UNIVERSITY OF JOHANNESBURG

FACULTY OF SCIENCE

Surname and initials: ______________________________

Student number: ______________________________

DEPARTMENT OF PHYSICS

MODULE: PHYL01A/PHYL1A1

PHYSICS FOR THE LIFE SCIENCES

CAMPUS: APK

JUNE EXAM

EXAMINER:	**MR K MURULANE**
MODERATOR:	**DR B SONDEZI**
DURATION: 150 MINUTES	**MARKS: 120**

NUMBER OF PAGES: 19 PAGES (including this information page)

INSTRUCTIONS:

1. Answer ALL the questions in the question paper.
2. For question 1, circle the letters of the correct answers only.
3. Programmable calculators are not permitted.
4. Pencil may be used for diagrams only.
5. Work neatly

QUESTION 1 [20]

1.1 An object has zero acceleration in the x-direction. In the y-direction, its acceleration must be which of the following?

(a) positive
(b) negative
(c) zero
(d) Any of the previous answers is possible **[2]**

1.2 What forces act on a ball that rolls on the floor after being kicked?

(a) the force from the floor
(b) the force exerted by the kick
(c) the force of gravity
(d) the force exerted by the kicker and gravity
(e) the force exerted by the floor and gravity
(f) the force exerted by the kicker, gravity, and the floor **[2]**

1.3 The figure above shows a round blue object on a table touching a green block. Which of the following six equations is the proper application of Newton's laws in the vertical direction describing the forces acting on the round object? Take $\vec{N}$ as the normal force, $\vec{w}$ as the weight, and $\vec{F}$ the contact force with the block.

(a) $\vec{F} + \vec{w} = 0$
(b) $\vec{F} - \vec{w} = 0$
(c) $\vec{N} + \vec{w} = 0$
(d) $\vec{N} - \vec{w} = 0$
(e) $\vec{N} - \vec{F} = 0$
(f) $\vec{N} + \vec{F} = 0$ **[2]**

1.4 A 70.0 kg person stands on a bathroom scale in an elevator. What does the scale read, in kg, if the elevator is slowing down at a rate of 3.50 m/s^2 while descending?

(g) 49.5 kg
(h) 82.0 kg
(i) 83.7 kg
(j) 95.0 kg
(k) 111.0 kg **[2]**

1.5 Two cars with the same mass travelling at right angles to each other collide and stick together. Both cars have the same speed of 10. m/s before the collision. Ignore friction between the tires and the surface of the road. What is the speed of the wreckage after the collision?

(a) 0
(b) 7.0 m/s
(c) 10. m/s
(d) 14.0 m/s
(e) 20.0 m/s **[2]**

1.6 When a torque acts on a rigid body, it always causes

(a) constant angular velocity.
(b) constant angular acceleration.
(c) rotational equilibrium.
(d) change in angular velocity.
(e) change in moment of inertia. **[2]**

1.7 When a system does work on something else in the environment, the sign of the work is

(a) positive.
(b) negative.
(c) zero.
(d) either positive, zero, or negative, depending on the details of the process. **[2]**

1.8 A standard man inhales a tidal volume of air at 20°C.When the air arrives in the lungs, it has a temperature of 37°C. Treating air as an ideal gas, the change in internal energy while travelling through the trachea is

(a) $\Delta U = 0$ J.
(b) about an 85% increase over the initial value.
(c) about a 5% increase over the initial value.
(d) unknown, because the amount of air is not specified.
(e) proportional to the change in the pressure of the air. **[2]**

1.9 When sound is absorbed in a medium, its intensity level IL decreases with distance travelled through the medium x as (Note: **β** is a constant)

a) IL $\propto e^{-\beta x}$.
b) IL $\propto$ −x.
c) IL $\propto$ b.
d) IL $\propto$ ln(−x). **[2]**

1.10 The intensity of a spherical wave 3.5 m from the source is 140 W/m^2. What is the intensity at a point 9.0 m away from the source?

(a) 19 W/m^2.
(b 21 W/m^2.
(c) 54 W/m^2.
(d)360 W/m^2.
(e) 925 W/m^2. **[2]**

QUESTION 2 [30]

2.1 A bus driver slams on the brakes when he sees a rock blocking the road. The bus slows uniformly with an acceleration of $-5\ m/s^2$ for 3.8 s making straight skid marks 80 m long ending at the rock. Calculate the speed for which the bus hit the rock. **[6]**

$v_f = v_i + at$ — ①

$x_f = x_i + \frac{1}{2}(v_i + v_f)t$ — ②

We have $a_i = -5 m/s^2$

$t = 3{,}8\ s$

$x_f = 80 m$

Now

$v_f = v_i - (5)(3{,}8)$

$v_f = v_i - 19$ — ③

from ②

$80 = 0 + \frac{1}{2}(v_i + v_i - 19)(3{,}8)$

$80 = \frac{1}{2}(2v_i - 19)(3{,}8)$

$\frac{80}{3{,}8} = \left(v_i - \frac{19}{2}\right)$

$\Rightarrow v_i = \frac{80}{3{,}8} + \frac{19}{2}$

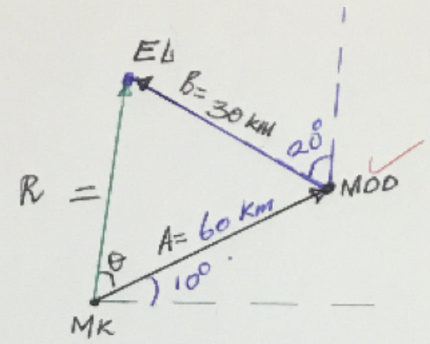
$v_i = 30{,}55 m/s$ — ④

Sub ④ in ③

$v_F = 30{,}55 - 19$

$= 11{,}55\ m/s$

2.2 In a map Mdd is $60\ km$ in the direction of 10^o North of Makhado. The same map shows that Elim is $30\ km$ in the direction 20^o West-North of Mdd. Modelling the earth as flat, find the displacement form Makhado to Elim. **[6]**



6

$Mk - El = R$.

$R_x = A_x + B_x = 60\cos 10^\circ - 30\sin 20^\circ = 48{,}8$

$R_y = A_y + B_y = 60\sin 10^\circ + 30\cos 20^\circ = -17{,}8$

$R = \sqrt{(48{,}8)^2 + (-17{,}8)^2}$

$= 51{,}9\ km$

$\tan\theta = \dfrac{-17{,}8}{48{,}8} = -20^\circ + 180$

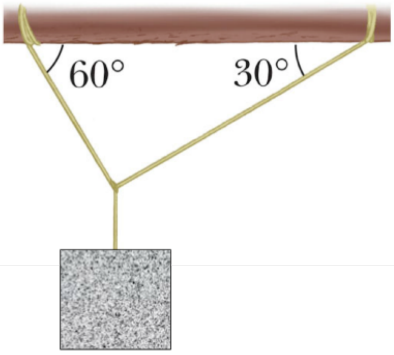
$= 159{,}9$

$\sim 160^\circ$

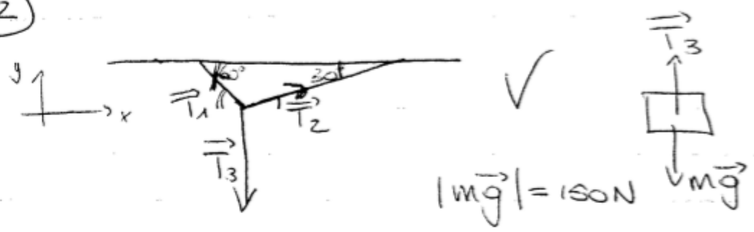
2.3 If superman goes from a radius $2R$ to radius $4R$ while circling the Earth, where R is the radius of the Earth, how much does the gravitational force on him change? **[3]**

Doubling the distance reduces the force by a factor of 4. So, at 2R, the gravitational force on him would be one fourth (a quarter) of his weight (gravitational force) on Earth. So, the gravitational force on him at 4R would be one fourth of the gravitational force at 2R and one sixteenth of that on the surface of Earth.

2.4 Three cables as shown in the figure below support an object weighing 150 N. Draw the free body diagram for the object and calculate the tension in each cable. **[6]**



3.2



$$T_3 - mg = 0$$
$$T_3 = mg = 150 N$$

$$\sum F_x = T_2 \cos 30° - T_1 \cos 60° = 0$$
$$T_2 = T_1\left(\frac{\cos 60°}{\cos 30°}\right) = 0.58\, T_1$$

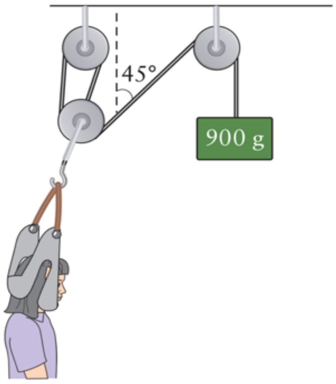
$$\sum F_y = T_2 \sin 30° + T_1 \sin 60° - T_3 = 0$$

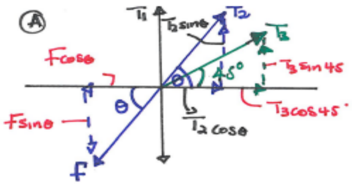
$$0.58 T_1 \sin 30° + T_1 \sin 60° - 150 N = 0$$

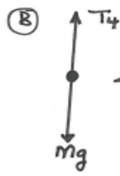
$$T_2 = 75 N$$
$$T_1 = 130 N$$

[7 MARKS]

2.5 Find the force applied to the patient's head by the traction device shown in the Figure below. **[9]**







$\Sigma F_{By} = T_4 - mg = 0$

$T_4 = mg$

$T = 8{,}82\,N$

$T = T_1 = T_2 = T_3 = T_4$ (Same string)

$\Sigma F_{Ax} = T_2 \cos\theta + T_3 \cos 45° - F\cos\theta = 0$

$T\cos 45° = (F-T)\cos\theta$ —— ①

$\Sigma F_{Ay} = T_1 + T_2 \sin\theta + T_3 \sin 45° - F\sin\theta = 0$

$T + T\sin 45° = (F-T)\sin\theta$

$T(1+\sin 45°) = (F-T)\sin\theta$ —— ②

Square both ① and ② we have:

$T^2(1+\sin 45°)^2 = (F-T)^2 \sin^2\theta$ —— ③

$T^2 \cos^2 45 = (F-T)^2 \cos^2\theta$ —— ④

Add ③ and ④

$T^2[(1+\sin 45°)(1+\sin 45°)] + T^2\cos^2 45° = (F-T)^2\sin^2\theta + (F-T)^2\cos^2\theta$

$T^2[1 + 2\sin 45° + \sin^2 45°] + T^2\cos^2 45° = (F-T)^2[\sin^2\theta + \cos^2\theta]$

$T^2[1 + \sqrt{2} + \underbrace{(\sin^2 45 + \cos^2 45)}_{=1}] = (F-T)^2 \underbrace{[\sin^2\theta + \cos^2\theta]}_{=1}$

$T^2[2+\sqrt{2}] = (F-T)^2$

$(F-T) = \sqrt{T^2(2+\sqrt{2})}$ (9 marks)

$= T(\sqrt{2+\sqrt{2}})$

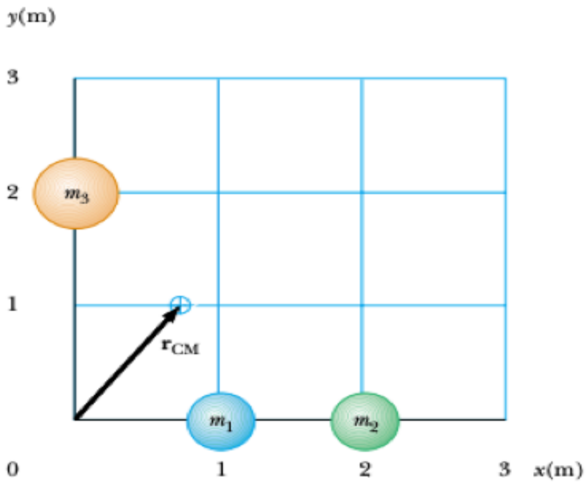
$F = T(\sqrt{2+\sqrt{2}}) + T$

$= T(\sqrt{2+\sqrt{2}} + 1) = 8{,}82(\sqrt{2+\sqrt{2}} + 1)$

$F = 25\ N$

QUESTION 3 [20]

3.1 A system consists of three particles located as shown in the figure. Find the center of mass of the system given $m_1 = m_2 = m$ and $m_3 = m$. **[6]**



$$\vec{r}_{c.m} = \frac{1}{M} \cdot \sum_i^n m_i r_i$$

$\vec{r}_{cm} = (x_{cm}, y_{cm}, z_{cm})$ · for 3D case

$\vec{r}_{c.m} = (x_{cm}, y_{cm})$ for 2D case.

Now

$$x_{cm} = \frac{1}{M} \cdot \sum_i^n m_i x_i$$

$$= \frac{1}{4m} \cdot [m_1 x_1 + m_2 x_2 + m_3 x_3]$$

$$= \frac{1}{4m} \cdot [m \cdot 1 + m \cdot 2 + 2m \cdot 0]$$

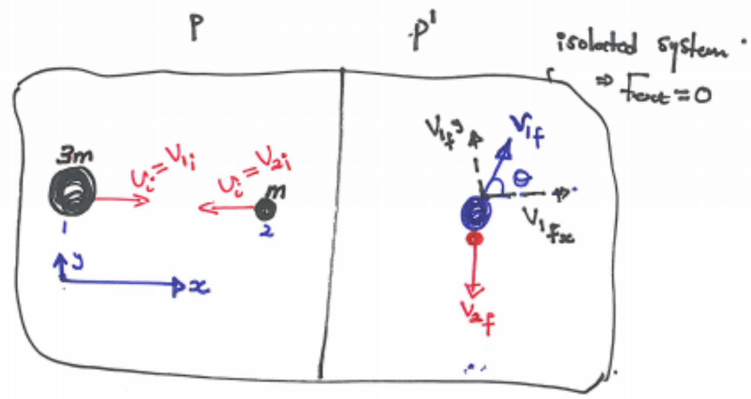
$$= \frac{3m}{4m} = \frac{3}{4} \text{ (length units)}.$$

$$y_{cm} = \frac{1}{4m} \cdot [m \cdot 0 + m \cdot 0 + 2m \cdot 2]$$

$$= \frac{4m}{4m} = 1 \text{ (length units)}.$$

$$\therefore \vec{r}_{cm} = (3/4, 1) = \frac{3}{4}\hat{x} + \hat{y}.$$

3.2 Two particles with masses m and $3m$ are moving towards each other along the x axis with the same initial speeds v_i. Particle m is traveling to the left, while particle $3m$ is traveling to the right. They undergo an elastic glancing collision such that particle m is moving downward after the collision at a right angle with respect to its initial direction. Find the final speeds of the two particles and the angle at which the particle $3m$ is scattered. **[7]**



For an isolated system $\vec{F}_{ext}=0$

$$\therefore \underline{P = P'}$$

This is a 2D problem.

$$\therefore P = (P_x, P_y) \text{ and } P' = (P'_x, P'_y)$$

Now $P_x = P'_x \Rightarrow 3m\cdot v_{1i} - m v_{2i} = 3m V_{1f_x}$

$$= 3m v_i - m v_i = 3m V_{1f_x}$$

$$2\cancel{m} v_i = 3\cancel{m} V_{1f_x}$$

$$V_{1f_x} = \frac{2}{3} v_i$$

$$P_y = P'_y \Rightarrow 0 = 3m v_{1f_y} - m v_{2f}$$

$$\Rightarrow 3m v_{1f_y} = m v_{2f}, \text{ but } v_{2f} = v_i$$

$$\therefore 3\cancel{m} v_{1f_y} = \cancel{m} v_i \Rightarrow v_{1f_y} = \frac{1}{3} v_i$$

$$\therefore v_f = \left(\frac{2}{3}, \frac{1}{3}\right) v_i$$

Now $\theta = \tan^{-1}\left(\frac{1/3\, v_i}{2/3\, v_i}\right) = \underline{26.56^\circ}$.

8 marks

3.3 Show that the angular momentum of a system is conserved if no net torque acts on the system. Show all steps. **[7]**

Angular momentum is define as

$$\vec{L} = \vec{r} \times \vec{p}$$

Now change in angular momentum is given by

$$\frac{\Delta \vec{L}}{dt} = \frac{d\vec{L}}{dt} = \frac{d}{dt}(\vec{r} \times \vec{p})$$

Using differentiation laws,

$$\frac{d\vec{L}}{dt} = \vec{r} \times \frac{d\vec{p}}{dt} + \frac{d\vec{r}}{dt} \times \vec{p} \quad \text{— ①}$$

but $\frac{d\vec{r}}{dt} = \vec{v}$

∴ ① becomes $\frac{d\vec{L}}{dt} = \vec{r} \times \frac{d\vec{p}}{dt} + \vec{v} \times \vec{p}$

als $\vec{p} = m\vec{v}$

Now $\frac{d\vec{L}}{dt} = \vec{r} \times \frac{d\vec{p}}{dt} + \vec{v} \times \vec{v}$

but If $\vec{A}$ is vector $\underline{\vec{A} \times \vec{A} = 0} \Rightarrow \vec{v} \times \vec{v} = 0$

∴ $\frac{d\vec{L}}{dt} = \vec{r} \times \frac{d\vec{p}}{dt}$, also $\frac{dp}{dt} = F_{net}$

$$\Rightarrow \frac{d\vec{L}}{dt} = \vec{r} \times \vec{F}_{net} = \tau_{net}$$

For an isolated System $\tau_{net} = 0$

$$\Rightarrow \frac{d\vec{L}}{dt} = 0 \quad \Rightarrow L' = L$$

$\Rightarrow$ Total Angular momentum is Conserved. <u>8 marks</u>

QUESTION 4 [10]

4.1 A standard man climbs the stairs in a building. Assume that he reaches the fourth floor (16 m above the ground floor) in 15 seconds. Calculate the amount work he has done. **[4]**

$$W_g = m\vec{g} \cdot \Delta\vec{r}. \qquad \textbf{(1)}$$

Given the scalar product in Eq. [1], only the displacement collinear with the gravitational force ends up being relevant; that is, only the vertical displacement from the ground floor to the fourth floor. Furthermore, since the gravitational force is directed down and the vertical displacement is directed up, the work done by gravity will be negative. The result is that Eq. [1] becomes:

$$W_g = -mgh, \qquad \textbf{(2)}$$

where $h = 16$ m, $g = 9.8$ m/s^2, and $m = 70$ kg is the mass of the standard man. Since the work done by the man W is of the same magnitude and opposite sign of the work done by the gravitational force, we find:

$$\begin{aligned} W &= -W_g = mgh \\ &= 11\text{kJ}. \end{aligned} \qquad \textbf{(3)}$$

4.2 A boy in a wheelchair (total mass 47.0 kg) wins a race with a skateboarder. The boy has speed 1.40 m/s at the crest of a slope 2.60 m high and 12.4 m long. At the bottom of the slope his speed is 6.20 m/s. If air resistance and rolling resistance can be modelled as a constant friction force of 41.0 N, find the work he did in pushing forward on his wheels during the downhill ride. **[6]**

$$\Delta E_{\text{mech}} = \left(K_f - K_i\right) + \left(U_{gf} - U_{gi}\right)$$

But $\Delta E_{\text{mech}} = W_{\text{app}} - f\Delta x$, where W_{app} is the work the boy did pushing forward on the wheels.

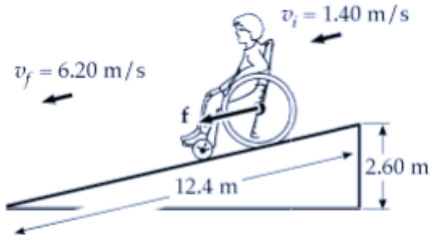


FIG. P8.32

Thus, $$W_{\text{app}} = \left(K_f - K_i\right) + \left(U_{gf} - U_{gi}\right) + f\Delta x$$

or $$W_{\text{app}} = \frac{1}{2}m\left(v_f^2 - v_i^2\right) + mg(-h) + f\Delta x$$

$$W_{\text{app}} = \frac{1}{2}(47.0)\left[(6.20)^2 - (1.40)^2\right] - (47.0)(9.80)(2.60) + (41.0)(12.4)$$

$$W_{\text{app}} = \boxed{168\text{ J}}$$

QUESTION 5 [20]

5.1 Imagine a baby alien playing with the spherical balloon of the size of the Earth in the outer solar system. Hydrogen gas inside the balloon has uniform temperature of 500K due to the radiation of the sun. The uniform pressure of the hydrogen gas in the balloon is equal to standard atmospheric pressure of the Earth. Determine the number of hydrogen gas molecules inside the balloon.
Given $r_{earth} = 6.37 \times 10^6 m.$ **[5]**

$pV = nRT$

$n = \frac{pV}{RT}$

5

$V = \frac{4}{3}\pi R_E^3$, $R_E = 6{,}37 \times 10^6 m$.

$R = 8{,}314 \, J/K\,mol$

$T = 500K$

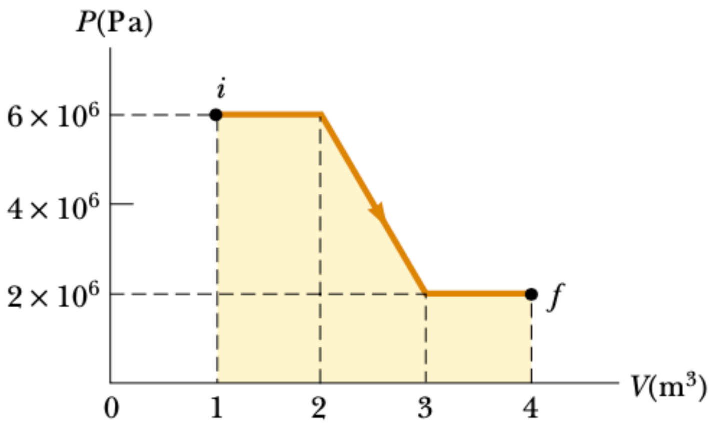
$P = 101325 \, kPa \doteq 101325 \times 10^3 \, J/m^3$

Since $1 \, kPa = 1000 \, J/m^3$.

$\therefore n = \frac{(101325 \times 10^3) \, J/m^3 \cdot \frac{4}{3}\pi (6{,}37 \times 10^6)^3 m^3}{8{,}314 \, J/K\,mol \cdot 500K}$

$= 26390249{,}38 \, mol$.

5.2 (a) Determine the work done on a fluid that expands from i to f as indicated in the figure below. (b) **What If?** How much work is performed on the fluid if it is compressed from f to i along the same path? **[5]**



(a) $W = -\int P dV$

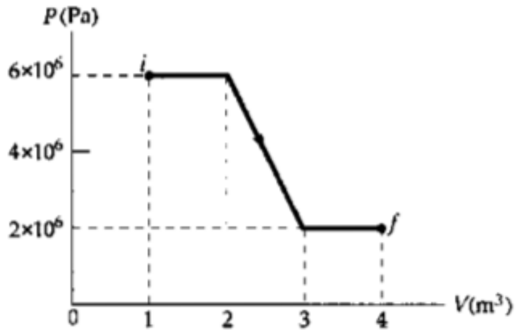
$W = -(6.00 \times 10^6 \text{ Pa})(2.00 - 1.00) \text{ m}^3 +$

$-(4.00 \times 10^6 \text{ Pa})(3.00 - 2.00) \text{ m}^3 +$

$-(2.00 \times 10^6 \text{ Pa})(4.00 - 3.00) \text{ m}^3$

$W_{i \to f} = \boxed{-12.0 \text{ MJ}}$

(b) $W_{f \to i} = \boxed{+12.0 \text{ MJ}}$



5.3 A 1.0-mol sample of an ideal gas is kept at 0.0°C during an isothermal expansion from 3.0 L to 10.0 L. (a)Calculate the work done on the gas during the expansion and (b) the energy transferred by heat that occurs with the surroundings in this process .

[5]

$$W = nRT\ln\left(\frac{V_i}{V_f}\right)$$

$$= (1.0\text{ mol})(8.31\text{ J/mol}\cdot\text{K})(273\text{ K})\ln\left(\frac{3.0\text{ L}}{10.0\text{ L}}\right)$$

$$= -2.7\times10^3\text{ J}$$

Solution From the first law, we find that

$$\Delta E_{\text{int}} = Q + W$$

$$0 = Q + W$$

$$Q = -W = 2.7\times10^3\text{ J}$$

5.4 A 1.00-mol sample of a diatomic ideal gas has pressure P and volume V. When the gas is heated, its pressure triples and its volume doubles. This heating process includes two steps, the first at constant pressure (isobaric process) and the second at constant volume (Isochoric/ Isovometric process). Determine the amount of energy transferred to the gas by heat. **[3]**

$$Q = (nC_P\Delta T)_{\text{isobaric}} + (nC_V\Delta T)_{\text{isovolumetric}}$$

In the isobaric process, V doubles so T must double, to $2T_i$.

In the isovolumetric process, P triples so T changes from $2T_i$ to $6T_i$.

$$Q = n\left(\frac{7}{2}R\right)(2T_i - T_i) + n\left(\frac{5}{2}R\right)(6T_i - 2T_i) = 13.5nRT_i = \boxed{13.5PV}$$

QUESTION 6 [20]

6.1 If a child and his twin each cry with an intensity level of 80 dB, what is the intensity level of both together? **[6]**

$$IL\,(\text{dB}) = 10\log_{10}\left(\frac{I}{I_0}\right)$$

$$I_0 = 10^{-12}\frac{\text{W}}{\text{m}^2}, \text{ and } I_1 = I_2$$

$$80 = 10\log_{10}\left(\frac{I_1}{I_0}\right) \Rightarrow 8 = \log_{10}\left(\frac{I_1}{I_0}\right) \Rightarrow \frac{I_1}{I_0} = 10^8$$

$$I_1 = 10^8 I_0 = 10^8\left(10^{-12}\frac{\text{W}}{\text{m}^2}\right) = 10^{-4}\frac{\text{W}}{\text{m}^2}\text{W}$$

$$I_{\text{total}} = I_1 + I_2 = 2 \times 10^{-4}\frac{\text{W}}{\text{m}^2}.$$

Now, again using Eq. [15.26], the total intensity level of the crying twin sound is given by:

$$IL_{\text{total}} = 10\log_{10}\left(\frac{I_{\text{total}}}{I_0}\right) = 10\log_{10}\left(\frac{2 \times 10^{-4}\frac{\text{W}}{\text{m}^2}}{10^{-12}\frac{\text{W}}{\text{m}^2}}\right) = 83\,\text{dB}.$$

So doubling the intensities changes the intensity level by 3 dB.

6.2 Define acoustic impedance. **[2]**

For a plane longitudinal wave, "Acoustic Impedance" is the product of the density of the medium and the speed of propagation in it.

$\Rightarrow Z = \rho c$

2

6.3 An ultrasound signal with frequency $f = 5.0\ MHz$ and an incident intensity $I = 3.8\ \times 10^{-2}\ W/cm^2$ is released by the transducer at the skin surface of a patient. Calculate intensity which the signal loses before it reaches the fat-muscle interface which is $1.5\ cm$ below the skin surface given that $a_{fat} = 1.0\ dB/MHz$. **[3]**

a

$$\Delta IL = -\alpha f x$$

$$= -\left(1.0 \frac{dB}{MHz\ cm}\right) \cdot (5\ MHz)(1.5 cm).$$

$$= -7.5\ dB.$$

6.4 Explain why an observer moving toward or away from a stationary source of sound perceives an apparent frequency that is not the true frequency of the source. **[4]**

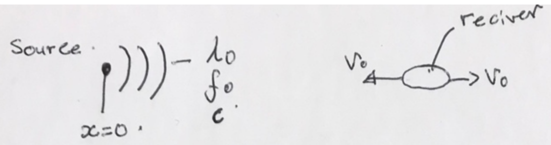
When an observer moves toward a stationary source of sound, the wavelength of the sound itseff does not change; it is a property of the source. However, the observer hears an apparent frequency because he percieives the crests more frequently than he would if was stationary (If he were moving away from the source he would perceive crests less frequently, and the frequency would seem to be lower than the frequency of the source).

This is doppler effect.

3

6.5 Derive an expression for the apparent frequency f in terms of the true frequency f_0 and the speed of the observer v_0 and the speed of sound c. **[5]**

(b)



Moving toward the Source the reciever percives frequency. $f = \frac{V}{\lambda_0}$, where $V = c + V_0$.

and moving away from the Source $V = c - V_0$.

Now the apparent frequency f is given by;

3

$$f = \frac{c \pm V_0}{\lambda_0}, \text{ but } \lambda_0 = \frac{c}{f_0}.$$

$$\Rightarrow f = \frac{c \pm V_0}{c/f_0} = f_0\left(\frac{c \pm V_0}{c}\right)$$

$$= f_0\left(1 \pm \frac{V_0}{c}\right)$$

----End of paper----