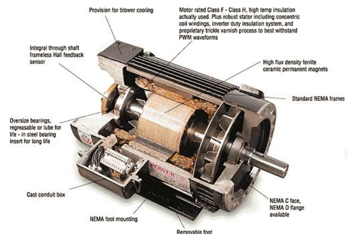
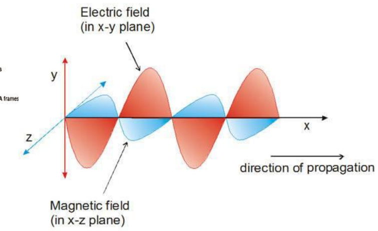
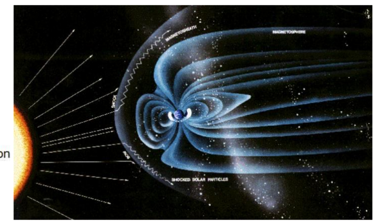
Today:

- **Magnetic Fields**
- **Next Week Wednesday April 9th– EXAM 2**
- **HW6 due next lecture, Wed April 2**

Magnets and Magnetic Fields (Chapter 28 - will be still on EXAM 2!!!)



Most of us are familiar with magnets in one way or another, from toys to refrigerator magnets. But magnetic fields play a more important role in our lives than most of us understand.

Magnetic fields are at the heart of:

– Electric motors, generators, transformers, most electrical circuits.

– Radio, wireless and light transmission.

– And play an important role in allowing life on our planet.

Magnets

Magnets exert the magnetic force on each other

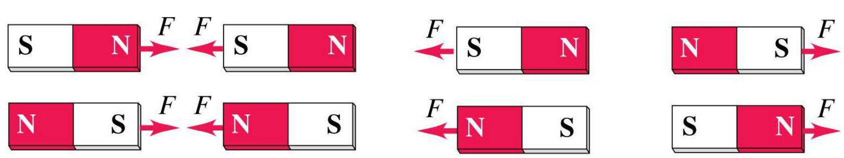
Poles - The location on a magnet where the magnetic force has its largest magnitude

North Pole - Geographically-Northward-seeking pole

South Pole - Geographically-Southward-seeking pole

A bar magnet has poles at its ends:

(a) Opposite poles attract. (b) Like poles repel.



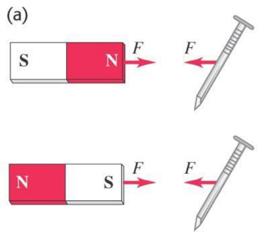
– **Magnets have two "poles**".

– **Opposite poles attract, and like poles repel**.

This makes us wonder if perhaps magnetic forces are just somehow caused by electric fields (since we have seen the whole like charges repel thing before).

Well, it turns out that there is a relationship, but it is much more complicated.

Magnets and Non-magnets



But, if your refrigerator door isn't made of a magnet, why do magnets stick to it?
We will learn later in this chapter, that in a similar way that electric fields can polarize neutral objects and create a force, magnetic force can also polarize neutral objects and create a force. We will return to this later and be more quantitative.

Magnetic Fields (vector associated with every point in space)
How does one magnet exert the magnetic force on another? By creating a magnetic field.

Magnetic Field, $\vec{B}$ - Invisible aura surrounding every magnet. It is the magnetic field that exerts the magnetic force.

To define the magnetic field, we use a small "**Test Compass**" (The red side is its north pole.)

B tells us how strong the torque will be when a small magnet is placed at a given location. Unit of magnetic field = T (Tesla).

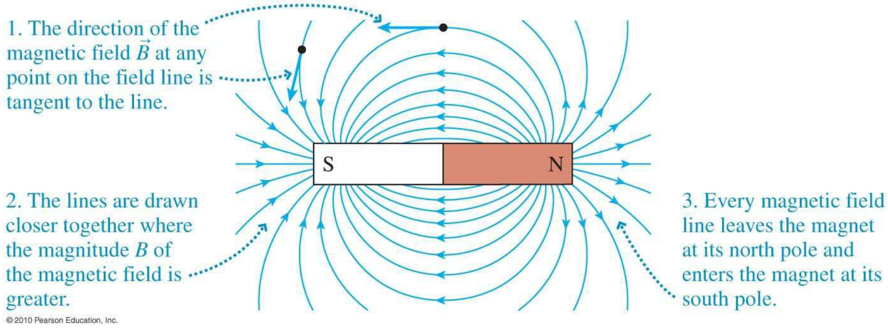
$\vec{B}$'s angle tells us the direction of the force on the test-compass's north pole.

Magnetic fields are vector fields – at every point in space there is a direction and magnitude for the magnetic field.

Magnetic Field Lines (pictorial representation of the B-field)

To represent magnetic fields, we draw magnetic field lines
Magnetic Field Lines - Curves that show the magnitude and direction of the magnetic field at every point

DEMO: Show Bar magnet field lines on overhead projector

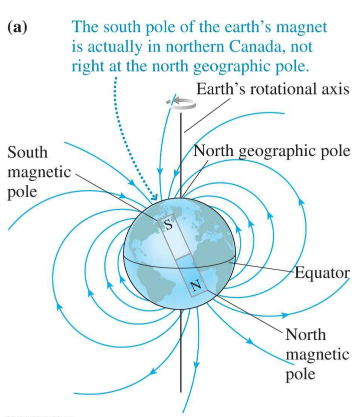


- Magnetic field lines always form closed loops
- Magnetic field lines start at north pole and end at south pole
- Magnetic field lines follow the direction of the field (the field is always tangential to the lines), and the density of lines (how closely spaced they are) is an indication of the field strength.

Remember that the field IS NOT THE LINES! The field is a set of vectors at every point in space. The lines are just a way of representing the field.

The earth has a magnetic field, and a compass will align itself to the direction of the field. The earth creates a magnetic field that is very similar in shape to that of a bar magnet. **What type of magnetic pole is at the earth's north pole – it is a South magnetic pole.** Which way do the earth's field lines go? Field lines go from the south geographic pole to the north pole

Earth's magnetic Field Strength $B_E \sim 5 \times 10^{-5}$ T
Another Magnetic Field Unit: The Gauss (G) 1G = 10^{-4} T ➔ $B_E \sim 0.5$ G



Magnetism is NOT the Electric Force

There are no magnetic monopoles! (As far as we can tell)

Magnetic Field "Sources" (more in chapter 29)

•The smallest source of a magnetic field is a magnetic dipole – there is still no beginning or end to the magnetic field lines!

•As we will learn in the next chapter 29, the source of magnetic fields is a moving charge, and in a magnet, it is the electrons in the atoms that cause the field.

Magnetic Force on Moving Charged Particle

Electricity and Magnetism always studied together because they are interrelated!

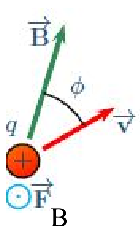
We determined the electric field $\vec{E}$ at a point by putting a test particle of charge q at rest at that point and measuring the electric force acting on the particle. We then defined $\vec{E}$ as

$$\vec{E} = \frac{\vec{F}_E}{q}$$

If a magnetic monopole were available, we could define $\vec{B}$ in a similar way. Because such particles have not been found, we must define $\vec{B}$ in another way, in terms of the magnetic force exerted on a moving electrically charged test particle.

If we would do an experiment, i.e. fire a charged particle between the poles of a permanent magnet we would find the following **four key characteristics of the magnetic force on a moving charge:**

1) The magnitude of the magnetic force is proportional to the charge
2) The magnitude of the magnetic force is proportional to the "strength" of the magnetic field
3) The magnitude of the magnetic force depends on the particle velocity
4) The direction of the magnetic force is always perpendicular to the direction of the magnetic field and direction of velocity. (This smells like a cross/vector product)



$\vec{F}_B = q\ \vec{v} \times \vec{B}$ (vector/cross product)

$\vec{F}_B$ direction is 90° to BOTH $\vec{v}$ and $\vec{B}$

The force $\vec{F}_B$ acting on a charged particle moving with velocity $\vec{v}$ through a magnetic field $\vec{B}$ is always perpendicular to $\vec{v}$ and $\vec{B}$.

magnitude: $F_B = |q| vB \sin\phi$ (ϕ is the angle between $\vec{v}$ and $\vec{B}$)

Units: $Tesla: T = \frac{N}{Cm/s} = \frac{N}{Am}$

Example 1: Book 28.3 An electron that has velocity $\vec{v} = (2.0\times10^6\, m/s)\hat{i} + (3.0\times10^6\, m/s)\hat{j}$ moves through the uniform magnetic field $\vec{B} = (0.030T)\hat{i} - (0.15T)\hat{j}$

a) Find the force on the electron due to the magnetic field.
b) Repeat your calculation for a proton having the same velocity.

$$\vec{F}_B = q\,\vec{v}\times\vec{B}$$

$$\vec{v} = (2.0\times10^6 \tfrac{m}{s})\hat{i} + (3.0\times10^6 \tfrac{m}{s})\hat{j} = \begin{pmatrix}2.0\times10^6\\3.0\times10^6\end{pmatrix}\frac{m}{s}$$

$$\vec{B} = (0.030T)\hat{i} + (-0.15T)\hat{j} = \begin{pmatrix}0.030\\-0.15\end{pmatrix}T$$

$$\vec{v}\times\vec{B} = \begin{vmatrix}\hat{i} & \hat{j} & \hat{k} & \hat{i} & \hat{j}\\ 2.0 & 3.0 & 0 & 2.0 & 3.0\\ 0.03 & -0.15 & 0 & 0.03 & -0.15\end{vmatrix}\times10^6$$

$$= [(3.0\times10^6)(0) - (-0.15)(0)]\hat{i} + [0(0.03) - (2.0\times10^6)(0)]\hat{j} + [(2.0\times10^6)(-0.15) - (3.0\times10^6)(0.03)]\hat{k}$$

$$= 0\hat{i} + 0\hat{j} + (-0.39\times10^6 \tfrac{m}{s}T)\hat{k}$$

$$\vec{F}_B = q\,\vec{v}\times\vec{B} \Rightarrow$$

a) $q = -1.603\times10^{-19}\,C$

$$\vec{F}_B = (-0.39\times10^6)(-1.6\times10^{-19})N\,\hat{k}$$

$$\vec{F}_B = (6.24\times10^{-14}N)\hat{k} = (6.2\times10^{-14}N)\hat{k}$$

b) $q = +1.603\times10^{-19}\,C$

$$\vec{F}_B = -(6.2\times10^{-14}N)\hat{k}$$

Right hand Rule (RHR) for Magnetic Force:
Start fingers in direction of $\vec{v}$ so that they can curl towards $\vec{B}$, thumb points in direction of $\vec{F}_B$ on positive q.

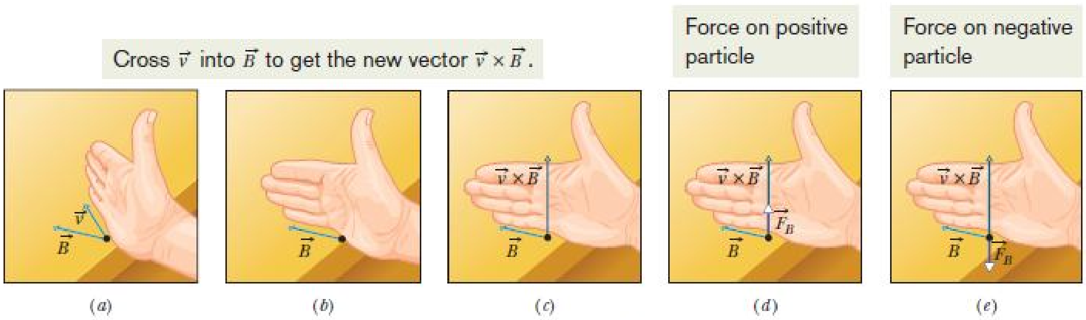


Fig. 28-2 (*a*) – (*c*) The right-hand rule (in which $\vec{v}$ is swept into $\vec{B}$ through the smaller angle ϕ between them) gives the direction of $\vec{v} \times \vec{B}$ as the direction of the thumb. (*d*) If q is positive, then the direction of $\vec{F}_B = q\vec{v} \times \vec{B}$ is in the direction of $\vec{v} \times \vec{B}$. (*e*) If q is negative, then the direction of $\vec{F}_B$ is opposite that of $\vec{v} \times \vec{B}$.

Since it has been a while since we dealt with cross products, let's take a few minutes to review what this means.

•There is **no force** on a charge **moving in the same or opposite direction as the magnetic field (**ϕ = 0 or 180).

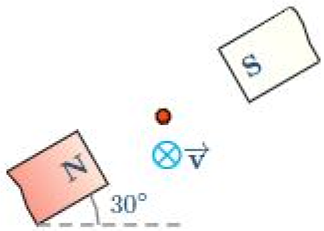
•The **force** on a moving charge in a magnetic field is **perpendicular to both the field direction and the direction of motion**.

•The direction of the **force on a negative** charge is **opposite to that on a positive charge** moving in the same direction.

•Since the **force is perpendicular to the direction of motion, no work is done by the magnetic force**.

Do practice problems on sheet: 27 and 28

Example 2: A 10 μC point charge is fired between the poles of a permanent magnet as shown. If the charge's speed is 4×10^6 m/s and B = 0.5 T, what is the magnitude and direction of the force on the charge?



Example 2:

use $|\vec{F}_B| = |q| v B \sin\phi$

ϕ angle between $\vec{v}$ & $\vec{B}$

$\phi = 90°$

$q = 10 \times 10^{-6}$ C
$v = 4 \times 10^6$ m/s
$B = 0.5$ T

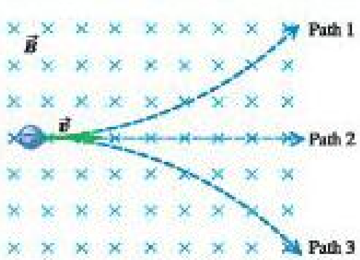
$|\vec{F}_B| = q v B \underbrace{\sin(90)}_{1} = (10 \times 10^{-6})(4 \times 10^6)(0.5) = 20N$

direction: us RHR

$\theta = 60°$

Consequence of a magnetic fore on a moving charged particle is that the particle trajectory will be curved:

Example 3: The Figure shows a uniform magnetic field $\vec{B}$ directed into the plane of the paper (x). A particle with negative charge moves in the plane. Which of the three paths - 1,2, or 3 - does the particle follow?



Answer: path 3!