2022

AP CollegeBoard

AP® Physics 1: Algebra-Based

Sample Student Responses and Scoring Commentary

Inside:

Free-Response Question 2

- ☑ **Scoring Guidelines**
- ☑ **Student Samples**
- ☑ **Scoring Commentary**

Question 2: Qualitative/Quantitative Translation — 12 points

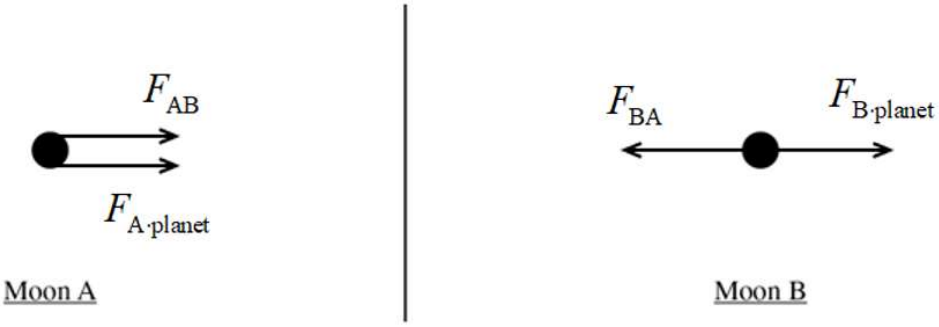
(a) For two forces directed to the right on Moon A, correctly labeled, with no extraneous forces — **1 point**

For two horizontal forces in opposite directions on Moon B. The labels on the forces must be correct and distinguishable from each other, with no extraneous forces. — **1 point**

Scoring Notes:

- Acceptable labels for forces include: F_{AB}, $F_{A\text{ on }B}$, F_{planet}, F_{moon}, F_0, F_p, F_{gA}, etc.
- Maximum 1 point can be earned if the arrows do not start on the dot.

Example Response



Total for part (a) — **2 points**

(b)(i) For indicating the force vectors on Moon A point in the same direction and therefore, the magnitudes add, while the force vectors on Moon B point in opposite directions and the magnitudes are to be subtracted — **1 point**

Example Response

The force vectors on Moon A point in the same direction and therefore add, while the force vectors on Moon B point in opposite directions and will subtract.

(b)(ii) For a justification based on the inverse relation between gravitational force and distance — **1 point**

Scoring Note: This point may be earned in either part (b)(i) or (b)(ii).

For indicating Moon B is closer to the planet than Moon A, and therefore, the gravitational force exerted by the planet is larger for Moon B than for Moon A — **1 point**

Example Response

The gravitational force is greater for objects that are closer together, and Moon B is closer to the planet than Moon A, so the gravitational force from the planet is greater for Moon B than for Moon A.

Total for part (b) — **3 points**

(c) For using the law of gravitation at least once **1 point**

For substituting in correct distances in all expressions **1 point**

For substituting in correct masses in all expressions **1 point**

For correctly adding terms for ΣF_A and subtracting terms for ΣF_B **1 point**

Scoring Note: An overall negative sign on either force is acceptable.

Example Response

Moon A

$F_g = G\frac{m_1 m_2}{r^2}$

$\Sigma F_A = F_{A\cdot planet} + F_{AB}$

$\Sigma F_A = G\frac{m_0 m_p}{R_A{}^2} + G\frac{m_0{}^2}{(R_A - R_B)^2}$

$\Sigma F_A = Gm_0\left(\frac{m_p}{R_A{}^2} + \frac{m_0}{(R_A - R_B)^2}\right)$

Moon B

$F_g = G\frac{m_1 m_2}{r^2}$

$\Sigma F_B = F_{B\cdot planet} - F_{BA}$

$\Sigma F_B = G\frac{m_0 m_p}{R_B{}^2} - G\frac{m_0{}^2}{(R_A - R_B)^2}$

$\Sigma F_B = Gm_0\left(\frac{m_p}{R_B{}^2} - \frac{m_0}{(R_A - R_B)^2}\right)$

Total for part (c) 4 points

(d)(i) For addressing the functional dependence expressed in the equations from part (c) **1 point**

Scoring Notes:

- It is not necessary to use the functional dependence correctly to earn this point.
- This point may be earned in either part (d)(i) or (d)(ii).

For a correct explanation for why the expressions in part (c) either support or do not support the reasoning consistent with response in part (b)(i) **1 point**

Example Response

Yes. For the net force on Moon A, both force terms have the same sign, so they add, while for the net force on Moon B, the two terms have opposite signs, so they have a canceling effect.

(d)(ii) For a correct explanation for why the expressions in part (c) either support or do not support the reasoning consistent with response in part (b)(ii) **1 point**

Example Response

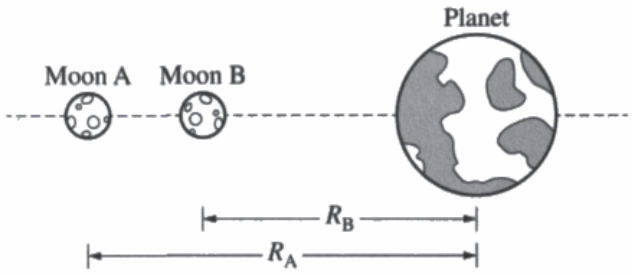
The gravitational force has an inverse relationship with distance. If Moon A is very far away, ΣF_A *from part (c) will be small. If Moon B is close to the planet while Moon A is far away, the force toward the planet would be big while the force toward the moon would be small such that* ΣF_B *could be larger than* ΣF_A.

Total for part (d) 3 points

Total for question 2 12 points

Question 2

Begin your response to **QUESTION 2** on this page.

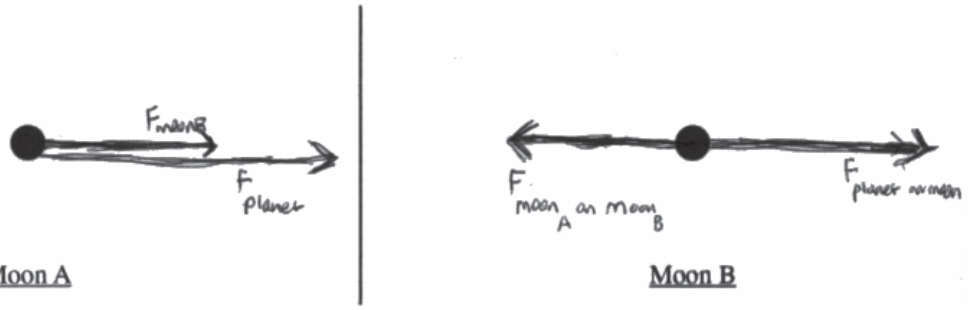


Note: Figure not drawn to scale.

2. (12 points, suggested time 25 minutes)

Two identical moons, Moon A and Moon B, orbit a planet. The mass m_0 of each moon is significant, but less than the mass m_p of the planet. At some point in their orbits, the planet and the two moons are aligned as shown in the figure.

(a) The following dots represent the two moons when they are at the locations shown in the previous figure. On each dot, draw and label the forces (not components) exerted on Moon A and on Moon B. Each force must be represented by a distinct arrow starting on, and pointing away from, the appropriate dot.



(b) Consider the net gravitational force exerted on each moon due to the planet and the other moon.

i. Justify why the magnitude of the net force exerted on Moon A could be larger than the magnitude of the net force exerted on Moon B.

All applied forces on Moon A are in the same direction, equating to a larger net force. On Moon B however, the two main forces applied are in opposite directions, equating to a smaller net force applied.

Question 2

Continue your response to **QUESTION 2** on this page.

ii. Justify why the magnitude of the net force exerted on Moon B could be larger than the magnitude of the net force exerted on Moon A.

The distance of each moon from the planet is different. Since Moon A is farther from the planet than Moon B, the gravitational force of the planet on Moon A is much smaller. If Moon A is very far while Moon B is very close to the planet, then the net force on Moon B will be greater than that of Moon A.

(c) Derive expressions for both of the following quantities. Express your answers in terms of m_0, m_p, R_A, R_B, and physical constants, as appropriate.

- The net force F_A exerted on Moon A

$$F_g = G\frac{m_1 m_2}{r}$$

$$F_{g(\text{planet})_A} = G\frac{m_0 m_p}{R_A}$$

$$F_{g(\text{moon B})} = G\frac{m_0^2}{R_A - R_B}$$

$$F_{\text{net on A}} = G\frac{m_0 m_p}{R_A} + G\frac{m_0^2}{R_A - R_B}$$

- The net force F_B exerted on Moon B

$$F_{g(\text{planet})_B} = G\frac{m_0 m_p}{R_B}$$

$$F_{g(\text{moon A})} = G\frac{m_0^2}{R_A - R_B}$$

$$F_{\text{net on B}} = G\frac{m_0 m_p}{R_B} - \frac{G m_0^2}{R_A - R_B}$$

GO ON TO THE NEXT PAGE.

Question 2

Continue your response to **QUESTION 2** on this page.

(d)

i. Could the expressions in part (c) support your reasoning in part (b)(i) ?

✓ Yes ___ No

Explain your reasoning.

If R_A is a relatively small value while being larger than R_B, then both $F_{g_{planet_A}}$ and $F_{g_{moon\,B}}$ are relatively large values. Since the sum of these values is taken, the resulting net force would be larger for Moon A than Moon B. Moon B's net force value would be closer to 0 because $F_{g_{moon\,A}}$ would negate a larger value of the $F_{g_{planet_A}}$.

ii. Could the expressions in part (c) support your reasoning in part (b)(ii) ?

✓ Yes ___ No

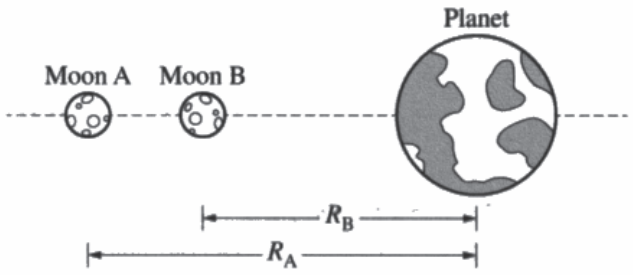
Explain your reasoning.

If R_A is a relatively large value while R_B is a small value, then $F_{g_{planet_A}}$ would be a relatively small value due to the denominator R_A being larger. This also would mean $F_{g_{moon\,B}}$ is a small value because the difference $R_A - R_B$ would be closer to R_A.

Since R_B is a small value, $F_{g_{planet_B}}$ would be a large value (inversely proportional) and this would thus result in $F_{net\,on\,B} > F_{net\,on\,A}$

Question 2

Begin your response to **QUESTION 2** on this page.



Note: Figure not drawn to scale.

2. (12 points, suggested time 25 minutes)

Two identical moons, Moon A and Moon B, orbit a planet. The mass m_0 of each moon is significant, but less than the mass m_p of the planet. At some point in their orbits, the planet and the two moons are aligned as shown in the figure.

(a) The following dots represent the two moons when they are at the locations shown in the previous figure. On each dot, draw and label the forces (not components) exerted on Moon A and on Moon B. Each force must be represented by a distinct arrow starting on, and pointing away from, the appropriate dot.

(b) Consider the net gravitational force exerted on each moon due to the planet and the other moon.

i. Justify why the magnitude of the net force exerted on Moon A could be larger than the magnitude of the net force exerted on Moon B.

If the mass of Moon A is greater than the mass of Moon B, the magnitude of the net force exerted on Moon A could be larger than the magnitude of the net force exerted on Moon B, by $|\vec{F}_g| = \frac{Gm_0m_p}{r^2}$

*M_0 is in the numerator.

GO ON TO THE NEXT PAGE.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 2

Continue your response to **QUESTION 2** on this page.

ii. Justify why the magnitude of the net force exerted on Moon B could be larger than the magnitude of the net force exerted on Moon A.

By $|\vec{F}_g| = \frac{Gm_0m_p}{r^2}$, since the radius of Moon B (R_B) is less than the radius of Moon A (R_A), the net force exerted on Moon B is larger than the net force on Moon A.

Smaller radius equals a larger force since 'r' is in the denominator

(c) Derive expressions for both of the following quantities. Express your answers in terms of m_0, m_p, R_A, R_B, and physical constants, as appropriate.

- The net force F_A exerted on Moon A

$$|\vec{F}_A| = \frac{Gm_0m_p}{(R_A)^2}$$

- The net force F_B exerted on Moon B

$$|\vec{F}_B| = \frac{Gm_0m_p}{(R_B)^2}$$

GO ON TO THE NEXT PAGE.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

0089043

Q5330/7

Question 2

Continue your response to **QUESTION 2** on this page.

(d)

i. Could the expressions in part (c) support your reasoning in part (b)(i) ?

✓ Yes ___ No

Explain your reasoning.

Since "m_0" is in the numerator of $|\vec{F}_g| = \frac{G m_0 m_p}{r^2}$, as '$m_0$' increases, so does the magnitude of the net force exerted on Moon A. (F_A)

ii. Could the expressions in part (c) support your reasoning in part (b)(ii) ?

✓ Yes ___ No

Explain your reasoning.

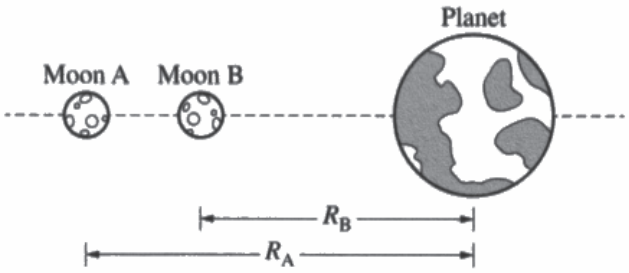
Since "r" is in the denominator of $|\vec{F}_g| = \frac{G m_0 m_p}{r^2}$, as '$r$' decreases, then the magnitude of the net force (F_B) exerted on Moon B will increase.

GO ON TO THE NEXT PAGE.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 2

Begin your response to **QUESTION 2** on this page.



Note: Figure not drawn to scale.

2. (12 points, suggested time 25 minutes)

Two identical moons, Moon A and Moon B, orbit a planet. The mass m_0 of each moon is significant, but less than the mass m_p of the planet. At some point in their orbits, the planet and the two moons are aligned as shown in the figure.

(a) The following dots represent the two moons when they are at the locations shown in the previous figure. On each dot, draw and label the forces (not components) exerted on Moon A and on Moon B. Each force must be represented by a distinct arrow starting on, and pointing away from, the appropriate dot.

(b) Consider the net gravitational force exerted on each moon due to the planet and the other moon.

i. Justify why the magnitude of the net force exerted on Moon A could be larger than the magnitude of the net force exerted on Moon B.

The magnitude of the net force exerted on Moon A could be larger because the mass (inertia) of Moon A can be greater than the mass (inertia) of Moon B.

Question 2

Continue your response to **QUESTION 2** on this page.

ii. Justify why the magnitude of the net force exerted on Moon B could be larger than the magnitude of the net force exerted on Moon A.

The magnitude of the net force exerted on moon B could be larger because moon B has a smaller radius / distance to the planet.

(c) Derive expressions for both of the following quantities. Express your answers in terms of m_0, m_p, R_A, R_B, and physical constants, as appropriate.

- The net force F_A exerted on Moon A

$F_g = G\frac{m_1 m_2}{r^2}$ $\quad F_A = G\frac{2m_0}{R_A^2}$

- The net force F_B exerted on Moon B

$F_g = \frac{G m_1 m_2}{r^2}$ $\quad F_B = \frac{G(m_0 + m_0 + m_p)}{(R_A + R_B)^2}$

GO ON TO THE NEXT PAGE.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

0067249

Q5330/7

Question 2

Continue your response to **QUESTION 2** on this page.

(d)

i. Could the expressions in part (c) support your reasoning in part (b)(i) ?

✓ Yes ___ No

Explain your reasoning.

Yes, because if F_A is only being influenced by the gravitational force of Moon B while F_B is influenced by both the gravitational force of Moon A and the planet. The greater the mass, the more gravitational force is being exerted. If there is a greater distance, the gravitational force is less.

$$F_G = \frac{G m_1 m_2}{r^2}$$

ii. Could the expressions in part (c) support your reasoning in part (b)(ii) ?

✓ Yes ___ No

Explain your reasoning.

Yes, because if there is a greater distance between both objects, the gravitational force is less. since Moon A has a larger distance, the F_B would be less than F_B.

GO ON TO THE NEXT PAGE.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 2

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

Overview

The responses were expected to demonstrate the ability to:

- Describe the gravitational forces between multiple objects of different masses and different distances from each other.
- Create appropriately labeled free-body diagrams for multiple forces exerted on a single object.
- Make a conceptual argument about gravitational interactions between objects.
- Derive an equation using Newton's second law.
- Determine consistency between reasoning based on a conceptual argument and a derived equation.

Sample: 2A
Score: 11

Part (a) earned 2 points. The first point was earned because the free-body diagram for Moon A is correctly drawn and labeled. The second point was earned because the free-body diagram for Moon B is correctly drawn and labeled with different labels for each force. Part (b)(i) earned 1 point because the response correctly states that all applied forces on Moon A are in the same direction while the forces on Moon B are in opposite directions. Part (b)(ii) earned 2 points. The first point was earned because the response correctly states that a larger distance will result in a smaller gravitational force. The second point was earned because the response states that because Moon B is closer to the planet than Moon A, Moon B will experience a larger gravitational force from the planet. Part (c) earned 3 points. The first point was not earned because the response has an incorrect form of the law of gravitation. The second point was earned because the response shows the correct substitutions of moon distances. The third point was earned because the response shows the correct substitutions of moon and planet masses. The fourth point was earned because the response shows the addition of forces on Moon A and the difference of forces on Moon B. Part (d)(i) earned 1 point because the response correctly relates the force described as being in the same direction in part (b)(i) to the addition of forces in the equation in part (c). Part (d)(ii) earned 2 points. The first point was earned because the response correctly reasons that a smaller distance between Moon B and the planet results in an increase in gravitational force. The second point was earned because the response correctly states that the increase in force between Moon B and the planet could overcome the opposing force caused by Moon A if the distance between the moons is large enough.

Sample: 2B
Score: 6

Part (a) earned 0 points. The first point was not earned because the response shows only one arrow that is not labeled as a force. The second point was not earned because the response shows only one arrow that is not labeled as a force. Part (b)(i) earned 0 points because the response incorrectly states that the mass of Moon A is greater than Moon B and does not address the summation of forces. Part (b)(ii) earned 2 points. The first point was earned for an equation that demonstrates the inverse relationship between distance and the gravitational force. The second point was earned for correctly reasoning that Moon B is closer to the planet than Moon A and could, therefore, have a larger net force. Part (c) earned 3 points. The first point was earned for a response that uses the correct form of the law of gravitation. The second point was earned for a response that correctly substitutes the distance to each planet into the law of gravitation relationship. The third point was earned for correctly substituting the masses of the moons and planet. The fourth point was not earned because the response does not show the addition or subtraction of forces. Part (d)(i) earned 0 points because the response incorrectly suggests that the mass of the moon may be increased and does not address the summation of forces. Part (d)(ii) earned 1 point. The first point was earned for a response that correctly recognizes a functional relationship between distance and force of gravity. The second point was not earned because the response does not describe how the net force on Moon B relates to Moon A.

Question 2 (continued)

Sample: 2C
Score: 4

Part (a) earned 1 point. The first point was not earned because the response shows only one arrow. The second point was earned because the free-body diagram for Moon B is correctly drawn and labeled with different labels for each force. Part (b)(i) earned 0 points because the response incorrectly states that the mass of Moon A is greater than the mass of Moon B and does not address the summation of forces. Part (b)(ii) earned 1 point. The first point was not earned because the response does not address the inverse relationship between distance and gravitational force. The second point was earned for a response that correctly reasons that Moon B is closer to the planet than Moon A and could, therefore, have a larger net force. Part (c) earned 1 point. The first point was earned for a response that used the correct form of the law of gravitation. The second point was not earned because the response does not correctly substitute the distance to Moon B. The third point was not earned because the response does not correctly substitute the masses into the law of gravitation. The fourth point was not earned because the response does not correctly show the addition and subtraction of the forces. Part (d)(i) earned 0 points because the response does not complete the argument for how the direction of the gravitational forces influence the net force. Part (d)(ii) earned 1 point. The first point was earned for a response that correctly recognizes a functional relationship between distance and force of gravity. The second point was not earned because the response incorrectly states the argument that the equation in part (c) agrees with the argument in part (b)(ii).