AP® Physics C: Mechanics
2010 Scoring Guidelines

The College Board

AP® PHYSICS
2010 SCORING GUIDELINES

General Notes

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for the 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 — for example, 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 1 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 sheets. 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 1

15 points total — **Distribution of points**

(a) 2 points

Starting with Newton's second law:

$F_{net} = mg - Cv^2 = ma$

For correctly indicating that at terminal velocity ($v = v_T$), the net force and acceleration are zero — 1 point

$mg - Cv_T^2 = 0$

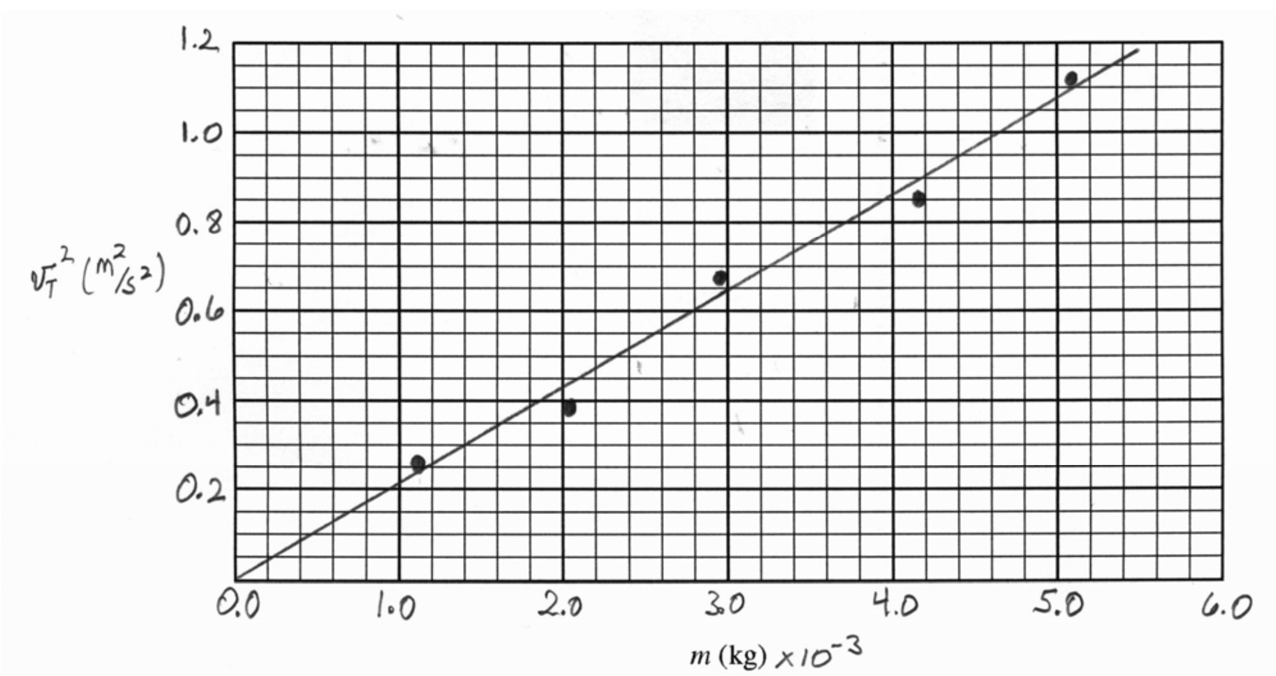
For a correct relationship between v_T and m — 1 point

$v_T^2 = \frac{g}{C} m$

(b)

(i) 4 points

Mass of the stack of filters, m (kg)	1.12×10^{-3}	2.04×10^{-3}	2.96×10^{-3}	4.18×10^{-3}	5.10×10^{-3}
Terminal speed, v_T (m/s)	0.51	0.62	0.82	0.92	1.06
v_T^2 (m²/s²)	0.26	0.38	0.67	0.85	1.12



Question 1 (continued)

Distribution of points

(b) (i) (continued)

For recording in the table a row of calculated data points that involve only v_T or a combination of v_T and g — 1 point

For graphing v_T^2 (or the equivalent) on the vertical axis to obtain a linear graph — 1 point

For including an appropriate linear scale on both axes — 1 point

For drawing a reasonable best-fit straight line — 1 point

Note: Correct graphs of v_T versus $\sqrt{m}$ are given credit provided the quantities being plotted are clearly indicated.

(ii) 3 points

For a correct calculation of the slope, using points on the student's best-fit line (not points from the data table) — 1 point

Using the example graph shown:

$$\text{slope} = \frac{(0.95 - 0.30)\,\text{m}^2/\text{s}^2}{\left[(4.4 - 1.4) \times 10^{-3}\right]\,\text{kg}} = 217\ \text{m}^2/\text{kg}\bullet\text{s}^2$$

For a correct expression relating the slope to C — 1 point

$$\text{slope} = 217\,\text{m}^2/\text{kg}\bullet\text{s}^2 = \frac{g}{C}$$

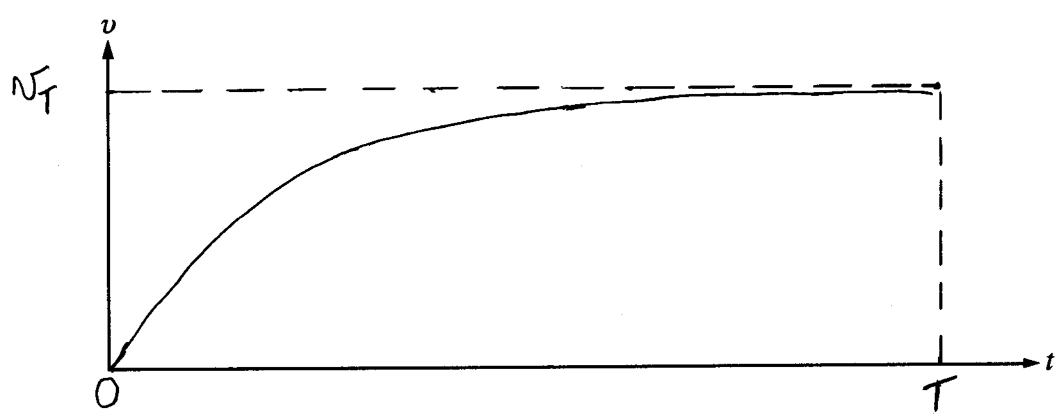
$$C = \frac{g}{\text{Slope}} = \frac{9.8\ \text{m/s}^2}{217\ \text{m}^2/\text{kg}\bullet\text{s}^2}$$

For correct units on C — 1 point

$C = 0.045\ \text{kg/m}$ $\quad (0.046\ \text{kg/m using } g = 10\ \text{m/s}^2)$

(c)

(i) 3 points



For a graph that starts at the origin with an initial positive slope — 1 point

For a graph that is concave down throughout — 1 point

Question 1 (continued)

Distribution of points

For labeling υ_T and T at a point where the slope of the graph approaches zero — 1 point

(c) (continued)

(ii) 1 point

For a verbal statement that clearly indicates the distance Y is the area under the curve between times $t = 0$ and $t = T$ — 1 point

Or an equivalent statement referring to the area under the curve when the υ versus t graph ends at T

Or an equivalent mathematical expression with limits: $Y = \int_0^T \upsilon(t)\, dt$

(d) 2 points

For a correct indication that the mechanical energy dissipated is the change in mechanical energy during the time the stack falls a distance y — 1 point

$$\Delta E = \left(U_{final} + K_{final}\right) - \left(U_{initial} + K_{initial}\right) \quad \left(\text{or } \Delta E = \int_0^y C\upsilon^2 dy\right)$$

$$\Delta E = \Delta U + \Delta K$$

For correct substitutions of y, m, and υ_T — 1 point

$$\Delta U = -mgy$$

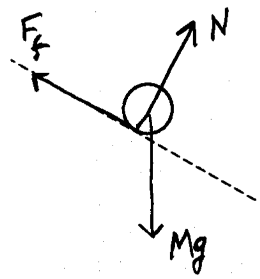
$$\Delta K = \frac{1}{2} m\upsilon_T^2$$

$\Delta E = \frac{1}{2} m\upsilon_T^2 - mgy$ (or any equation with an additional negative sign that has the correct relative signs for potential and kinetic energies)

Question 2

15 points total | **Distribution of points**

(a) 3 points



For each correct force for which the vector is drawn with the correct direction, label and point of application, 1 point was awarded. — 3 points

One earned point was deducted if any components or extraneous forces are present.

(b) 5 points

Starting with Newton's second law (linear form):

$F_{net} = Ma$

For expressing F_{net} in terms of gravitational and frictional forces — 1 point

For including the correct component of the weight — 1 point

$Mg\sin\theta - F_f = Ma$

$\tau = I\alpha$

For correct substitution of torque into Newton's second law (angular form) — 1 point

$RF_f = I\alpha$

$RF_f = (2/5)MR^2\alpha$

For the correct relationship between angular and linear acceleration (either explicitly stated or used in the calculation) — 1 point

$\alpha = a/R$

$RF_f = (2/5)MR^2(a/R)$

Solving for Ma

$Ma = (5/2)F_f$

Substituting into the linear equation above

$Mg\sin\theta - F_f = (5/2)F_f$

$F_f = (2/7)Mg\sin\theta = (2/7)(6.0\text{ kg})(9.8\text{ m/s}^2)(\sin 30°)$

For the correct value of F_f — 1 point

$F_f = 8.4\text{ N}$

Notes: Credit is awarded for solutions that use the value of v calculated in (c) to calculate acceleration and, from there, the value of the frictional force.
If $Mg\cos\theta$ is used, the point was awarded for a value of 14.5 N.

Question 2 (continued)

Distribution of points

(c) 3 points

For an expression of conservation of energy — 1 point
For including gravitational potential energy, translational kinetic energy and rotational kinetic energy in a correct energy equation or statement — 1 point

$$Mg\Delta h = \frac{1}{2}Mv^2 + \frac{1}{2}I\omega^2$$

$$Mgd\sin\theta = \frac{1}{2}Mv^2 + \frac{1}{2}\left(\frac{2}{5}MR^2\right)\omega^2$$

$$\omega = v/R$$

$$Mgd\sin\theta = \frac{1}{2}Mv^2 + \frac{1}{5}Mv^2 = \frac{7}{10}Mv^2$$

$$v = \sqrt{(10/7)gd\sin\theta} = \sqrt{(10/7)\left(9.8\ \text{m/s}^2\right)(4.0\ \text{m})(\sin 30°)}$$

For a correct numerical answer — 1 point
$v = 5.3\ \text{m/s}$

Alternate solution (kinematics method) — *Alternate points*
For determination of the linear acceleration in terms of mass and frictional force — *1 point*
$a = 5F_f/2M$ from work shown in part (b)

$$a = 5(8.4\ \text{N})/2(6.0\ \text{kg}) = 3.5\ \text{m/s}^2$$

For a correct substitution into an appropriate kinematics equation using $v_0 = 0$ — *1 point*

$$v^2 = v_0^2 + 2ad = 2ad$$

$$v = \sqrt{2ad} = \sqrt{(2)\left(3.5\ \text{m/s}^2\right)(4.0\ \text{m})}$$

For a correct numerical answer — *1 point*
$v = 5.3\ \text{m/s}$

(d) 3 points

For a correct statement of conservation of momentum — 1 point
$M_i v_i = M_f v_f$

$$v_f = \left(M_i/M_f\right)v_i$$

For correctly equating v_i with the horizontal component of the ball as it leaves the roof — 1 point
For setting M_f equal to the total mass of the ball and the wagon/box — 1 point

$$v_f = \left(M_i/M_f\right)v\cos\theta = [(6.0\ \text{kg})/(18.0\ \text{kg})]\left(5.3\ \text{m/s}^2\right)\cos 30°$$

$$v_f = 1.5\ \text{m/s}$$

Units 1 point
For correct units in at least two of the parts (b), (c) and (d) — 1 point

Question 3

15 points total | **Distribution of points**

(a) 4 points

For a correct relationship between velocity and acceleration — 1 point

$$\upsilon = \int a(t)\,dt \quad \textbf{OR} \quad \upsilon = \int_0^t a(t)\,dt \quad \textbf{OR} \quad \frac{d\upsilon}{dt} = a$$

For a correct substitution of the expression for acceleration into the integral relationship — 1 point

$$\upsilon = \int \left(a_{\max} \sin\frac{\pi t}{T} \right) dt \quad \textbf{OR} \quad \upsilon = \int_0^t \left(a_{\max} \sin\frac{\pi t}{T} \right) dt \qquad (0 < t < T)$$

For a correct evaluation of the integral, with an integration constant or correct limits — 1 point

$$\upsilon = -\frac{a_{\max} T}{\pi} \cos\frac{\pi t}{T} + C \quad \textbf{OR} \quad \upsilon = -\frac{a_{\max} T}{\pi} \cos\frac{\pi t}{T}\bigg|_0^t \qquad (0 < t < T)$$

For a correct determination of the integration constant or evaluation between the limits — 1 point

$$\upsilon(0) = -\frac{a_{\max} T}{\pi} + C = 0 \;\Rightarrow\; C = \frac{a_{\max} T}{\pi} \quad \textbf{OR} \quad \upsilon = -\frac{a_{\max} T}{\pi} \left(\cos\frac{\pi t}{T} - 1 \right) \qquad (0 < t < T)$$

$$\upsilon = \frac{a_{\max} T}{\pi} \left(1 - \cos\frac{\pi t}{T} \right) \qquad (0 < t < T)$$

(b) 2 points

For indicating that the work done by the net force is equal to the change in kinetic energy — 1 point

$$W = \frac{1}{2} m \left(\upsilon_f^2 - \upsilon_i^2 \right)$$

For a correct substitution of velocity from (a) into the work-energy expression — 1 point

$$\upsilon_f = \upsilon_T = \frac{a_{\max} T}{\pi} (1 - \cos\pi) = \frac{2 a_{\max} T}{\pi}$$

$$\upsilon_i = \upsilon_0 = \frac{a_{\max} T}{\pi} (1 - \cos 0) = 0$$

$$W = \frac{1}{2} m \left(\frac{2 a_{\max} T}{\pi} \right)^2$$

$$W = \frac{2 m a_{\max}^2 T^2}{\pi^2}$$

Alternate solution (integral form) — *Alternate points*

$$W = \int F \cdot dx$$

For a correct substitution of the expression for force into the integral — *1 point*

$$W = \int m a_{\max} \sin\frac{\pi t}{T}\, dx$$

For a correct expression for dx in terms of time — *1 point*

Question 3 (continued)

Distribution of points

(b) (continued)

$$W = \int_0^T ma_{\max} \sin\frac{\pi t}{T} \left(\frac{a_{\max}T}{\pi}\left(1 - \cos\frac{\pi t}{T}\right)\right)dt$$

$$W = \frac{ma_{\max}^2 T}{\pi} \int_0^T \left(\sin\frac{\pi t}{T} - \left(\sin\frac{\pi t}{T}\cos\frac{\pi t}{T}\right)\right) dt$$

$$W = \frac{ma_{\max}^2 T}{\pi} \int_0^T \left(\sin\frac{\pi t}{T} - \frac{1}{2}\sin\frac{2\pi t}{T}\right) dt$$

$$W = \frac{ma_{\max}^2 T^2}{\pi^2}\left(-\cos\frac{\pi t}{T} - \frac{1}{4}\cos\frac{2\pi t}{T}\right)\Bigg|_0^T$$

$$W = \frac{2ma_{\max}^2 T^2}{\pi^2}$$

(c) 1 point

Starting with Newton's second law:

$F_{net} = F_{rope} - mg\sin\theta = ma$

At terminal velocity, the net force and acceleration are zero:

$F_{rope} - mg\sin\theta = 0$

For a correct expression for the force — 1 point

$F_{rope} = mg\sin\theta$

(d) 2 points

$J = \int F\,dt$

For a correct substitution of force into the impulse-time relationship — 1 point

$$J = ma_{\max}\int_0^T \sin\frac{\pi t}{T}\,dt$$

$$J = \frac{ma_{\max}T}{\pi}\left(-\cos\frac{\pi t}{T}\right)\Bigg|_0^T$$

For evaluation at the limits of integration — 1 point

$$J = \frac{ma_{\max}T}{\pi}\left[-\cos\pi + \cos 0\right]$$

$$J = \frac{2ma_{\max}T}{\pi}$$

Alternate solution (impulse-momentum) — *Alternate points*

$J = \Delta p = m\upsilon_T$

Question 3 (continued)

Distribution of points

(d) (continued)

For a correct substitution of the velocity — *1 point*

$J = \frac{ma_{\max}T}{\pi}\left(1 - \cos\frac{\pi t}{T}\right)$

For setting $t = T$ — *1 point*

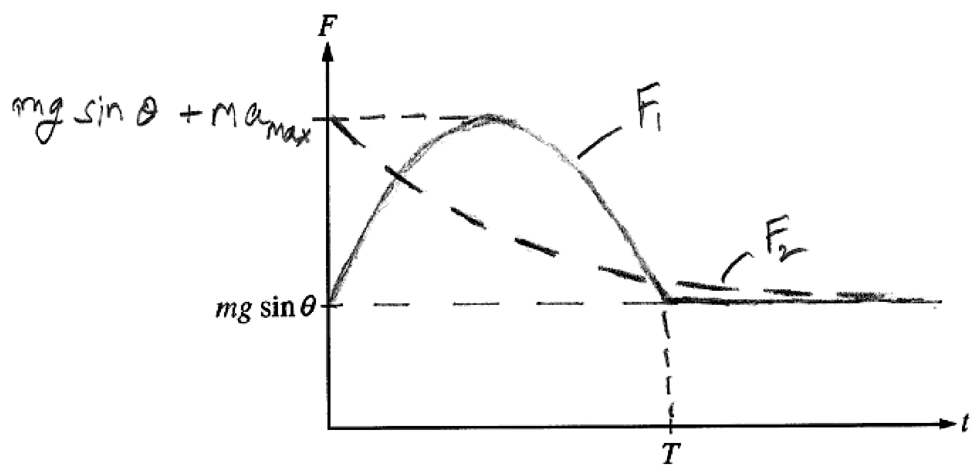
$J = \frac{ma_{\max}T}{\pi}(1 - \cos\pi)$

$J = \frac{2ma_{\max}T}{\pi}$

(e) 6 points

$F_1 = mg\sin\theta + ma_{\max}\sin\left(\frac{\pi t}{T}\right) \qquad (0 < t < T)$

$F_2 = mg\sin\theta + ma_{\max}\, e^{-\pi t/2T}$



For a graph labeled F_1:

- for starting at $mg\sin\theta$ — 1 point
- for half a sine wave with a maximum at $\sim T/2$ — 1 point
- for returning to original starting point at $t = T$ — 1 point
- for a horizontal line at the original starting point for $t > T$ — 1 point

For a graph labeled F_2:

- for starting on the vertical axis at a point above the starting point of F_1 (if there is no F_1 graph, this point was awarded if the F_2 graph starts above $mg\sin\theta$) — 1 point
- for an exponential decay graph — 1 point