AP® PHYSICS C: MECHANICS
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 Exams 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*.

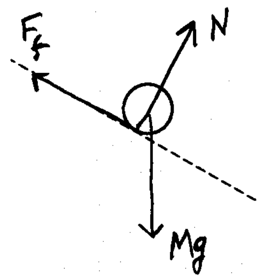
4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

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 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

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

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

$$\omega = v/R$$

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

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

For a correct numerical answer — 1 point

$$v = 5.3\ \mathrm{m/s}$$

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)

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

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

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

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

For a correct numerical answer — *1 point*

$$v = 5.3\ \mathrm{m/s}$$

(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

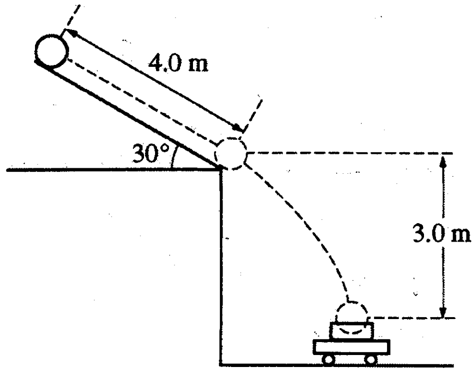
For setting M_f equal to the total mass of the ball and the wagon/box — 1 point

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

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

Units 1 point

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

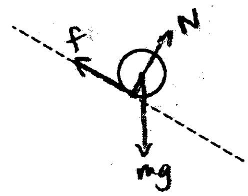


Note: Figure not drawn to scale.

Mech. 2.

A bowling ball of mass 6.0 kg is released from rest from the top of a slanted roof that is 4.0 m long and angled at 30°, as shown above. The ball rolls along the roof without slipping. The rotational inertia of a sphere of mass M and radius R about its center of mass is $\frac{2}{5}MR^2$.

(a) On the figure below, draw and label the forces (not components) acting on the ball at their points of application as it rolls along the roof.



(b) Calculate the force due to friction acting on the ball as it rolls along the roof. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

$\Sigma \tau = I\alpha$

$f\cancel{R} = \frac{2}{5}m\cancel{R^2}\frac{a}{\cancel{R}}$

$f = \frac{2}{5}ma$

$\Sigma F = ma$

$mg\sin 30 - f = ma$

$\frac{mg}{2} - f = ma$

$\frac{\cancel{m}g}{2} - \frac{2}{5}\cancel{m}a = \cancel{m}a$

$\frac{5}{7}\frac{g}{2} = \frac{7}{5}a$

$\frac{5g}{14} = a$

$f = \frac{\cancel{2}}{\cancel{5}}m\left(\frac{\cancel{5}g}{\cancel{14}_{7}}\right)$

$f = \frac{mg}{7} = \frac{6(9.8)}{7} = \boxed{8.4\text{ N}}$

(c) Calculate the linear speed of the center of mass of the ball when it reaches the bottom edge of the roof.

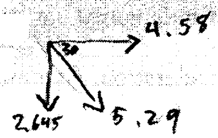
$$mgh = \frac{1}{2} I\omega^2 + \frac{1}{2} mv^2$$

$$mg(4\sin 30) = \frac{1}{\cancel{2}}\left(\frac{\cancel{2}}{5} m\cancel{R^2}\right)\frac{v^2}{\cancel{R^2}} + \frac{1}{2} mv^2$$

$$2\cancel{m}g = \frac{1}{5} mv^2 + \frac{1}{2} mv^2 = \frac{7}{10}\cancel{m}v^2$$

$$\sqrt{\frac{20g}{7}} = v \qquad \boxed{v = 5.29 \text{ m/s}}$$

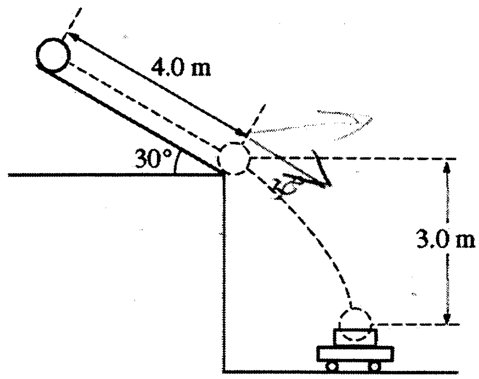
(d) A wagon containing a box is at rest on the ground below the roof so that the ball falls a vertical distance of 3.0 m and lands and sticks in the center of the box. The total mass of the wagon and the box is 12 kg. Calculate the horizontal speed of the wagon immediately after the ball lands in it.



$$V_x = 4.58 \text{ m/s}$$

$$6(4.58) = 18(V_x)$$

$$\boxed{V_x = 1.53 \text{ m/s}}$$

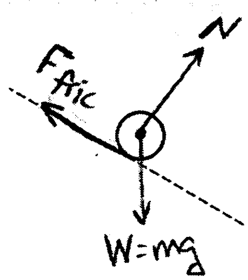


<u>Note:</u> Figure not drawn to scale.

Mech. 2.

A bowling ball of mass 6.0 kg is released from rest from the top of a slanted roof that is 4.0 m long and angled at 30°, as shown above. The ball rolls along the roof without slipping. The rotational inertia of a sphere of mass M and radius R about its center of mass is $\frac{2}{5}MR^2$.

(a) On the figure below, draw and label the forces (not components) acting on the ball at their points of application as it rolls along the roof.



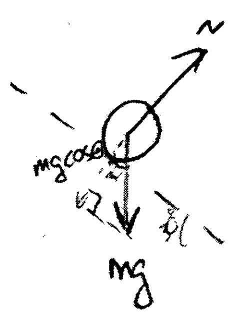
(b) Calculate the force due to friction acting on the ball as it rolls along the roof. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

$m = 6\ kg$

$\theta = 30°$

$I_R = \frac{2}{5}MR^2$

$F_f = \mu N$



$\Sigma F = ma$

$N = -mg\cos\theta$

$h = 4\sin 30 = 2\,m$

(c) Calculate the linear speed of the center of mass of the ball when it reaches the bottom edge of the roof.

$\cancel{K_{RF}} + \cancel{K_0} + U_0 = K_T + \cancel{U_f} + K_{RF}$

$U_0 = K_T + K_R$

$mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$

$2mgh = mv^2 + (\frac{2}{5}MR^2)\omega^2$

$\omega = \frac{v}{r}$

$2\cancel{M}gh = \cancel{M}v^2 + \frac{2}{5}\cancel{M}R^2(\frac{v}{R})^2$

$2gh = v^2 + \frac{2}{5}\frac{\cancel{R^2}\cdot v^2}{\cancel{R^2}}$

$2gh = v^2 + \frac{2}{5}v^2 = \frac{7}{5}v^2$

$\sqrt{\frac{10}{7}gh} = v$ $\boxed{v = 5.29\,m/s}$

(d) A wagon containing a box is at rest on the ground below the roof so that the ball falls a vertical distance of 3.0 m and lands and sticks in the center of the box. The total mass of the wagon and the box is 12 kg. Calculate the horizontal speed of the wagon immediately after the ball lands in it.

$v_{ox} = 5.29\cos 30 = 4.58\,m/s$

$v_{oy} = 5.29\sin 30 = 2.65\,m/s$

* CONSERVATION OF MOMENTUM

$p_0 = p_f$

$m_1 v_0 = (m_1 + m_2)v_f$

$(6\,kg)(4.58\,m/s) = (6kg + 12kg)\,v_f$

$27.48 = (18\,kg)v_f$

$h = 3.0\,m$

$\cancel{m}gh = \frac{1}{2}\cancel{m}v^2$

$v = \sqrt{2gh}$

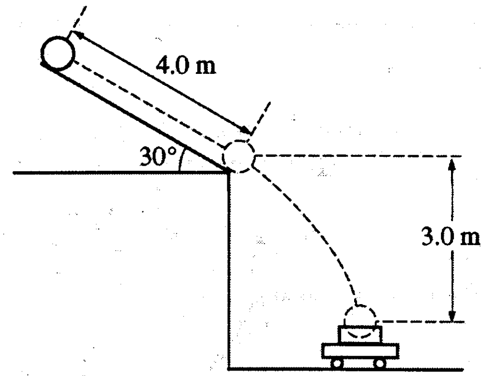
$v_{fy} = 7.67\,m/s$

$t = \frac{v_f - v_0}{a}$

$= \frac{7.67 - 2.65}{9.8}$

$= 0.5\,s$

t



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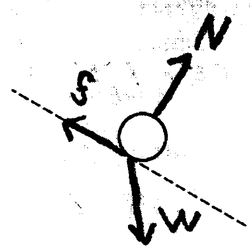

(b) Calculate the force due to friction acting on the ball as it rolls along the roof. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

$\Sigma F = 0$

$f = \mu_K N$

$f = \mu_K (mg\cos\theta)$

$f = \mu_K (6(9.8)\cos 30)$

$\boxed{f = 50.922\,\mu_K}$

(c) Calculate the linear speed of the center of mass of the ball when it reaches the bottom edge of the roof.

$$U_i + K_i = U_f + K_f$$

$$\cancel{m}gh = \frac{1}{2}\cancel{m}v^2$$

$$9.8(L\sin 30) = \frac{1}{2}v^2$$

$$39.2 = v^2$$

$$\boxed{v = 6.26\ m/s}$$

(d) A wagon containing a box is at rest on the ground below the roof so that the ball falls a vertical distance of 3.0 m and lands and sticks in the center of the box. The total mass of the wagon and the box is 12 kg. Calculate the horizontal speed of the wagon immediately after the ball lands in it.

$$U_i + K_i = U_f + K_f$$

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

$$6(9.8)(3) + \frac{1}{2}(6)(6.26)^2 = \frac{1}{2}(12)v^2$$

$$176.4 + 117.56 = 6v^2$$

$$\boxed{v = 6.999\ m/s}$$

AP® PHYSICS C: MECHANICS
2010 SCORING COMMENTARY

Question 2

Overview

Part (a) assessed students' ability to identify forces acting on a bowling ball that rolls down an incline without slipping and to produce a free-body diagram. Parts (b) and (c) assessed students' ability to determine the frictional force acting on the bowling ball as it is rolling and to determine the velocity of the ball at the end of an incline. The solution required various combinations of Newton's second law for linear motion, Newton's second law for rotational motion, conservation of energy, and kinematics, depending on the methodology employed. Part (d) assessed students' understanding of the principles of projectile motion and the ability to solve for the final velocity of a system undergoing an inelastic collision that is constrained to move in one dimension after the collision.

Sample: M2-A
Score: 15

This full-credit response is neat and well organized.

Sample: M2-B
Score: 8

Part (a) earned 2 points for the correctly drawn frictional and gravitational force vectors. The normal force is not at the correct point of application. Part (b) earned no credit. Parts (c) and (d) earned full credit. The units point was not awarded since only one part has an answer with units.

Sample: M2-C
Score: 3

Part (a) earned 1 point for the correctly drawn frictional force vector. The other forces are not at the correct points of application. Part (b) earned no credit. Part (c) earned 1 point for an expression of conservation of energy. Part (d) earned no credit. Finally, 1 point was earned for including units on two numerical answers.