AP® Physics C: Mechanics
2011 Scoring Guidelines

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Question 1

15 points total | **Distribution of points**

(a) 2 points

$\mathbf{J} = \int \mathbf{F}\, dt$

For a correct equation relating the given force, time and impulse — 1 point

$J_p = F_{avg} \Delta t$

For the correct answer — 1 point

$\Delta t = J_p / F_{avg}$

Alternate solution — *Alternate points*

For using both kinematics and Newton's second law — *1 point*

$\upsilon_x = 0 + a_{avg} \Delta t$

$\mathbf{F}_{avg} = m\mathbf{a}_{avg}$

Combining the above equations

$F_{avg} = m\left(\frac{\upsilon_x}{\Delta t}\right)$

$F_{avg} \Delta t = m\upsilon_x = J_p$

For the correct answer — *1 point*

$\Delta t = J_p / F_{avg}$

(b) 2 points

For the correct relationship between impulse and the change in momentum — 1 point

$\mathbf{J} = \Delta \mathbf{p} = m\Delta \mathbf{v}$

$J_p = m(\upsilon_x - 0) = m\upsilon_x$

For the correct answer — 1 point

$m = J_p / \upsilon_x$

Note: A correct kinematics and Newton's laws approach is also acceptable.

Question 1 (continued)

Distribution of points

(c) 3 points

For using the work-energy theorem — 1 point

$$W = \Delta K$$

$$W = 0 - \frac{1}{2}m\upsilon_x^2$$

For substituting the expression for m from part (b) — 1 point

$$W = -\frac{1}{2}\frac{J_p}{\upsilon_x}\upsilon_x^2$$

$$W = -\frac{1}{2}J_p\upsilon_x$$

For an indication that the work done is negative — 1 point

Alternate Solution — *Alternate points*

Using kinematics and Newton's second law to determine the average net force

$$\upsilon_f^2 - \upsilon_i^2 = 2a_{avg}d$$

$$-\upsilon_x^2 = 2a_{avg}d$$

$$a_{avg} = -\frac{\upsilon_x^2}{2d}$$

$$\mathbf{F}_{avg} = m\mathbf{a}_{avg}$$

$$F_{net} = m\left(-\frac{\upsilon_x^2}{2d}\right)$$

For substituting this expression for the force into the equation for work — *1 point*

$$W = \int \mathbf{F} \cdot d\mathbf{r} = F_{avg}d = m\left(-\frac{\upsilon_x^2}{2d}\right)d$$

$$W = -m\frac{\upsilon_x^2}{2}$$

For substituting the expression for m from part (b) — *1 point*

$$W = -\frac{J_p}{\upsilon_x}\frac{\upsilon_x^2}{2}$$

$$W = -\frac{1}{2}J_p\upsilon_x$$

For an indication that the work done is negative — *1 point*

Question 1 (continued)

Distribution of points

(d) 2 points

$W = \int \mathbf{F} \cdot d\mathbf{r} = \mathbf{F}_{avg} \cdot \mathbf{r}$

For using F_b as the average force in the equation for work — 1 point

$W = F_b d$

$F_b = \frac{W}{d}$

For substituting the expression for W from part (c), with or without a negative sign — 1 point

$F_b = \frac{J_p v_x}{2d}$

(e) 4 points

Applying the work-energy relationship

$K_i + W = K_f$

For correctly relating the initial kinetic energy of the projectile with the work done by the block on the projectile and the work done on the block by friction with the table — 1 point

$K_i + W_{block} + W_{friction} = 0$

For substituting for the work done by the block on the projectile (i.e., the energy lost to heat in the block-projectile collision) — 1 point

$K_i - F_b d_n + W_{friction} = 0$

For substituting the work done on the block by friction with the table (i.e., the energy lost to heat as the block slides to rest on the table) — 1 point

$K_i - F_b d_n - f_T D = 0$

The initial kinetic energy of the projectile is the same as in the first case when the block was clamped. Therefore, it can be equated to the work done in stopping the projectile from part (d).

For substituting $F_b d$ for the initial kinetic energy of the block — 1 point

$F_b d - F_b d_n - f_T D = 0$

$F_b d_n = F_b d - f_T D$

Full credit could not be earned for just writing this equation. The student needed to have some indication that the work-energy relationship was being applied, and that F_d was associated with the initial kinetic energy.

$d_n = \frac{F_b d - f_T D}{F_b}$

$d_n = d - \frac{f_T}{F_b} D$

Question 1 (continued)

Distribution of points

(f) 2 points

For a correct application of conservation of momentum to the block-projectile collision — 1 point

$$mv_x = (M+m)V$$

$$V = \frac{m}{(M+m)}v_x$$

The kinetic energy of the block/projectile system immediately after the collision is equal to the work done by friction in stopping it.

$$\frac{1}{2}(M+m)V^2 = f_T D$$

For substituting for V — 1 point

$$\frac{1}{2}(M+m)\left(\frac{m}{(M+m)}v_x\right)^2 = f_T D$$

$$\frac{1}{2}\frac{m^2 v_x^2}{(M+m)} = f_T D$$

$$\frac{m}{M+m}\left(\frac{1}{2}mv_x^2\right) = f_T D$$

From part (c) the kinetic energy factor in the equation above is equal to the total work done. From part (d) that work is equal to $F_b d$.

$$\frac{m}{M+m}F_b d = f_T D$$

Using the expression $F_b d_n = F_b d - f_T D$ from part (e) to substitute for $f_T D$

$$\frac{m}{M+m}F_b d = F_b d - F_b d_n$$

$$\frac{m}{M+m}d = d - d_n$$

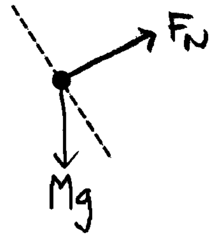
$$d_n = d\left(1 - \frac{m}{M+m}\right)$$

Note: Because the work for parts (e) and (f) is interrelated, the two parts are scored as a whole. Credit is earned for work related to part (f) even when it is shown in part (e) and vice versa.

Question 2

15 points total **Distribution of points**

(a) 2 points



For either a weight force or a normal force, correctly drawn and labeled — 1 point
For the second correct force and no additional forces, arrows or components — 1 point

(b) 1 point

For a correct expression for the centripetal force in terms of the forces drawn in part (a) — 1 point
For the example above:
$F_c = F_N - Mg\sin\theta$

Alternate Solution — *Alternate points*
Applying conservation of energy, with the loss of potential energy equal to the kinetic energy at point C
$Mg\,\Delta h = Mv_C^2/2$
$v_C^2 = 2g\,\Delta h$
$\Delta h = 3R/4 + R\sin\theta$
$v_C^2 = 2g(3R/4 + R\sin\theta)$
$F_c = Mv_C^2/R$
$F_c = M\left(2g(3R/4 + R\sin\theta)\right)/R$
For a correct answer — *1 point*
$F_c = 2Mg(3/4 + \sin\theta)$

(c) 2 points

For applying conservation of energy, with the loss of potential energy equal to the kinetic energy at point *D* — 1 point
$Mg\,\Delta h = Mv_D^2/2$
$v_D^2 = 2g\,\Delta h$
$\Delta h = 3R/4 + R = 7R/4$
$v_D^2 = 2g(7R/4)$
For a correct answer — 1 point
$v_D = \sqrt{(7/2)gR}$

Question 2 (continued)

Distribution of points

(d) 3 points

Work-energy approach

For equating the work done by the friction force to the kinetic energy of the compartment at point D — 1 point

$$W = \Delta K = 0 - \frac{1}{2}Mv_D^2$$

For a correct expression for the frictional force — 1 point

$$f = \mu N = \mu Mg$$

$$W = \mathbf{F} \bullet \Delta\mathbf{r} = fd\cos 180 = -(\mu Mg)d$$

$$(\mu Mg)d = \frac{1}{2}Mv_D^2$$

For substituting the expression for v_D from part (c), and $d = 3R$ — 1 point

$$(\mu Mg)3R = \frac{1}{2}M\left(\frac{7}{2}gR\right)$$

$$3\mu = \frac{1}{2}\left(\frac{7}{2}\right)$$

$$\mu = 7/12$$

Note: Full credit is also earned for setting the initial potential energy at point A, $U_A = mg\left(\frac{7R}{4}\right)$, equal to the work done by the frictional force, and solving for μ.

Alternate solution — *Alternate points*

For using both Newton's second law and a correct kinematics equation — *1 point*

$$\mathbf{F}_{net} = m\mathbf{a}$$

$$v_f^2 - v_i^2 = 2ad$$

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

$$f = \mu N = \mu Mg$$

$$-\mu Mg = Ma$$

$$a = -\mu g$$

Substituting for a, and the final and initial speeds in the kinematic equation

$$-v_D^2 = 2(-\mu g)d$$

For substituting the expression for v_D from part (c), and $d = 3R$ — *1 point*

$$\frac{7}{2}gR = 2(\mu g)3R$$

$$\mu = 7/12$$

Question 2 (continued)

Distribution of points

(e)

i. 2 points

$\Sigma F = ma$

For substituting the braking force into Newton's second law as the net force — 1 point

For substituting the time derivative of velocity for the acceleration — 1 point

$-k\upsilon = M(d\upsilon/dt)$

ii. 2 points

For separating the variables and integrating — 1 point

$d\upsilon/\upsilon = -(k/M)\,dt$

$\int_{\upsilon_D}^{\upsilon} d\upsilon/\upsilon = -(k/M)\int_0^t dt$

$\ln \upsilon\big|_{\upsilon_D}^{\upsilon} = -(k/M)t$

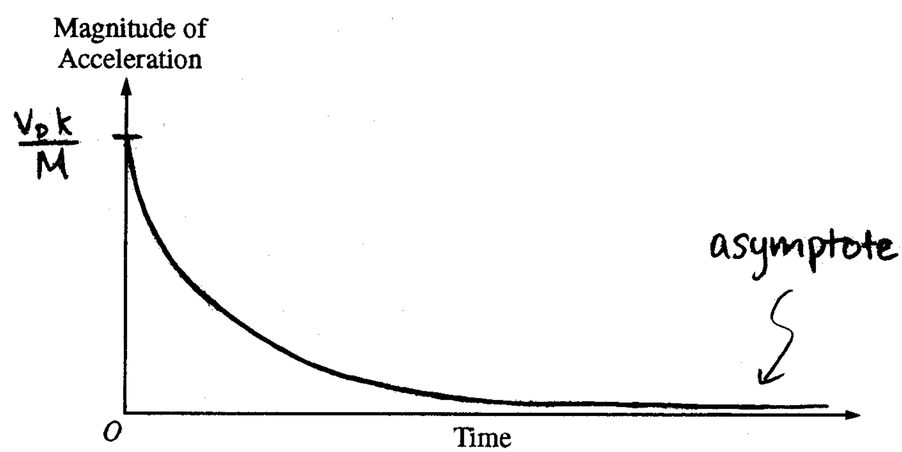
$\ln \upsilon - \ln \upsilon_D = \ln(\upsilon/\upsilon_D) = -(k/M)t$

$\upsilon/\upsilon_D = e^{-kt/M}$

For a correct expression for the velocity as a function of time — 1 point

$\upsilon = \upsilon_D e^{-kt/M}$

iii. 3 points



Taking the derivative of the equation for υ from part (e) ii

$a = d\upsilon/dt = d\left(\upsilon_D e^{-kt/M}\right)/dt = -(k/M)\upsilon_D e^{-kt/M}$

At $t = 0$, $a = -k\upsilon_D/M$

For a graph with a finite intercept on the vertical axis — 1 point

For a graph that is concave upward and asymptotic to zero — 1 point

For labeling the initial acceleration with the correct value — 1 point

Question 3

15 points total **Distribution of points**

(a) 3 points

For a statement of Newton's second law for rotation — 1 point

$\Sigma\tau = I\alpha$

For substituting the given torque expression for the net torque $\Sigma\tau$ — 1 point

$I\alpha = -\beta\theta$

For substituting the second derivative of angular position for angular acceleration — 1 point

$I\dfrac{d^2\theta}{dt^2} = -\beta\theta$

(b) 3 points

Applying Newton's second law for translation to a mass on a spring gives

$m\dfrac{d^2x}{dt^2} = -kx$, and $\omega = \sqrt{\dfrac{k}{m}}$.

For this torsion pendulum, $I\dfrac{d^2\theta}{dt^2} = -\beta\theta$.

Comparing differential equations, I is analogous to m and β is analogous to k.

For the correct expression for ω — 1 point

$\omega = \sqrt{\dfrac{\beta}{I}}$

For the correct relationship between ω and T — 1 point

$T = \dfrac{2\pi}{\omega}$

For the correct answer — 1 point

$T = 2\pi\sqrt{\dfrac{I}{\beta}}$

Alternate Solution — *Alternate points*

The period of a mass on a spring is $T = 2\pi\sqrt{\dfrac{m}{k}}$.

For recognizing that I is analogous to m — *1 point*

For recognizing that β *is analogous to k* — *1 point*

For the correct answer — *1 point*

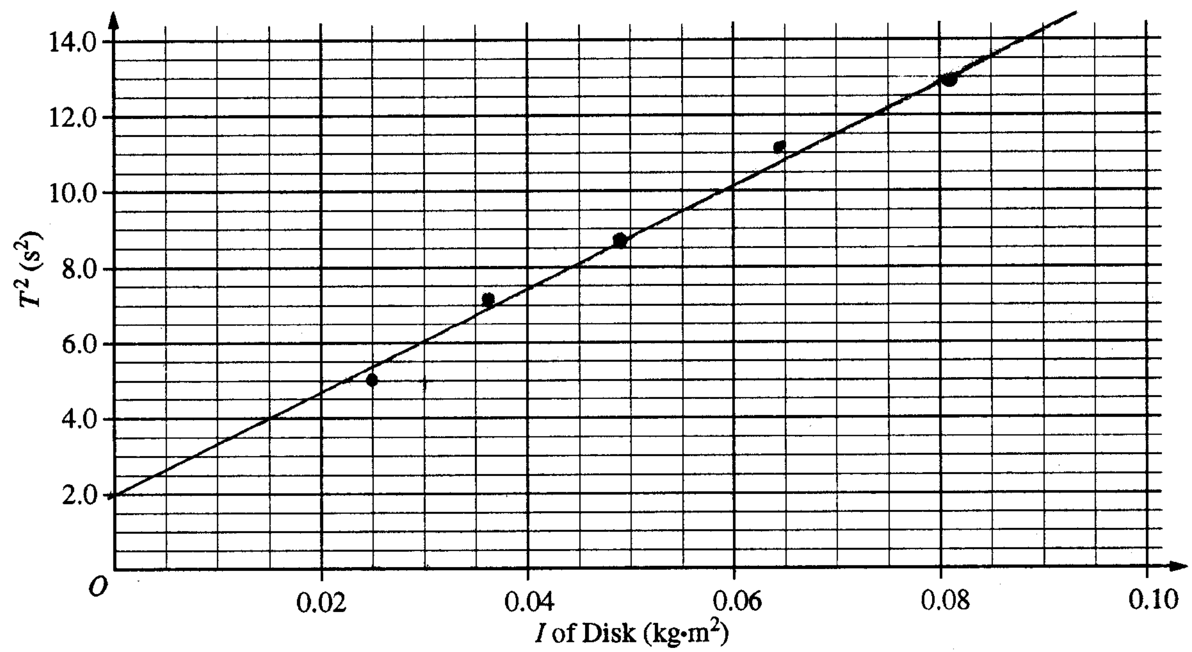
$T = 2\pi\sqrt{\dfrac{I}{\beta}}$

Question 3 (continued)

Distribution of points

(c) 2 points

Sample graph



For correctly plotting the data — 1 point

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

Note: For correctly plotted data, a reasonable, best-fit straight line does NOT pass through the origin.

(d) 3 points

The general equation for a straight line is $y(x) = mx + b$, where m is the slope and b is the y-intercept.

$T^2 = mI + b$

$m = \Delta\left(T^2\right)/\Delta I$

For using two points from the best-fit line to calculate the slope — 1 point

Example from the graph shown: $m = \dfrac{\left(11.5\ \text{s}^2 - 2.0\ \text{s}^2\right)}{\left(0.07\ \text{kg•m}^2 - 0.00\ \text{kg•m}^2\right)}$

$m = 135\ \text{s}^2/\text{kg•m}^2$

For an intercept calculated or directly read from the graph — 1 point

$b = 2.0\ \text{s}^2$

For using the variables T^2 and I in the equation — 1 point

$T^2 = \left(135\ \text{s}^2/\text{kg•m}^2\right)I + 2.0\ \text{s}^2$

Question 3 (continued)

Distribution of points

(e) 3 points

Using the equation from part (b)

$$T = 2\pi\sqrt{\frac{I}{\beta}}$$

$$T^2 = 4\pi^2\frac{I}{\beta} = \frac{4\pi^2}{\beta}I$$

For comparing this to part (d) and noting that $\frac{4\pi^2}{\beta}$ is the slope of the line — 1 point

$$\frac{4\pi^2}{\beta} = m$$

For using the value of the slope determined in part (d) — 1 point

$$\beta = \frac{4\pi^2}{m} = \frac{4\pi^2}{135\ \text{s}^2/\text{kg}\bullet\text{m}^2}$$

$$\beta = 0.292\ \text{kg}\bullet\text{m}^2/\text{s}^2$$

For the correct units on the numerical answer — 1 point

(f) 1 point

For a correct physical explanation for the intercept that mentions the effect of the flexible rod — 1 point

Example: The intercept is the square of the period of oscillation of the flexible rod.