Solutions

# students: 79

Duration: 120 minutes
Show all your work for full/partial credit!
Include the correct units in your final answers for full credit!
Unless otherwise stated, quote your results in SI units!
1) Multiple Choice  

For each statement below, circle the correct answer (TRUE or FALSE, no reasoning required).

(a) In projectile motion, the acceleration of the object keeps changing.  
TRUE  FALSE

(b) If the speed of an object changes, a nonzero net force is acting on that object.  
TRUE  FALSE

(c) If the speed of an object is constant, there is no net force acting on the object.  
TRUE  FALSE

(d) A potential energy must be based on a conservative force.  
TRUE  FALSE

(e) If in a 2-body collision momentum is conserved, kinetic energy must also be conserved.  
TRUE  FALSE

(f) In the 1st law of thermodynamics, positive work done by a gas requires the gas to expand.  
TRUE  FALSE

(g) If the internal energy of an ideal gas increases, the average speed of the gas molecules decreases.  
TRUE  FALSE

<table>
<thead>
<tr>
<th>No.</th>
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<tr>
<td>1</td>
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<td>8</td>
<td>jv</td>
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<tr>
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<td>jv</td>
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2.) Projectile Motion

A boy is throwing a baseball with initial speed of 22m/s toward a tall vertical building which is 50m away. The baseball hits the building after 2.8s. Ignore air resistance and assume the baseball to be launched from ground level.

(a) What is the launch angle of the baseball?

(b) What is the maximal height reached by the ball, and what is its acceleration at that point?

(c) How high above the ground does the ball strike the building and how fast is the ball at that moment?

\[
\begin{align*}
\text{(a) } x\text{-comp. } x &= V_{ox}t \\
&\Rightarrow V_{ox} = \frac{x}{t} \\
&\Rightarrow V_{ox} = \frac{x}{t} \\
&\Rightarrow \theta_0 = 51.9^\circ \quad [44^\circ]
\end{align*}
\]

\[
\begin{align*}
\text{(b) } V_y^2 &= V_{oy}^2 - 2g\Delta y \\
&\Rightarrow \Delta y_{max} = \frac{V_{oy}^2}{2g} = \frac{V_{0}^2 \sin \theta_0}{2g} = 15.3\text{m} \quad [12.1\text{m}]
\end{align*}
\]

\[
\alpha_y = -\frac{g}{t}
\]

\[
\begin{align*}
\text{(c) } V_f &= V_0 + V_{oy}t - \frac{1}{2}gt^2 \\
&= 10.1\text{m} \quad [47\text{m/s}]
\end{align*}
\]

\[
\begin{align*}
V_f &= V_{oy} - gt \\
&= -10.1\text{m/s} \quad (-12.05)
\end{align*}
\]

\[
\begin{align*}
V_f &= \sqrt{V_{f x}^2 + V_{f y}^2} \\
&= \sqrt{16.2^2 + 10.1^2} \\
&= 19.8\text{m/s} \quad [19.8 \text{m/s}]
\end{align*}
\]
A truck is carrying a cargo box placed on its loading deck. The coefficient of static friction between the box and the bed surface is 0.45. On a horizontal road, the truck starts from rest and accelerates uniformly to 65 mph. 

(a) Draw a free-body diagram of the box during the acceleration process.
(b) What is the maximal acceleration the truck can have without the box starting to slide?
(c) What is the shortest time for the truck to reach 65 mph without the box starting to slide?
A cart of mass 2.2 kg is pressed against another cart of mass 1 kg with a spring compressed by 0.25 m from its relaxed state. The spring constant is 3.1 N/m. The carts are released on a horizontal frictionless table. Calculate the speed of each cart once it has moved free from the spring.

Energy conservation:
\[
\frac{1}{2} k x^2 = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2
\]
\[ x = 0.25 \text{ m} \]
\[ v = 9 \text{ m/s} \]

Momentum conservation:
\[ 0 = m_1 v_1 + m_2 v_2 \]
\[ \Rightarrow v_2 = \frac{m_1}{m_2} v_1 \]

\[
\frac{1}{2} k x^2 = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 \left( \frac{m_1}{m_2} v_1 \right)^2 = \frac{1}{2} v_1^2 \left( m_1 + \frac{m_1^2}{m_2} \right)
\]
\[
\Rightarrow v_1 = \left( \frac{k x^2}{m_1 - \frac{m_1^2}{m_2}} \right)^{1/2} = \frac{0.28 m_1}{0.51 m_1} [0.51 \text{ m/s}]
\]
\[
\Rightarrow v_2 = \frac{m_1}{m_2} v_1 = 0.63 \text{ m/s} \]
5. Angular Momentum Conservation

A professor is sitting on a frictionless rotating stool. He holds a pair of dumbbells at a distance of 1.0 m from the axis of rotation. The dumbbells have a mass of 8 kg each, and the moment of inertia of the professor is 7 kg m². The initial rotation frequency is 0.75 Hz.

(a) Calculate the initial angular momentum of the system.

\[ I_0 = I_{p0} + 2 \left( m r^2 \right) = 21.52 \text{ kg m}^2 \text{ s}^{-1} \]

\[ L_0 = I_0 \omega_0 \]

\[ \omega_c = 2 \pi f_c \]

\[ \omega_c = 4.71 \text{ rad/s} \]

\[ L_c = I_{p0} + 2 \left( m r^2 \right) = 7.75 \text{ kg m}^2 \text{ s}^{-1} \]

\[ L_c = L_f \]

(b) Calculate the final angular momentum of the system.

\[ \omega_f = \frac{I_0}{I_f} \omega_0 = 13.1 \text{ rad/s} \]

(c) Calculate the final angular velocity of the system.

\[ \omega_f = \frac{1}{2} I_f \omega_f^2 = 665 \text{ rad/s} \]

Final is larger because professor did work!
6.) Interference

Two small loudspeakers are each emitting a pure tone of frequency $800 \text{Hz}$ in phase (or in step). Originally, the speakers are at the same position, 6.5m away from the ear of a person. Then, one of the speakers is slowly moved away from the person, by an increasing distance $d$. 

(a) At what distance $d$ does the sound first produce a destructive interference at the position of the person's ear?

(b) At what distance $d > 0$ does the sound produce again a constructive interference at the position of the person's ear?

\[ \text{(a) first destructive interference} \quad \Delta L = \frac{\lambda}{2} = 0.1 \]

\[ \lambda = \frac{v}{f} = \frac{0.43 \text{m}}{0.85 \text{Hz}} \quad \Rightarrow \quad d_{\text{min}} = 0.214 \text{ m} \quad [0.26 \text{m}] \]

\[ \text{(b) first constructive interference} \quad d = \Delta L = \lambda \]

\[ d_{\text{min}} = 0.43 \text{ m} \quad [0.53 \text{m}] \]
7.) Archimedes' Principle

An ore sample which looks like gold from the outside has a mass of 2.5 kg. The sample is suspended by a light and thin cord and completely immersed into water. The tension in the cord is measured to be 21.1 N.

\( \rho_{\text{water}} = 1000 \text{kg/m}^3, \rho_{\text{gold}} = 19300 \text{kg/m}^3 \)

(a) What is the volume of the sample?

(b) What is the density of the sample? Is it solid gold?
8. Heat Transfer

(a) A cooking pot with a circular steel bottom of radius 18cm and thickness 0.7cm rests on a hot stove plate. The water inside the pot is at the boiling point ($T = 100\, ^\circ C$) and evaporates at a rate of 0.124g/min. \[ 2 \times 10^{-5} \times 5 \times 10^{-2} \times 50 \, W \, m^{-2} \, K^{-1} \] (latent heat of vaporization for water: $L_v = 2.256 \times 10^6$)

\[ k_{steel} = 50.2 \, W \, m^{-1} \, K^{-1} \]

How much thermal power flows into the water?

(b) What is the temperature at the lower surface of the pot (which is in contact with the stove plate)?

\[ P = \frac{Q}{t} = \frac{mL_v}{t} = \frac{W}{E} \cdot L_v = \frac{4512 \, W}{200 \, W/\text{min}} = 225.6 \, \text{W/} \text{min} \]

\[ A = \pi r^2 = 0.1018 \, \text{m}^2 \]

\[ \Delta T = \frac{PL}{KA} = 6.2 \, ^\circ C \]

\[ T = T_w + \Delta T = 106.2 \, ^\circ C \]
9.) First Law of Thermodynamics and Ideal Gas  

120 moles of an ideal gas are held in a cylinder at a constant pressure of \( 2.7 \times 10^5 \) Pa. The gas is cooled and compressed from 2.1 m\(^3\) to 1.6 m\(^3\).

(a) By how much did the internal energy of the gas change (include the correct sign)?

(b) How much work has been done by/on the gas?

(c) How much heat has been extracted from/added to the gas?

\[ pV = nRT \quad \Rightarrow \quad T_0 = \frac{pV_0}{nR} = 569 \, \text{°K} \quad \left[ \text{Gas changes} \right] \]

\[ T_1 = \frac{pV_1}{nR} = 433 \, \text{°K} \quad \left[ \text{Gas changes} \right] \]

\[ \Delta U = \frac{3}{2} n R \Delta T = -2.03 \times 10^5 \quad \left[ -2.03 \times 10^5 \right] \]

\[ W = P \Delta V = -1.25 \times 10^5 \quad \left[ -1.25 \times 10^5 \right] \]

\[ \Delta U = Q - W \]

\[ Q = \frac{3}{2} n R \Delta T \]

\[ Q = \Delta U + W = -2.38 \times 10^5 \quad \left[ -2.38 \times 10^5 \right] \]