AP® PHYSICS C: MECHANICS
2009 SCORING GUIDELINES

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 $g = 9.8 \text{ m/s}^2$, but use of 10 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 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

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

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

For correct integration — 1 point

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

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

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* Δh_{cm} — *1 point*

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

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

(d) 3 points

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

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

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

For substituting M into expression for ΔK — 1 point

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

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

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

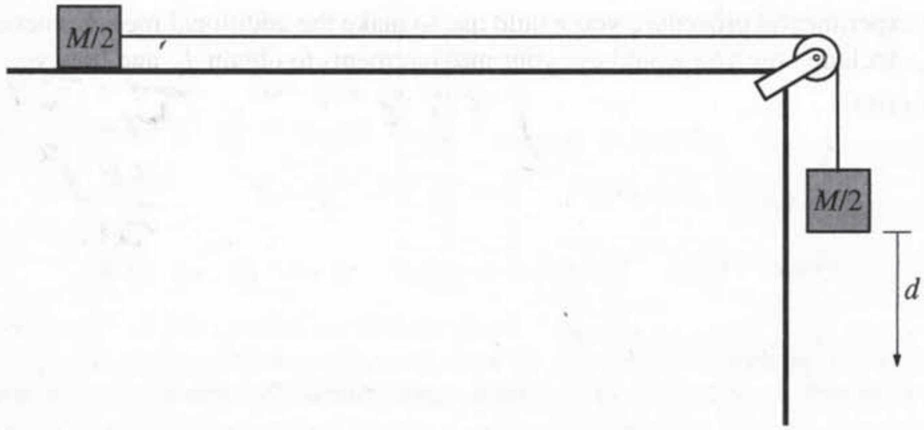
For a complete and correct justification, conceptual or symbolic — 2 points

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.



Mech. 3.

A block of mass $M/2$ rests on a frictionless horizontal table, as shown above. It is connected to one end of a string that passes over a massless pulley and has another block of mass $M/2$ hanging from its other end. The apparatus is released from rest.

(a) Derive an expression for the speed v_h of the hanging block as a function of the distance d it descends.

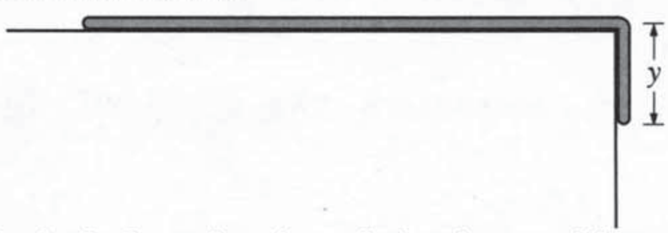
$$Ma = \frac{M}{2}g$$

$$a = \frac{1}{2}g$$

$$v_h^2 = 2 \cdot \frac{1}{2}g \cdot d = gd$$

$$v_h = \sqrt{gd}$$

Now the block and pulley system is replaced by a uniform rope of length L and mass M, with one end of the rope hanging <u>slightly</u> over the edge of the frictionless table. The rope is released from rest, and at some time later there is a length y of rope hanging over the edge, as shown below. Express your answers to parts (b), (c), and (d) in terms of y, L, M, and fundamental constants.



(b) Determine an expression for the force of gravity on the hanging part of the rope as a function of y.

Let $\lambda = \frac{M}{L}$ be the linear mass density

$$F_g = mg = \lambda y g = \frac{M}{L} y g$$

(c) Derive an expression for the work done by gravity on the rope as a function of y, assuming y is initially zero.

$$W = \int_0^y F_g\, dy = \int_0^y \frac{M}{L} y g\, dy = \frac{Mg}{L} \cdot \frac{1}{2} y^2$$

$$= \frac{Mgy^2}{2L}$$

(d) Derive an expression for the speed v_r of the rope as a function of y.

$$\frac{\cancel{M}gy^2}{2L} = \frac{1}{2} \cancel{M} v^2$$

$$v = y\sqrt{\frac{g}{L}}$$

(e) The hanging block and the right end of the rope are each allowed to fall a distance L (the length of the rope). The string is long enough that the sliding block does not hit the pulley. Indicate whether v_h from part (a) or v_r from part (d) is greater after the block and the end of the rope have traveled this distance.

____ v_h is greater. ____ v_r is greater. __✓__ The speeds are equal.

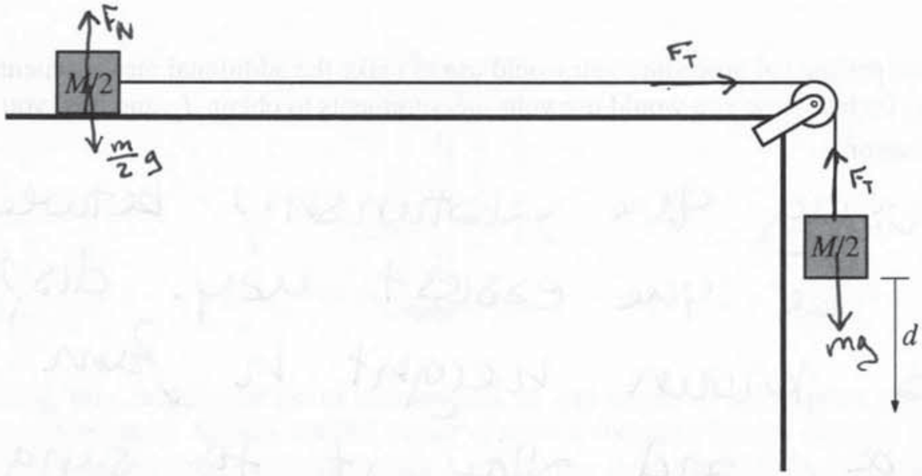
Justify your answer.

When the block has traveled a distance L, its speed is

$$v_h = \sqrt{gL}.$$

When the rope has traveled a distance L, its speed is

$$v = L\sqrt{\frac{g}{L}} = \sqrt{\frac{gL^2}{L}} = \sqrt{gL}$$



Mech. 3.

A block of mass $M/2$ rests on a frictionless horizontal table, as shown above. It is connected to one end of a string that passes over a massless pulley and has another block of mass $M/2$ hanging from its other end. The apparatus is released from rest.

(a) Derive an expression for the speed v_h of the hanging block as a function of the distance d it descends.

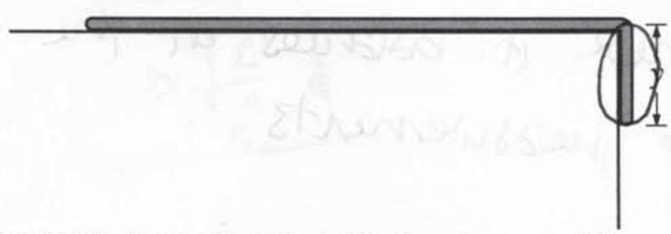
$F = ma = mg \longrightarrow$ without friction, $a = g$

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

$gd = \frac{v^2}{2} \longrightarrow v_h = \boxed{\sqrt{2gd}}$

Now the block and pulley system is replaced by a uniform rope of length L and mass M, with one end of the rope hanging slightly over the edge of the frictionless table. The rope is released from rest, and at some time later there is a length y of rope hanging over the edge, as shown below. Express your answers to parts (b), (c), and (d) in terms of y, L, M, and fundamental constants.

given
y, L, M



(b) Determine an expression for the force of gravity on the hanging part of the rope as a function of y.

$F = mg$ $\qquad \rho_{rope} = \frac{M}{L}$

$F = \boxed{\frac{M}{L}yg}$

(c) Derive an expression for the work done by gravity on the rope as a function of y, assuming y is initially zero.

$$W = F \cdot d = \left(\frac{M}{L} y g\right) \cdot y$$

$$= \boxed{\frac{M}{L} \cdot g \cdot y^2}$$

(d) Derive an expression for the speed v_r of the rope as a function of y.

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

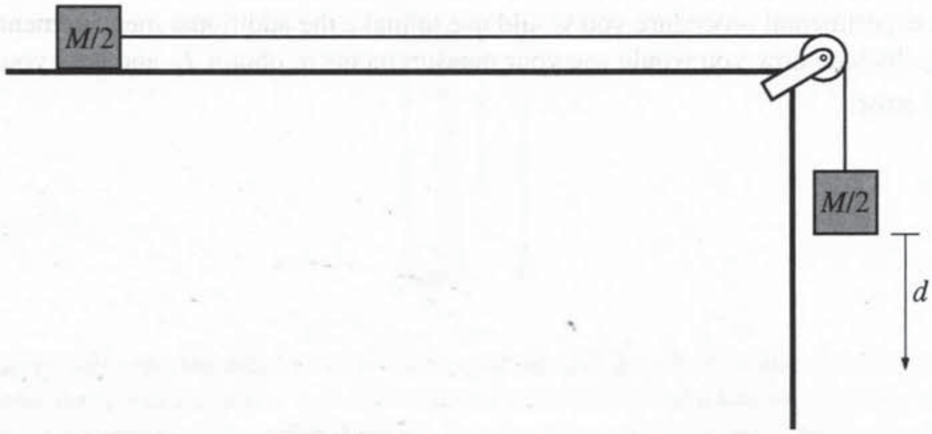
$$gy = \frac{v^2}{2} \longrightarrow v = \boxed{\sqrt{2gy}}$$

(e) The hanging block and the right end of the rope are each allowed to fall a distance L (the length of the rope). The string is long enough that the sliding block does not hit the pulley. Indicate whether v_h from part (a) or v_r from part (d) is greater after the block and the end of the rope have traveled this distance.

____ v_h is greater. ____ v_r is greater. _✓_ The speeds are equal.

Justify your answer.

without friction, the only relevant force is the gravitational force, which does not depend on mass. Therefore, the rope and the block will have the same acceleration.



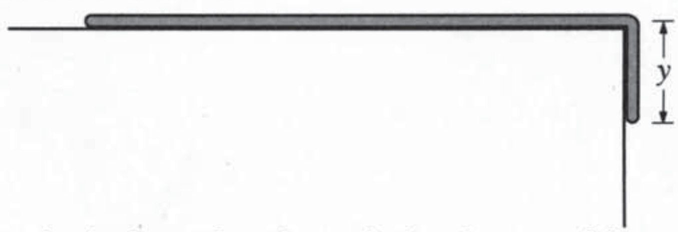
Mech. 3.

A block of mass $M/2$ rests on a frictionless horizontal table, as shown above. It is connected to one end of a string that passes over a massless pulley and has another block of mass $M/2$ hanging from its other end. The apparatus is released from rest.

(a) Derive an expression for the speed v_h of the hanging block as a function of the distance d it descends.

$$V_f^{\,2} - \cancel{V_0^{\,2}}^{\,0} = 2ax$$
$$(V_f)^2 = 2ad$$
$$V_f^{\,2} = 2(-9.8)d$$
$$V_f = \sqrt{+19.6d}$$

Now the block and pulley system is replaced by a uniform rope of length L and mass M, with one end of the rope hanging slightly over the edge of the frictionless table. The rope is released from rest, and at some time later there is a length y of rope hanging over the edge, as shown below. Express your answers to parts (b), (c), and (d) in terms of y, L, M, and fundamental constants.



(b) Determine an expression for the force of gravity on the hanging part of the rope as a function of y.

Mg

$$F_g = mg$$
$$= \left(\frac{y}{L} \cdot M\right) g$$

$$mg = \left(\frac{y}{L} M\right) g$$

$\left(\frac{y}{L}\right) M$ = mass of hanging part

(c) Derive an expression for the work done by gravity on the rope as a function of y, assuming y is initially zero.

$$W = \int F \cdot dr \qquad W = F \cdot d \qquad F = ma$$

$$W = F \cdot y$$

$$W = ma \cdot y$$

$$W = M(-9.8)y$$

$$W = -9.8My.$$

(d) Derive an expression for the speed v_r of the rope as a function of y.

$$Vf^2 \cancel{- V_1^2}^{\,0} = 2ax$$

$$Vf^2 = 2(-9.8)y$$

$$= -19.6y$$

$$Vf = \sqrt{19.6y}$$

(e) The hanging block and the right end of the rope are each allowed to fall a distance L (the length of the rope). The string is long enough that the sliding block does not hit the pulley. Indicate whether v_h from part (a) or v_r from part (d) is greater after the block and the end of the rope have traveled this distance.

____ v_h is greater. ____ v_r is greater. _✓_ The speeds are equal.

Justify your answer.

Question 3

Overview

The intent of this question was to test students' ability to utilize energy conservation (or, alternatively, Newton's second law) to determine the speeds of two systems of masses, one discrete and one continuous, and to compare them.

The first system was two discrete objects attached by a string, one on a horizontal table and the second hanging over a massless pulley. The second system was a rope with constant mass density hanging over the edge of a table. The level table was frictionless, and the mass over the edge of the table was accelerated by gravity.

Sample: CM-3A
Score: 15

This is a very complete and well laid-out response, including a mathematical justification for part (e).

Sample: CM-3B
Score: 8

Part (a) earned 3 out of 4 points, as an incorrect substitution of M instead of $M/2$ is made in the potential energy expression. Part (b) earned both available points. Part (c) earned no points. Part (d) earned 2 out of 3 points for expressing conservation of energy and correctly substituting M into the kinetic energy expression. Part (e) earned 1 point, with no credit for the justification.

Sample: CM-3C
Score: 5

Part (a) earned 2 points in the alternate solution for use of the correct kinematics equation and a correct substitution of the distance d into that equation; no valid work is done to determine the acceleration a. Two points were also earned in part (b). Both the integral and nonintegral forms of the expression for work are present in part (c), but it is the nonintegral form that is used so no points were earned in this part. No points were earned in part (d) since a constant-acceleration kinematics equation, entirely inappropriate for the situation, is used. One point was earned in part (e) for correctly indicating that the speeds are equal.