Begin your response to **QUESTION 4** on this page.

4. (10 points, suggested time 20 minutes)

Two particles, 1 and 2, have different mass and charge as described by the following.

- Particle 1 has mass M and negative charge $-Q$.
- Particle 2 has mass $\frac{M}{2}$ and positive charge $+2Q$.

In separate trials, a device is used to accelerate each particle in the $-y$-direction from rest through a potential difference of absolute value $|\Delta V|$. The polarity of the potential difference can be adjusted so that a particle with either positive charge or negative charge can be accelerated in the $-y$-direction by the device. Gravitational effects are negligible.

After moving through the potential difference, particles 1 and 2 exit the device with kinetic energies K_1 and K_2, respectively.

(a) **Calculate** the ratio $\frac{K_2}{K_1}$.

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Continue your response to **QUESTION 4** on this page.

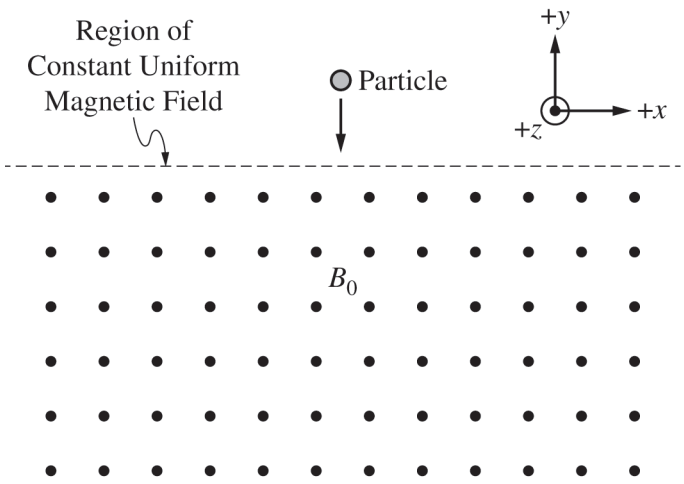

Figure 1

After exiting the device, the particles enter a large region of constant uniform magnetic field of magnitude B_0 that is directed in the $+z$-direction (out of the page), as shown in Figure 1. Each particle is moving in the $-y$-direction when entering the region, and each particle is moving in the $+y$-direction when exiting the region.

(b)

i. **Determine** an expression for the speed of Particle 2 in the region. Express your answer in terms of M, K_2, and physical constants, as appropriate.

ii. **Derive** an expression for the horizontal distance Δx between the locations where Particle 2 enters and leaves the region. Express your answer in terms of M, Q, K_2, B_0, and physical constants, as appropriate.

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Continue your response to **QUESTION 4** on this page.

(c) On the following diagram in Figure 2, **sketch** and clearly **label** the paths of both particles 1 and 2 in the region.

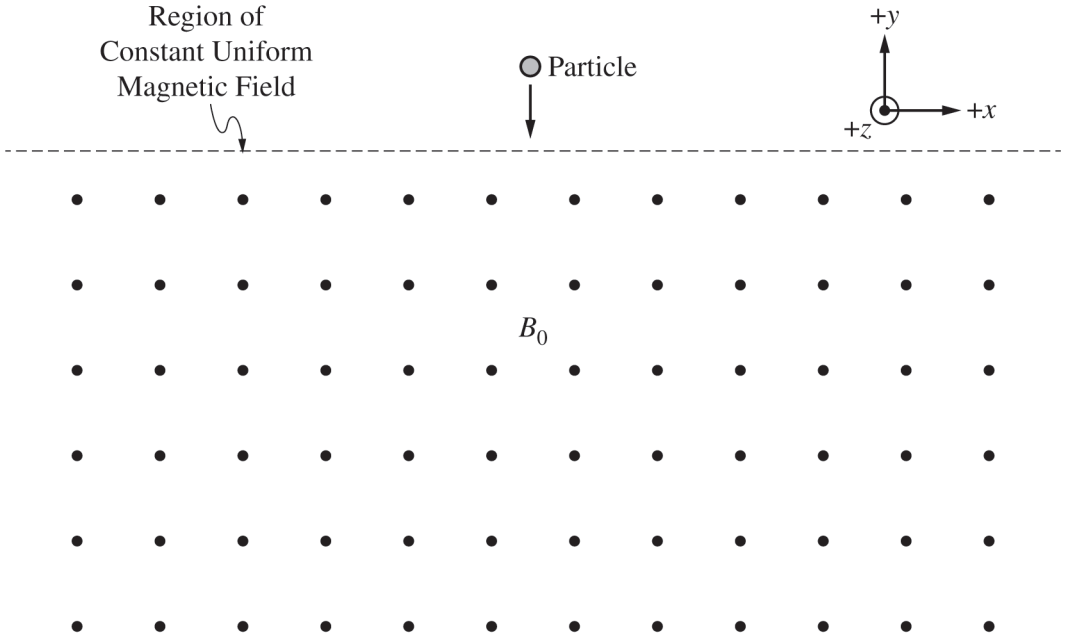

Figure 2

(d) A uniform electric field is added to the region such that Particle 1 of negative charge $-Q$ travels with constant speed in a straight line through the region. **Determine** the direction of the electric field.

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Question 4: Short Answer/Other — 10 points

(a) For indicating that the final kinetic energy of a particle is equal to $|q\Delta V|$ — **1 point**

Scoring Note: Explicit indication of an absolute value is not required for this point to be earned.

Example Response

$|q\Delta V| = K$

For $\frac{K_2}{K_1} = 2$ — **1 point**

Example Solution

$E_0 = E_f$

$\Delta U + \Delta K = 0$

$-\Delta U_E = \Delta K$

$|q\Delta V| = K$

$K_1 = |-Q\Delta V| = Q\Delta V$

$K_2 = |+2Q\Delta V| = 2Q\Delta V$

$\frac{K_2}{K_1} = \frac{2Q\Delta V}{Q\Delta V}$

$\frac{K_2}{K_1} = 2$

Total for part (a) — **2 point**

Scoring Note: Parts (b)(i) and (b)(ii) can be scored together.

(b)(i) For a correct expression for the speed of Particle 2 in terms of K_2 and M — **1 point**

Example Response

$v = 2\sqrt{\frac{K_2}{M}}$

Example Solution

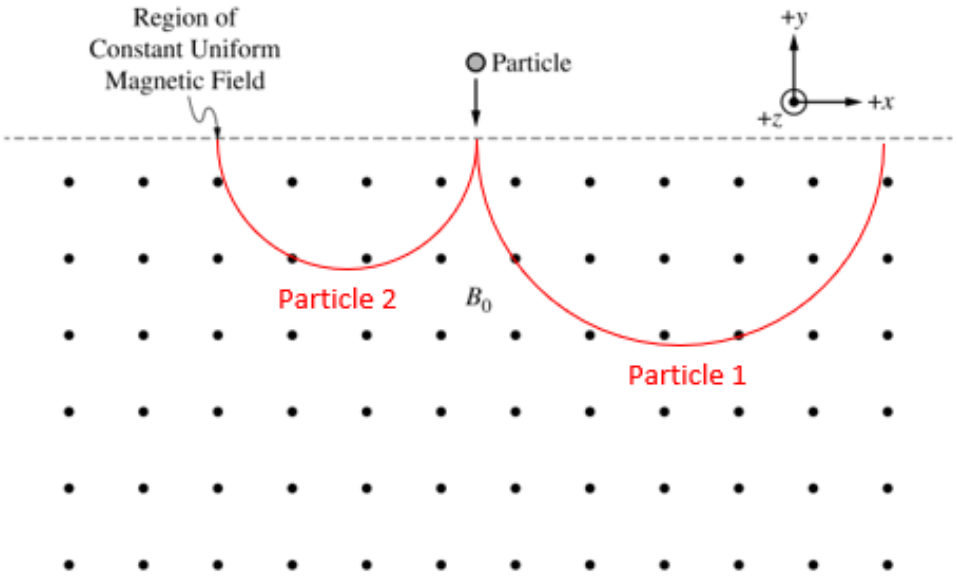
$K = \frac{1}{2}mv^2$

$K_2 = \frac{1}{2}\left(\frac{M}{2}\right)v^2$

$v = 2\sqrt{\frac{K_2}{M}}$

(c)	For drawing a path for Particle 1 that is concave up and to the right	**1 point**
	For drawing a path for Particle 2 that is concave up and in the opposite direction of Particle 1	**1 point**
	For drawing the path for Particle 1 with a larger radius of curvature than the path for Particle 2	**1 point**

Example Response



Total for part (c) **3 points**

(d)	For indicating **one** of the following: • That the electric field is directed in the $+x$-direction • A direction of the electric field that is consistent with the path of Particle 1 drawn in part (c)	**1 point**

Example Response

$+x$-direction

Total for part (d) **1 point**

Total for question 4 **10 points**