2018

AP CollegeBoard

AP Physics 1: Algebra-Based

Sample Student Responses and Scoring Commentary

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Free Response Question 1

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AP® PHYSICS
2018 SCORING GUIDELINES

General Notes About 2018 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. The requirements that have been established for the paragraph-length response in Physics 1 and Physics 2 can be found on AP Central at https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf.

3. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based Course and Exam Description* and the *AP Physics 2: Algebra-Based Course and Exam Description*.

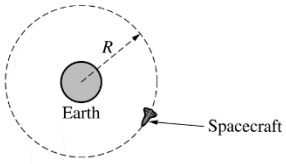
5. The scoring guidelines typically show numerical results using the value $g = 9.8\ \text{m/s}^2$, but the use of $10\ \text{m/s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

6. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

AP® PHYSICS 1
2018 SCORING GUIDELINES

Question 1

7 points total **Distribution of points**

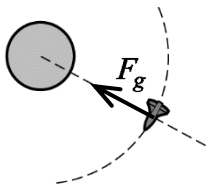


Note: Figure not drawn to scale.

A spacecraft of mass m is in a clockwise circular orbit of radius R around Earth, as shown in the figure above. The mass of Earth is M_E.

(a) LO / SP: 3.A.2.1 / 1.1; 3.B.2.1 / 1.1, 1.4
2 points

In the figure below, draw and label the forces (not components) that act on the spacecraft. Each force must be represented by a distinct arrow starting on, and pointing away from, the spacecraft.



Note: Figure not drawn to scale.

For an arrow directed toward Earth's center		1 point
For a correct label on the arrow representing the gravitational force, where the arrow is pointing toward Earth's center		1 point
Note: A maximum of 1 point may be earned if extraneous forces are present.		

Question 1 (continued)

Distribution of points

(b) LO / SP: 2.B.2.1 / 2.2; 3.A.1.1 / 1.5, 2.2; 3.B.1.3 / 1.5, 2.2; 3.B.2.1 / 1.1, 1.4, 2.2, 3.C.1.2 / 2.2
4 points

i. 3 points

Derive an equation for the orbital period T of the spacecraft in terms of m, M_E, R, and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

For using (or implying) Newton's second law and equating the centripetal force to the gravitational force: $F_g = ma = \frac{mv^2}{R}$ $\qquad$ $\frac{GmM_E}{R^2} = \frac{mv^2}{R}$		1 point
For explicitly or implicitly determining that the speed of the spacecraft is: $v = \frac{2\pi R}{T}$		1 point
For a correct answer algebraically equivalent to: $T = \sqrt{\frac{4\pi^2 R^3}{GM_E}}$		1 point
Note: It is acceptable to leave answer in terms of T^2 $T^2 = \frac{4\pi^2 R^3}{GM_E}$		

ii. 1 point

A second spacecraft of mass $2m$ is placed in a circular orbit with the same radius R. Is the orbital period of the second spacecraft greater than, less than, or equal to the orbital period of the first spacecraft?

____ Greater than ____ Less than ____ Equal to

Briefly explain your reasoning.

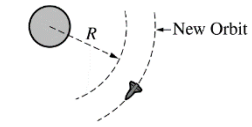
Correct answer: "Equal to" Note: For an incorrect answer consistent with part (b)(i), the explanation is still graded for consistency with part (b)(i).		
For a correct explanation that the period of the spacecraft does not depend on the spacecraft mass (or only depends on the mass of Earth and the radius of the orbit) OR an explanation consistent with the answer from (b)(i)		1 point
Note: The explanation must be consistent with the checked answer.		

Question 1 (continued)

Distribution of points

(c) LO / SP: 2.B.1.1 / 2.2; 3.A.1.1 / 1.5, 2.2; 3.B.1.3 / 1.5, 2.2; 3.B.2.1 / 1.1, 1.4, 2.2; 3.C.1.2 / 2.2
1 point

The first spacecraft is moved into a new circular orbit that has a radius greater than R, as shown in the figure below.



Note: Figure not drawn to scale.

Is the speed of the spacecraft in the new orbit greater than, less than, or equal to the original speed?

____ Greater than ____ Less than ____ Equal to

Briefly explain your reasoning.

Correct answer: "Less than" Note: If the wrong selection is made, the explanation is not graded.		
For a correct explanation of why speed decreases with increasing orbital radius		1 point
Example: Derivation step in (b)(i) shows that speed decreases with increasing R.		

Question 1 (continued)

Learning Objectives (LO)

LO 2.B.1.1: The student is able to apply $F = mg$ to calculate the gravitational force on an object with mass m in a gravitational field of strength g in the context of the effects of a net force on objects and systems. [See Science Practices 2.2 and 7.2]

LO 2.B.2.1: The student is able to apply $g = GM/r^2$ to calculate the gravitational field due to an object with mass M, where the field is a vector directed toward the center of the object of mass M. [See Science Practice 2.2]

LO 3.A.1.1: The student is able to express the motion of an object using narrative, mathematical, and graphical representations. [See Science Practices 1.5, 2.1, and 2.2]

LO 3.A.2.1: The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [See Science Practice 1.1]

LO 3.B.1.3: The student is able to re-express a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. [See Science Practices 1.5 and 2.2]

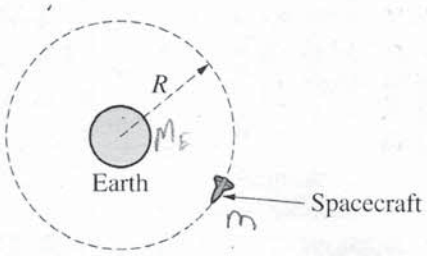
LO 3.B.2.1: The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [See Science Practices 1.1, 1.4, and 2.2]

LO 3.C.1.2: The student is able to use Newton's law of gravitation to calculate the gravitational force between two objects and use that force in contexts involving orbital motion (for circular orbital motion only in Physics 1). [See Science Practice 2.2]

P1 Q1 A p1

PHYSICS 1
Section II
Time—1 hour and 30 minutes
5 Questions

Directions: Questions 1, 4, and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.

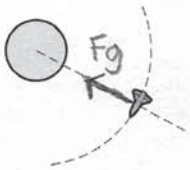


Note: Figure not drawn to scale.

1. (7 points, suggested time 13 minutes)

A spacecraft of mass m is in a clockwise circular orbit of radius R around Earth, as shown in the figure above. The mass of Earth is M_E.

(a) In the figure below, draw and label the forces (not components) that act on the spacecraft. Each force must be represented by a distinct arrow starting on, and pointing away from, the spacecraft.



Note: Figure not drawn to scale.

(b)

i. Derive an equation for the orbital period T of the spacecraft in terms of m, M_E, R, and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

$\Sigma F = ma$

$F_g = ma$

$G\frac{mM_E}{r^2} = \frac{mv^2}{r}$

$\frac{GM_E}{r} = \left(\frac{2\pi \cdot r}{T}\right)^2$

$\frac{GM_E}{r} = \frac{4\pi^2 \cdot r^2}{T^2}$

$T^2 = \frac{4\pi^2 \cdot r^2}{\left(\frac{GM_E}{r}\right)}$

$T^2 = \frac{4\pi^2 \cdot r^3}{GM_E}$

$T = \sqrt{\frac{4\pi^2 \cdot r^3}{GM_E}}$

GO ON TO THE NEXT PAGE.

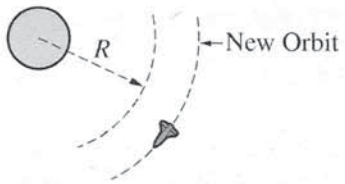
ii. A second spacecraft of mass $2m$ is placed in a circular orbit with the same radius R. Is the orbital period of the second spacecraft greater than, less than, or equal to the orbital period of the first spacecraft?

____ Greater than ____ Less than X Equal to

Briefly explain your reasoning.

The orbital period of the second spacecraft is the same as the first because in the equation $G\frac{mM_E}{r^2} = \frac{mv^2}{r}$, the mass of the spacecraft cancels on both sides of the equation, which means it does not affect the period. (No m in equation $T = \sqrt{\frac{4\pi^2 \cdot r^3}{GM_E}}$)

(c) The first spacecraft is moved into a new circular orbit that has a radius greater than R, as shown in the figure below.



Note: Figure not drawn to scale.

Is the speed of the spacecraft in the new orbit greater than, less than, or equal to the original speed?

____ Greater than X Less than ____ Equal to

Briefly explain your reasoning.

The speed of the spacecraft in the second orbit will be slower because in the equation $G\frac{mM_E}{r^2} = \frac{mv^2}{r}$ the m's and r's cancel and you get the eqvation $\frac{GM_E}{r} = v^2$. In the second orbit, r increases and so the number on the left side of the equation is smaller, This means that v^2 equals a smaller number than before, so therefore v decreases. (speed decreases).

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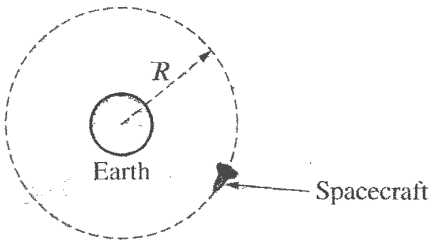

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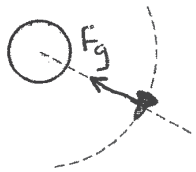
1. (7 points, suggested time 13 minutes)

A spacecraft of mass m is in a clockwise circular orbit of radius R around Earth, as shown in the figure above. The mass of Earth is M_E.

(a) In the figure below, draw and label the forces (not components) that act on the spacecraft. Each force must be represented by a distinct arrow starting on, and pointing away from, the spacecraft.



Note: Figure not drawn to scale.

(b)

i. Derive an equation for the orbital period T of the spacecraft in terms of m, M_E, R, and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

$\frac{mv^2}{R} = \frac{GmM_E}{R^2}$ $\quad v \sim \frac{1}{T}$

$v^2 = \frac{GM_E}{R}$ $\quad T = \frac{1}{\sqrt{\frac{GM_E}{R}}}$

$v = \sqrt{\frac{GM_E}{R}}$

ii. A second spacecraft of mass $2m$ is placed in a circular orbit with the same radius R. Is the orbital period of the second spacecraft greater than, less than, or equal to the orbital period of the first spacecraft?

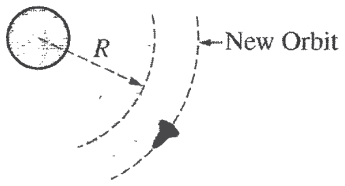
____ Greater than ____ Less than ✓ Equal to

Briefly explain your reasoning.

$T = \frac{1}{\sqrt{\frac{GM_E}{R}}}$

m is not in equation, therefore mass of spacecraft doesn't affect the orbital period.

(c) The first spacecraft is moved into a new circular orbit that has a radius greater than R, as shown in the figure below.



Note: Figure not drawn to scale.

Is the speed of the spacecraft in the new orbit greater than, less than, or equal to the original speed?

____ Greater than ✓ Less than ____ Equal to

Briefly explain your reasoning.

$v = \sqrt{\frac{GM_E}{R}}$ If R increases then $\sqrt{\frac{GM_E}{R}}$ decreases

PHYSICS 1
Section II
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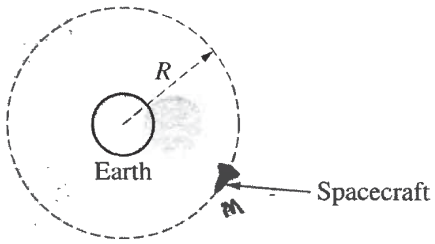

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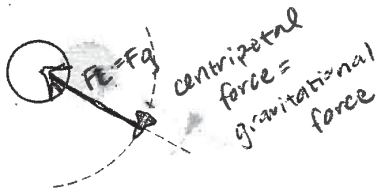
1. (7 points, suggested time 13 minutes)

A spacecraft of mass m is in a clockwise circular orbit of radius R around Earth, as shown in the figure above. The mass of Earth is M_E.

(a) In the figure below, draw and label the forces (not components) that act on the spacecraft. Each force must be represented by a distinct arrow starting on, and pointing away from, the spacecraft.



Note: Figure not drawn to scale.

(b)

i. Derive an equation for the orbital period T of the spacecraft in terms of m, M_E, R, and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

$F_g = G\frac{m_1 m_2}{r}$ $\quad T = 2\pi\sqrt{\quad}$

$|F_g| = G\frac{m M_E}{R}$

GO ON TO THE NEXT PAGE.

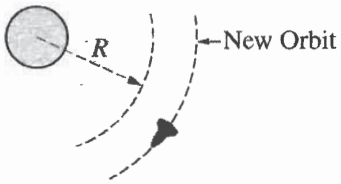
ii. A second spacecraft of mass $2m$ is placed in a circular orbit with the same radius R. Is the orbital period of the second spacecraft greater than, less than, or equal to the orbital period of the first spacecraft?

____ Greater than X Less than ____ Equal to

Briefly explain your reasoning.

The increase in mass causes the decrease in T due to the derived formula.

(c) The first spacecraft is moved into a new circular orbit that has a radius greater than R, as shown in the figure below.



Note: Figure not drawn to scale.

Is the speed of the spacecraft in the new orbit greater than, less than, or equal to the original speed?

X Greater than ____ Less than ____ Equal to

Briefly explain your reasoning.

As seen in the derived formula, an increase in R will increase T.

AP® PHYSICS 1
2018 SCORING COMMENTARY

Question 1

Overview

This question assessed learning objectives 2.B.1.1, 2.B.2.1, 3.A.1.1, 3.A.2.1, 3.B.1.3, 3.B.2.1, and 3.C.1.2.

The responses to this question were expected to demonstrate the following:

- The ability to construct free-body diagrams, only including the relevant forces without extraneous forces.
- Recognition of cases in which the net force is centripetal in the context of universal gravitation.
- An understanding of how changing one quantity in an equation may or may not affect other quantities.
- Recognition that direct and inverse relationships only hold when other variables are kept constant.

Sample: Q1 P1 A
Score: 7

Part (a) earned 2 points. The response earned 1 point for an arrow directed toward Earth's center, and the response earned 1 point because the arrow is correctly and appropriately labeled as a gravitational force. Part (b)(i) earned 3 points. The response earned 1 point because it uses Newton's second law by equating the centripetal force to the gravitational force exerted on the spacecraft. The response earned 1 point for determining the speed of the spacecraft, which is substituted for v in the derivation. The response earned 1 point for a correct algebraic answer. Part (b)(ii) earned 1 point for a correct explanation that the period of the spacecraft does not depend on the spacecraft's mass. Part (c) earned 1 point for a correct explanation of why the speed of the spacecraft decreases with increasing orbital radius.

Sample: Q1 P1 B
Score: 5

Part (a) earned 2 points. The response earned 1 point for an arrow directed toward Earth's center, and the response earned 1 point because the arrow is correctly and appropriately labeled as a gravitational force. Part (b)(i) earned 1 point because it uses Newton's second law by equating the centripetal force to the gravitational force exerted on the spacecraft. The response uses an incorrect expression for the speed, resulting in an incorrect solution for the orbital period. Part (b)(ii) earned 1 point because the response is consistent with the incorrect solution in part (b)(i); the response references that the (incorrect) derived equation for the spacecraft's period in part (b)(i) does not include the mass of the spacecraft. Part (c) earned 1 point for a correct explanation of why the speed of the spacecraft decreases with increasing orbital radius.

Sample: Q1 P1 C
Score: 2

Part (a) earned 2 points. The response earned 1 point for an arrow directed toward Earth's center, and the response earned 1 point because the arrow is correctly and appropriately labeled as a gravitational force. Part (b)(i) earned no points. The response does not use Newton's second law or (in the designated answer space) equate the centripetal force to the gravitational force exerted on the spacecraft. The response does not determine the speed of the spacecraft or include a correct final answer. Part (b)(ii) earned no points. The incorrect response is not consistent with the equations indicated in part (b)(i). Part (c) earned no points because the wrong selection is indicated.