AP® Physics B
2010 Scoring Guidelines

The College Board

The College Board is a not-for-profit membership association whose mission is to connect students to college success and opportunity. Founded in 1900, the College Board is composed of more than 5,700 schools, colleges, universities and other educational organizations. Each year, the College Board serves seven million students and their parents, 23,000 high schools, and 3,800 colleges through major programs and services in college readiness, college admission, guidance, assessment, financial aid and enrollment. Among its widely recognized programs are the SAT®, the PSAT/NMSQT®, the Advanced Placement Program® (AP®), SpringBoard® and ACCUPLACER®. The College Board is committed to the principles of excellence and equity, and that commitment is embodied in all of its programs, services, activities and concerns.

Visit the College Board on the Web: www.collegeboard.com.
AP Central is the official online home for the AP Program: apcentral.collegeboard.com.

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) 3 points

For a correct relationship between the vertical distance and time — 1 point

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

For substitution of the vertical height and the acceleration due to gravity — 1 point

$$t = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2(0.80\ \text{m})}{9.8\ \text{m/s}^2}}$$

For the correct answer — 1 point

$$t = 0.40\ \text{s}$$

Note: Credit was awarded for an alternate solution using $\upsilon_y^2 = 2gh$ with appropriate substitutions to find the vertical velocity when the block lands, followed by substitution of this velocity into $\upsilon_y = gt$ (or equivalent) to find the time.

(b) 2 points

For a correct relationship between the horizontal distance and time — 1 point

$$x = \upsilon t$$

For a consistent substitution of time from part (a) into the correct equation — 1 point

$$\upsilon = \frac{x}{t} = \frac{1.2\ \text{m}}{0.40\ \text{s}}$$

$$\upsilon = 3.0\ \text{m/s}$$

(c) 3 points

For any statement of conservation of energy — 1 point

For correct use of appropriate energy equations — 1 point

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

For a consistent substitution of velocity from part (b) into the correct equation — 1 point

$$x = \sqrt{\frac{m}{k}}\upsilon = \sqrt{\frac{4\ \text{kg}}{650\ \text{N/m}}}(3.0\ \text{m/s})$$

$$x = 0.24\ \text{m}$$

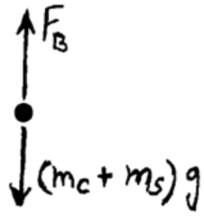
Question 1 (continued)

	Distribution of points
(d) 4 points	
For any statement of conservation of momentum	1 point
$m_A v_i = (m_A + m_B) v_f$	
For substitution of both masses into the equation	1 point
For substitution of the velocity from part (b) into the equation	1 point
$v_f = \left(\dfrac{m_A}{m_A + m_B}\right) v_i = \left(\dfrac{4\text{ kg}}{4\text{ kg} + 4\text{ kg}}\right) 3.0\text{ m/s} = 1.5\text{ m/s}$	
For substitution of time from part (a) into a correct relationship between the horizontal distance and time	1 point
$d = v_f t = (1.5\text{ m/s})(0.40\text{ s})$	
$d = 0.60\text{ m}$	
(e) 2 points	
For indicating that $E_2 < E_1$	1 point
For a correct justification stating one of the following: • the kinetic energy (or energy) is transformed into other forms of energy during the collision (e.g., by reference to heat, internal energy, sound) • the kinetic energy is not conserved in an inelastic collision • a numerical calculation of the relevant energies	1 point
Units 1 point	
For correct units on all completed answers	1 point

Question 2

15 points total | **Distribution of points**

(a) 2 points



For a single upward force, appropriately labeled, representing the buoyant force — 1 point

For downward gravitational force (or forces), appropriately labeled, representing the cup and the sample — 1 point

One earned point was deducted if any extraneous forces were present.

(b) 3 points

For any statement of equilibrium — 1 point

$F_B = F_g$

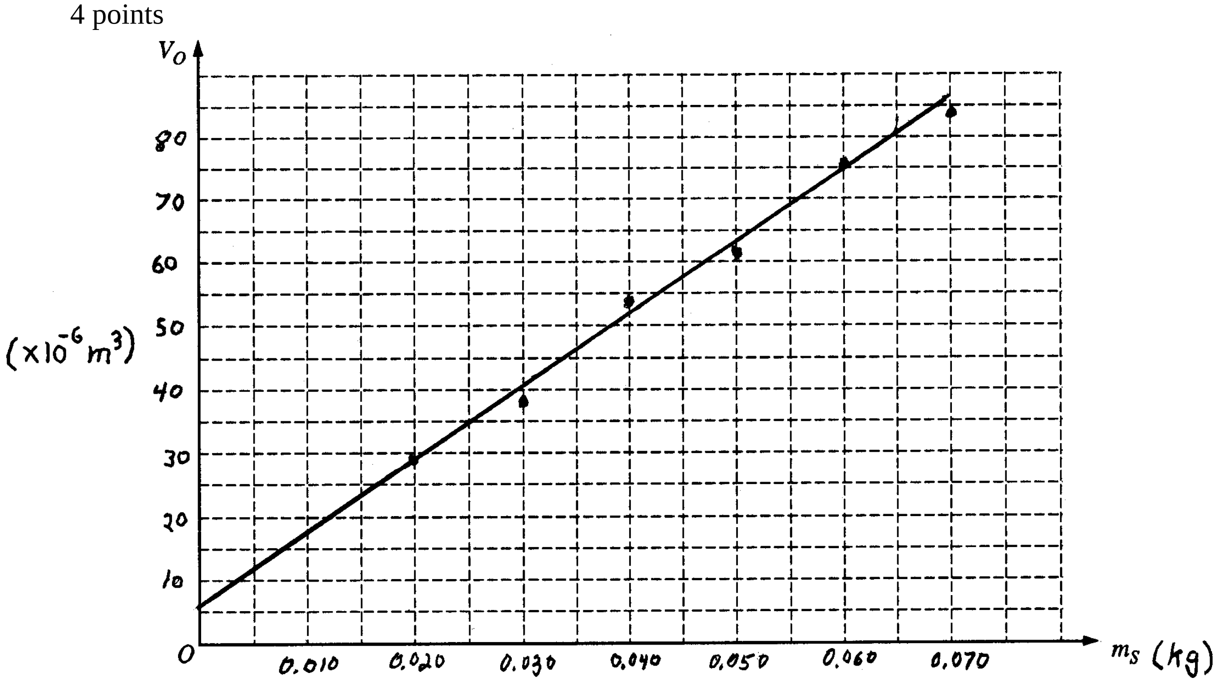
For a correct substitution including both masses m_C and m_S — 1 point

$\rho_O V_O g = (m_C + m_S)g$

For correct statement of the overflow volume, V_O — 1 point

$$V_O = \frac{m_C + m_S}{\rho_O}$$

(c) 4 points



Question 2 (continued)

	Distribution of points
(c) (continued)	
For data plotted correctly	1 point
For correct units on both axes	1 point
For numerical scales that are linear and allow the plotted data to extend over about half the grid area	1 point
For a reasonable single straight best-fit line that does not go through (0,0)	1 point

(d) 4 points

From part (b), $V_O = \dfrac{m_C}{\rho_O} + \dfrac{1}{\rho_O} m_S$

For properly calculating a slope using points on the straight line drawn, including data points only if they are on that line	1 point

Example: Using the two points (0.060 kg, $75 \times 10^{-6}\ \text{m}^3$) and (0.025 kg, $35 \times 10^{-6}\ \text{m}^3$) that are on the line in the graph above

For calculating a reasonable value of slope	1 point

$$\text{slope} = \frac{1}{\rho_0} = \frac{(75 - 35) \times 10^{-6}\ \text{m}^3}{(.060 - 0.025)\ \text{kg}} = 1.14 \times 10^{-3}\ \text{m}^3/\text{kg}$$

For an explicit or implicit indication of inverting the slope	1 point
For calculating a reasonable value for the oil's density (including units and four significant figures or less)	1 point

$$\rho_O = 8.8 \times 10^2\ \text{kg}/\text{m}^3$$

(e) 2 points

For a complete statement that the *y* intercept is the volume of the oil displaced by the empty cup	2 points

Note: 1 point is given for a partially correct answer

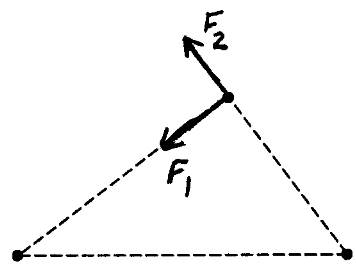
Question 3

10 points total | **Distribution of points**

(a) 1 point

For an indication that q_1 is negative and q_2 is positive — 1 point

(b) 2 points



For force $\mathbf{F}_1$ drawn and labeled correctly — 1 point

For force $\mathbf{F}_2$ drawn and labeled correctly — 1 point

Notes: The force vectors must either originate or terminate on q_3.
Forces on other particles are ignored.

(c) 3 points

For a correct statement or use of Coulomb's law — 1 point

Applying Coulomb's law to determine the magnitude of the forces $\mathbf{F}_1$ and $\mathbf{F}_2$:

$$F_1 = \frac{kq_1q_3}{{r_{13}}^2} = \frac{\left(9\times10^9\ \mathrm{N\cdot m^2/C^2}\right)\left(4.0\times10^{-6}\ \mathrm{C}\right)\left(1.0\times10^{-6}\ \mathrm{C}\right)}{(4.0\ \mathrm{m})^2} = 2.25\times10^{-3}\ \mathrm{N}$$

$$F_2 = \frac{kq_2q_3}{{r_{23}}^2} = \frac{\left(9\times10^9\ \mathrm{N\cdot m^2/C^2}\right)\left(1.7\times10^{-6}\ \mathrm{C}\right)\left(1.0\times10^{-6}\ \mathrm{C}\right)}{(3.0\ \mathrm{m})^2} = 1.70\times10^{-3}\ \mathrm{N}$$

For any indication that $\mathbf{F}$ is the vector sum of the two forces: $\mathbf{F} = \mathbf{F}_1 + \mathbf{F}_2$ — 1 point

Since $\mathbf{F}_1$ and $\mathbf{F}_2$ are at right angles to each other, the magnitude can be found using the Pythagorean theorem.

$$F = \sqrt{{F_1}^2 + {F_2}^2} = \sqrt{\left(2.25\times10^{-3}\ \mathrm{N}\right)^2 + \left(1.70\times10^{-3}\ \mathrm{N}\right)^2}$$

Alternate solution: The y components cancel, so the magnitude of $\mathbf{F}$ *is the sum of the x components.*

$$F = F_{1x} + F_{2x} = F_1\cos 37^\circ + F_2\cos 53^\circ$$

$$F = \left(2.25\times10^{-3}\ \mathrm{N}\right)\cos 37^\circ + \left(1.70\times10^{-3}\ \mathrm{N}\right)\cos 53^\circ$$

$$F = 1.8\times10^{-3}\ \mathrm{N} + 1.0\times10^{-3}\ \mathrm{N}$$

For the correct answer with units — 1 point

$$F = 2.8\times10^{-3}\ \mathrm{N}$$

Question 3 (continued)

Distribution of points

(d) 2 points

For substituting the value of F from part (c) and using the correct value for q_3 — 1 point

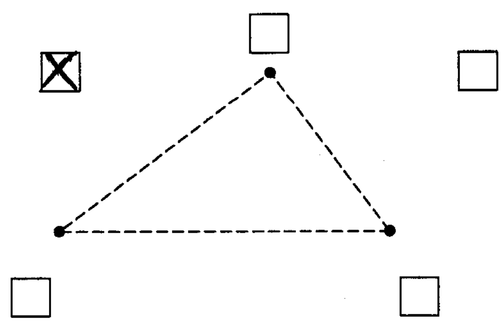
$$E = \frac{F}{q_3} = \frac{2.8 \times 10^{-3}\ \text{N}}{1.0 \times 10^{-6}\ \text{C}}$$

This point could also be earned for substituting F_1 and F_2 from part (c) into $E = F/q_3$ and then calculating the magnitude of the vector sum, or calculating E_1 and E_2 from $E = kq/r^2$ with correct q's and r's and then calculating the magnitude of the vector sum.

For a calculated answer with correct units — 1 point

$E = 2.8 \times 10^3\ \text{N/C}$

(e) 2 points



For an $\times$ in the correct position as shown above — 1 point

For a correct justification that refers to forces — 1 point

For example: Positive charges repel and a force to the right would cancel force **F** .

Question 4

10 points total **Distribution of points**

(a) 3 points

$e = W_{out}/Q_{in}$ or $e = P_{out}/P_{in}$ $\left(\text{i.e. } \dfrac{W_{out}/t}{Q_{in}/t}\right)$

For a correct substitution of the efficiency into a correct equation — 1 point

$0.12 = W_{out}/Q_{in}$ or $0.12 = P_{out}/P_{in}$

For a correct recognition of the relationship between power, energy and time — 1 point

Examples of exhibiting that relationship include: starting with $e = P_{out}/P_{in}$, using $P = W/t$ or Q/t in the efficiency equation or referring to the power as a rate.

$P_{in} = P_{out}/e = 4.5 \times 10^6 \text{ W}/0.12$

For a correct answer with correct units — 1 point

$P_{in} = 3.8 \times 10^7 \text{ W}$

(b) 2 points

$P_{out} = Fv\cos\theta$

$F = P_{out}/(v\cos\theta)$

For a correct substitution of P_{out} into a correct expression — 1 point

The resistive force acts opposite to the velocity, so $\theta = 180°$.

$F = 4.5 \times 10^6 \text{ W}/[(7.0 \text{ m/s})(\cos 180°)]$

For an answer consistent with the value of P_{out} substituted, with correct units — 1 point

$|F| = 6.4 \times 10^5 \text{ N}$

(c)

(i) 1 point

For an answer that uses the word “work” to represent the area — 1 point

(ii) 2 points

For a correct calculation of the work (either on the gas or by the gas) represented by the rectangular path — 1 point

$W = \text{base} \times \text{height} = (V_D - V_A)(P_B - P_A)$

$W = \left(0.60 \text{ m}^3 - 0.20 \text{ m}^3\right)\left(3.0 \times 10^5 \text{ N/m}^2 - 1.0 \times 10^5 \text{ N/m}^2\right) = 8.0 \times 10^4 \text{ J}$

There are four cycles per second, so the time for one cycle is 0.25 s.

$P_{out} = W_{out}/\Delta t = 8.0 \times 10^4 \text{ J}/0.25 \text{ s}$

For a consistent calculation of the power output from the work calculated, with units — 1 point

$P_{out} = 3.2 \times 10^5 \text{ W}$

Question 4 (continued)

	Distribution of points
(d) 2 points	
For indicating *AB* as a correct process	1 point
For indicating *BC* as a correct process	1 point
One point is deducted for each incorrect process indicated, up to the number of points earned for correct processes.	

Question 5

10 points total | **Distribution of points**

(a) 2 points

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_2 = \dfrac{n_1 \sin\theta_1}{n_2}$

For correct substitutions into Snell's Law — 1 point

$\sin\theta_2 = \dfrac{(1.0)\sin 40^\circ}{1.65} = 0.390$

For the correct answer — 1 point

$\theta_2 = 22.9^\circ$ or 23°

(b) 3 points

In order for total internal reflection to occur, θ_3 must increase until it is greater than θ_{critical}. For this to occur, θ_2 must decrease. Finally, to decrease θ_2 there must be an increase in θ_1.

For stating that θ_3 must increase to become greater than θ_{critical} — 1 point

For stating that θ_2 must decrease — 1 point

For stating that θ_1 must decrease — 1 point

Alternate solution — *Alternate points*

For calculating the minimum value of θ_3 that will result in total internal reflection — *1 point*

$\theta_{\text{critical}} = \sin^{-1}\left(\dfrac{1}{1.65}\right) = 37.3^\circ$

For calculating the corresponding value of θ_2 — *1 point*

$\theta_2 = 60^\circ - \theta_3 = 22.7^\circ$

For calculating the corresponding value of θ_1 — *1 point*

$\theta_1 = \sin^{-1}\left[1.65(\sin 22.7^\circ)\right] = 39.5^\circ$, *therefore θ_1 must be decreased.*

Other correct methods also received appropriate credit.

Question 5 (continued)

Distribution of points

(c)

(i) 2 points

For a correct relationship between the wavelength in air and the wavelength in the film, which can be derived from $\lambda = vf$ and $n = c/v$ — 1 point

$$\lambda_{film} = \frac{\lambda_{air}}{n_{film}}$$

$$\lambda_{film} = \frac{6.65 \times 10^{-7}\ \text{m}}{1.38}$$

For the correct answer with units — 1 point

$$\lambda_{film} = 4.82 \times 10^{-7}\ \text{m}$$

Alternate solution — *Alternate points*

For the correct calculation of either the velocity of light in the medium or the frequency of the light — *1 point*

$$v_{film} = \frac{c}{n_{film}} = \frac{3.00 \times 10^{8}\ \text{m/s}}{1.38} = 2.17 \times 10^{8}\ \text{m/s}$$

$$\text{OR} \quad f = \frac{c}{\lambda_{air}} = \frac{3.00 \times 10^{8}\ \text{m/s}}{6.65 \times 10^{-7}\ \text{m}} = 4.51 \times 10^{14}\ \text{Hz}$$

$$\lambda_{film} = \frac{v_{film}}{f} = \frac{2.17 \times 10^{8}\ \text{m/s}}{4.51 \times 10^{14}\ \text{Hz}}$$

For the correct answer with units — *1 point*

$$\lambda_{film} = 4.81 \times 10^{-7}\ \text{m}$$

(ii) 3 points

The light that enters the film and reflects off the prism travels a total distance $2t$ through the film. At both interfaces, there is a 180° phase change when the light is reflected, so the relative phase change of the interfering rays is zero. For destructive interference, the minimum path length in the film must equal $\lambda_{film}/2$. Therefore, we have the relationship $2t = \lambda_{film}/2$.

For the relationship between the thickness of the film and the wavelength of light in the film — 1 point

$$t = \frac{\lambda_{film}}{4} \text{ or } t = \frac{\lambda_{air}}{4n_{film}}$$

For the correct substitution of the wavelength of light in the film — 1 point

$$t = \frac{\lambda_{film}}{4} = \frac{4.82 \times 10^{-7}\ \text{m}}{4} \quad \text{OR} \quad t = \frac{\lambda_{air}}{4n_{film}} = \frac{6.65 \times 10^{-7}\ \text{m}}{4(1.38)}$$

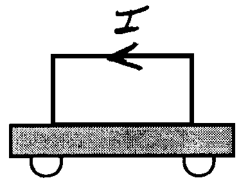
For the correct answer with units — 1 point

$$t = 1.20 \times 10^{-7}\ \text{m}$$

Question 6

10 points total **Distribution of points**

(a) 3 points



For an unambiguous indication that the induced current in the loop is in the counterclockwise direction — 1 point

For a justification that includes <u>two</u> correct and relevant principles, such as the following: — 2 points

The flux is changing (or increasing into the page).
The induced current will oppose the change in flux.
A counterclockwise current will produce flux out of the page.
The magnetic forces on charges in the right-hand wire will drive a counterclockwise current.
Velocity is to the right, and $\mathbf{B}$ into the page, so $q\mathbf{v} \times \mathbf{B}$ points toward the top of the page.
The induced current must produce a magnetic drag force (opposite the motion).

A single relevant principle earns 1 point.

(b)

(i) 2 points

For writing relevant algebraic expressions for both the current and the emf somewhere in the part (b) answer space — 1 point

$I = \dfrac{\mathcal{E}}{R}$ and $\mathcal{E} = -\dfrac{\Delta\phi_m}{\Delta t}$ or $\mathcal{E} = B\ell v$

$I = B\ell v/R = (2.0\ \text{T})(0.10\ \text{m})(3.0\ \text{m/s})/4.0\ \Omega$

For the correct magnitude of the current — 1 point

$I = 0.15\ \text{A}$

(ii) 1 point

$F_B = BI\ell\sin\theta$, where $\theta = 90°$ because the field is perpendicular to the direction of the current.

For an unambiguous substitution of current and wire length consistent with part (i) and the correct magnetic field into a correct expression for force — 1 point

$F_B = (2.0\ \text{T})(0.15\ \text{A})(0.10\ \text{m})\sin 90°$

$F_B = 0.030\ \text{N}$

Units 1 point

For correct units in the answers to both parts (i) and (ii) — 1 point

Question 6 (continued)

Distribution of points

(c) 3 points

For an unambiguous indication that the net force is zero	1 point
For stating that the current is zero	1 point
For either correctly explaining why the current is zero (such as “there is no change in magnetic flux” or “magnetic forces on charges in the two sides of the loop push the charges in opposite directions”) or explaining how zero current results in zero magnetic force on the wire loop	1 point

Question 7

10 points total | **Distribution of points**

(a) 2 points

$v = f\lambda$

For substitution of the appropriate values of the speed of light and the wavelength into the correct expression — 1 point

$$f = \frac{v}{\lambda} = \frac{c}{\lambda} = \frac{3.0 \times 10^{8} \text{ m/s}}{400 \times 10^{-9} \text{ m}}$$

For the correct answer — 1 point

$f = 7.5 \times 10^{14}$ Hz

(b) 2 points

$K_{\max} = hf - \phi$

$\phi = hf - K_{\max}$

For consistent substitution of the maximum kinetic energy into the correct expression — 1 point

For consistent substitution of the frequency into the correct expression — 1 point

$$\phi = \left(6.63 \times 10^{-34} \text{ J•s}\right)\left(7.5 \times 10^{14} \text{ Hz}\right) - 1.1 \times 10^{-19} \text{ J}$$

$\phi = 3.9 \times 10^{-19}$ J

(c) 2 points

$eV = K_{\max}$

For substitution of the appropriate values of the maximum kinetic energy and the charge of the electron into the correct expression — 1 point

$$V = \frac{K_{\max}}{e} = \frac{1.1 \times 10^{-19} \text{ J}}{1.6 \times 10^{-19} \text{ C}}$$

For the correct magnitude of the stopping potential — 1 point

$V = 0.69$ V

Question 7 (continued)

Distribution of points

(d) 3 points

$K = \frac{1}{2}mv^2$ — 1 point

For substitution of the appropriate values of the maximum kinetic energy and the mass of the electron into the correct expression

$$v = \sqrt{\frac{2K_{max}}{m}} = \sqrt{\frac{2\left(1.1\times10^{-19}\ \text{J}\right)}{9.11\times10^{-31}\ \text{kg}}} = 4.91\times10^{5}\ \text{m/s}$$

For consistent substitution of velocity and mass of the electron into the correct expression — 1 point

$$p = mv = \left(9.11\times10^{-31}\ \text{kg}\right)\left(4.91\times10^{5}\ \text{m/s}\right)$$

For the correct answer — 1 point

$$p = 4.5\times10^{-25}\ \text{kg}\bullet\text{m/s}$$

Units 1 point

For using correct units in completed answers — 1 point