AP® Physics C: Mechanics
2015 Scoring Guidelines

Question 1

15 points total — **Distribution of points**

(a)

i. 1 points

Using Newton's second law with down the incline as the positive direction

$F_{net} = ma$

$mg\sin\theta = ma$

For a correct expression of a positive acceleration — 1 point

$a = g\sin\theta$

ii. 2 points

Using a correct kinematics equation to solve for velocity

$v_2 = v_1 + at$

For substitution into a correct kinematics equation consistent with the acceleration from part (a)i — 1 point

For having a negative sign on v_0 — 1 point

$v = -v_0 + (g\sin\theta)t$

iii. 1 points

Using a correct kinematics equation to solve for position

$x = x_0 + v_1 t + \frac{1}{2}at^2$

For substitution into a correct kinematics equation consistent with expressions from parts (a)i and (a)ii — 1 point

$x = D - v_0 t + \frac{1}{2}(g\sin\theta)t^2$

(b) 2 points

Using an equation that can be solved for the closest position to the sensor

$v_2^2 = v_1^2 + 2ad$

For substitution into a correct kinematic equation consistent with part (a) — 1 point

For setting v_2 to zero and using D for the initial position — 1 point

$0 = v_0^2 + 2(g\sin\theta)(x - D)$

$x = D - \frac{v_0^2}{2g\sin\theta}$

Question 1 (continued)

Distribution of points

(b) (continued)

Alternate solution: *Alternate points*

Using a conservation of energy approach to find the highest point the cart moves along the incline

$K_1 + U_{g1} = K_2 + U_{g2}$

$K_1 = U_{g2}$

$\frac{1}{2}mv_0^2 = mgh_2$

For using the correct energy statement with the correct initial velocity *1 point*

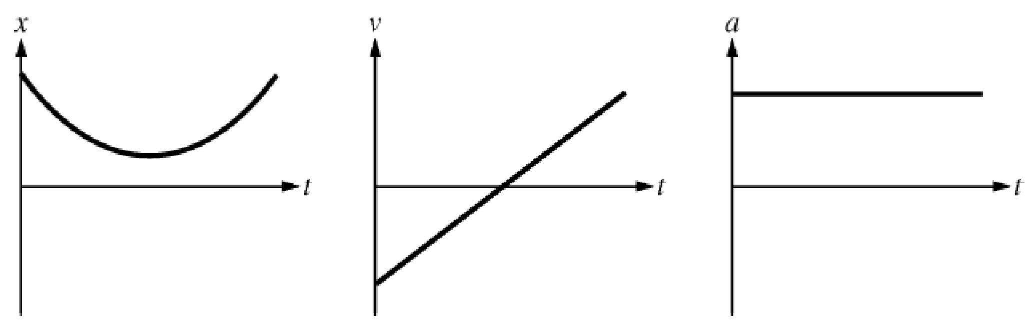
For a correct statement of the height of the cart along the incline *1 point*

$h = (D - x)\sin\theta$

$\frac{1}{2}v_0^2 = g(D - x)(\sin\theta)$

$x = D - \frac{v_0^2}{2g\sin\theta}$

(c) 4 points



For a position graph that is a parabola that does not cross the t-axis and has a vertex that does not touch the t-axis 1 point

For a velocity graph that is a straight line and crosses the t-axis 1 point

For an acceleration graph that is a horizontal line 1 point

For a set of graphs that are consistent with each other 1 point

Question 1 (continued)

Distribution of points

(d) 2 points

Using an equation that can be solved for the distance

$v_2^2 = v_1^2 + 2ad$

For a correct expression of the frictional force — 1 point

$f = -\mu_k mg = ma$

$a = -\mu_k g$

$0 = v_0^2 - 2\mu_k gd$

For a correct answer — 1 point

$d = \dfrac{v_0^2}{2\mu_k g}$

Alternate solution: — *Alternate points*

Using an equation that can be solved for the distance

$Fd = \frac{1}{2}m\left(v_2^2 - v_1^2\right)$

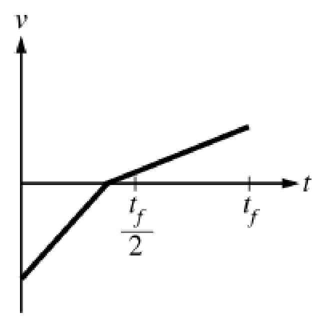
For a correct expression of the frictional force — *1 point*

$-\mu_k mgd = \frac{1}{2}m\left(0 - v_0^2\right)$

For a correct answer — *1 point*

$d = \dfrac{v_0^2}{2\mu_k g}$

(e) 3 points



The graph has two straight line portions.

For having a change in slope at $v = 0$ — 1 point

For having slope values of each segment that have the same sign and the correct relative magnitudes (segment I slope magnitude greater than segment II slope magnitude, as shown in the graph above) — 1 point

For having a graph that crosses the t-axis earlier than $t_f/2$ and extends to t_f — 1 point

Question 2

15 points total | **Distribution of points**

(a) 1 point

Writing an equation to solve for the speed when the dart is at its maximum height

$v = v_x = v_0(\cos\theta)$

$v = (10\ \text{m/s})(\cos 30°)$

For a correct answer — 1 point

$v = 8.7\ \text{m/s}$

(b) 2 points

Writing an equation to solve for time using motion in the vertical direction

$v_y = v_{y0} + a_y t$

$0 = (10\ \text{m/s})(\sin 30) + \left(-9.8\ \text{m/s}^2\right)t$

For a correct value for the time — 1 point

$t = 0.51\ \text{s}$ (or $t = 0.50\ \text{s}$ if using $g = 10\ \text{m/s}^2$)

For substituting into an equation for the horizontal motion consistent with the speed from part (a), or for determining the correct answer — 1 point

$x = v_x t$

$x = (8.7\ \text{m/s})(0.51\ \text{s})$

$x = 4.4\ \text{m}$

(c) 3 points

For a correct expression of conservation of momentum — 1 point

$p_i = p_f$

For a correct expression that represents a totally inelastic collision between the dart and the block — 1 point

$m_1 v_{1i} = (m_1 + m_2)v_f$

$(0.020\ \text{kg})(8.66\ \text{m/s}) = (0.020\ \text{kg} + 0.10\ \text{kg})v_f$

For an answer consistent with the speed from part (a) and correct mass substitutions — 1 point

$v = 1.4\ \text{m/s}$

Question 2 (continued)

Distribution of points

(d) 3 points

For a correct expression of conservation of energy — 1 point

$$K_1 + U_{g1} = K_2 + U_{g2}$$

$$\frac{1}{2}mv_1^2 = mgh_2$$

For a correct expression for the height reached by the block — 1 point

$$h = L - L(\cos\theta)$$

For substituting the speed value from part (c) into a correct conservation of energy equation — 1 point

$$\frac{1}{2}mv_1^2 = mgL(1 - \cos\theta)$$

$$\cos\theta = 1 - \frac{v_1^2}{2gL}$$

$$\cos\theta = 1 - \frac{(1.44\text{ m/s})^2}{2\left(9.8\text{ m/s}^2\right)(1.2\text{ m})}$$

$$\theta = 24°$$

(e) 2 points

For substituting the correct length into the correct equation for the period — 1 point

$$T = 2\pi\sqrt{\frac{\ell}{g}} = 2\pi\sqrt{\frac{(1.2\text{ m})}{\left(9.8\text{ m/s}^2\right)}} = 2.2\text{ s}$$

For correctly dividing the period in half to solve for the time — 1 point

$$t = T/2 = (2.2\text{ s})/2$$

$$t = 1.1\text{ s}$$

(f)

i. 2 points

For selecting "Increase" — 1 point

For a correct justification of the larger angle for the block-dart system — 1 point

Example: A more massive dart would cause the speed after the collision with the block to increase. A greater speed after the collision would cause the block to reach a greater height and thus the angle θ would increase.

Question 2 (continued)

Distribution of points

(f) (continued)

ii. 2 points

For selecting "Stay the same" — 1 point

For a correct justification — 1 point

Example: A more massive dart would not affect the period of the pendulum. Only changing the length of the string would change the period.

Note: If the student correctly points out the changes to the simple pendulum could be outside the small angle approximation, then the student's entire answer will be considered (both check box and justification are consistent and physically correct).

Question 3

15 points total | **Distribution of points**

(a) 3 points

Writing an integral to derive the rotational inertia of the rod

$I = \int r^2 dm$

For a correct expression for dm — 1 point

$\lambda = M/L$, $M = \lambda L$, $dm = \lambda dr$

For using the correct limits of integration or a correct constant of integration — 1 point

$$I = \int_{r=0}^{r=L} \lambda r^2 dr$$

For correctly evaluating the integral above, leading to the answer $ML^2/3$ — 1 point

$$I = \left[\frac{\lambda r^3}{3}\right]_{r=0}^{r=L} = \frac{1}{3}\lambda\left(L^3 - 0\right) = \frac{1}{3}\left(\frac{M}{L}\right)\left(L^3\right) = \frac{1}{3}ML^2$$

(b) 4 points

For using any expression of conservation of energy — 1 point

$K_1 + U_{g1} = K_2 + U_{g2}$

For a correct energy expression relating gravitational potential energy to rotational kinetic energy — 1 point

$$mgh_1 = \frac{1}{2}I\omega_2^2$$

For correctly substituting $L/2$ for the change in height — 1 point

$$Mg(L/2) = \frac{1}{2}\left(\frac{1}{3}ML^2\right)\omega^2$$

For using $v = r\omega$ with $r = L$ to solve for the velocity of the end of the rod — 1 point

$$\frac{MgL}{2} = \frac{1}{6}ML^2\left(\frac{v}{L}\right)^2$$

$v = \sqrt{3gL}$

(c) 1 point

For correctly identifying a relationship between length and velocity that will result in a straight line — 1 point

Example 1: Horizontal axis: velocity
Vertical axis: $\sqrt{\text{length}}$

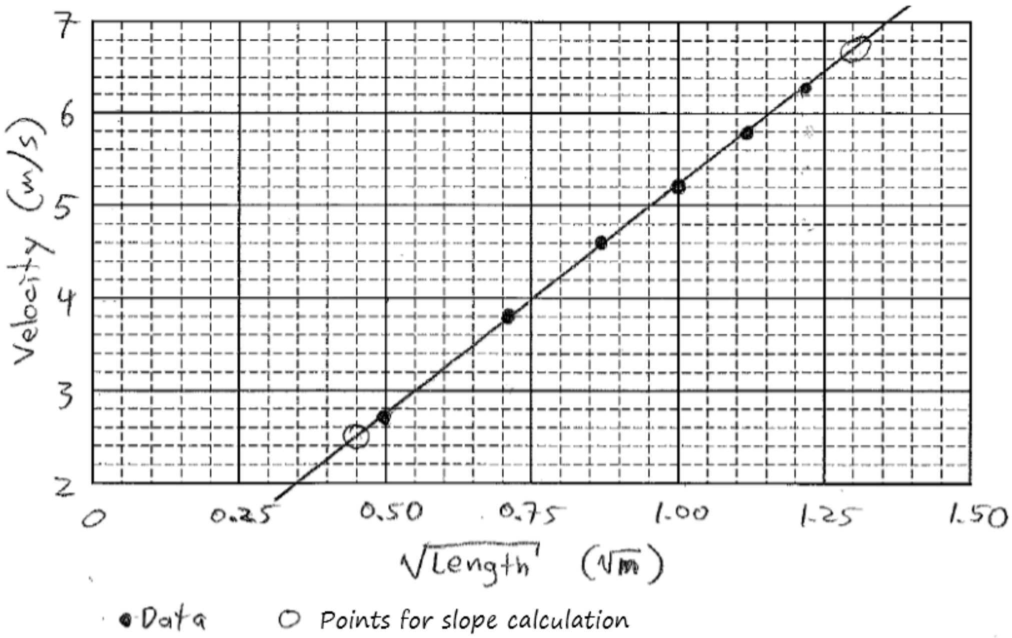
Example 2: Horizontal axis: $(\text{velocity})^2$
Vertical axis: length

Note: Each of the above axis choices can also be switched to yield a straight line.

Question 3 (continued)

Distribution of points

(d) 3 points



For a correct scale that uses at least half the grid and for correctly labeling the axes, including units — 1 point

For plotting data consistent with quantities in the data table in part (c) — 1 point

For drawing a straight line consistent with the data in part (c) — 1 point

(e)

i. 2 points

For correctly calculating the slope using the straight line drawn in part (d), and not using data points unless the points lie on the line — 1 point

$$m = \frac{(y_2 - y_1)}{(x_2 - x_1)} = \frac{(6.70 - 2.50)}{(1.30 - 0.45)} = 4.94\ \sqrt{\text{m}}/\text{s}$$

For correctly calculating g using the slope — 1 point

$$m = \sqrt{3g}$$

$$g = m^2/3 = \left(4.94\ \sqrt{\text{m}}/\text{s}\right)^2/3 = 8.1\ \text{m/s}^2$$

Alternate Solution — *Alternate points*

For stating that linear regression was used and getting one of the results noted below — *1 point*

For correctly calculating g using the slope — *1 point*

When plotting velocity as a function of $\sqrt{\text{length}}$, *the slope is* $4.94\ \sqrt{\text{m}}/\text{s}$ *and* $g = 8.14\ \text{m/s}^2$.

When plotting the square of velocity as a function of length, the slope is $25.77\ \text{m/s}^2$ *and* $g = 8.59\ \text{m/s}^2$.

Question 3 (continued)

Distribution of points

(e) (continued)

ii. 2 points

For one example that directly decreases the effect of air resistance	1 point
For another example that directly decreases the effect of air resistance	1 point

Some examples include:

- Do the experiment in a vacuum
- Use shorter rod lengths
- Use more massive (or denser) rods
- Use a more aerodynamic shape for the rods