2025

AP® Physics C: Electricity and Magnetism

Sample Student Responses and Scoring Commentary

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Free-Response Question 4

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Question 4: Qualitative Quantitative Translation (QQT) — 8 points

A

For indicating that $F_2 > F_1$ — **Point A1**

For correctly relating the magnitude of the magnetic force to the magnitude of the magnetic field — **Point A2**

For indicating that the magnitude of the magnetic field at the location of Sphere 2 is greater than the magnitude of the magnetic field at the location of Sphere 1 by referring to either: — **Point A3**

- The relative distance from the spheres to Wires S and T
- The direction of the magnetic fields from Wires S and T at the locations of the spheres

Example Response

The magnitude of the magnetic force exerted on a sphere is directly proportional to Q, v, and B. Because Q and v are the same for both spheres, the difference in the magnitudes of the magnetic forces is due to the difference in the magnitudes of the magnetic fields at the locations of the spheres. The magnitude of the magnetic field is greater at the location of Sphere 2 than at the location of Sphere 1 because the fields from the wires are in the same direction. Therefore, $F_2 > F_1$.

B

For a multistep derivation that includes the equation $\oint \vec{B} \cdot d\vec{\ell} = \mu_0 I_{\text{enc}}$ or — **Point B1**

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I\left(d\vec{\ell} \times \hat{r}\right)}{r^2}$$

Scoring Note: Vector notation is not required for this point to be earned. A multistep derivation that includes $B = \frac{\mu_0 I}{2\pi d}$ can earn this point.

For a correct expression for the magnitude of the magnetic field due to the current in one wire at the location of Sphere 2 — **Point B2**

For indicating that the magnitude of the total field is twice that due to one wire — **Point B3**

Example Response

Determine the magnitude B of the magnetic field due to one wire.

$\oint \vec{B} \cdot d\vec{\ell} = \mu_0 I_{\text{enc}}$

$B(2\pi d) = \mu_0 I$

$B = \frac{\mu_0 I}{2\pi d}$

Determine B_{tot}.

$B_{\text{tot}} = \frac{\mu_0 I}{2\pi d} + \frac{\mu_0 I}{2\pi d}$

$B_{\text{tot}} = \frac{\mu_0 I}{\pi d}$

C	For indicating $F_{\text{new}} = F_2$	**Point C1**
	For indicating $B_{\text{tot}} = \frac{3\mu_0 I}{2\pi d} - \frac{\mu_0 I}{2\pi d}$ OR For indicating that the net magnitude of the magnetic field at the location of Sphere 2 will remain the same even though the field from Wire T will change	**Point C2**
	Example Response *The magnetic field at the location of Sphere 2 due to the current in Wire T is in the opposite direction to the magnetic field due to the current in Wire S. The current in Wire T is increased by a factor of 3. Therefore,* $B_{\text{tot}} = \frac{3\mu_0 I}{2\pi d} - \frac{\mu_0 I}{2\pi d} = \frac{\mu_0 I}{\pi d}$ *in this scenario. Thus,* $F_{\text{new}} = F_2$.	

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Question 4

PART A

$F_2 > F_1$

Since both spheres have the same charge and velocity the magnetic field strength determines the magnitude of the force on the spheres. At sphere 2 both wires produce a magnetic field in the $-z$ direction according to the right hand rule so the net magnetic field and therefore the net force on sphere 2 will be greater than that generated by a single wire d away from the sphere. At sphere 1 wire S produces a magnetic field in the $+z$ direction but wire T produces one in the $-z$ direction. This means the net magnetic field and therefore the magnetic force is less than that generated by a single wire d away. This means $F_2 > F_1$

PART B

$\oint B \cdot dl = \mu_0 I_{enc}$

$B_s(2\pi d) = \mu_0 I$ $\qquad B_S = B_T$

$B_s = \frac{\mu_0 I}{2\pi d}$

$B_{TOT} = B_S + B_T = 2B_S$

$\boxed{B_{TOT} = \frac{\mu_0 I}{\pi d}}$

Question 4 is continued on the next page.

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Question 4

PART C

$F_{new} = F_2$

since the sphere's velocity and charge didn't change, the magnitude of the magnetic field is what determines the magnitude of the force acting on the sphere. Wire T's new current will produce a magnetic field in the +z direction by the right hand rule which will mean the net magnetic force is the difference between the magnitudes of the magnetic fields.

Therefore $|B_{TOT_{new}}| = \frac{\mu_0(3I)}{2\pi d} - \frac{\mu_0(I)}{2\pi d} = \frac{\mu_0 I}{\pi d}$ so.

The magnitude of the magnetic force is the same.

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Question 4

PART A

$F_1 \leq F_2$

Although Sphere 1 has some negative force, Sphere 2 has a net force of 0 from the wires since it is equidistant from both, and the wires carry oppositely pointing currents.

PART B

$$B = \frac{\mu_0}{2\pi}\frac{I}{d}$$

$$B_{tot} = \frac{\mu_0}{2\pi}\frac{I}{d} + \frac{\mu_0}{2\pi}\frac{I}{d} = \frac{\mu_0 I}{\pi d}$$

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Question 4

PART C

$$F_B = qvB = \frac{qv\mu_0 I}{2\pi d}$$

$F_{New} \neq F_2$ & different magnitude

with I's in the same direction, the forces no longer cancel out, but since v_q and B both point positive F_{New} is negative and thus less than F_2

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Question 4

PART A

$F_2 < F_1$

The force is given by $F = ILB$.

Both wires have the same current I, and since sphere two is between the wires with current going opposite directions, net force = 0.

Sphere 1 is only acted on by wire 5, so the current is greater

PART B

$\oint B \cdot dl = \mu_0 I_{enc}$

$B \cdot 2\pi r = \mu_0 I_{enc}$

$B = \frac{\mu_0 I_{enc}}{2\pi r}$

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Question 4

PART C $F_{New} > F_e$

Now, the currents in the wire are going the same direction, so they are additive. Therefore, the magnitude of force is greater than it was. As shown by the derivation $B = \frac{\mu_0 I}{2\pi r}$, a greater current I leads to greater magnetic field magnitude. $F = IlB$, so greater B means that force will be greater,

Question 4

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

Overview

NEW for 2025: The question overviews can be found in the *Chief Reader Report on Student Responses* on AP Central.

Sample: 4A
Score: 8

Part A earned all three points. The first point (A1) was earned for correctly indicating F_2 is greater than F_1. The second point (A2) was earned for correctly relating the magnitude of the magnetic force to the magnitude of the magnetic field. The third point (A3) was earned for correctly indicating the magnitude of the magnetic field at the location of Sphere 2 is greater than the magnitude of the magnetic field at the location of Sphere 1 and referring to the directions of the magnetic fields from wires S and T at the location of the spheres.

Part B earned all three points. The first point (B1) was earned for including Ampere's law in a multistep derivation. The second point (B2) was earned for including a correct expression for the magnitude of the magnetic field due to the current in one wire at the location of Sphere 2. The third point (B3) was earned for correctly indicating that the magnitude of the total magnetic field is twice the magnitude of the magnetic field due to one wire.

Part C earned both points. The first point (C1) was earned for correctly indicating that F_{new} is equal to F_2. The second point (C2) was earned for indicating the correct expression for B_{tot}.

Sample: 4B
Score: 4

Part A earned one out of three points. The first point (A1) was earned for correctly indicating F_2 is greater than F_1. The second point (A2) was not earned because the response does not correctly relate the magnitude of the magnetic force to the magnitude of the magnetic field. The third point (A3) was not earned because the response does not correctly indicate that the magnitude of the magnetic field at the location of Sphere 2 is greater than the magnitude of the magnetic field at the location of Sphere 1.

Part B earned all three points. The first point (B1) was earned for providing a multistep derivation that includes a correct equation for the magnetic field due to the current in a long wire, as allowed by the scoring note for Point B1. The second point (B2) was earned for including a correct expression for the magnitude of the magnetic field due to the current in one wire at the location of Sphere 2. The third point (B3) was earned for correctly indicating that the magnitude of the total magnetic field is twice the magnitude of the magnetic field due to one wire.

Part C did not earn either point. The first point (C1) was not earned because the response does not correctly indicate that F_{new} is equal to F_2. The second point (C2) was not earned because the response does not indicate the correct expression for B_{tot} or indicate that the net magnetic field at the location of Sphere 2 will remain the same even though the magnetic field from Wire T will change.

Question 4 (continued)

Sample: 4C
Score: 1

Part A did not earn any of the three points. The first point (A1) was not earned because the response incorrectly indicates F_1 is greater than F_2. The second point (A2) was not earned because the response does not correctly relate the magnitude of the magnetic force to the magnitude of the magnetic field. The third point (A3) was not earned because the response does not correctly indicate that the magnitude of the magnetic field at the location of Sphere 2 is greater than the magnitude of the magnetic field at the location of Sphere 1.

Part B earned one out of three points. The first point (B1) was earned for including Ampere's law in a multistep derivation. The second point (B2) was not earned because the response does not include a correct expression for the magnitude of the magnetic field due to the current in one wire at the location of Sphere 2, in terms of the given variables. The third point (B3) was not earned because the response does not indicate that the magnitude of the total magnetic field is twice the magnitude of the magnetic field due to one wire.

Part C did not earn either point. The first point (C1) was not earned because the response incorrectly indicates that F_{new} is greater than F_2. The second point (C2) was not earned because the response does not indicate the correct expression for B_{tot} or indicate that the net magnitude of the magnetic field at the location of Sphere 2 will remain the same even though the magnetic field from Wire T will change.