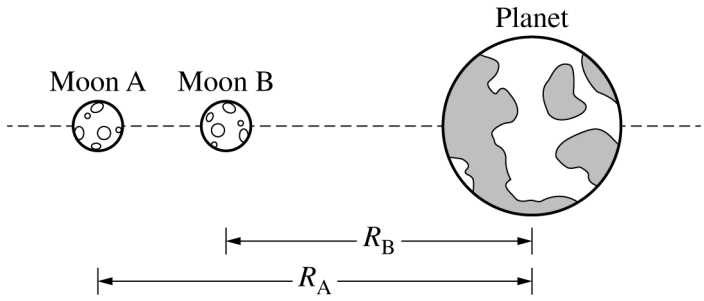
Begin your response to **QUESTION 2** on this page.




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.

Moon A

Moon B

(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.

**GO ON TO THE NEXT PAGE.**

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.

(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

• The net force $F_B$ exerted on Moon B

**GO ON TO THE NEXT PAGE.**

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.

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

___ Yes ___ No

Explain your reasoning.

**GO ON TO THE NEXT PAGE.**

## Question 2: Qualitative/Quantitative Translation — 12 points

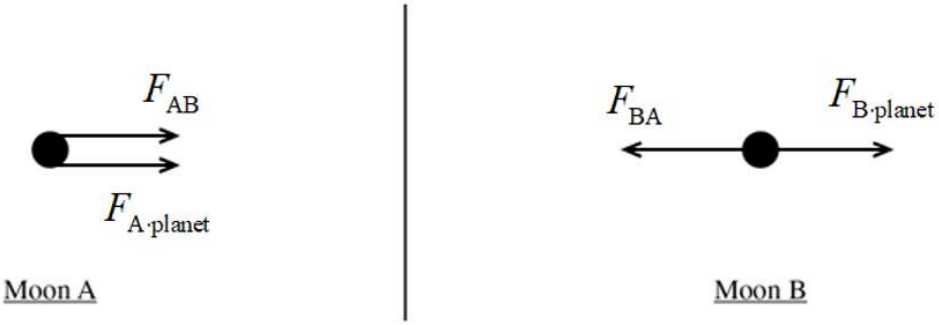
**(a)** For two forces directed to the right on Moon A, correctly labeled, with no extraneous forces — **1 point**

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 $\Sigma F_A$ and subtracting terms for $\Sigma F_B$ **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, $\Sigma F_A$ 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 $\Sigma F_B$ could be larger than $\Sigma F_A$.*

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

**Total for question 2 12 points**