Notes

1) There are four (4) problems in this exam. Please make sure that your copy has all of them.

2) Please show your work indicating clearly what formula you used and what the symbols mean. Just writing the answer will not get you full credit. In stating vectors give both magnitude and direction.

3) Write your answers on the sheets provided.

4) Do not forget to write the units.

5) Do not hesitate to ask for clarification at any time during the exam. You may buy a formula at the cost of one point.

God Bless You!

\[
k_B = 1.383 \times 10^{-23} \text{ J/K} \\
N_A = 6.02 \times 10^{23} \\
m_p = 1.6 \times 10^{-27} \text{ kg}
\]
Problem 1a
What is the difference between force and torque? Support your answers with examples.

Linear
Force causes acceleration and translation
\[ \sum F_i = \sum \frac{d^2 x}{dt^2} \]

Driving Rigid Body

Torque causes angular acceleration and hence rotation about an axis. To have \( \tau \) you must apply a force \( F \) at some distance \( r \) from the axis, and \( F \) must be perpendicular to \( r \).

To \( \tau \),
\[ \tau = r \times F \]

\[ \tau = \sum \tau_i \text{ for rigid body} \]

Screw driver applies torque.
Opening screw causes torque.
Problem 1b
A uniform bar of length 3m is placed on a vertical support located at 0.6m from the left end. If hanging a mass of 10kg at a distance of 0.3m from the end brings the bar into equilibrium in the horizontal position. What is the mass of the bar? Why?

\[ \begin{align*}
\text{For } \Sigma \text{w of a rigid body} \\
\text{Total Force } \Sigma \vec{F} &= 0 \\
\text{Total Torque } \Sigma \vec{M} &= 0.
\end{align*} \]

Take Torques about P

Torque due to \( M_B g \) \( \propto \) \( 10 \times 9.8 \times 0.3 = 0 \)

\[- M_B \times 9.8 \times 0.9 + 10 \times 9.8 \times 0.3 = 0 \]

\[- M_B \times 9.8 \times 0.9 + 10 \times 9.8 \times 0.3 = 0 \]

\[ M_B = \frac{10 \times 0.3}{0.9} = 3.33 \text{ kg} \]
Problem 2a
You are stopped at a red light on a horizontal road when the coefficient of static friction is 0.5. When the light turns green, what is the maximum acceleration at which you can take off? Why?

\[ \text{NR} - Mg = 0 \]

To get going, you engage engine torque \( T \) on wheel which pushes a torque \( T \) on in wheel tries to turn pushing with \( fs \) on car rear, when

\[ fs \leq \mu s \text{NR}. \]

**Static friction**

By Newton's 3rd law, road pushed, wheel forward,

\[ Mg_s = fs \]

\[ Mg_s \leq \mu s \text{NR} \]

\[ Mg_s \leq \mu s Mg \]

\[ a_s \leq Mg \]

\[ a_{\text{max}} = 0.5 \times 9.8 = 4.9 \text{m/s}^2 \]
Problem 2b
What is the relationship between the angular momentum (magnitude) and the rotational kinetic energy of a rigid body? Why?

\[ \frac{L}{\omega} = I \]

\[ k_{rot} = \frac{1}{2} I \omega^2 \]

**Magnitude**

\[ L = I \omega \]
\[ L^2 = I^2 \omega^2 \]
\[ \frac{L^2}{I} = I \omega^2 \]
\[ \frac{L^2}{2I} = \frac{1}{2} I \omega^2 = k_{rot} \]
Problem 3a
Near Earth, why does the pressure in a gas or liquid reduce with height above the surface of earth?

Consider a layer lying between y and y + dy. If it is to be in Em total force on it must be zero. Earth pulls it down \( W_g = -mg \), \( P_A \) must be less than to give an upward force to balance \( W_g \).
Problem 3b
A gas is contained in a stationary enclosure at a temperature of 500K. What is the average velocity of the particles in it? Why?

The motion is random therefore average velocity is zero

\[ \langle v \rangle = 0 \]
Problem 3c
Why does a gas exert pressure on the walls of its container?

1. The atoms are in random motion.

2. Each time an atom bounces off a wall, it delivers momentum \(2mv\) to the wall because collision is Elastic.

3. If there are \(Nc\) collisions per second on a wall of area \(A\), the wall experiences a force

\[2mv Nc\]

4. Pressure is force/area.
Problem 4a
Consider the setup of two thermodynamic systems which are isolated from the surroundings but have a conducting wall between them. Use it to develop the concept of temperature.

Let the initial pressures and volumes be $P_1, V_1$ and $P_2, V_2$ respectively. There are two possibilities:

1. There is no change when system begins almost completely:
   $$P_1 \neq P_2, \quad V_1 \neq V_2$$

2. Both systems change but after a while changes stop. Again the new values:
   $$P_2' \neq P_1', \quad V_1' \neq V_2'$$

Conclusion
- When there is no change systems must be in equilibrium (not dynamic).
- $P + V$ are irrelevant for this Em.
- We need a new parameter whose equality ensures Em. This is temperature so we call it thermal Em.

And states. Two systems can be in Em if and only if they have same TEMPERATURE.
Problem 4b
A 100 cm$^3$ beaker of Aluminum (Coefficient of linear expansion $\alpha = 23 \times 10^{-6} \, C^{-1}$) is filled to the brim with water ($\gamma = 210 \times 10^{-6} \, C^{-1}$) at 15°C. Next, it is warmed to a temperature of 90°C. How much water, if any, will overflow in this experiment? Why?

Both the beaker and water will expand.

Beaker

$$V_B = V_0 \left[ 1 + \alpha (t - t_0) \right]^3 \quad \alpha \rightarrow \text{lin-exp}$$

$$= V_0 \left[ 1 + 3 \alpha (t - t_0) \right]$$

Water

$$V_W = V_0 \left[ 1 + \gamma (t - t_0) \right]$$

$$V_W - V_B = V_0 \left[ (\gamma - 3 \alpha) (t - t_0) \right]$$

$$= 100 \left[ (210 - 69) \times 10^{-6} \times 75 \right] \text{cm}^3$$

$$= (100 \times 75 \times 141 \times 10^{-6}) \text{cm}^3$$

$$= 103.575 \times 10^{-3} \text{cm}^3 = 1.03575 \text{cm}^3$$