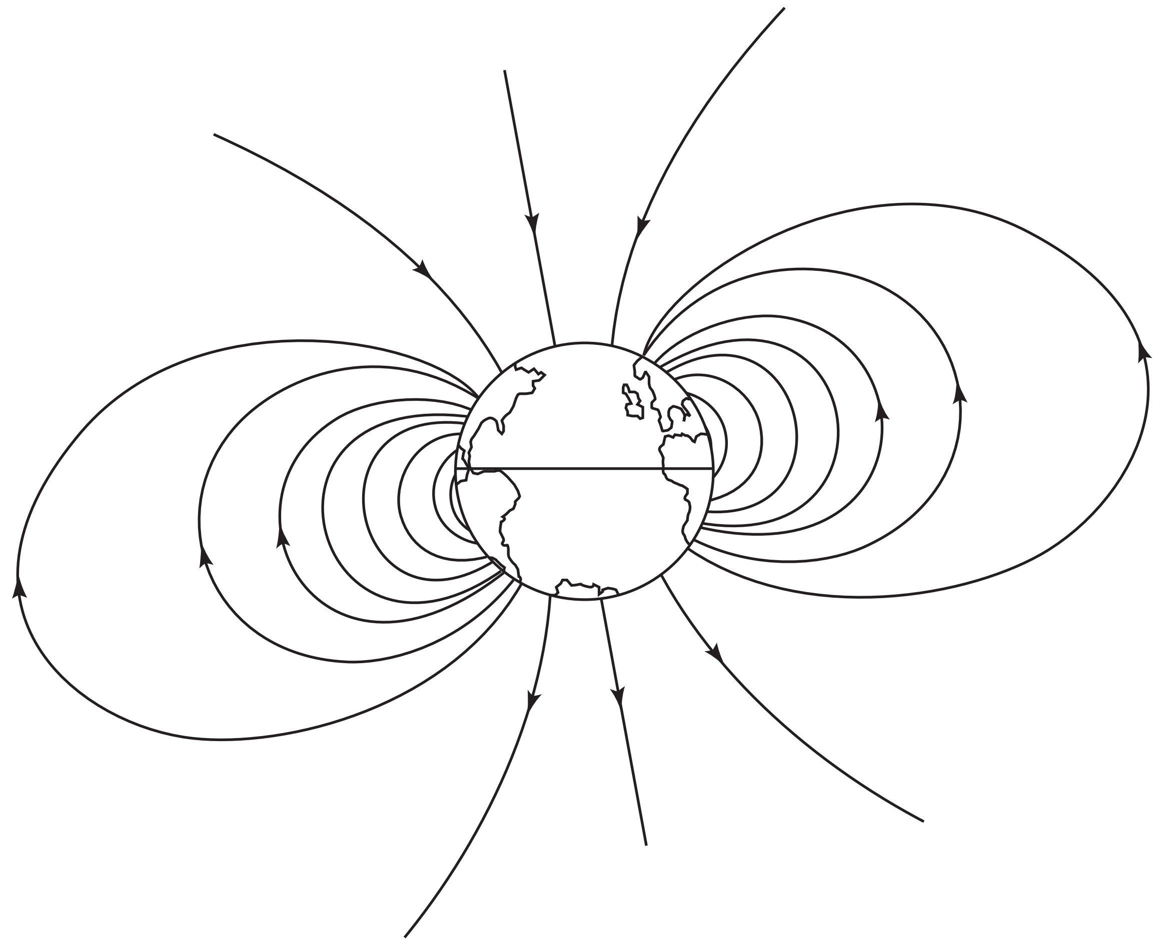
Introduction to Magnetism

"Magnets—how to they work?"

Cosmic rays (atomic nuclei stripped bare of their electrons) would continuously bombard Earth's surface if most of them were not deflected by Earth's magnetic field. Given that Earth is, to an excellent approximation, a magnetic dipole, the intensity of cosmic rays bombarding its surface is greatest at the

A. north pole only.
B. both poles.
C. mid-latitudes.
D. equator.



ANS: B—Cosmic rays mostly hit Earth at both poles.

In general the cosmic rays will be deflected from Earth by magnetic forces on the particles. Cosmic rays that approach Earth's poles are nearly parallel or anti-parallel to the field lines. Therefore, the magnetic forces on these lines are nearly zero, and many make it all the way to Earth's surface. Particles approaching the equator will have velocities perpendicular to the field lines and therefore should experience the greatest deflecting force.

A negative particle moves upward along the trajectory shown. A magnetic field points toward the right. In which direction is the magnetic force on the particle?

A. up.

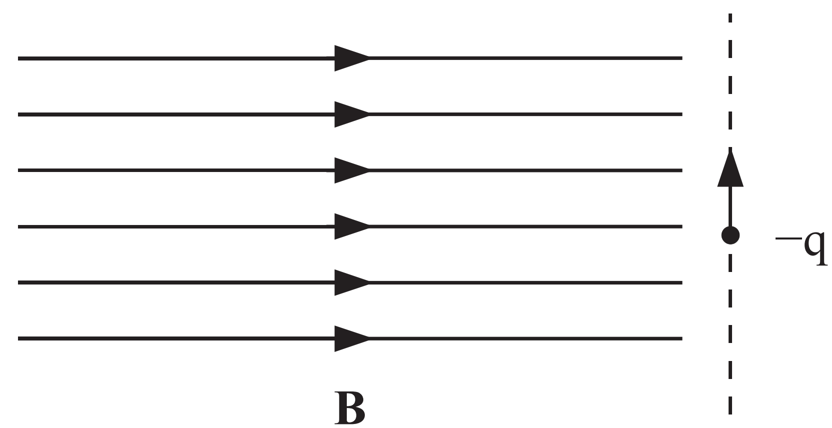
B. down.

C. into the plane of the drawing.

D. out of the plane of the drawing.

E. left.

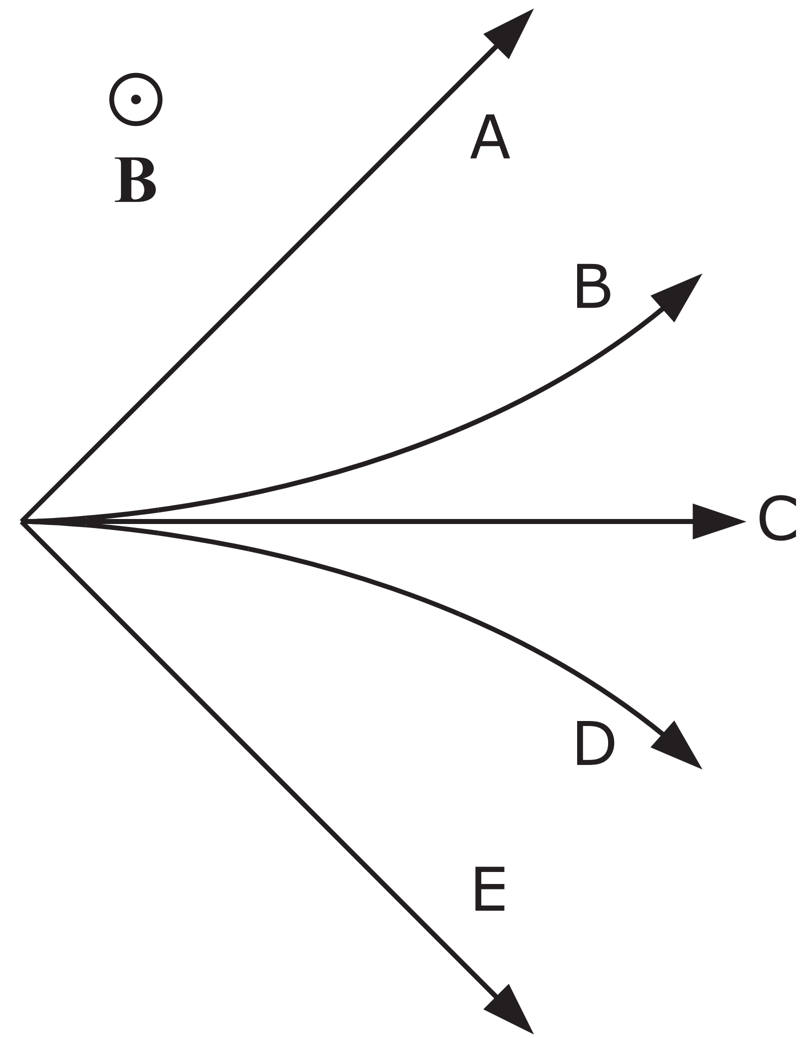
F. right.



ANS: D—The force points out of the plane of the drawing.

The force on the particle is $\vec{F}_B = q\vec{v} \times \vec{B}$. Using the right hand rule you can see that the cross product $\vec{v} \times \vec{B}$ points into the plane of the drawing. However, this is a negative particle. The negative charge changes the direction of $\vec{F}_B$ from being parallel to $\vec{v} \times \vec{B}$ to being anti-parallel to $\vec{v} \times \vec{B}$. Therefore, the magnetic force on the charge points out of the plane of the drawing.

A negatively charged particle is released from rest. It is subjected to the influence of a magnetic field $\vec{B}$ (directed out of the page) and no electric field. Which of the paths shown best represents the subsequent trajectory of the particle? (ignore gravity)



A.–E. (as in figure)

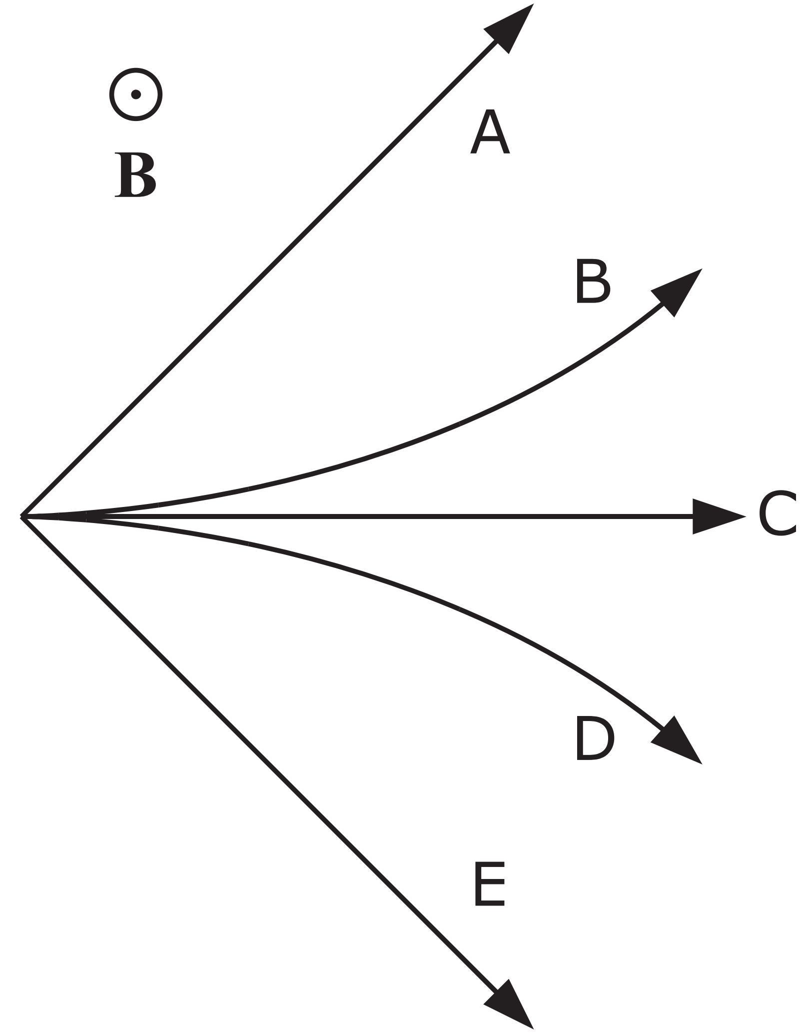
F. The particle remains at rest.

G. The particle moves out of the plane of drawing.

ANS: F—The particle remains at rest.

Magnetic force depends on velocity. The particle is initially at rest, so there will be no magnetic force on it. This means that initially the particle will not accelerate, and therefore will remain at rest, with zero magnetic force and acceleration.

A negatively charged particle initially moves to the right. It is subjected to the influence of a magnetic field $\vec{B}$ (directed out of the page) and no electric field. Which of the paths shown best represents the subsequent trajectory of the particle? (ignore gravity)



A.–E. (as in figure)

F. The particle remains at rest.

G. The particle moves out of the plane of drawing.

ANS: The particle follows path **B**.

The particle is initially moving perpendicular to the magnetic field, so there will most definitely be a magnetic force on the particle. Initially, $\vec{v}$ points to the right, and $\vec{B}$ points out of the page. Therefore, the cross product $\vec{v} \times \vec{B}$ points downward. Because the particle is negatively charged, the magnetic force on it will therefore point upward.

This force is perpendicular to the velocity of the particle, so it will change the particle's direction but not its magnitude. As the particle's path turns, the force remains perpendicular to the velocity, and the particle will trace out curve B. (Can you see this?)

Warmup Question

The force $\vec{F}_B$ experienced by a particle with charge q moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$ is given by the equation

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

The force is zero if the particle is not moving ($\vec{v} = 0$), or if there is no magnetic field ($\vec{B} = 0$).

There are other cases where a particle will not experience any force even when moving in a magnetic field. Please describe these situations.

ANS: The force can be zero whenever the velocity is parallel to the field (moving along the field line) or anti-parallel to the field (moving against the field line). In these cases the cross product between the velocity and field is zero.

Warmup Question

Earth's magnetic field in our classroom points north (out of the board) and downward at about a 45 degree angle. Suppose I drop a positively-charged ball. In what direction will the magnetic force point?

A. Up (toward the ceiling)
B. Down (toward the floor)
C. North (away from the board)
D. South (toward the board)
E. East (toward the window)
F. West (toward the hallway)
G. There will be no magnetic force.

ANS: E—The magnetic force will point east, toward the window.

There will be a magnetic force on a charge if the velocity, $\vec{v}$, and the magnetic field, $\vec{B}$, are not co-linear (parallel or anti-parallel). In this problem the velocity points downward, so there will be a magnetic force due to the horizontal (out of the board) component of $\vec{B}$, but not due to the vertical component.

Using the right-hand rule with $\vec{v}$ pointing down and $\vec{B}$ pointing out of the board, we see that $\vec{v} \times \vec{B}$ points toward the classroom window, which is the East direction. The moving charge is positive, so this is also the direction of the force.