AP Physics C: Mechanics
2001 Scoring Guidelines

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General Notes about 2001 AP Physics Solutions

1. The solutions contain the most common method(s) of solving the free-response questions, and the allocation of points for these solutions. Other methods of solution also receive appropriate credit for correct work.
2. 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.
3. An 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 one point, and a solution contains the application of the equation to the problem but does not separately list the basic equation, the point is still awarded.

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Question 1

15 points total

1. (a) **6 points** **Distribution of Points**

The average acceleration is the change in velocity divided by the time interval

For correct subtraction to find the time interval **1 point**

$\Delta t = t_f - t_i = 0.37 - 0.33 = 0.04$ s

From graph: $v_i = 0.22$ m/s

For getting v_i in the range $0.2 < v_i \leq 0.25$ m/s **1 point**

From graph: $v_f = -0.18$ m/s

For getting v_f in the range $-0.15 \geq v_f > -0.20$ m/s **1 point**

For getting Δv consistent with the student's values of v_i and v_f, including subtracting in the correct direction **1 point**

$\Delta v = v_f - v_i = -0.18 \text{ m/s} - 0.22 \text{ m/s} = -0.40 \text{ m/s}$

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{-0.4 \text{ m/s}}{0.04 \text{ s}}$$

For correct substitution of values in the above equation **1 point**

$\bar{a} = -10 \text{ m/s}^2$

For showing deceleration (e.g., with a minus sign) **1 point**

Note: There were three alternate methods for solving parts (b) and (c) that could receive full credit.

Method 1.

1. (b) **3 points**

For any indication of the concept of finding the area under the curve in the second graph **1 point**

$\Delta p = \int F\,dt$ or $\Delta p =$ the area under the F *vs.* t curve

$\Delta p = 0.6 \text{ N} \cdot \text{s}$ or $\Delta p = 0.6 \ \frac{\text{kg} \cdot \text{m}}{\text{s}}$

For correct numerical value of 0.6 **1 point**

For correct units **1 point**

1. (c) **2 points**

For any statement of the correct equation for the change in momentum **1 point**

$\Delta p = m \Delta v$

For correct substitution of values consistent with those obtained above **1 point**

$$m = \frac{\Delta p}{\Delta v} = \frac{0.6 \text{ N} \cdot \text{s}}{0.4 \text{ m/s}} = 1.5 \text{ kg}$$

Question 1 (cont.)

Method 2.

1. (b) **3 points** **Distribution of Points**

Expressing the change in momentum in terms of the average force:
$\Delta p = \overline{F}\Delta t$

For some method of using the graph to find the average force for the four non-zero intervals such as indicating that the area is equivalent to 6 boxes each with a height of 10 N, so that $\overline{F} = 60/4 = 15 \text{ N}$ **1 point**

$\Delta p = (15 \text{ N})(0.04 \text{ s}) = 0.6 \text{ N}\cdot\text{s}$ or $\Delta p = 0.6 \ \frac{\text{kg}\cdot\text{m}}{\text{s}}$

For correct numerical value of 0.6 **1 point**
For correct units **1 point**

1. (c) **2 points**

Expressing the average force in terms of the average acceleration:
$\overline{F} = m\overline{a}$

For correct equation ($F = ma$ also accepted) **1 point**
For correct substitution of values consistent with those obtained above **1 point**

$$m = \frac{\overline{F}}{\overline{a}} = \frac{15 \text{ N}}{10 \text{ m/s}^2} = 1.5 \text{ kg}$$

Method 3. Student solved part (c) first and went back to part (b)

1. (c) **3 points**

For some method of using the graph to find the average force for the four non-zero intervals such as indicating that the area is equivalent to 6 boxes each with a height of 10 N, so that $\overline{F} = 60/4 = 15 \text{ N}$ **1 point**

For a correct expression for Newton's second law **1 point**
$\overline{F} = m\overline{a}$

For correct substitution of values consistent with those obtained above **1 point**

$$m = \frac{\overline{F}}{\overline{a}} = \frac{15 \text{ N}}{10 \text{ m/s}^2} = 1.5 \text{ kg}$$

Question 1 (cont.)

Method 3. (continued)

1. (b) **2 points** **Distribution of Points**

$\Delta p = m\Delta v = (1.5\text{ kg})(0.4\text{ m/s}) = 0.6\text{ N}\cdot\text{s}$ or $\Delta p = 0.6\ \frac{\text{kg}\cdot\text{m}}{\text{s}}$

For correct substitution of values consistent with those obtained above **1 point**
For correct units **1 point**

1. (d) **4 points**

For a correct statement of energy change **1 point**
$\Delta E = E_f - E_i$

For a kinetic energy equation **1 point**
$E = \frac{1}{2}mv^2$

For correct substitution of values consistent with those obtained above including the squared velocities **1 point**
$\Delta E = \frac{1}{2}(1.5\text{ kg})(0.22\text{ m/s})^2 - \frac{1}{2}(1.5\text{ kg})(-0.18\text{ m/s})^2$
$\Delta E = 0.012\text{ J}$

For correct units **1 point**

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Question 2

15 points total

2. (a) i. **3 points** **Distribution of Points**

There were two methods generally used to solve this part.

Method 1.

$F = ma_c$

$F = \frac{GM_J m}{R^2}$

For a statement of at least one of Newton's laws above **1 point**

Equating the two equations above and substituting expression for centripetal force:

$ma_c = \frac{GM_J m}{R^2}$

For substituting the expression for centripetal force **1 point**

$\frac{mv^2}{R} = \frac{GM_J m}{R^2}$

For a solution for v that follows algebraically from previous work **1 point**

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

Method 2.

$a = \frac{GM_J}{R^2}$ or $g = \frac{GM_J}{R^2}$

For statement of either of the above, which are derived from Newton's laws **1 point**

For a correct statement of centripetal acceleration **1 point**

$a_c = \frac{v^2}{R}$

Equating the two expressions above for a_c and solving for v:

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

For a solution for v that follows algebraically from previous work. **1 point**

Two points were awarded for an approach that started with $K = \frac{1}{2}mv^2 = \frac{GM_J m}{2R}$ and solved for v as long as there was no sign error in the equation and there were no incorrect statements regarding energy prior to the equation.

Question 2 (cont.)

2. (a) ii. **3 points** **Distribution of Points**

There were three methods generally used to solve this part.

Method 1.

$$v = \frac{d}{t} = \frac{2\pi R}{T}$$

For an expression for v in terms of the period T **1 point**

For substitution of $2\pi R$ for the length d of the orbital path **1 point**

Solving for T gives $T = \frac{2\pi R}{v}$

For correct substitution for v from (a) i. **1 point**

$$T = \frac{2\pi R}{\sqrt{\frac{GM_J}{R}}} = \sqrt{\frac{4\pi^2 R^3}{GM_J}}$$

Method 2.

$$T = \frac{2\pi}{\omega} = \frac{2\pi R}{v}$$

For the equation for T in terms of ω **1 point**

For substitution of v/R for ω in the equation **1 point**

For correct substitution for v from (a) i. **1 point**

$$T = \frac{2\pi R}{\sqrt{\frac{GM_J}{R}}} = \sqrt{\frac{4\pi^2 R^3}{GM_J}}$$

Method 3.

2 points

$$F = \frac{mv^2}{R} = m\omega^2 R = m\left(\frac{2\pi}{T}\right)^2 R = \frac{GmM_J}{R^2}$$

$$\frac{4\pi^2 mR}{T^2} = \frac{GmM_J}{R^2}$$

For $T^2 = \frac{4\pi^2 R^3}{GM_J}$ **1 point**

Note: Direct use of $T^2 = \frac{4\pi^2 R^3}{GM_J}$ was awarded **1 point** only, if it was defined as Kepler's law or Law of Orbits.

Question 2 (cont.)

2. (b) **3 points** **Distribution of Points**

For use of correct equation for T from (a) ii. or derivation of this relationship **1 point**

$$T = \sqrt{\frac{4\pi^2 R^3}{GM_J}}$$

For correct solution for R or R^3, numerical or symbolic, from above equation **1 point**

$$R^3 = \frac{GM_J T^2}{4\pi^2} \quad \text{or} \quad R = \left(\frac{GM_J T^2}{4\pi^2}\right)^{1/3} \quad \text{or}$$

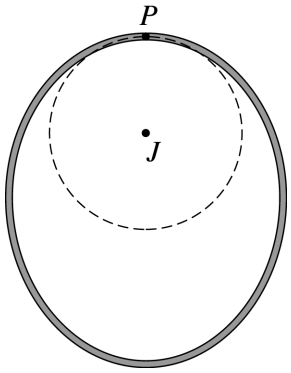
$$R = \left[\left(6.67\times10^{-11}\ \text{N}\bullet\text{m}^2/\text{kg}^2\right)\left(1.9\times10^{27}\ \text{kg}\right)\left(3.55\times10^{4}\ \text{s}\right)^2 / 4\pi^2\right]^{1/3}$$

For a correct answer **1 point**

$$R = 1.59\times10^{8}\ \text{m}$$

Note: If R_J was subtracted from R the answer point was only awarded if the difference was clearly indicated to be the height of the orbit above the surface.

2. (c) i. **3 points**



For stating that the orbit is an ellipse **1 point**

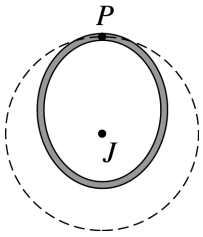
For diagram with orbit drawn completely outside the circle with point of contact only at point P and major axis along PJ. **2 points**

Partial credit of **1 point** awarded for any path or orbit completely outside the circle.

No points were awarded in any part of path or orbit was inside the circle.

Question 2 (cont.)

2. (c) ii. **3 points**



Distribution of Points

For stating that the orbit is an ellipse **1 point**

For diagram with orbit drawn completely inside the circle with point of contact only at point *P* and major axis along *PJ*. **2 points**
Partial credit of **1 point** awarded for any path or orbit completely inside the circle.
No points were awarded if any part of path or orbit was outside the circle.

Note: **Three points** may also be awarded in this part for a path in which the satellite "crashes" into Jupiter only if there is specific reference to the scale of the orbit from part (b) and the given radius of Jupiter.

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Question 3

15 points total

3. (a) **3 points**

Distribution of Points

For a correct formula for the rotational inertia **1 point**

$I = \sum mr^2$

For a sum containing a term of the form mL^2 (may include extra incorrect terms, but the point was not awarded if the expression does not contain an mL^2 term) **1 point**

$I = mL^2 + mL^2$

For the correct answer **1 point**

$I = 2mL^2$

3. (b) **6 points**

For a correct expression of Newton's 2nd law **1 point**

$F = ma$

For correct substitutions into Newton's law **1 point**

$4mg - T = 4ma$

For a correct formula for torque **1 point**

$\tau = I\alpha$ or Tr

$I\alpha = Tr$

$T = \dfrac{I\alpha}{r}$

From Newton's 2nd law equation above:

$T = 4mg - 4ma$

Substituting into the torque equation:

$\dfrac{I\alpha}{r} = 4mg - 4ma$

For substituting the expression for *I* from part (a) into Newton's law **1 point**

$\dfrac{2mL^2\alpha}{r} = 4mg - 4ma$

For the expression $\alpha = a/r$ **1 point**

Substituting this expression into the previous equation:

$\dfrac{2mL^2 a}{r^2} = 4mg - 4ma$

For the correct answer **1 point**

$a = \dfrac{2gr^2}{L^2 + 2r^2}$

Note: For the solution $a = \dfrac{4mg - T}{4m}$, obtained by solving $4mg - T = 4ma$ for *a* directly, a maximum of **3 points** was awarded for part (b) as follows; **1 point** for Newton's law, **1 point** for substitutions, and **1 point** for answer.

Question 3 (cont.)

3. (c) **3 points**

Distribution of Points

For correctly checking the space in front of "Equal to 4*mgD*" **1 point**
For correct justification, such as "The kinetic energy gained by the two smaller blocks comes from the decrease in the potential energy of the 4*m* block." OR "Total energy is conserved." **2 points**

Note: **No points** awarded for part (c) if wrong box was checked.

3. (d) **3 points**

For correctly checking the space in front of "Less" **1 point**
For correct justification, such as "The small blocks rise and gain potential energy. The total energy available is still 4*mgD*. Therefore the kinetic energy must be less than in part (c)." **2 points**

Note: **No points** awarded for part (d) if wrong box was checked.