CollegeBoard
Advanced Placement Program

AP® Physics C: Mechanics
2004 Scoring Guidelines

General Notes about 2004 AP Physics Scoring Guidelines

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. 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.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded.

4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable.

5. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. The exception is usually 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.

Question 1

15 points total	**Distribution of points**
(a) 2 points	
For any statement of conservation of energy	1 point
Taking the zero of potential to be at the height of point B, and setting the kinetic energy at point B equal to the potential energy at point A:	
$\frac{1}{2}m_1 v_B^2 = m_1 g L$	
For the correct answer	1 point
$v_B = \sqrt{2gL}$	
(b) 4 points	
For any indication that there are two forces acting on the person	1 point
For an indication that the acceleration of the person is centripetal, i.e. equal to v^2/r or v^2/L	1 point
For a correct application of Newton's second law that includes the two forces (tension T and weight) and a non-zero acceleration	1 point
$T - m_1 g = \frac{m_1 v_B^2}{r}$	
$T = \frac{m_1 v_B^2}{r} + m_1 g$	
For substitution of the expression for v_B from part (a) and L for the radius	1 point
$T = \frac{m_1(2gL)}{L} + m_1 g = 2m_1 g + m_1 g$	
$T = 3m_1 g$	
(c) 3 points	
For any statement of conservation of momentum	1 point
For a correct application of conservation of momentum, with a clear indication that both masses have a common final velocity	1 point
$m_1 v_B = (m_1 + m_2) v_{\text{after}}$	
$v_{\text{after}} = \frac{m_1}{(m_1 + m_2)} v_B$	
For an answer in terms of the required quantities and of the form: $\frac{m_1}{(m_1 + m_2)}$(answer from part(a))	1 point
$v_{\text{after}} = \frac{m_1}{(m_1 + m_2)} \sqrt{2gL}$	

Question 1 (continued)

Distribution of points

(d) 2 points

For correct expressions for the kinetic energy before and after the collision, using the answers to parts (a) and (c) — 1 point

$$K_{\text{before}} = \frac{1}{2}m_1 v_B^2 = \frac{1}{2}m_1(2gL) = m_1 gL$$

$$K_{\text{after}} = \frac{1}{2}(m_1 + m_2)v_{\text{after}}^2 = \frac{1}{2}(m_1 + m_2)\frac{m_1^2}{(m_1 + m_2)^2}2gL = \frac{m_1^2}{(m_1 + m_2)}gL$$

For constructing the ratio $K_{\text{before}}/K_{\text{after}}$ from valid expressions for kinetic energy, in terms of the required quantities. The ratio does not need to be simplified, but if it is the algebra needs to be correct. — 1 point

$$\frac{K_b}{K_a} = \frac{m_1 gL}{\left(\dfrac{m_1^2 gL}{(m_1 + m_2)}\right)}$$

$$\frac{K_b}{K_a} = \frac{(m_1 + m_2)}{m_1}$$

(e) 4 points

For a correct expression relating the distance fallen, L, to the time it takes to fall from point B to the water: — 1 point

$$L = \frac{1}{2}gt^2$$

For indicating that the horizontal displacement from B to D is the answer to part (c) multiplied by the time — 1 point

$$x_{BD} = v_{\text{after}}t$$

For correctly solving the first equation for t and substituting two quantities into the second equation (this must yield an expression in terms of the required given quantities) — 1 point

$$t = \sqrt{2L/g}$$

$$x_{BD} = v_{\text{after}}t = \left(\frac{m_1}{m_1 + m_2}\sqrt{2gL}\right)\sqrt{2L/g} = \frac{2m_1 L}{m_1 + m_2}$$

For indicating that the total horizontal displacement from A to D is x_{BD} plus L — 1 point

$$x_{\text{tot}} = x_{BD} + L = \frac{2m_1 L}{m_1 + m_2} + L$$

$$x_{\text{tot}} = \frac{(3m_1 + m_2)L}{m_1 + m_2}$$

Question 2

15 points total | **Distribution of points**

(a) 2 points

Using the kinematic equation:

$x = v_0 t + \frac{1}{2}at^2$

For applying this equation with $x = D$ and $v_0 = 0$ — 1 point

$D = \frac{1}{2}at^2$

For the correct answer — 1 point

$a = \frac{2D}{t^2}$

(b)

i. 2 points

For indicating a correct pair of quantities to graph — 1 point

For a correct explanation — 1 point

Method 1: Graph quantities such as D versus t^2 or v versus t. Such graphs are linear and the slope will yield the acceleration.

Method 2: Graph quantities such as a versus t or a versus x, using the equation from part (a) to determine the accelerations. Such graphs are linear and the a intercept will yield the acceleration.

Method 3: Graph D versus t, which is parabolic. The equation that describes the best fit curve is quadratic, and the second derivative is the acceleration.

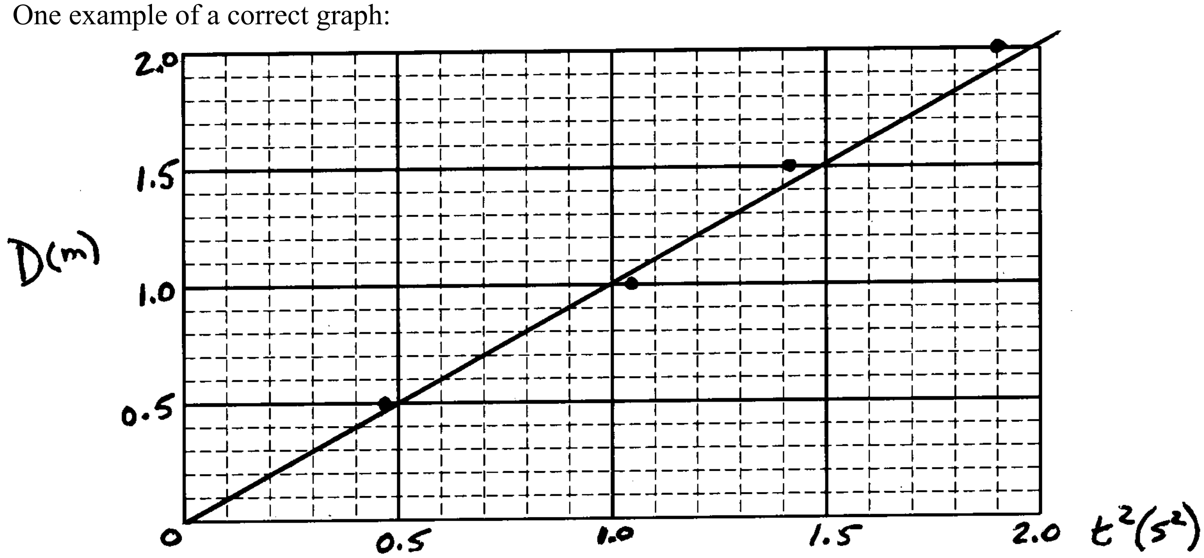
Question 2 (continued)

Distribution of points

(b) (continued)

ii. 3 points

One example of a correct graph:



For using data consistent with the answer to (b) i. 1 point
For plotting the data correctly, including labeling the axes and their scales 1 point
For constructing a best fit line or curve, depending on the data graphed 1 point

iii. 2 points

For using points from the best fit line, not data points 1 point
For correctly determining the acceleration, including correct units and explicitly showing how the points yield the answer 1 point
For example, using the graph shown:

$$a = 2(\text{slope}) = 2\left(\frac{2.0\text{ m} - 0.5\text{ m}}{1.97\text{ s}^2 - 0.5\text{ s}^2}\right) = 2\left(\frac{1.5\text{ m}}{1.47\text{ s}^2}\right) = 2.04\text{ m/s}^2$$

Question 2 (continued)

Distribution of points

(c) 4 points

For a correct torque equation that includes the tension T in the string — 1 point

$TR = I\alpha$

For the correct relationship between α and a — 1 point

$\alpha = a/R$

Substituting for α and solving for I:

$TR = I\dfrac{a}{R}$

$I = TR^2/a$

For correctly applying Newton's second law for the block — 1 point

$ma = mg - T$

Solving for T:

$T = m(g - a)$

For the correct answer, obtained for substituting T into the equation for I — 1 point

$$I = \frac{m(g-a)R^2}{a} \quad \text{or} \quad I = mR^2\left(\frac{g}{a} - 1\right)$$

Alternate solution — *Alternate points*

For a correct application of conservation of energy for the system — *1 point*

The change in potential energy of the block equals the change in linear kinetic energy of the block plus the change in rotational kinetic energy of the pulley

$mgD = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$

For the correct relationship between the rotational and linear speeds — *1 point*

$\omega = \dfrac{v}{R}$

For a correct relationship between the linear speed, the acceleration, and the distance D — *1 point*

$v^2 = 2aD$

Substituting the last two expressions into the energy equation:

$$mgD = \frac{1}{2}mv^2 + \frac{1}{2}I\frac{v^2}{R^2} = \frac{1}{2}v^2\left(m + \frac{I}{R^2}\right)$$

$$mgD = \frac{1}{2}(2aD)\left(m + \frac{I}{R^2}\right)$$

For the correct answer — *1 point*

$$I = \frac{m(g-a)R^2}{a} \quad \text{or} \quad I = mR^2\left(\frac{g}{a} - 1\right)$$

Question 2 (continued)

	Distribution of points
(d) 2 points	
For a reasonable analysis of the answer to part (c) that explicitly indicates either the effective mass or radius is greater than given in the initial paragraph of the question, or the experimental acceleration is obtained in (b) iii is greater than it would be without experimental error.	1 point
For a possible physical reason for the discrepant value	1 point
Examples: The string was wrapped around the pulley several times, causing the effective radius at which the torque acted to be larger than the radius of the pulley used in the calculation.	
The string slipped on the pulley, allowing the block to accelerate faster than it would have otherwise, resulting in a smaller experimental moment of inertia.	

Note: Friction is not a correct answer, since the presence of friction would make the experimental value of the moment of inertia too large.

Question 3

15 points total | **Distribution of points**

(a) 4 points

Using the integral expression for the moment of inertia:

$I = \int r^2\, dm$

For a correct change of variables — 1 point

$dm = (M/L)\,dr$

For correct limits of integration — 1 point

$I = \int_{-L/3}^{2L/3} \frac{M}{L} r^2\, dr$ $\left(\begin{array}{l}\text{or other appropriate combination of limits and distance expression,} \\ \text{such as replacing } r \text{ by } x-(L/3) \text{ and integrating from zero to } L\end{array}\right)$

For correctly integrating — 1 point

$I = \frac{M}{L}\left.\frac{r^3}{3}\right|_{-L/3}^{2L/3}$

$I = \frac{M}{3L}\left[\left(\frac{2L}{3}\right)^3 - \left(-\frac{L}{3}\right)^3\right]$

For the correct answer — 1 point

$I = \frac{ML^2}{9}$

Alternate Solution | *Alternate points*

For any statement of the parallel axis theorem — *1 point*

$I = I_{cm} + mr^2$, where r is the distance from the center of mass to the pivot point

For a correct value of the center of mass inertia (calculated or remembered) — *1 point*

$I_{cm} = \frac{1}{12}ML^2$

For indicating that $r = L/6$ — *1 point*

$I = \frac{1}{12}ML^2 + M\left(\frac{L}{6}\right)^2$

For the correct answer — *1 point*

$I = \frac{ML^2}{9}$

Appropriate credit was also awarded for adding inertias for the parts of the rod on either side of the pivot. Credit was given for either calculating the inertias or remembering an appropriate expression for inertia.

Question 3 (continued)

	Distribution of points
(b) 7 points	
For any indication of conservation of energy	2 points
For correctly calculating the change in potential energy of the rod (or the work done on it)	2 points
For example: $\Delta U = Mgh_{cm} = Mg\left(\frac{L}{6}\right)$	
For writing a conservation equation that includes a rotational kinetic energy (regardless of whether the potential energy is correct)	1 point
$\frac{1}{2}I\omega^2 = \frac{MgL}{6}$	
For any indication that ω is linear speed divided by a distance (regardless of whether the correct distance is used)	1 point
Substituting and solving for υ:	
$\frac{1}{2}\left(\frac{ML^2}{9}\right)\left(\frac{\upsilon}{r}\right)^2 = \frac{MgL}{6}$	
$\frac{\upsilon^2}{r^2} = \frac{MgL}{6}\,\frac{18}{ML^2} = \frac{3g}{L}$	
$\upsilon^2 = \frac{3g}{L}r^2 = \frac{3g}{L}\left(\frac{2L}{3}\right)^2 = \frac{4}{3}gL$	
For the correct answer	1 point
$\upsilon = 2\sqrt{\frac{gL}{3}}$	
(c) 4 points	
For an equation for the period of a physical pendulum	1 point
$T = 2\pi\sqrt{\frac{I}{mgd}}$	
For substitution of the inertia from part (a)	1 point
For indicating that the distance d is the distance from the pivot to the center of mass, i.e. $d = \frac{L}{2} - \frac{L}{3} = \frac{L}{6}$	1 point
$T = 2\pi\sqrt{\frac{ML^2/9}{MgL/6}}$	
For the correct answer	1 point
$T = 2\pi\sqrt{\frac{2L}{3g}}$	

Question 3 (continued)

Distribution of points

(c) (continued)

Alternate solution — *Alternate points*

For an equation relating the angular acceleration to the torque and inertia — *1 point*

$$\alpha = \frac{d^2\theta}{dt^2} = \frac{\tau}{I}$$

For substituting the inertia from part (a) and the torque as a function of θ — *1point*

$$\frac{d^2\theta}{dt^2} = \frac{-Mg\left(L/6\right)\sin\theta}{ML^2/9} = -\frac{3}{2}\frac{g}{L}\sin\theta$$

For using the approximation $\sin\theta \approx \theta$ — *1 point*

$$\frac{d^2\theta}{dt^2} = -\frac{3}{2}\frac{g}{L}\theta$$

Taking $\theta = k\sin\omega t$, the second derivative is $\dfrac{d^2\theta}{dt^2} = -\omega^2 k\sin\omega t$

Substituting into the differential equation and solving for ω:

$$-\omega^2 k\sin\omega t = -\frac{3}{2}\frac{g}{L}k\sin\omega t$$

$$\omega = \sqrt{\frac{3}{2}\frac{g}{L}}$$

Using the relationship between T and ω:

$$T = 2\pi/\omega$$

For the correct answer — *1 point*

$$T = 2\pi\sqrt{\frac{2L}{3g}}$$

No credit was awarded for the incorrect approach of using the period of a simple pendulum, $T = 2\pi\sqrt{\ell/g}$, and the length $2L/3$, which happens to give the same result as the correct method