AP® Physics C: Mechanics
2002 Scoring Guidelines

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General Notes About
2002 AP Physics Scoring Guidelines

1. The solutions contain the most common method(s) of solving the free-response questions, and the allocation of points for these solutions. 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.

4. The scoring guidelines typically show numerical results using the approximate value $g = 10\ \text{m}/\text{s}^2$ for ease of calculation, but use of $9.8\ \text{m}/\text{s}^2$ is of course also acceptable.

5. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. The exception is usually when rounding makes a difference in obtaining a reasonable answer. For example, in calculations of mass differences in a nuclear reaction, rounding to too few digits can lose the accuracy required to determine a mass difference.

Question 1

15 points total	**Distribution of points**
(a) 4 points	
For any statement of conservation of momentum	1 point
$p_{before} = p_{after}$	
For correctly substituting quantities into the left side of the above equation	1 point
For correctly substituting quantities into the right side of the above equation	1 point
$m_{car}\,\upsilon_{before} = (M + m_{car})\upsilon_{after}$	
$(1{,}000\text{ kg})(12\text{ m/s}) = (M + 1{,}000\text{ kg})\left(\dfrac{8}{1+5t}\text{ m/s}\right)$	
p_{after} occurs just after the collision, i.e. at $t = 0$	
$(1{,}000\text{ kg})(12\text{ m/s}) = (M + 1{,}000\text{ kg})(8\text{ m/s})$	
For the correct answer	1 point
$M = 500\text{ kg}$	
(b) 3 points	
For any indication that the velocity υ is the time derivative of position x	1 point
$\dfrac{dx}{dt} = \dfrac{8}{1+5t}$	
For correctly expressing the above equation as an integral, with or without using limits	1 point
$x = \displaystyle\int \frac{8}{1+5t}\,dt$	
Substituting $u = 1 + 5t$ and $du = 5dt$	
$x = \dfrac{8}{5}\displaystyle\int \frac{du}{u} = \frac{8}{5}\ln u + C = \frac{8}{5}\ln(1+5t) + C$ (or equivalent using limits)	
The condition $x = 0$ at $t = 0$ gives $C = 0$	
For the correct answer	1 point
$x = \dfrac{8}{5}\ln(1+5t)$	

Question 1 (cont'd.)

	Distribution of points
(c) 4 points	
For use of Newton's second law	1 point
$F = ma$	
For any indication that the acceleration a is the time derivative of velocity υ	1 point
$a = \dfrac{d\upsilon}{dt} = \dfrac{d}{dt}\left(\dfrac{8}{1+5t}\right)$	
$a = -\dfrac{40}{(1+5t)^2}$	
$F = (1500)\left(-\dfrac{40}{(1+5t)^2}\right)$	
For the including the minus sign in the final expression for the force	1 point
For having the proper expression for the magnitude of the force	1 point
$F = -\dfrac{60,000}{(1+5t)^2}$	
	Alternate points
Alternate solution	
For any indication that the force F is the time derivative of momentum p	*1 point*
$F = \dfrac{dp}{dt}$	
For expressing the force in terms of the derivative of the velocity	*1 point*
$F = m\dfrac{d\upsilon}{dt} = m\dfrac{d}{dt}\left(\dfrac{8}{1+5t}\right) = (1500)\left(-\dfrac{40}{(1+5t)^2}\right)$	
For the including the minus sign in the final expression for the force	*1 point*
For having the proper expression for the magnitude of the force	*1 point*
$F = -\dfrac{60,000}{(1+5t)^2}$	

Question 1 (cont'd.)

	Distribution of points
(d) 3 points	
For a correct expression for the impulse	1 point
$J = \Delta p$ or $m\,\Delta v$	
For correct substitution into the equation above	1 point
$J = m_{total}\left[v(2) - v(0)\right] = (1500\text{ kg})\left(\frac{8}{11} - 8\right)\text{m/s}$	
For the correct sign on the final answer	1 point
$J = -10{,}909\,\text{kg}\cdot\text{m/s}$ or $\text{N}\cdot\text{s}$	
Alternate solution	*Alternate points*
For a correct expression for the impulse	*1 point*
$J = \int F\,dt$ or $F_{average}\,\Delta t$	
For correct substitution into the equation above	*1 point*
$J = \int_0^2 -\frac{60{,}000}{(1+5t)^2}\,dt$	
For the correct sign on the final answer	*1 point*
$J = -10{,}909\,\text{kg}\cdot\text{m/s}$ or $\text{N}\cdot\text{s}$	
Units point	
For correct units on the answers to both part (a) and part (d)	1 point

Question 2

15 points total	**Distribution of points**
(a) 2 points	
For determining the rotational inertia of each tire	1 point
$I = \frac{1}{2}ML^2 = \frac{1}{2}\frac{m}{4}r^2 = \frac{1}{8}mr^2$	
For the correct total rotational inertia for all 4 tires	1 point
$I_{tot} = 4I = \frac{1}{2}mr^2$	
(b) 7 points	
For an indication of the conservation of mechanical energy	1 point
$E_{top} = E_{bottom}$; $\Delta U = -\Delta K$; or equivalent	
For correct expressions for energies at the top	1 point
$K_{top} = 0;\ U_{top} = mgh + 4\left(\frac{1}{4}mgh\right) = 2mgh$	
For a correct expression for potential energy at the bottom and for recognizing that kinetic energy at the bottom is the sum of translational and rotational kinetic energies	1 point
$U_{bottom} = 0;\ K_{bottom} = K_{trans} + K_{rot}$	
For a correct expression for translational kinetic energy at the bottom	1 point
$K_{trans} = \frac{1}{2}(2m)v^2 = mv^2$	
For a correct expression for rotational kinetic energy at the bottom	1 point
$K_{rot} = \frac{1}{2}I\omega^2$	
For recognition of the relationship between translational and rotational velocity	1 point
$\omega = \frac{v}{r}$	
Substituting these expressions to determine total kinetic energy at the bottom	
$K_{bottom} = mv^2 + \frac{1}{2}\left(\frac{1}{2}mr^2\right)\frac{v^2}{r^2} = \frac{5}{4}mv^2$	
Setting potential energy at the top equal to the kinetic energy at the bottom	
$\frac{5}{4}mv^2 = 2mgh$	
For the correct solution for v	1 point
$v = \sqrt{\frac{8}{5}gh}$	

Question 2 (cont'd.)

Distribution of points

(c) 4 points

For recognition that energy is conserved (Although it is an inelastic collision, the mass of the bumper is negligibly small, thus its kinetic energy is negligible and there is no loss of energy.) — 1 point

For a correct expression for potential energy of the spring at maximum compression — 1 point

$U_K = \frac{1}{2}kx_m{}^2$

For applying conservation of energy by equating the potential energy of the spring at maximum compression EITHER to the gravitational potential energy of the cart and wheels at the top of the inclined plane OR to the kinetic energy of the cart and wheels at the bottom of the inclined plane — 1 point

$\frac{1}{2}kx_m^2 = 2mgh$ OR $\frac{1}{2}kx_m^2 = \frac{5}{4}Mv^2$

For a correct solution of either of these equations for x_m (including a correct substitution for v from part (b) for the second equation) or an answer consistent with work done in (b) — 1 point

$x_m = 2\sqrt{\frac{mgh}{k}}$

Notes:

If there was no attempt to use energy then 1 point only was given for $F = -kx = ma = \frac{dp}{dt}$ or a similar expression.

Further, if there was written recognition of the necessity to slow down the wheel rotation, torque, angular acceleration, etc, then 1 point was given.

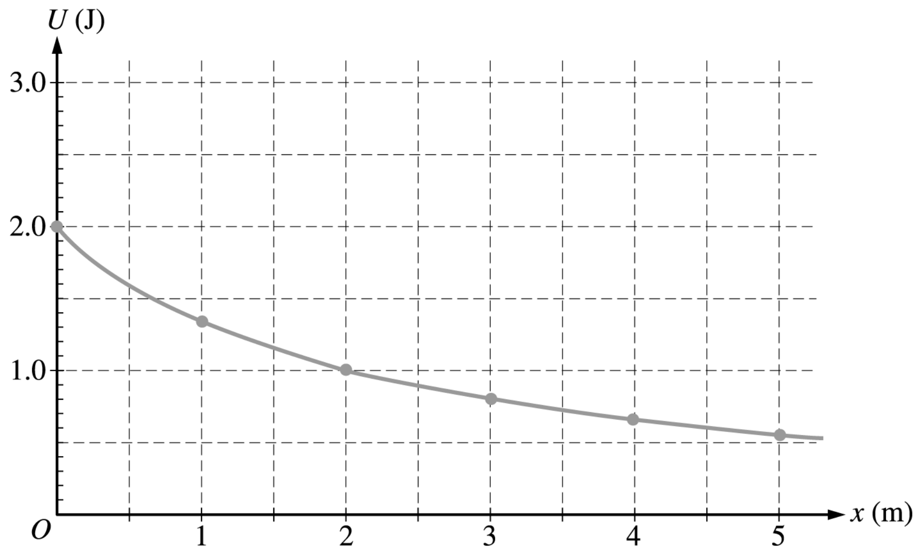
(d) 2 points

For an explanation that discusses the inelastic collision with a loss of mechanical energy or a reduced velocity resulting in a smaller compression. The discussion should have been correctly stated. If there were any incorrect statements, then 1 point was subtracted. Points were neither added or subtracted for irrelevant statements, such as references to friction. — 2 points

Question 3

15 points total | **Distribution of points**

(a) 3 points



For correct shape: concave upward and monotonically decreasing — 1 point
For correct y intercept: $U(0) = 2.0$ J — 1 point
For value of U at $x = 5$ within the range $0.50 \text{ J} \le U(5) \le 0.75 \text{ J}$ — 1 point

(b) 4 points

For the expression for force as a derivative of potential relative to position — 2 points

$$F = -\frac{dU}{dx}$$

Only one point was awarded if the negative sign was missing. A non-calculus statement such as $F = -\frac{\Delta U}{\Delta x}$ earned no credit.

For taking a derivative of the potential function — 1 point

$$F = -\frac{d}{dx}\left(\frac{4.0}{2.0 + x}\right)$$

For the correct answer or answer consistent with non-inclusion of minus sign in above equation — 1 point

$$F = \frac{4.0}{(x + 2.0)^2}$$

Question 3 (cont'd.)

	Distribution of points
(c) 3 points	
For explicitly indicating the use of conservation of energy or the net work-energy theorem in words or by an equation (but not just $K = U$)	1 point
$\Delta U = U(0) - U(2) = \frac{1}{2}mv^2$	
$2.0\ \text{J} - 1.0\ \text{J} = \frac{1}{2}(0.5\ \text{kg})v^2$	
For the correct answer $v = 2.0$ m/s	2 points
(d) 2 points	
For indicating items of equipment consistent with the procedure described in part (e) (at least two of the items if more than two were used) Note: If part (e) was not attempted, only 1 point maximum was awarded. Unreasonable indications, such as all the items being checked, were not awarded any points.	2 points
(e) 3 points	
For a complete description of any correct procedure.	3 points

Partial credit was awarded for less complete descriptions. The following were common examples. Other examples, though rarely cited, could receive partial or full credit.

1. Using photogates

   Place the photogates near $x = 2$ m and a small distance apart (such as a glider length). Measure the distance between the photogates. Measure the time the glider takes to travel between the photogates. Obtain the speed from distance/time.

   Note: No points were given if the distance measured was from 0 to 2 m and the time to travel 2 m was used.

2. Using a spring

   The spring constant k of the spring must be known, or if not, then measured. Set up the spring at $x = 2$ m so that it is compressed when struck by the glider. Measure the distance of maximum compression x_m. The velocity can then be determined from the equation $\frac{1}{2}kx_m = \frac{1}{2}mv^2$.

3. Treating the glider as a projectile

   Adjust the starting point so that $x = 2$ m is at end of the track. Thus the glider leaves the track at this point and becomes a projectile. The height of the track determines the time interval t that the glider is in the air. The horizontal distance x from the end of the track to the point where the glider hits the ground is measured and then the velocity is computed from x/t.