2024

AP

AP® Physics 2: Algebra-Based

Sample Student Responses and Scoring Commentary

Inside:

Free-Response Question 4

☑ Scoring Guidelines

☑ Student Samples

☑ Scoring Commentary

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

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

(b)(ii) For substituting an appropriate expression for the magnetic force exerted on a moving charged particle in a magnetic field into a Newton's second law equation **1 point**

Example Response

$$\vec{a}_c = \frac{q\vec{v} \times \vec{B}}{m}$$

For correct substitutions of the mass, charge, and speed of Particle 2 from the response in part (b)(i) into an appropriate expression **1 point**

Example Response

$$r = \frac{\left(\frac{M}{2}\right)\left(2\sqrt{\frac{K_2}{M}}\right)}{2QB_0}$$

For indicating that $\Delta x = 2r$ **1 point**

Example Solution

$$\vec{a} = \frac{\sum \vec{F}}{m}$$

$$\vec{a}_c = \frac{q\vec{v} \times \vec{B}}{m}$$

$$\frac{v^2}{r} = \frac{qvB}{m}$$

$$r = \frac{mv}{qB}$$

$$r = \frac{\left(\frac{M}{2}\right)\left(2\sqrt{\frac{K_2}{M}}\right)}{2QB_0}$$

$$r = \frac{\sqrt{K_2 M}}{2QB_0}$$

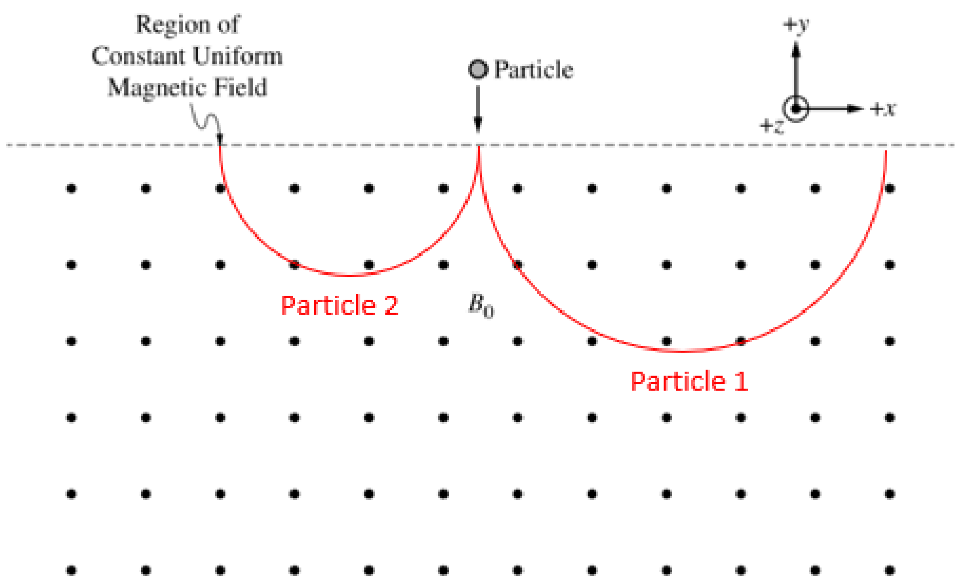
$$\Delta x = 2r$$

$$\Delta x = \frac{\sqrt{K_2 M}}{QB_0}$$

Total for part (b) 4 points

(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**

Question 4

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 $\frac{K_2}{K_1}$.

$K_1 = q\Delta V = Q\Delta V$

$K_2 = q\Delta V = 2Q\Delta V$

$\frac{K_2}{K_1} = \frac{2Q\Delta V}{Q\Delta V} = \boxed{\frac{2}{1}}$

Question 4

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

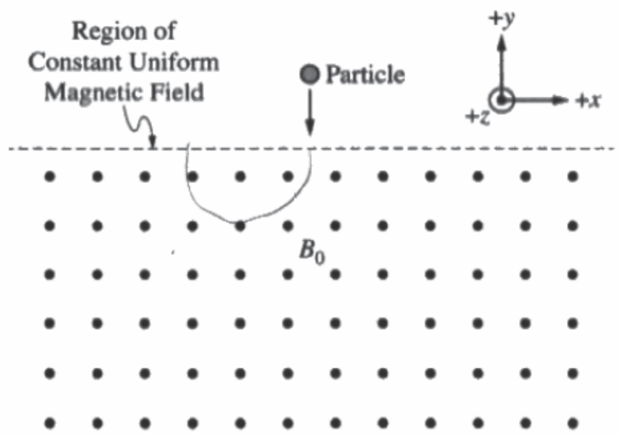


Figure 1

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.

$\frac{1}{2}(\frac{1}{2}M)v^2 = K_2$ $\quad v = \sqrt{\frac{4K_2}{M}}$

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.

$(2Q)vB = F_m = F_c = \frac{\frac{1}{2}Mv^2}{r} = \frac{\frac{1}{2}M(\frac{4K_2}{M})}{r} = \frac{2K_2}{r}$ $\quad r = \frac{2K_2}{2QvB_0}$

$\Delta x = 2r = \frac{2K_2}{Q\sqrt{\frac{4K_2}{M}}B_0}$

GO ON TO THE NEXT PAGE.

Question 4

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.

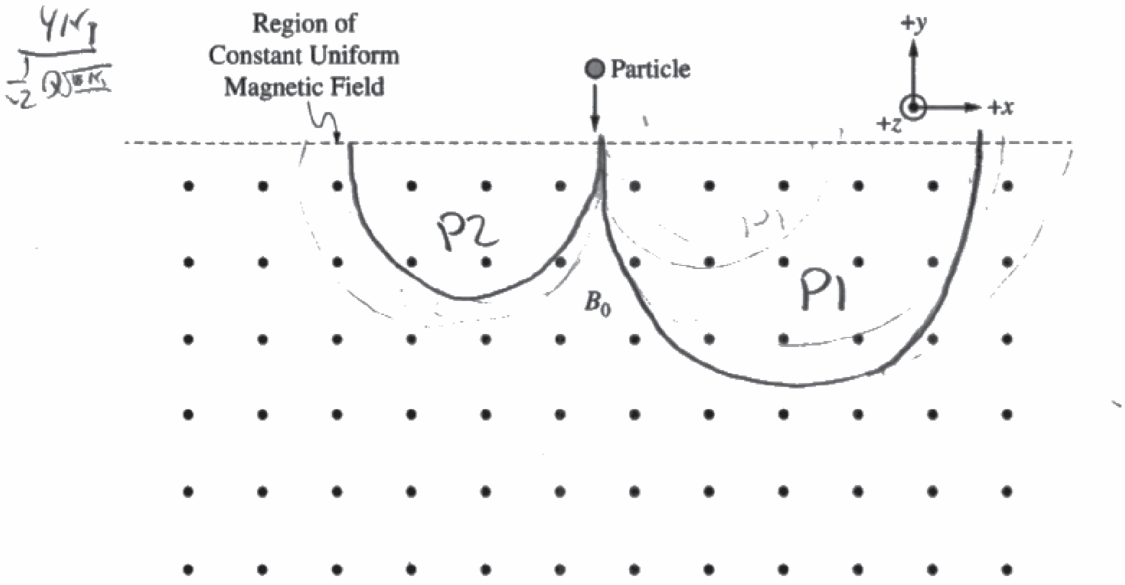


Figure 2

(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.

The direction must be to the right.

Question 4

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.

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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 $\frac{K_2}{K_1}$.

$K = \Delta U_E = q\Delta V$

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

$\frac{K_2}{K_1} = \frac{(+2Q)\Delta V}{(-Q)\Delta V} = 2$

Question 4

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

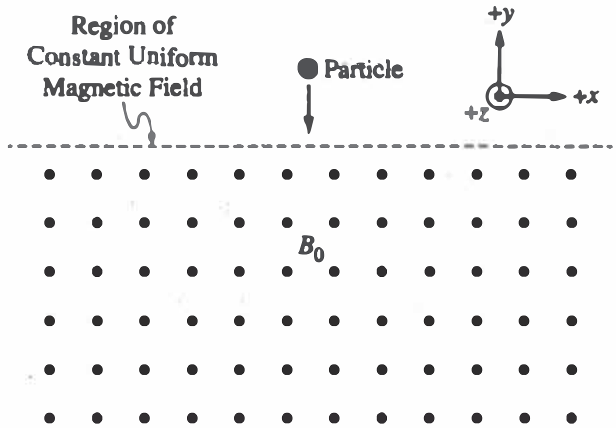


Figure 1

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.

$F_M = qvB = \frac{mv^2}{r}$

$K_2 = \Delta U_E = q\Delta V$

$2QB_0 = \frac{Mv}{r2}$

$v = \frac{QB_0 r}{M}$

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.

$\Delta x = 2r$

$r = \frac{\Delta x}{2}$

$qvB_0 = \frac{Mv^2}{r}$ ← $F_m = F_c$

$QB_0 r = MV$

$QB_0 \cdot \frac{\Delta x}{2} = MV$

$\Delta x = \frac{2MV}{QB_0}$

Question 4

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.

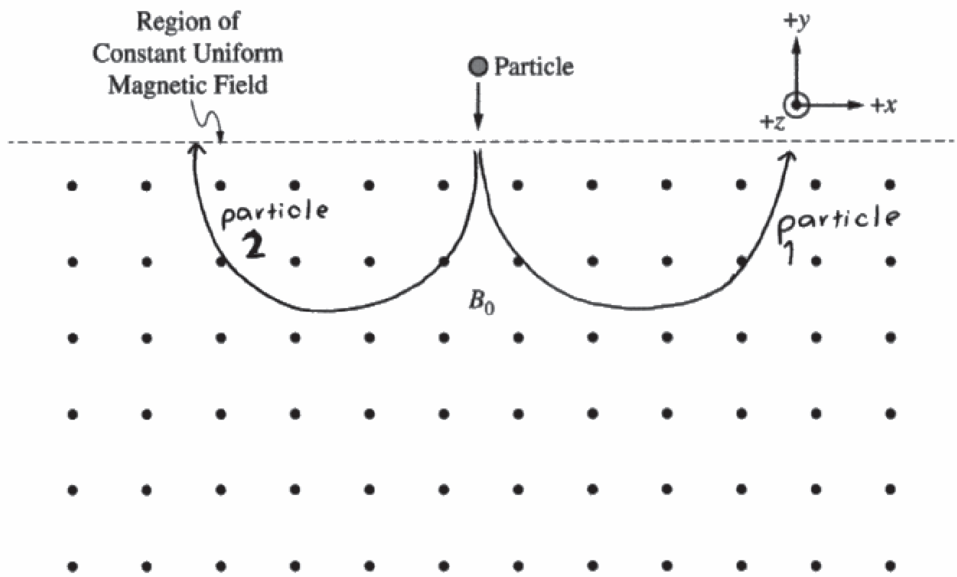
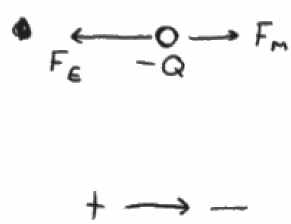


Figure 2

(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.

The electric field is directed in the +x direction.



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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.

$\Delta V = Q/C$

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

$$\frac{K_2 \Rightarrow \frac{1}{2}mv^2}{K_1 = \frac{1}{2}mv^2} \Rightarrow \frac{\frac{1}{2}\cdot\left(\frac{M}{2}\right)\cdot\left(\frac{2Q}{C}\right)^2}{\frac{1}{2}\cdot M\cdot\left(\frac{-Q}{C}\right)^2} \Rightarrow \frac{\left(\frac{m}{2}\right)\cdot\left(\frac{2Q^2}{C^2}\right)}{M\cdot\left(\frac{-Q^2}{C^2}\right)}$$

Question 4

Continue your response to QUESTION 4 on this page.

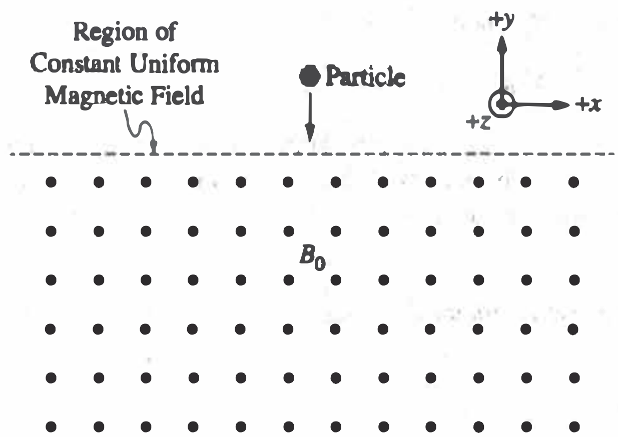

Figure 1

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.

$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$ $\quad K_2 = \frac{1}{2}mv^2$

$K_2 = \frac{1}{2}\left(\frac{M}{2}\right)\cdot\left(\frac{1}{4\pi\varepsilon_0}\cdot\frac{2q}{r}\right)^2$

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.

$B_0 = \frac{\mu_0}{2\pi}\frac{I}{r} \Rightarrow r = \frac{\mu_0 I}{2\pi \cdot B_0}$ $\quad \Delta X = K \cdot r \Rightarrow \frac{1}{2}\left(\frac{M}{2}\right)\cdot\left(\frac{1}{4\pi\varepsilon_0}\cdot\frac{2q}{\mu_0 I / 2\pi \cdot B_0}\right)^2$

Question 4

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.

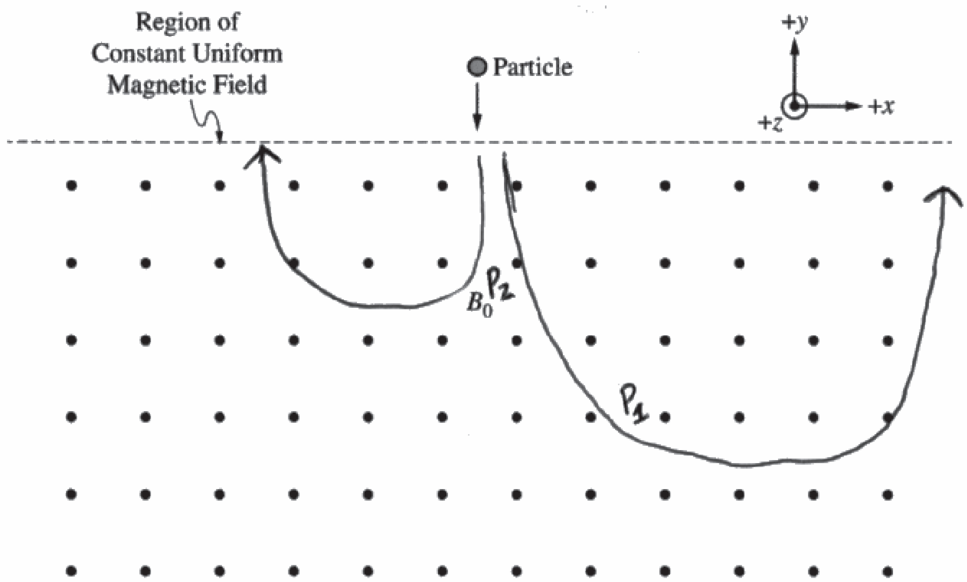

Figure 2

(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.

The electric field would be directed to the left out of the page such that it counteracts the current field leaving the particle 2 to travel straight through and feel no force.

Question 4

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

The responses were expected to demonstrate the ability to:

- Relate the kinetic energies of two charged particles that are accelerated from rest through an electric potential difference as a ratio.
- Determine an expression for the speed of a particle using its kinetic energy.
- Derive an expression for the speed of a charged particle in the presence of a magnetic field using Newton's second law of motion.
- Sketch the path of a charged particle moving through a uniform magnetic field.
- Determine the direction of an electric field that would allow a charged particle to move through a magnetic field with a constant velocity.

Sample: 4A
Score: 10

Part (a) earned 2 points. The first point was earned for correctly indicating that the final kinetic energy of a particle is equal to $|q\Delta V|$. The second point was earned for giving the correct ratio between K_2 and K_1 ($\frac{K_2}{K_1} = 2$). Part (b) earned 4 points. The first point was earned for determining a correct expression for v in terms of K_2 and M. The second point was earned for correctly substituting an expression for magnetic force into a Newton's second law equation. The third point was earned for correctly substituting the mass, charge, and speed of Particle 2 from part (b)(i) into an appropriate expression. The fourth point was earned for correctly indicating that $\Delta x = 2r$. Part (c) earned 3 points. The first point was earned for correctly drawing the path for Particle 1 as concave up and to the right. The second point was earned for correctly drawing the path for Particle 2 as concave up and in the opposite direction as the path for Particle 1. The third point was earned for correctly drawing the path of Particle 1 with a larger radius of curvature than the path for Particle 2. Part (d) earned 1 point for correctly indicating that the electric field is directed in the $+x$-direction.

Sample Identifier: 4B
Score: 7

Part (a) earned 2 points. The first point was earned for correctly indicating that the final kinetic energy of a particle is equal to $|q\Delta V|$. The second point was earned for giving the correct ratio between K_2 and K_1 ($\frac{K_2}{K_1} = 2$). Part (b) earned 2 points. The first point was not earned because the response determines an incorrect expression for v that is not in terms of K_2 and M. The second point was earned for correctly substituting an expression for the magnetic force into a Newton's second law equation. The third point was not earned because the response does not correctly substitute the mass, charge, and speed of Particle 2 from part (b)(i) into an appropriate expression. The fourth point was earned for correctly indicating that $\Delta x = 2r$. Part (c) earned 2 points. The first point was earned for correctly drawing the path for Particle 1 as concave up and to the right. The second point was earned for correctly drawing the path for Particle 2 as concave up and in the opposite direction as the path for Particle 1. The third point was not earned because the response does not draw the path of Particle 1 with a larger radius of curvature than the path for Particle 2. Part (d) earned 1 point for correctly indicating that the electric field is directed in the $+x$-direction.

Question 4 (continued)

Sample: 4C
Score: 2

Part (a) did not earn any points. The first point was not earned because the response does not indicate that the final kinetic energy of a particle is equal to $|q\Delta V|$. The second point was not earned because the response does not give the correct ratio between K_2 and K_1 ($\frac{K_2}{K_1} = 2$). Part (b) did not earn any points. The first point was not earned because the response did not determine a correct expression for v in terms of K_2 and M. The second point was not earned because the response does not substitute an expression for magnetic force into a Newton's second law equation. The third point was not earned because the response does not substitute the mass, charge, and speed of Particle 2 from part (b)(i) into an appropriate expression. The fourth point was not earned because the response does not indicate that $\Delta x = 2r$. Part (c) earned 1 point. The first point was not earned because the response correctly draws the path for Particle 1 as concave up but incorrectly to the left rather than to the right. The second point was not earned because the response draws the path for Particle 2 as concave up but not in the direction opposite the path of Particle 1. The third point was earned for correctly drawing the path of Particle 1 with a larger radius of curvature than the path for Particle 2. Part (d) earned 1 point for correctly indicating that the electric field is directed in the $+x$-direction.