Conceptual Questions: Answer any three of the following four questions. Indicate which ones you have chosen to submit if you attempt all four, otherwise the first three will be graded.

1. (4 pts) Explain why a person trying to walk across a thin cable (a tight-rope walker at circuses, for example) finds it easier when holding a long pole.

   If person starts to fall, can hit pole which will cause a torque opposing his falling motion & give him a chance to regain balance. Also, rotational inertia is increased so he has more time to react (slower fall).

2. (4 pts) If the Sun suddenly compressed to half its current radius, how would the Earth’s orbit be affected?

   Distance to centre of Sun is not changed, so Earth’s orbit is not affected.

3. (4 pts) What must be true of the force on an object if it is to exhibit simple harmonic motion?

   \[ F = -kx \quad \text{or} \quad a = -\omega^2 x \]

   The force/acceleration is restoring & magnitude is proportional to the distance from equilibrium.

4. (4 pts) Schematically draw a PT diagram to help explain the significance of a substance’s critical temperature, \( T_c \).

   Above \( T_c \), there is no longer a phase change between liquid & gas.
Problems: All of the following problems are required (though problem 5 offers you a choice between two questions).

Problem 1 (11 pts) Chp 3 – Motion in a Plane: A paint-ball sniper is lying down with his rifle perched 10 cm above the ground and has in his sights a target 41.45 m away as shown schematically in the figure below. His rifle has a muzzle speed of 65 m/s and he is aiming for the target's torso 1.5 m above the ground. As usual, neglect the effects of air resistance in this problem.

(a) If the paintball reaches the target 0.640 secs after the weekend warrior pulled the trigger, what is the angle \( \theta \)?

\[
\begin{align*}
\chi &= v \cos \theta t \\
\theta &= \cos^{-1} \left( \frac{x}{v_0 t} \right) \\
&= 4.87^\circ \quad (4.01^\circ)
\end{align*}
\]

Ans: ______________________

(b) What height above the ground did the paintball hit the target (i.e. did he hit the spot he was aiming for)?

\[
y = 0.1 + 65 \cos 4.87 \times 0.64 - \frac{1}{2} (9.8)(0.64)^2
\]

\[
\approx 1.62 \text{ m} \quad (0.74 \text{ m})
\]

Ans: ______________________

Problem 2 (10 pts) Chp 4 – Newton’s Laws of Motion: You walk into an elevator, step onto a scale, and push the “up” button. You also recall that your normal weight is 745 N. Start each of the following parts with a free-body diagram.

(a) If the elevator has an acceleration of magnitude 2.70 m/s², what does the scale read?

\[
\begin{align*}
\Sigma F_y &= ma \\
F_n - mg &= ma \\
F_n &= ma + mg \\
&= 76.0(9.8 + 2.7) \\
&= 950.3 \text{ N} \quad (902.5 \text{ N})
\end{align*}
\]

Ans: ______________________

(b) If you start holding a 3.60 kg package by a light vertical string, what will be the tension in this string once the elevator begins accelerating?

\[
\begin{align*}
T &= 3.6(9.8 + 2.7) \\
&= 45 \text{ N} \quad (39 \text{ N})
\end{align*}
\]

Ans: ______________________
Problem 3 (11 pts) Chp 7 - Work and Energy: A 75 kg ski-jumper starts from rest at the top of a 120 m long ramp which makes an angle of 37° to the horizontal.

(a) If his speed at the point bottom is \( v = 25 \) m/s, what is the average frictional force that retarded his descent?
\[
h = 120 \sin 37 = 72.22 \text{ m}
\]
\[
U_{gy} + W_{fnc} = K_{tans}
\]
\[
W_{fnc} = \frac{1}{2} m v^2 - m g h
\]
\[
= - 29.643 \text{ J}
\]
\[
(- 38.401 \text{ J})
\]
Ans: 

(b) If this friction was solely due to kinetic friction between his skis and the snow, what would be the effective coefficient of kinetic friction?
\[
f = \mu_k \cdot F_N
\]
\[
\mu_k = \frac{f}{m g \cos 37} = 0.421
\]
\[
(0.490)
\]
Ans: 

Problem 4 (13 pts) Chp 8 - Momentum: Particle A (with mass \( m_A = 2.0141 \) u) with velocity \( \vec{v}_A = 7 \times 10^5 \) m/s in the +\( \hat{x} \)-direction collides with particle B (\( m_B = 3.0160 \) u) which has a velocity \( \vec{v}_B = 5 \times 10^5 \) m/s in the +\( \hat{y} \)-direction. After this inelastic collision, particles C and D emerge with masses \( m_C = 1.0087 \) u and \( m_D = 4.0026 \) u (don't freak out over the particles changing labels and masses – it doesn’t change anything inherent to the problem you’re asked to solve!). Particle C is seen to have a speed of \( 4 \times 10^7 \) m/s in a direction 40° below \( \hat{x} \) as shown in the figure below. What is the velocity (speed and direction) of particle D? (note: you do not need to convert the unified atomic mass units to SI)
\[
\hat{x}: \quad m_A \vec{v}_A = m_C \vec{v}_C \cos 40 - m_B \vec{v}_B \Rightarrow \vec{v}_{bx} = \frac{1}{m_B} (m_C \vec{v}_C \cos 40 - m_A \vec{v}_A)
\]
\[
= 7.37 \times 10^6 \text{ m/s}
\]
\[
\hat{y}: \quad m_B \vec{v}_B = m_D \vec{v}_D - m_C \vec{v}_C \sin 40 \Rightarrow \vec{v}_{by} = \frac{1}{m_D} (m_B \vec{v}_B + m_C \vec{v}_C \sin 40)
\]
\[
= 6.86 \times 10^6 \text{ m/s}
\]
\[
| \vec{v}_D | = \sqrt{v_{bx}^2 + v_{by}^2} = 1.01 \times 10^7 \text{ m/s}
\]
\[
\theta = \tan^{-1} \left( \frac{6.86 \times 10^6}{7.37} \right) = 42.9^\circ \text{ as shown in figure}
\]
\[
= 137.1^\circ \text{ from } \hat{x} \text{ axis}
\]
Ans: 

4
Problem 5  (11 pts) Since sound was not stressed in the MP homework, you can do either one of the following two problems. Indicate which problem you have chosen to submit if you attempt both, otherwise Option I will be graded; you will not get extra credit if you do both.

**Option I**  Chp 12 - Mechanical Waves and Sound: At a Dinosaur Jr. concert I went to with my friend, they played the music through two 100 W speakers.

i. What was the intensity of the sound waves I heard when standing 20 m in front of the two speakers? Assume the sound propagated uniformly into a hemisphere (half a three-dimensional sphere) from each speaker.

\[
I_1 = \frac{P}{\frac{1}{2} (4\pi R^2)} = \frac{2(100)}{2\pi (20)^2} = 0.080 \text{ W/m}^2
\]

(Ans: 0.080 W/m^2)

ii. Use proportional reasoning (or any other means) to find the decibel level difference between my friend and I if she was standing 60 m from the speakers.

\[
\Delta \beta = 10 \log \left( \frac{I_1}{I_2} \right) = 10 \log \left( \frac{I_1}{I_2} \right)
\]

\[
= 10 \log \left( \frac{I_1}{I_2} \right)
\]

\[
= 10 \log \left( \frac{100}{20} \right) = 10 \log \left( \frac{100}{20} \right) = 9.5 \text{ dB}
\]

(Ans: 9.5 dB)

Option II  Chp 10 - Dynamics of Rotational Motion: A 2 m long uniform beam weighing 150 N is connected to a wall by a frictionless hinge and supported by a cable at the free end. A 50 N weight is placed as shown in the figure below. What is the magnitude of the tension in the cable?

\[
\Theta = \tan^{-1} \left( \frac{1.37}{2.5 - 2} \right) = 69.9^\circ
\]

\[
\sum \tau = 0 \Rightarrow 2T \sin 69.9^\circ - 1.6(50) - 1(150) = 0
\]

\[
T = \frac{230}{1.88} = 122.5 \text{ N}
\]

(Ans: 122.5 N, 218.3 N)
Problem 6 (10 pts) Chp 13 - Fluid Mechanics: A spherical balloon of radius 5.00 m can carry an additional load of up to 550 kg before starting to sink in air. Using the fact that the density of air is $\rho_{\text{air}} = 1.20 \text{ kg/m}^3$ and the volume of a sphere is $\frac{4}{3}\pi R^3$, find the density of the gas that the balloon is filled with.

\[
\begin{align*}
\rho_{\text{air}} V &= \rho_{\text{gas}} V + 550 \\
\rho_{\text{gas}} &= \rho_{\text{air}} - \frac{550}{523.6} \\
&= 0.150 \text{ kg/m}^3 \\
&= (0.146 \text{ kg/m}^3)
\end{align*}
\]

Ans: 

Problem 7 (11 pts) Chp 14 - Temperature and heat: A ceramic mug which has a mass of 0.500 kg contains 0.250 kg of coffee, and both are at a temperature of 75.0°C. A person pours 0.050 kg of cream at 5°C into the mug. Find the final temperature of the system, assuming no heat is lost to the surroundings. For this problem, take the heat capacities of ceramic, coffee and cream to be $C_{\text{mug}} = 800 \text{ J/(kg·K)}$, $C_{\text{coffee}} = 4000 \text{ J/(kg·K)}$, and $C_{\text{cream}} = 3770 \text{ J/(kg·K)}$.

\[
\begin{align*}
\sum Q &= 0 \Rightarrow \\
(M_{\text{mug}} C_{\text{mug}} + M_{\text{coffee}} C_{\text{coffee}})(T - 75) + M_{\text{cream}} C_{\text{cream}} (T - 5) &= 0 \\
T \left[ (0.5)(800) + (0.25)(4000) + (0.05)(3770) \right] &= 75 \left( 0.5(800) + 0.25(4000) + 5(0.05)(3770) \right) \\
1588.5 \cdot T &= 105342.5 \\
T &= 66.7^\circ \\
&= (69.4^\circ)
\end{align*}
\]

Ans: 

6
Problem 8 (11 pts) Chp 15 – Thermal Properties of Matter: When 2.0 moles of a monatomic ideal gas (so \( Cv \approx 12.47 \, \text{mol} \cdot \text{K}^{-1} \)) expands at a constant pressure of \( 7.0 \times 10^5 \, \text{Pa} \), the volume of the gas increases from \( 3.0 \times 10^{-3} \, \text{m}^3 \) to \( 8.0 \times 10^{-3} \, \text{m}^3 \). (6.0 \times 10^{-3}) (9.0 \times 10^{-3})

(a) What is the change in the internal energy of the gas? (make sure your sign indicates whether it increases or decreases).

\[
P \Delta V = n R \Delta T \quad \text{or} \quad n R \Delta T = P \Delta V
\]

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

\[
= \frac{3}{2} \left(7 \times 10^5\right) (8 - 3) \times 10^{-3}
\]

\[
= 5250 \, \text{J} \quad (4500 \, \text{J}) \quad \text{Ans:} \quad \text{increases}
\]

(b) What is the heat flow, \( Q \), for this process? (make sure your sign indicates whether it is into or out of the gas).

\[
W = P \Delta V = \frac{2}{3} \Delta U
\]

\[
Q = \Delta U + W
\]

\[
= \frac{5}{3} \Delta U
\]

\[
= 8750 \, \text{J} \quad (7500 \, \text{J})
\]

\( \text{Ans:} \quad \text{into gas} \)

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Bonus (5 pts) Only attempt if you have time to spare! Referring back to Problem 4, what is the change in kinetic energy between the initial and final states? Here you must convert to SI and express your answer in Joules. Can you explain where the energy came from? Even if you can’t, comment about how this fusion reaction has applications in energy sources and weapons of mass destruction. (FYI, particle A is “deuterium”, B is “tritium” [think Spiderman II], C is a neutron and D is “{}\text{He}”).

Initially: \( K = \frac{1}{2} \left(2.041 \times 10^5\right)^2 + \frac{1}{2} \left(3.0110 \times 5 \times 10^5\right)^2 \)

\[
= 8.70 \times 10^{10} \, \text{u} \cdot \text{m}^2/\text{s}^2
\]

\[
= 8.70 \times 10^{10} \left(1.66 \times 10^{-24}\right) \, \text{kg} \cdot \text{m}^2/\text{s}^2
\]

\[
= 1.45 \times 10^{-15} \, \text{J}
\]

Finally: \( K = \frac{1}{2} \left(1.087 \times 10^3\right)^2 + \frac{1}{2} \left(4.0026 \times 1.01 \times 10^3\right)^2 \)

\[
= 1.01 \times 10^{15} \left(1.46 \times 10^{-27}\right)
\]

\[
= 1.679 \times 10^{-15} \, \text{J}
\]

\[ \Delta K = \left(1.679 \times 1.4 \right) \times 10^{-15} \, \text{J} \]

\[ = 1.678 \times 10^{-15} \, \text{J} \]

Initially, \( M_\text{tot} = 5.0301 \, \text{u} \) but finally, \( M_\text{tot} = 5.0113 \); the 0.0188 \, \text{u} of mass got converted to energy. Note one mole of deuterium + tritium would give

\[ \Delta K \cdot N_A = 1.678 \times 10^{-12} \left(6.022 \times 10^{23}\right) = 10^{12} \, \text{J}. \] That's about a kiloton of TNT!!