

Note:

In this week's worksheet, the second problem should not have been there. We'll keep it for next week and the solution will be posted then.

Also, the first problem said  $B = 0.12 \text{ T}$  in the text and  $B = 1.2 \text{ T}$  in the figure. Part b is geometrically more involved when the field is small enough ( $0.12 \text{ T}$ ), because the proton exits through the right. We post the answers to both options.

## Magnetic forces

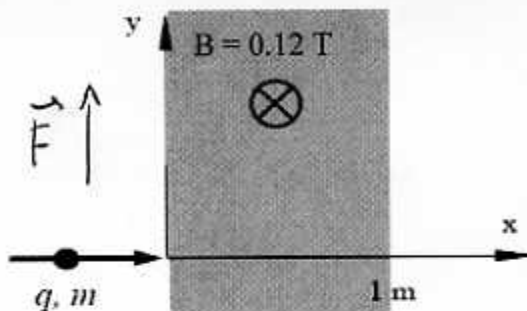
1. The figure below depicts a region of space (shaded) where there is a constant magnetic field  $B = 0.12 \text{ T}$ , directed along the negative  $z$  axis (into the page). The magnetic field region extends infinitely far in the positive and negative  $y$  directions, but is constrained to the region between  $x = 0$  and  $x = 1 \text{ m}$ . A proton travels along the  $x$  axis toward this region, with initial speed  $v_0$ .

Proton:

$$m = 1.67 \times 10^{-27} \text{ kg}$$

$$q = e = 1.6 \times 10^{-19} \text{ C}$$

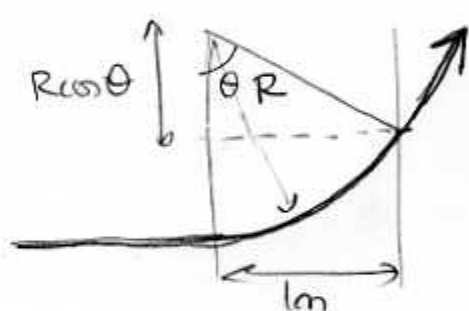
$$v_0 = 2.0 \times 10^7 \text{ m/s}$$



- a. What is the radius of curvature of the proton's path after it enters the magnetic field region?

$$R = \frac{mv}{qB} = \frac{(1.67 \times 10^{-27} \text{ kg})(2.0 \times 10^7 \text{ m/s})}{(1.6 \times 10^{-19} \text{ C})(0.12 \text{ T})} = \boxed{1.74 \text{ m}}$$

- b. At what  $x$  and  $y$  position will the proton leave the magnetic field region?



$$\boxed{x = 1.0 \text{ m}}$$

$$\sin \theta = \frac{1 \text{ m}}{R} = \frac{1}{1.74} \rightarrow \theta = 35.1^\circ$$

$$y = R - R \cos \theta = (1.74 \text{ m})(1 - \cos 35.1^\circ) = \boxed{0.32 \text{ m}}$$

- c. What is the proton's speed (magnitude) as it exits the magnetic field?

$$v = 2.0 \times 10^7 \text{ m/s} \quad (\text{B field cannot change speed since } \vec{F} \perp \vec{v})$$

- d. Finally, a constant electric field  $E$  is added to the shaded region. The effect of this field is that all charged particles launched with initial velocity  $v_0$  in the  $x$  direction travel straight through the field region without being deflected at all! What is the magnitude and direction of the field  $E$ ?

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

$$\vec{F} = 0 \Rightarrow \vec{E} = -\vec{v} \times \vec{B} = -v_0 B \hat{j} = \boxed{-(2.4 \times 10^6 \text{ N/C}) \hat{j}}$$

## Magnetic forces

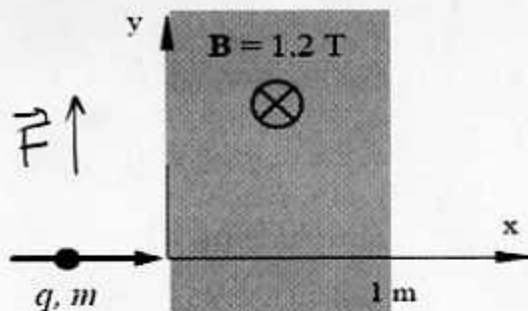
1. The figure below depicts a region of space (shaded) where there is a constant magnetic field  $B = 1.2 \text{ T}$ , directed along the negative  $z$  axis (into the page). The magnetic field region extends infinitely far in the positive and negative  $y$  directions, but is constrained to the region between  $x = 0$  and  $x = 1 \text{ m}$ . A proton travels along the  $x$  axis toward this region, with initial speed  $v_0$ .

Proton:

$$m = 1.67 \times 10^{-27} \text{ kg}$$

$$q = e = 1.6 \times 10^{-19} \text{ C}$$

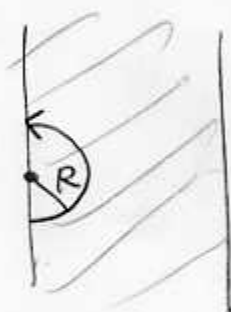
$$v_0 = 2.0 \times 10^7 \text{ m/s}$$



- a. What is the radius of curvature of the proton's path after it enters the magnetic field region?

$$R = \frac{mv}{qB} = \frac{(1.67 \times 10^{-27} \text{ kg})(2.0 \times 10^7 \text{ m/s})}{(1.6 \times 10^{-19} \text{ C})(1.2 \text{ T})} = \boxed{0.17 \text{ m}}$$

- b. At what  $x$  and  $y$  position will the proton leave the magnetic field region?



Since  $R < 1 \text{ m}$ , proton turns around

$$y = 2R = \boxed{0.35 \text{ m}}$$

$$\boxed{x = 0}$$

- c. What is the proton's speed (magnitude) as it exits the magnetic field?

$$v = 2.0 \times 10^7 \text{ m/s} \quad (\text{B cannot change speed since } \vec{F} \perp \vec{v})$$

- d. Finally, a constant electric field  $E$  is added to the shaded region. The effect of this field is that all charged particles launched with initial velocity  $v_0$  in the  $x$  direction travel straight through the field region without being deflected at all! What is the magnitude and direction of the field  $E$ ?

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

$$\vec{F} = 0 \Rightarrow \vec{E} = -\vec{v} \times \vec{B} = -v_0 B \hat{j} = -\left(2.4 \times 10^7 \frac{\text{N}}{\text{C}}\right) \hat{j}$$