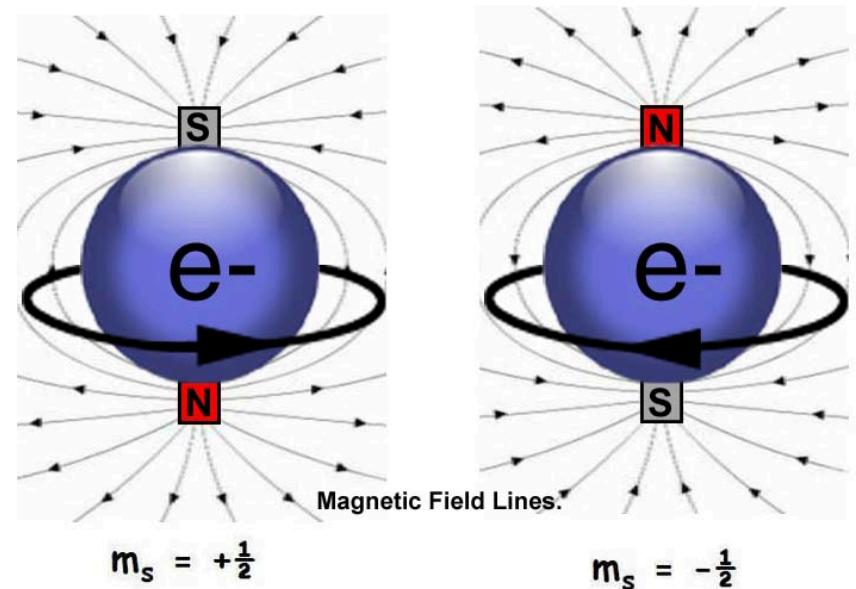


What produces a magnetic field?

- We saw yesterday that currents (moving electric charges) produce magnetic fields. We see the same thing around wires (remember the relativity introduction?). What does this tell us?
- **Magnetic fields are produced by moving charges!**
- So how are charges “moving” in something like a bar magnet?

Electrons are spinning inside the atoms. This produces a tiny magnetic field around each one, which sometimes can produce a net magnetic field around the object.

What would have to happen to produce a net magnetic field?



Magnetic materials

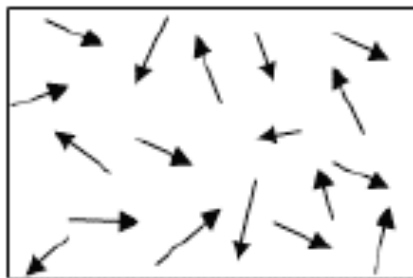
- **Ferromagnetic** materials show strong magnetic effects
 - **Iron** is the main element, along with cobalt, nickel, gadolinium, and certain alloys/compounds
- Other materials can show magnetic effects but those effects are usually weak and can often be ignored
 - Materials that are weakly magnetic are often called diamagnetic
 - Materials that can become temporarily magnetic are called paramagnetic
 - How can you temporarily induce a magnetization?

Put something in a strong magnetic field! That will temporarily align the domains in the normally non-magnetic material, until the strong field is removed.

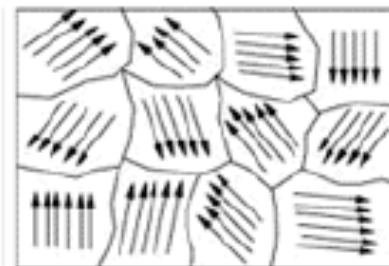
You can remove a magnetization by heating up the magnet (randomizing the domains), and if it's a weak magnet, dropping it or even letting it sit for awhile can also randomize the domains.

Ampere's Theory of Magnetism and Magnetic domains

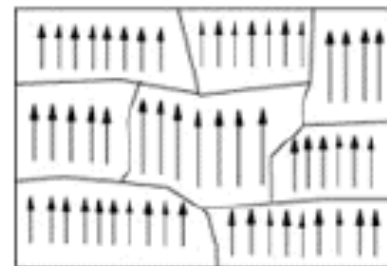
- Ferromagnetism is due to tiny regions within a material called **domains**. Each domain is like a tiny magnet.
- In unmagnetized objects, these domains are randomly oriented and cancel each other out.
- In magnetized objects, the domains align and produce a strong magnetic field.
- Objects can become magnetized if placed in a strong B-flds



Non-Magnetic Material
(no domains)



Magnetic Material
(domains, but not lined up)



Magnet

(domains, and all are lined up)

Magnetic fields vs. magnetic force

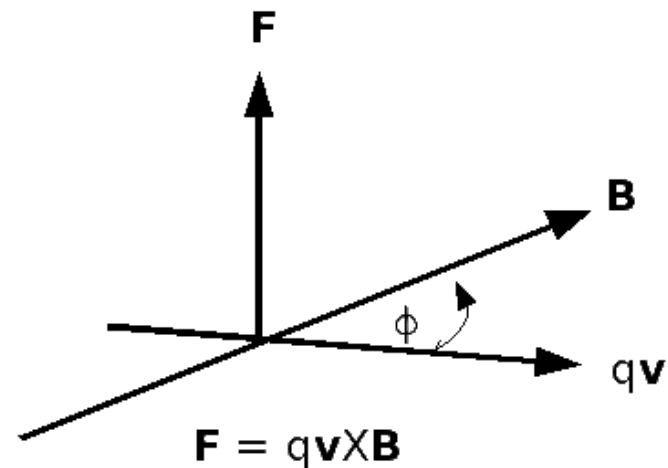
- Now we know what produces magnetic fields, but the presence of a field does not necessarily mean a force will be exerted on another object.
- Experiments have shown that stationary particles are not affected by a constant magnetic field - whether they're charged or not.
 - Compare this to electric fields: any charged object will be affected by an electric field, whether it's moving or not.
- What we do see is that **a charged particle that moves through a magnetic field is affected by a magnetic force.**
 - The magnetic force is strongest when the particle is moving perpendicular to the field, and weakest when the particle is moving parallel to the field.
 - We also see that the particle's velocity isn't affected, only its direction.
Does this sound familiar...?

Magnetic force on a charged particle

- Experimentally, we've seen that the magnetic force depends on three main things:
 - The charge on the particle (q) in coulombs
 - The strength of the magnetic field (B) in **Teslas** ($T = N/Am$)
 - The velocity component that is perpendicular to the magnetic field ($v\sin\theta$) in m/s
- In equation form: $\vec{F}_B = qvB\sin\theta = q\vec{v} \times \vec{B}$

Remember that a cross product produces a vector that is perpendicular to the two crossed vectors. In other words \rightarrow

Hang on. If the force is perpendicular to the velocity, then what will that force cause the particle to do?



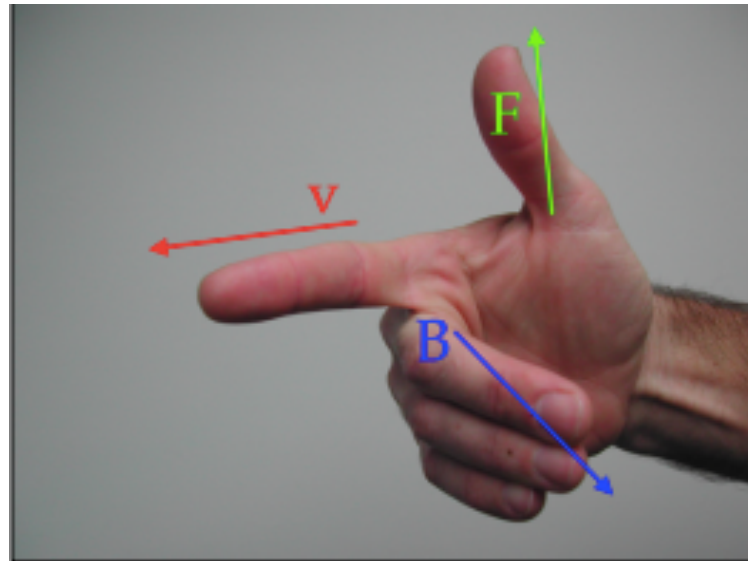
Magnetic force

- Because magnetic force is always perpendicular to the velocity of a moving charged particle, that force will change the particle's direction, but not its speed. That makes it a **centripetal force!**
 - Also remember that because $W = Fd\cos\theta$, a centripetal force will do no work.
- **Important bottom line things to remember:**
 - F_B only acts when a charge is moving relative to the magnetic field
 - F_B does no work and acts perpendicular to both the direction of velocity and direction of the field - this is a 3D thing!
 - Very important distinction:
 - In electric fields, F_E was parallel to the field lines (E pointed in direction of F)
 - In magnetic fields, F_B is perpendicular to field lines!

Directions...

- How can we tell the direction of the magnetic force if we know the directions of v and B ? We use our handy **right hand rule**.

1. Point fingers in direction of velocity vector.



3. Thumb will point in the direction a **positive** charge will be affected

2. Curl fingers in direction of magnetic field.

Thanks, Mr White!

For a negative charge, the force will be opposite the thumb (in this picture, down instead of up)

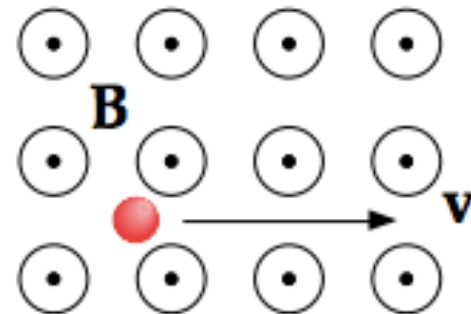
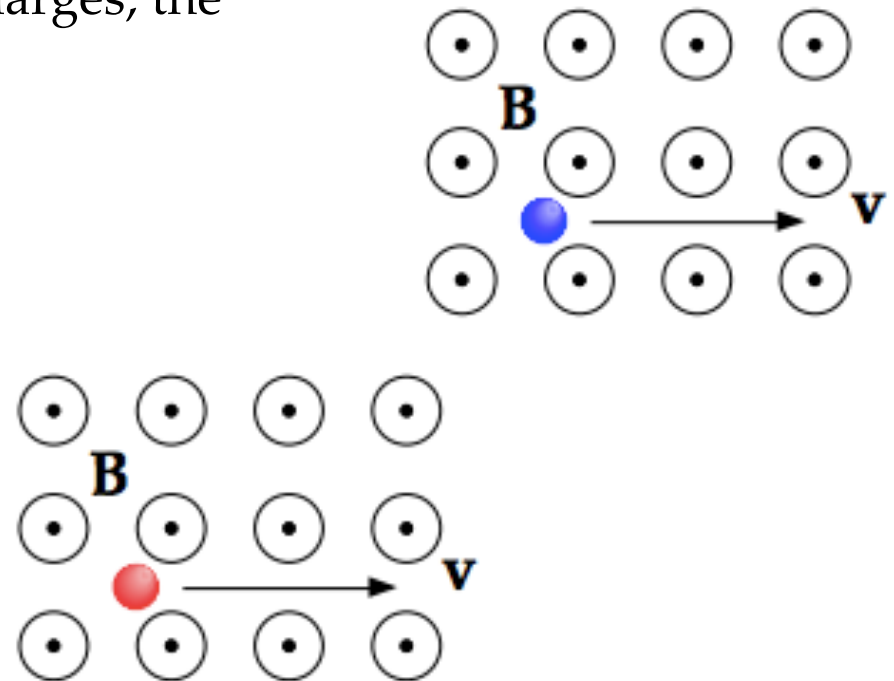
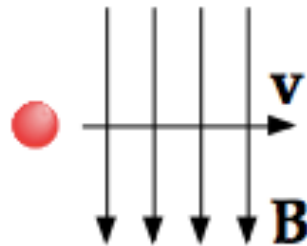
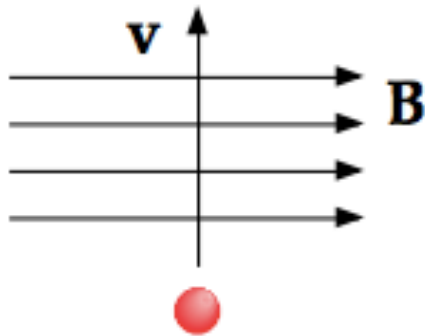
Practice with RHR

Note: since this is a 3D thing, we need a way to show vectors going in and out of the plane of the page. In this case, we use two symbols: \bullet and \times

Imagine an arrow coming out of the page at you. You'd see the tip of the arrowhead: \bullet

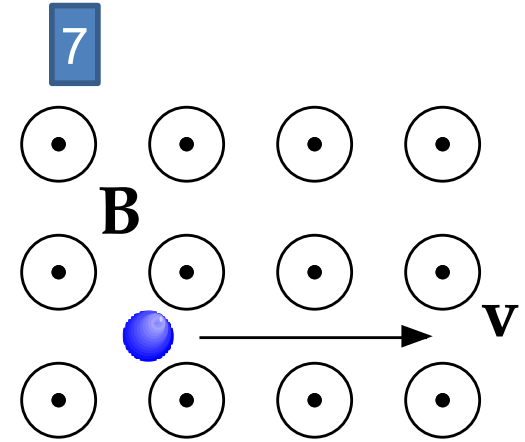
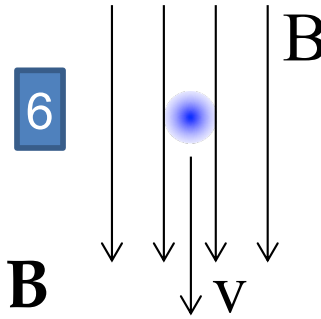
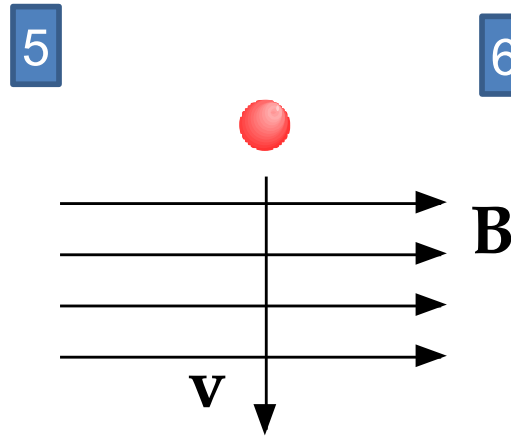
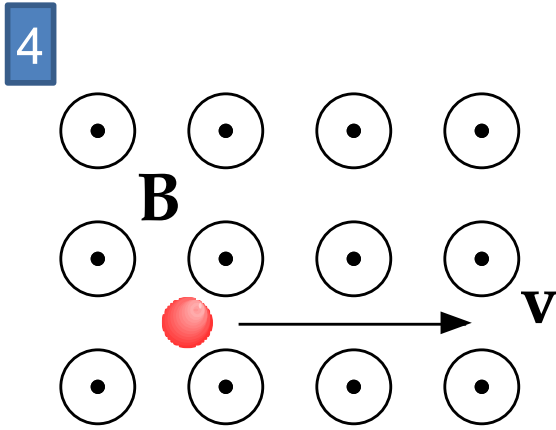
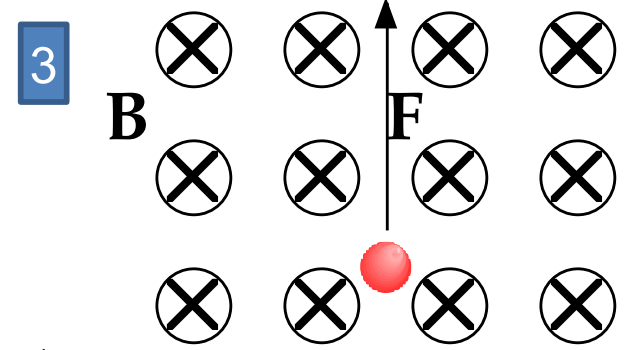
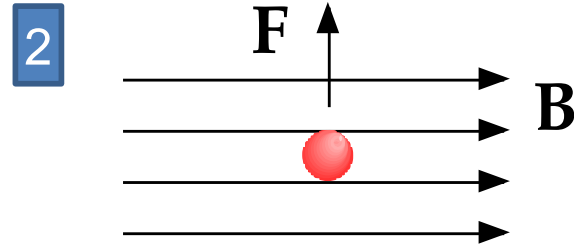
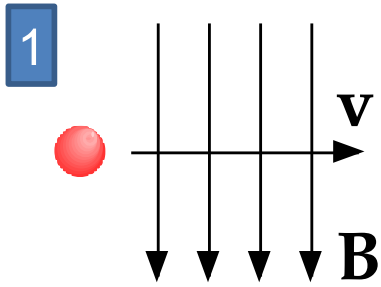
Imagine that arrow going into the page away from you. You'd see its tail feathers: \times

In which direction will the magnetic force be in each case? The red dots are positive charges; the blue dots are negative.



RHR practice

Identify the *missing* vector in these diagrams. Assume red signifies negative charges, blue positive charges. (thanks, Mr. White!)

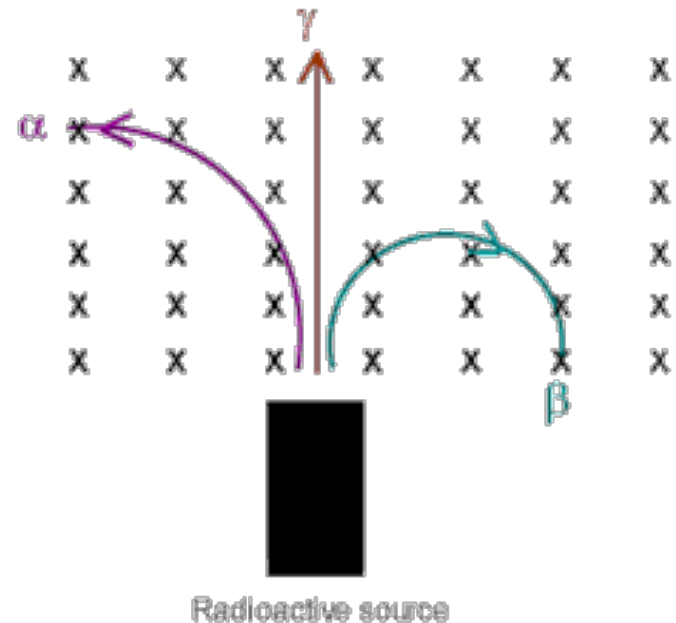


1) F out of board; 2) v into board; 3) v to the left; 4) F upward; 5) F into board; 6) no force; 7) F downward (positive charge!)

Magnetic deflection

- Back to that centripetal force idea - what path will a charged particle take, then, when it enters a magnetic field?
 - Because the force is perpendicular to the velocity at all times, the centripetal force will make the particle curve!
 - In some cases, the particle will move in a circle. If other forces are present, however, sometimes it'll move in a spiral. More on that later.

Remember radioactive decay? This is how we tell the three types of nuclear decay particles apart! Based on this diagram, what do you know about the relative charge and mass of α , β , and γ particles?



Conceptual practice

- A negative charge $-Q$ is placed at rest near a magnet.
 - No - no magnetic force on a stationary charge.
 - Will the charge begin to move?
 - No - no magnetic force on a stationary charge.
 - Will it feel a force?
 - STILL no.
 - What if the charge were positive?
- A moving proton feels a force towards the west when moving vertically upward, but feels zero force when moving horizontally in a northward direction. In which direction is the magnetic field oriented?

Zero force moving horizontally and northward means the field is horizontal and pointing either north or south. Since it's a positive charge feeling a force to the west when moving upward, the RHR tells us the field must be pointing south to NORTH.

Calculation example (19.7)

- What velocity would a proton need to circle the Earth 1000 km above the magnetic equator, where Earth's magnetic field is directly horizontally northward with a magnitude of 4×10^{-8} T?
 - Hint: draw a picture and think N2L!

Solution on class Website