetic field lines.

Gauss Law for magnetism

Magnetic flux through any closed surface is zero (Gauss Law for magnetism)



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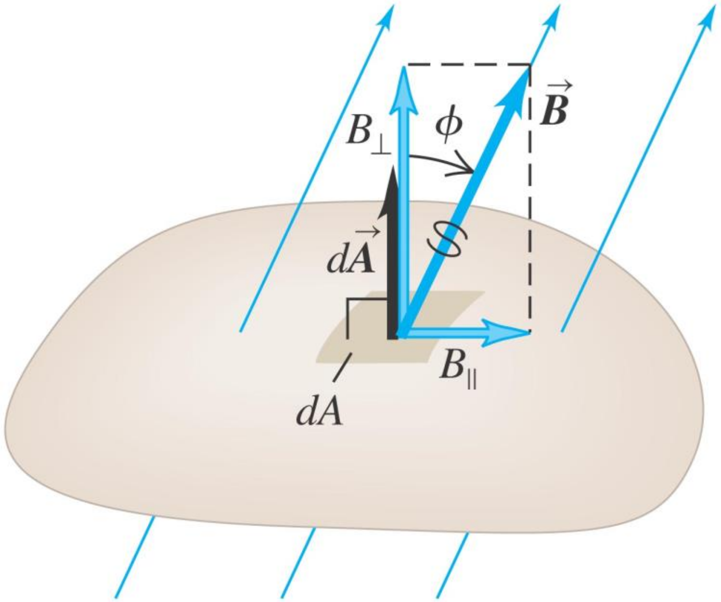

$$d\Phi_B = B_\perp\, dA = B\cos\phi\, dA = \vec{B}\cdot d\vec{A}$$

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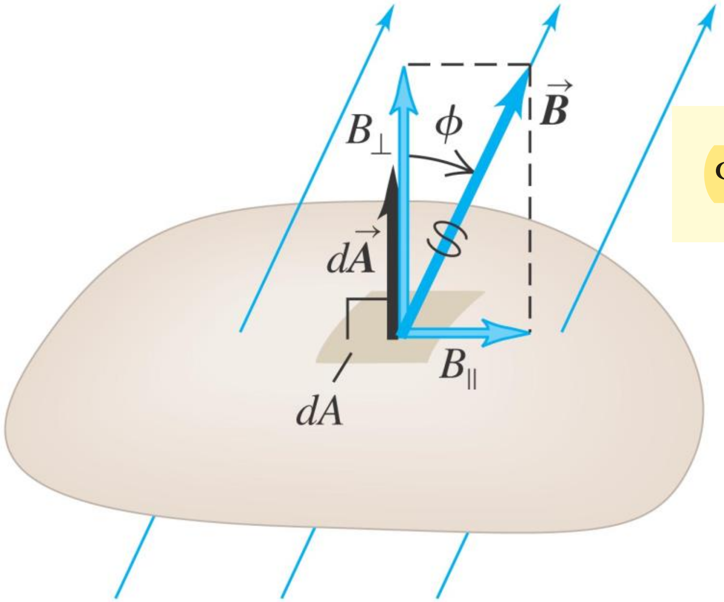

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$$\Phi_B = \int B_\perp \, dA = \int B\cos\phi \, dA = \int \vec{B} \cdot d\vec{A} \quad \text{(magnetic flux through a surface)}$$

$$1 \text{ Wb} = 1 \text{ T} \cdot \text{m}^2 = 1 \text{ N} \cdot \text{m/A}$$

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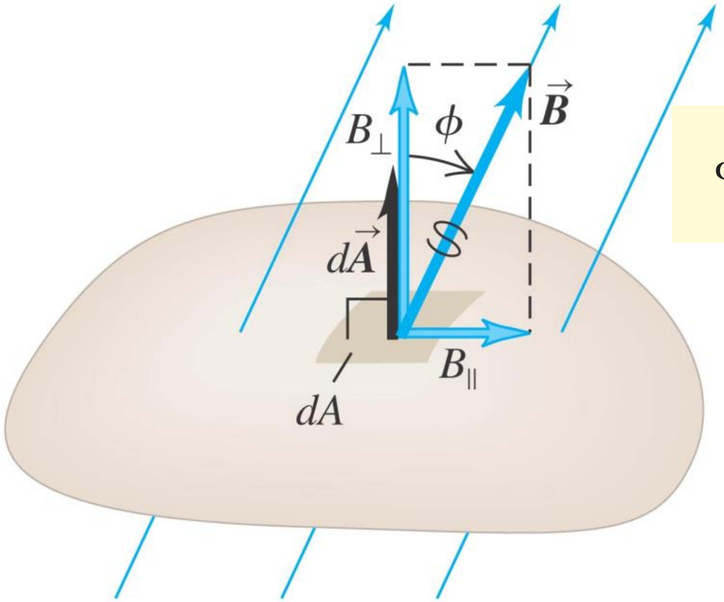

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There are no magnetic monopoles ➔

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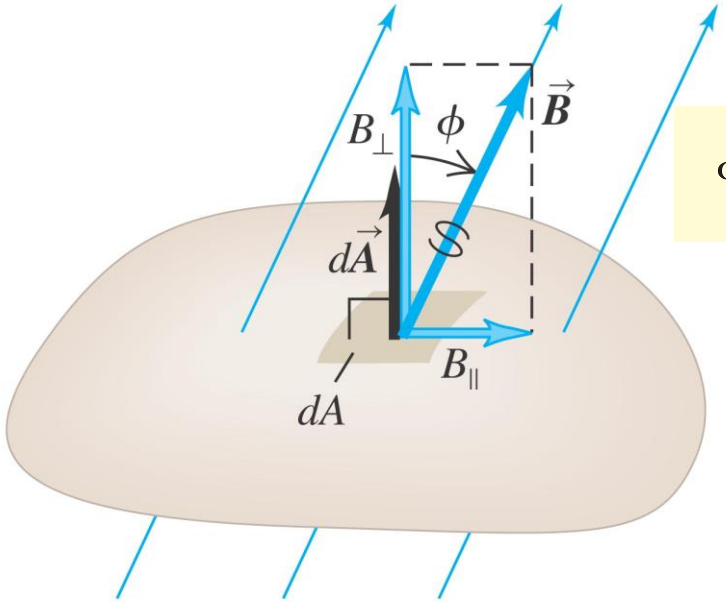

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Magnetic field $B = \dfrac{d\Phi_B}{dA_\perp}$ is also called magnetic flux density