1. A charged particle, passing through a certain region of space, has a velocity whose magnitude and direction remain constant, \( \vec{v} \)

(a) If it is known that the external magnetic field is zero everywhere in this region, can you conclude that the external electric field is also zero?

(b) If it is known that the external electric field is zero everywhere, can you conclude that the external magnetic field is also zero?

(a) If it is known that the external magnetic field is zero everywhere in the region, we can conclude that the electric field is also zero. Any charged particle placed in an electric field will experience a force given by \( \vec{F} = q \vec{E} \), where \( q \) is the charge and \( \vec{E} \) is the electric field. If the magnitude and direction of the velocity of the particle are constant, then the particle has zero acceleration. From Newton’s second law, we know that the net force on the particle is zero. But there is no magnetic field and, hence, no magnetic force. Therefore, the net force is the electric force. Since the electric force is zero, the electric field must be zero.

(b) If it is known that the external electric field is zero everywhere, we cannot conclude that the external magnetic field is also zero. In order for a moving charged particle to experience a magnetic force when it is placed in a magnetic field, the velocity of the moving charge must have a component that is perpendicular to the direction of the magnetic field. If the moving charged particle enters the region such that its velocity is parallel or antiparallel to the magnetic field, it will experience no magnetic force, even though a magnetic field is present. In the absence of an external electric field, there is no electric force either. Thus, there is no net force, and the velocity vector will not change in any way.

2. Three particles move through a constant magnetic field and follow the paths shown in the drawing. Determine whether each particle is positively charged, negatively charged, or neutral.

Since the paths of the particles are perpendicular to the magnetic field, we know that the velocities of the particles are perpendicular to the field. Since the velocity of particle #2 is perpendicular to the magnetic field and it passes through the field undeflected, we can conclude that particle #2 is neutral. Particles #1 and #3 move in circular paths. The figure at the right shows the direction of the (centripetal) magnetic force that acts on the particles. If the fingers of the right hand are pointed into the page so that the thumb points in the direction of motion of particle #1, the palm of the hand points toward the center of the circular path traversed by the particle. We can conclude, therefore, from RHR-1 that particle #1 is positively charged. If the fingers of the right hand are pointed into the page so that the thumb points in the direction of motion of particle #3, the palm of the hand points away from the center of the circular path traversed by the particle. We conclude, therefore, from RHR-1 that particle #3 is negatively charged.
3. The drawing shows a top view of four interconnected chambers. A negative charge is fired into chamber 1. By turning on separate magnetic fields in each chamber, the charge can be made to exit from chamber 4, as shown.

(a) Describe how the magnetic field in each chamber should be directed.

(b) If the speed of the charge is \( v \) when it enters chamber 1, what is the speed of the charge when it exits chamber 4?

The drawing shows a top view of four interconnected chambers. A negative charge is fired into chamber 1. By turning on separate magnetic fields in each chamber, the charge is made to exit from chamber 4.

(a) In each chamber the path of the particle is one-quarter of a circle. The drawing at the right also shows the direction of the centripetal force that must act on the particle in each chamber in order for the particle to traverse the path. The charged particle can be made to move in a circular path by launching it into a region in which there exists a magnetic field that is perpendicular to the velocity of the particle. Using RHR-1, we see that if the palm of the right hand were facing in the direction of \( \vec{F} \) in chamber 1 so that the thumb points along the path of the particle, the fingers of the right hand must point out of the page. This is the direction that the magnetic field must have to make a positive charge move along the path shown in chamber 1. Since the particle is negatively charged, the field must point opposite to that direction or into the page. Similar reasoning using RHR-1, and remembering that the particle is negatively charged, leads to the following conclusions: in region 2 the field must point out of the page, in region 3 the field must point out of the page, and in region 4 the field must point into the page.

(b) If the speed of the particle is \( v \) when it enters chamber 1, it will emerge from chamber 4 with the same speed \( v \). The magnetic force is always perpendicular to the velocity of the particle; therefore, it cannot do work on the particle and cannot change the kinetic energy of the particle, according to the work-energy theorem. Since the kinetic energy is unchanged, the speed remains constant.

4. The drawing shows a particle carrying a positive charge \(+q\) at the coordinate origin, as well as a target located in the third quadrant. A uniform magnetic field is directed perpendicularly into the plane of the paper. The charge can be projected in the plane of the paper only, along the positive or negative \( x \) or \( y \) axis. Thus, there are four possible directions for the initial velocity of the particle. The particle can be made to hit the target for only two of the four directions. Which two are they? Give your reasoning, and draw the two paths that the particle can follow on its way to the target.

When the particle is launched in the \( x, y \) plane, its initial velocity will be perpendicular to the magnetic field; therefore, the particle will travel on a circular path in the \( x, y \) plane. In order for the charged particle to hit the target, the target must lie on the circular path of the moving particle. This will occur if the particle moves in a counterclockwise circle that passes through the third quadrant of the coordinate system. RHR-1 can be used to determine possible trajectories in the following way. Place the fingers of the right hand into the page (direction of the magnetic field) and orient the thumb along one of the coordinate axes (direction of the particle’s initial velocity). The palm of the right hand will face the direction in which the force on the charged particle is directed. Since the particle travels on a circle, the direction of the force will point toward the center of the particle’s trajectory. The figures below show the results for two possible cases. Clearly, the charged particle can hit the target only if the initial velocity of the particle points either in the negative \( x \) direction or the positive \( y \) direction.
5. A proton is projected perpendicularly into a magnetic field with a certain velocity and follows a circular path. Then an electron is projected perpendicularly into the same magnetic field with the same velocity.

(a) Does the electron follow the exact same circular path that the proton followed?

(b) To make the electron follow the exact same circular path as the proton, what, if anything, should be done to the direction and the magnitude of the magnetic field?

(c) A proton is projected perpendicularly into a magnetic field that has a magnitude of 0.50 T. The field is then adjusted so that an electron will follow the exact same circular path when it is projected perpendicularly into the field with the same velocity that the proton had. What is the magnitude of the field used for the electron?

(a) Figure 21.12 shows an example of the circular path followed by the proton (positive charge). If the charge in that drawing were an electron (negative charge), the force on it at point 1 would be downward rather than upward. As a result, the electron would move downward in a clockwise direction around its circular path. Thus, the electron does not follow the exact same circular path as the proton.

(b) To make the electron follow the exact same circular path as the proton, it is necessary to make the force on it at point 1 in Figure 21.12 point upward just as it does for the proton. Therefore, the field direction in that figure must be reversed for the electron. Then, RHR-1 would predict an upward force for the electron. Equation 21.2 gives the radius of the circular path as \( r = \frac{mv}{qB} \). We wish the radius to be the same for both the proton and the electron. The speed \( v \) and the charge magnitude \( q \) are the same for the proton and the electron, but the mass of the electron is \( 9.11 \times 10^{-31} \text{ kg} \), while the mass of the proton is \( 1.67 \times 10^{-27} \text{ kg} \). Therefore, to offset the effect of the smaller electron mass \( m \) in Equation 21.2, the magnitude \( B \) of the field must be reduced for the electron.

(c) Applying Equation 21.2 to the proton and the electron, both of which carry charges of the same magnitude \( e \), we obtain

\[
\frac{r}{r} = \frac{\frac{m_p v}{eB_p}}{\frac{m_e v}{eB_e}} \quad \text{and} \quad \frac{r}{r} = \frac{\frac{m_e v}{eB_e}}{\frac{m_p v}{eB_p}}
\]

Dividing the proton-equation by the electron-equation gives

\[
\frac{r}{r} = \frac{m_p v}{m_e v} \quad \Rightarrow \quad 1 = \frac{m_p B_e}{m_e B_p}
\]

Solving for \( B_e \),

\[
B_e = \frac{m_e B_p}{m_p} = \frac{(9.11 \times 10^{-31})(0.50)}{1.67 \times 10^{-27}} = 2.7 \times 10^{-4} \text{ T}
\]