# AP® Physics C: Mechanics
# 2009 Scoring Guidelines

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## General Notes About 2009 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. 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. 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 AP Physics 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 Course Description*.

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

5. 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.

## Question 1

**15 points total** **Distribution of points**

(a) 2 points

For indication that total energy is the sum of kinetic and potential energy — 1 point

$E = U(x) + K(x)$

$E = 4.0x^2 + \frac{1}{2}m(\upsilon(x))^2$

$E = \left(4.0\ \text{J}/\text{m}^2\right)(-0.50\ \text{m})^2 + \frac{1}{2}(3.0\ \text{kg})(2.0\ \text{m/s})^2$

For correct calculation of the numerical value of the total energy — 1 point

$E = 7.0\ \text{J}$

(b) 3 points

For indication that $E = U$ when $K = 0$ — 1 point

$E = U(x)$

$E = 4.0x^2$

For substitution of $E$ from (a) into the equation — 1 point

$7.0\ \text{J} = \left(4.0\ \text{J}/\text{m}^2\right)x^2$

$x = \pm\sqrt{7.0/4.0}\ \text{m}$

For including plus and minus signs in final numerical answer — 1 point

$x = \pm 1.3\ \text{m}$

(c) 3 points

For clear indication that kinetic energy is total energy minus potential energy, using total energy from (a) — 1 point

$K = E_{tot} - U$

$K = 7.0\ \text{J} - \left(4.0\ \text{J}/\text{m}^2\right)(0.60\ \text{m})^2 \quad = 5.56\ \text{J}$

For using calculated $K$ to solve for $\upsilon$ — 1 point

$K = \frac{1}{2}m\upsilon^2$

$5.56\ \text{J} = \frac{1}{2}(3.0\ \text{kg})\upsilon^2$

$\upsilon = 1.92\ \text{m/s}$

For substituting calculated value of $\upsilon$ into expression for momentum — 1 point

$p = m\upsilon = (3.0\ \text{kg})(1.92\ \text{m/s}) = 5.8\ \text{kg}\cdot\text{m/s}$

Note: The final 2 points could also be earned by substituting the kinetic energy directly into the expression relating the kinetic energy and momentum $p = \sqrt{2mK}$ .

**Question 1 (continued)**

**Distribution of points**

(d) 3 points

For a correct relationship between force and potential energy — 1 point

Note: This point was awarded if the negative sign was not included, since the question asks for magnitude of the acceleration.

$$F = -\frac{dU(x)}{dx}$$

For an expression or calculated value for force consistent with relationship above — 1 point

$$F = -\left(\frac{d}{dx}4.0x^2\right) = -8.0x$$

For application of Newton's second law using a derived expression or calculated value for force — 1 point

$$a = \frac{F}{m} = \frac{8.0x}{m}$$

$$a = \frac{\left(8.0\ \text{kg/s}^2\right)(0.60\ \text{m})}{3.0\ \text{kg}}$$

$$a = 1.6\ \text{m/s}^2$$

*Alternate Solution* — *Alternate Points*

$E = U + K$

*For a correct energy relationship with potential and kinetic energy substituted* — *1 point*

$$7 = 4x^2 + \frac{1}{2}m\upsilon^2$$

$$14 - 8x^2 = m\upsilon^2$$

*For taking the derivative with respect to time of each side of this equation* — *1 point*

$$-16x\frac{dx}{dt} = 2m\upsilon\frac{d\upsilon}{dt}$$

$$-16x\upsilon = 2m\upsilon a$$

$$-8x = ma$$

*For algebraically solving for acceleration* — *1 point*

$$a = -\frac{8x}{m}$$

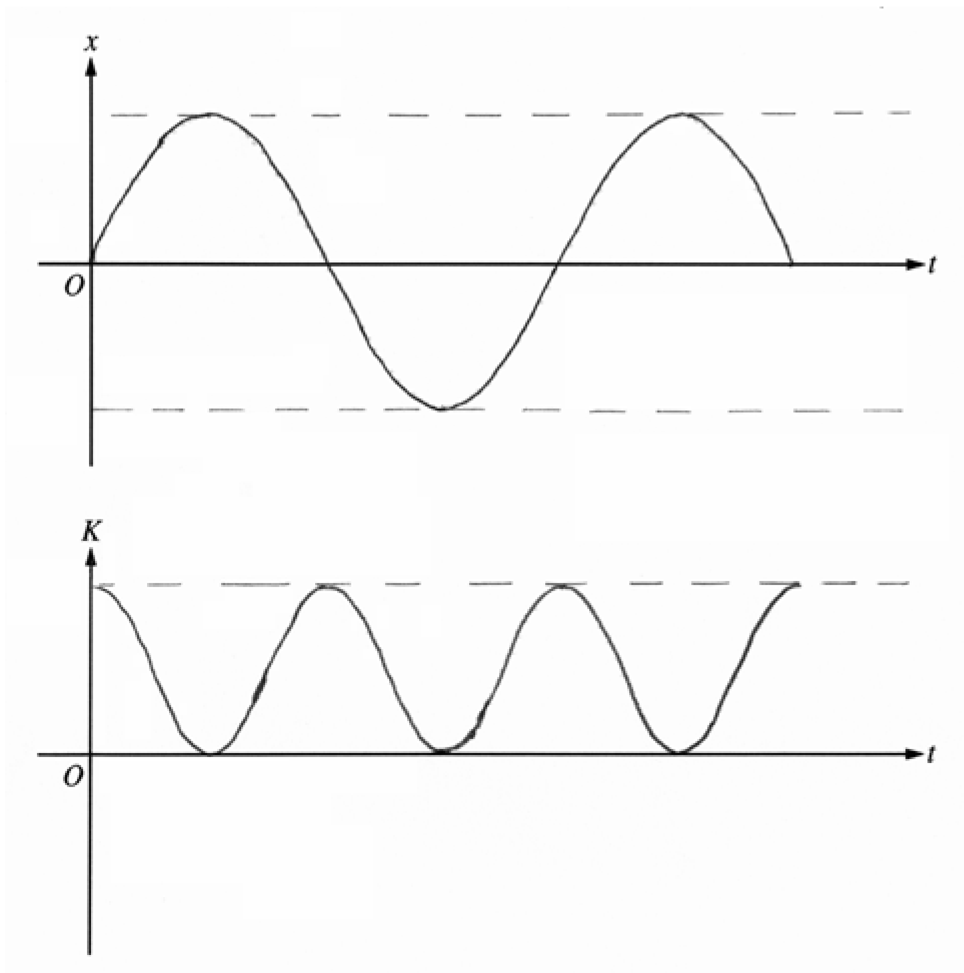
$$a = \frac{\left(8.0\ \text{kg/s}^2\right)(0.60\ \text{m})}{3.0\ \text{kg}}$$

$$a = 1.6\ \text{m/s}^2$$

**Question 1 (continued)**

**Distribution of points**

(e) 3 points




| | |
|---|---|
| For a minimum of one complete cycle of a sine curve starting at the origin on the $x$ versus $t$ graph | 1 point |
| For a minimum of one complete cycle of a cosine squared curve starting at the maximum value on the $K$ versus $t$ graph | 1 point |
| For maxima and minima of the $x$ graph matching the zeroes of the $K$ graph | 1 point |

Units point

| | |
|---|---|
| For correct units on <u>all</u> completed nonzero numerical answers | 1 point |

## Question 2

**15 points total** **Distribution of points**

(a)

(i) 4 points

For the rotational form of Newton's second law — 1 point

$\tau = I\alpha$

For a correct expression of the magnitude of torque — 1 point

For correctly labeling the torque as negative — 1 point

$-Mgx\sin\theta = I_b\alpha$

For expressing $\alpha$ as the second time derivative of $\theta$ — 1 point

$$-Mgx\sin\theta = I_b\left(\frac{d^2\theta}{dt^2}\right)$$

(ii) 4 points

For the appropriate small angle approximation — 1 point

For small angles, $\sin\theta \approx \theta$

$$-Mgx\theta = I_b\left(\frac{d^2\theta}{dt^2}\right)$$

$$\left(\frac{d^2\theta}{dt^2}\right) + \left(\frac{Mgx}{I_b}\right)\theta = 0$$

For recognizing that the coefficient of $\theta$ is $\omega^2$ — 1 point

$$\omega^2 = \frac{Mgx}{I_b}$$

For the relationship between $T$ and $\omega$ (this point was awarded for the equation alone or with relevant work, but NOT as part of multiple random equations) — 1 point

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

For the final expression for $T$ (this point was awarded for the final correct answer with no supporting work) — 1 point

$$T = 2\pi\sqrt{\frac{I_b}{Mgx}}$$

**Question 2 (continued)**

**Distribution of points**

(b) 5 points

For an experimental procedure that includes:

| | |
|---|---|
| A valid approach | 1 point |
| How the variables will be measured or calculated, including equipment to be used | 2 points |
| How these variables will be used to determine $I_B$ | 1 point |
| How to minimize error | 1 point |

Example 1: Displace the bar by a small angle and release it to oscillate. To reduce errors, time 10 complete oscillations with a stopwatch. Calculate the average value of the time for 10 oscillations and then divide by 10 to determine the period $T$. Calculate $I_B$ from $T = 2\pi\sqrt{I_b/Mgx}$, using known values of $M$ and $x$.

Example 2: Locate a photogate at the bottom of the bar's swing; set it to measure the amount of time the photogate is blocked. While the bar is hanging from its pivot point, displace the bar to a horizontal position and measure the height of the center of mass above the position of the photogate with a meter stick. Allow the bar to swing through the photogate and obtain the time the gate is blocked. To reduce errors, repeat this procedure five times and obtain an average time. Measure the width of the bar and use this and the time to determine the speed of the bar at the bottom of the swing, $\upsilon = \text{width}/\text{time}$. Calculate the angular speed of the bar from $\omega = \upsilon/\ell$. Apply conservation of energy to the bar: $Mgh = I_B\omega^2/2$. Calculate $I_B$ from $I_B = 2Mgh/\omega^2$, using known values of $M$, measured value of $h$, and calculated value of $\omega$.

(c) 2 points

| | |
|---|---|
| For a valid procedure to locate the center of mass | 1 point |
| For specifying the equipment to be used | 1 point |

Example 1: Place the bar on top of a fulcrum, e.g., the top of a prism. Adjust the position of the bar until it is balanced horizontally. The point at which this occurs is the center of mass.

Example 2: Place the bar near the edge of a desk or table. Slowly push the bar so it hangs off the table until it is just ready to tip. The point at which this occurs is the center of mass.

## Question 3

**15 points total** | **Distribution of points**

(a) 4 points

For an indication of conservation of energy — 1 point

$|\Delta U| = |\Delta K|$

$mgh = \frac{1}{2}mv^2$

The speed of both blocks is $v_h$ .

For substituting $M/2$ into the expression for $U$ — 1 point

For substituting $d$ for $h$ in the expression for $U$ — 1 point

For substituting the sum of the masses, $\frac{M}{2} + \frac{M}{2}$, into the expression for $K$ — 1 point

$\frac{M}{2}gd = \frac{1}{2}\left(\frac{M}{2} + \frac{M}{2}\right)v_h^2$

$\frac{M}{2}gd = \frac{1}{2}Mv_h^2$

$v_h = \sqrt{gd}$

*Alternate Solution* — *Alternate Points*

*For an indication that Newton's second law applies* — *1 point*

$F_{net} = ma$

$\frac{M}{2}g = 2\left(\frac{M}{2}\right)a$

*For solving for acceleration* — *1 point*

$a = \frac{g}{2}$

*For selecting correct kinematics equation(s)* — *1 point*

$v^2 = v_0{}^2 + 2a(x - x_0)$ OR $x = \frac{1}{2}at^2$ and $v = at$

*For substituting* $d$ *for the vertical + distance* — *1 point*

$v_h^2 = 2a(d) = 2\frac{g}{2}(d)$ OR $d = \frac{1}{2}\frac{g}{2}t^2$ and $v_h = \frac{g}{2}t$ (*and combining by eliminating* $t$)

$v_h = \sqrt{gd}$

(b) 2 points

$F_g = mg$

For a correct expression for the force — 2 points

$F_g = \frac{Mg}{L}y$

Note: Since the stem states "determine," no work was necessary to earn these points.
No partial credit was awarded for this part.

**Question 3 (continued)**

**Distribution of points**

(c) 3 points

For a correct integral expression for work. (If the nonintegral form of work was presented, no further work on this part was scored.) — 1 point

$W = \int F\,dy$

For substituting $F$ from part (b) into the integral — 1 point

$W = \int \dfrac{Mg}{L} y\,dy$

$W = \dfrac{Mg}{L}\int y\,dy$

For correct integration — 1 point

$W = \dfrac{Mg}{L}\dfrac{1}{2}y^2$

$W = \dfrac{Mg}{2L}y^2$

*Alternate Solution* — *Alternate Points*

*For a correct relationship between work and potential energy* — *1 point*

$W = -\Delta U$

$W = mg\,\Delta h_{cm}$

*For substituting the expression for force of gravity from (b)* — *1 point*

*For substituting $y/2$ for $\Delta h_{cm}$* — *1 point*

$W = \left(\dfrac{M}{L}y\right)g\,\dfrac{y}{2}$

$W = \dfrac{Mg}{2L}y^2$

(d) 3 points

For an indication of the work-energy relationship — 1 point

$W = \Delta K = \dfrac{1}{2}m\upsilon^2$

For substituting the expression for $W$ from part (c) — 1 point

For substituting $M$ into expression for $\Delta K$ — 1 point

$\dfrac{Mg}{2L}y^2 = \dfrac{1}{2}M\upsilon_{\mathrm{r}}^2$

$\upsilon_{\mathrm{r}} = \sqrt{g/L}\,y$

Note: An alternate solution using Newton's second law and kinematics was also possible.

**Question 3 (continued)**

**Distribution of points**

(e) 3 points

For indicating that the speeds are equal — 1 point

For a complete and correct justification, conceptual or symbolic — 2 points

Example 1: Substituting $L$ for $d$ and $y$ in the equations $\upsilon_h = \sqrt{gd}$ and $\upsilon_r = \sqrt{gy^2/L}$, respectively, yields $\sqrt{gL}$ in both cases.

Example 2: For the blocks, a mass of $M/2$ falls a distance $L$. For the rope, the center of mass of a mass of $M$ falls a distance of $L/2$. The same amount of potential energy becomes kinetic energy. Equal total masses gaining equal kinetic energies means they acquire equal speeds.

Notes:

- Since this part could be answered without making reference to the rest of the problem, it was scored independently.
- A correct but incomplete justification was awarded 1 point.