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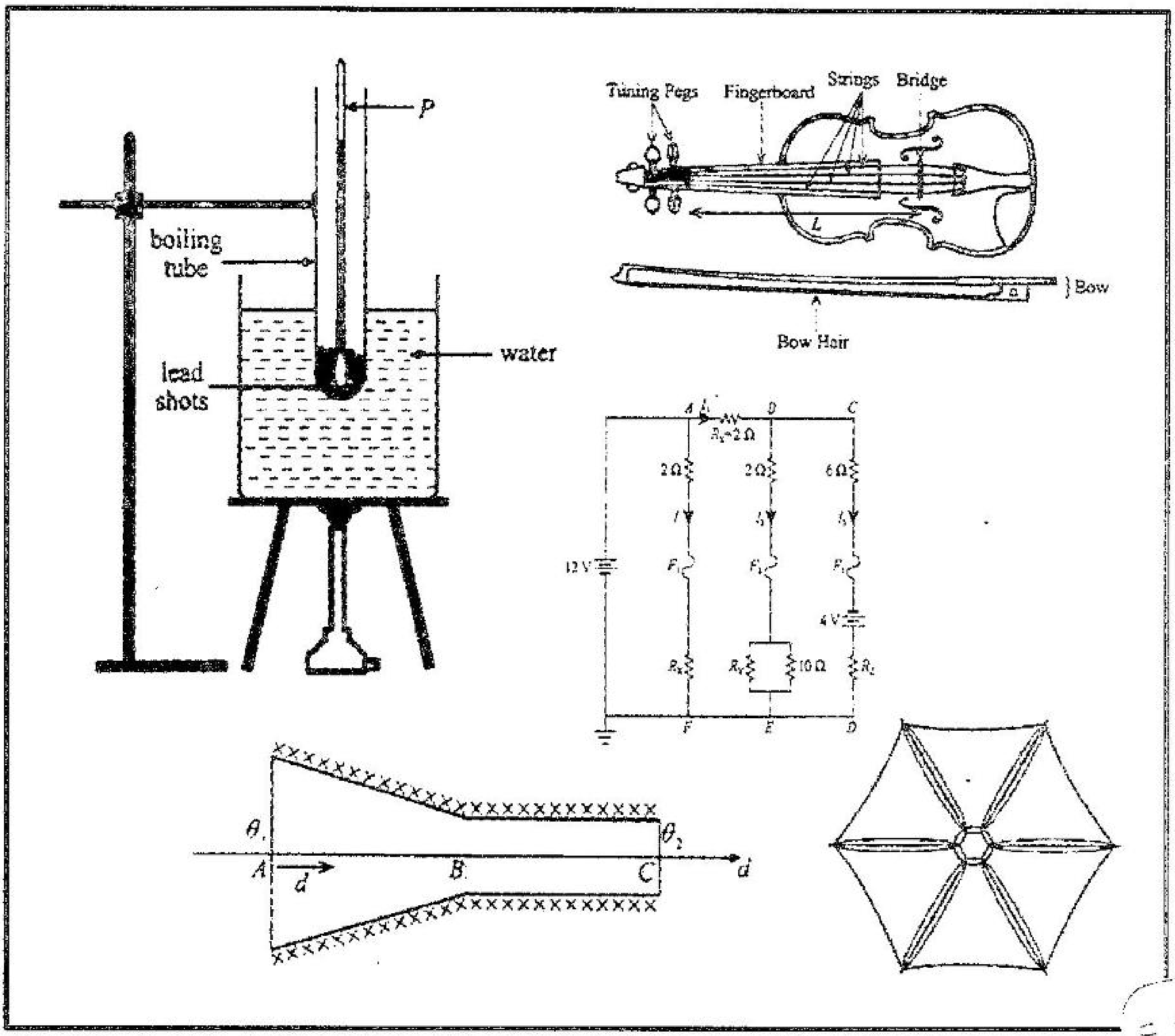
Department of Examinations – Sri Lanka

G.C.E. (A/L) Examination – 2025

01 – Physics

Marking Scheme



This has been prepared for the use of marking examiners. Some changes would be made according to the views presented at the Chief Examiners' meeting.

Amendments to be included

ශ්‍රී ලංකා විභාග දෙපාර්තමේන්තුව

இலங்கைப் பரீட்சைத் திணைக்களம்

අ.පො.ස. (උ.පෙළ) විභාගය/ க.பொ.த. (உயர் தர)ப் பரீட்சை - 2025

විෂය අංකය / பாட இலக்கம் : **01**

විෂයය / பாடம் : **Physics**

ලකුණු දීමේ පටිපාටිය / புள்ளி வழங்கும் திட்டம்

I පත්‍රය / பத்திரம் I

ප්‍රශ්න අංකය வினா இல.	පිළිතුරු අංකය விடை இல.	ප්‍රශ්න අංකය வினா இல.	පිළිතුරු අංකය விடை இல.	ප්‍රශ්න අංකය வினா இல.	පිළිතුරු අංකය விடை இல.	ප්‍රශ්න අංකය வினா இல.	පිළිතුරු අංකය விடை இல.	ප්‍රශ්න අංකය வினா இல.	පිළිතුරු අංකය விடை இல.
01.	**05**	11.	**02**	21.	**02**	31.	**01**	41.	**02**
02.	**03**	12.	**02**	22.	**03**	32.	**01**	42.	**03**
03.	**01**	13.	**04**	23.	**03**	33.	**01**	43.	**02**
04.	**04**	14.	**05**	24.	**04**	34.	**03**	44.	**03**
05.	**03**	15.	**02/04**	25.	**04**	35.	**01**	45.	**05**
06.	**05**	16.	**05**	26.	**01**	36.	**04**	46.	**02**
07.	**01**	17.	**03**	27.	**04**	37.	**03**	47.	**05**
08.	**02**	18.	**01**	28.	**05**	38.	**03**	48.	**02**
09.	**02**	19.	**02**	29.	**01**	39.	**04**	49.	**03**
10.	**01**	20.	**02**	30.	**05**	40.	**03**	50.	**04**

✪ විශේෂ උපදෙස් / விசேட அறிவுறுத்தல் :

එක් පිළිතුරකට / ஒரு சரியான விடைக்கு ලකුණු 01 බැගින් / புள்ளி வீதம்

මුළු ලකුණු / மொத்தப் புள்ளிகள் 1 × 50 = 50

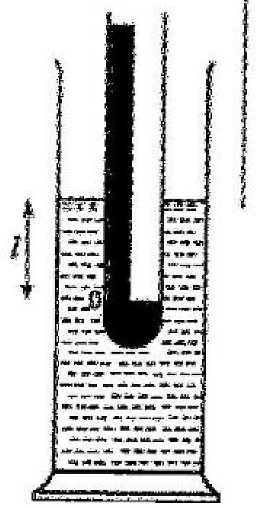
PART A — Structured Essay

Answer all four questions on this paper itself.

($g = 10\,\text{m s}^{-2}$)

1. You are asked to determine the density of a transparent liquid using a weighted boiling tube. A boiling tube, a tall jar containing the liquid, a sufficient number of 2 g weights, a paper strip marked in millimetres, lead shots and a small quantity of wax are provided.

The bottom of the boiling tube is filled with lead shots and sealed with wax. The marked strip is pasted inside the tube so that the zero mark of the strip be on the cylindrical part of the tube as shown in the figure. During the experiment, weights are inserted one by one into the tube immersing it further in the liquid. The length l of the immersed cylindrical part of the tube from the zero mark of the strip is shown in the figure.



(a) (i) What is the purpose of using lead shots in this experiment?

To float the boiling tube vertically/upright *OR* To lower the centre of gravity of the boiling tube so that it floats vertically/upright *OR* To lower the centre of gravity of the boiling tube so that it floats with stable equilibrium *OR* To lower the centre of gravity of the boiling tube (vertically) below the centre of buoyancy ....(01)

(ii) Why should the zero mark of the strip be on the cylindrical part of the tube?

The length l is (directly) proportional to the displaced liquid volume in the cylindrical part/added mass of the weights *OR* A linear variation exists between l and added mass of the weights *OR* The cross-sectional area of the cylindrical part does not change/constant with l *OR* l measurements can be taken accurately *OR* The cross-sectional area of the bottom/round/hemispherical part of the boiling tube varies with height *OR* The volume of the bottom/round/hemispherical part of the boiling tube is unknown/cannot measure ....(01)

(No mark for stating l measurements can be taken along the cylindrical part)

(b) (i) Let M be the mass of the boiling tube together with the lead shots and wax. Write down an expression for the upthrust U acting on the tube when floating.

$U = Mg$ ....(01)

(ii) To calculate the cross-sectional area of the immersed cylindrical portion of the tube, another measurement has to be taken. What is the measurement and the appropriate instrument for this purpose?

I. Measurement: External diameter (of the cylindrical part of the boiling tube) ....(01)

II. Instrument : Vernier Calliper ....(01)

(No mark for any other instrument)

(iii) You have to add a weight of mass m into the boiling tube and record the corresponding length l during the experiment. If A is the relevant cross-sectional area of the cylindrical part of the tube and V_0 is the relevant volume of the tube below zero mark of the strip, obtain an expression for the density of the liquid ρ in terms of m, M, A, l and V_0.

$(M + m)g = (V_0 + Al)\rho g$ ....(02)

(01 mark for L.H.S. and 01 mark for R.H.S. ; Award marks even if g is missing)

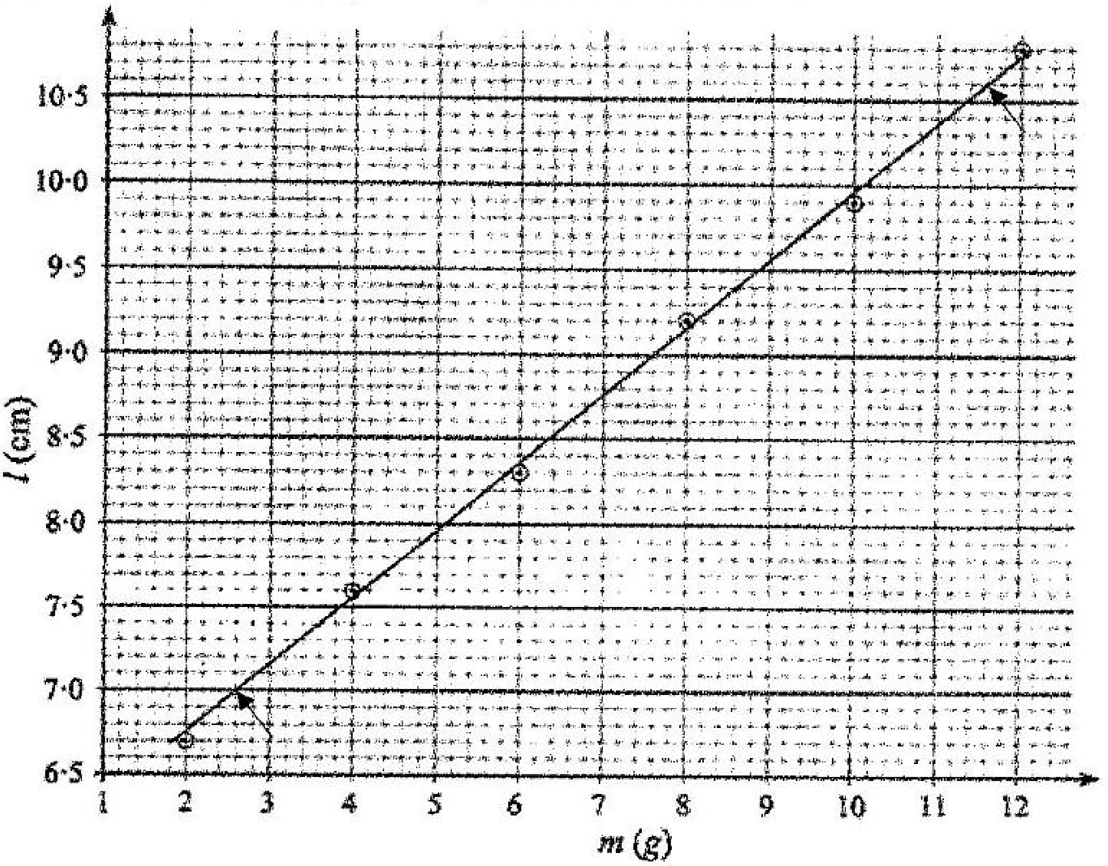
$\rho = \frac{(M+m)}{(V_0+Al)}$ ....(01)

(iv) Rearrange the expression you obtained in (b) (iii) above to plot the appropriate straight line graph.

$l = \left(\frac{1}{A\rho}\right)m + \frac{1}{A}\left(\frac{M}{\rho} - V_0\right)$ ....(02)

(*OR* any other correct form)

(c) The corresponding graph of l against m is shown below.



(i) Find the gradient of the graph.

Selecting the lower point as (2.6, 7.0) ....(01)

Selecting the higher point as (11.6, 10.6) ....(01)

(No marks for any other points)

Gradient $= \frac{(10.6-7.0)}{(11.6-2.6)}$ (for gradient calculation) ....(01)

$= \frac{3,6}{9}$

$= 0.4 \text{ cm g}^{-1}$ (4 m kg^{-1}) ....(02)

(01 mark for the correct unit)

{If a student has obtained the correct answer for the gradient selecting different points <u>on the line</u> for gradient calculation, award 03 marks only. i.e. for gradient calculation and the final answer}

(ii) If the measurement obtained in (*b*) (ii) above is 2·00 cm, calculate the density of the liquid (ρ) using the gradient of the above graph. Take $\pi = 3$. Give your answer to the nearest integer.

Gradient = $\frac{1}{A\rho}$ (identifying the gradient as $\frac{1}{A\rho}$) ....(01)

$A = \pi \times 10^{-4}$; $\rho = \frac{1}{3\times10^{-4}\times4}$

$\rho = 833$ kg m^{-3} (*OR* 0.833 g cm^{-3}) ....(01)

(*d*) Give one disadvantage of using fine sand instead of lead shots in this experiment.

The range of *l* measurements/readings will be reduced *OR* only few *l* measurements could be taken *OR* The length of the cylindrical part of the tube available for measurements will be shorter *OR* Much larger volume of sand is needed to achieve the weight of lead shots (due to lower density of sand) *OR* Sand will occupy some part of the cylindrical section of the tube not only the bottom of the tube ....(01)

(Any correct disadvantage)

(*e*) State two disadvantages of using a test tube with cross-sectional area $\frac{1}{4}$ of that of the boiling tube mentioned above in this experiment?

Only few *l* measurements/few readings can be taken (since the spread of *l* measurements will be large)

Immersed lengths/*l* per weight will be large (and therefore only few *l* measurements could be taken) *OR* only few weights could be utilised

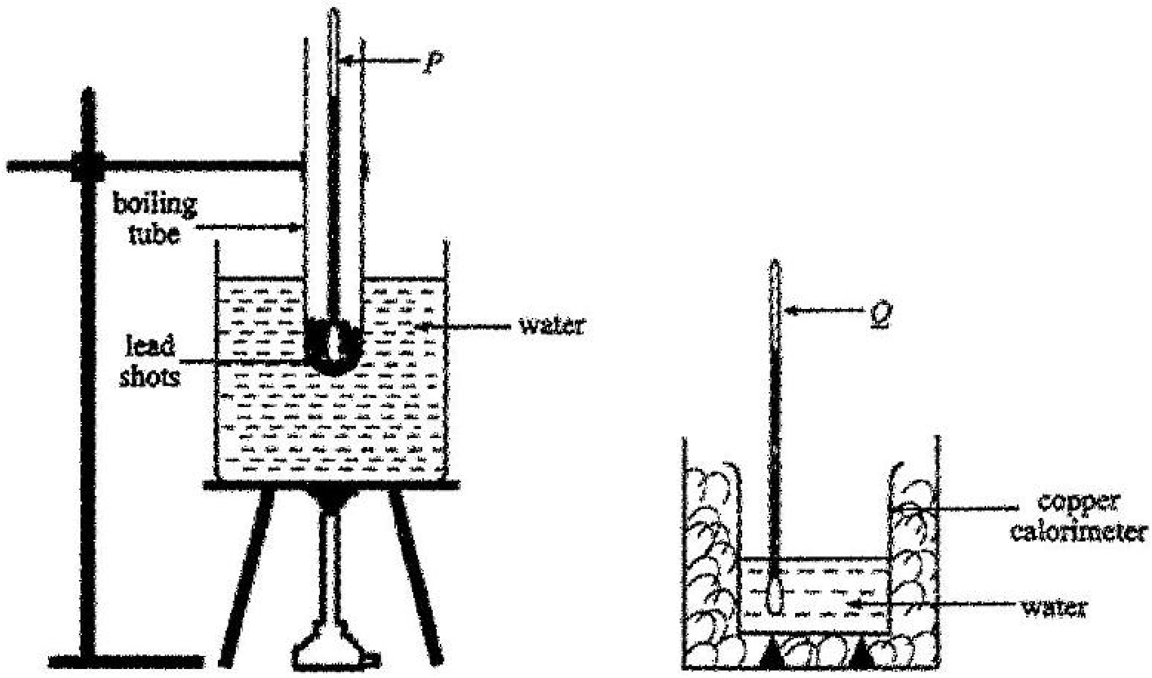
It may be difficult to paste the strip.

Weights may not be able to insert into the tube.

Percentage/fractional error of (external) diameter measurement/cross-sectional area will be large ....(02)

(Any one disadvantage – 01 mark; Any two disadvantages – 02 marks)

2. Following figure shows an experimental set-up used in a school laboratory to determine the specific heat capacity of lead given in the form of lead shots using the method of mixtures.



(a) (i) What is the other essential measuring instrument that you need for this experiment?

A four/triple-beam balance *OR* laboratory electronic balance ....**(01)**

(No marks for just stating balance)

(ii) What are the other essential items that you need for this experiment?

(1) Stirrer ....**(01)**

(2) Boiling tube holder/tongs *OR* Insulating glove/cloth *OR* Insulating screen/asbestos sheet *OR* plug for the boiling tube *OR* lid for the calorimeter. ....**(01)**

(b) Three thermometers *A*, *B* and *C* are available for the experiment.

The range of thermometer *A*, −10 °C to 250 °C

The range of thermometer *B*, −10 °C to 110 °C

The range of thermometer *C*, −10 °C to 60 °C

(i) Which one of the above must be used for thermometer *P*?

B (−10 °C to 110 °C) ....**(01)**

(ii) Which one of the above must be used for thermometer *Q*?

C (−10 °C to 60 °C) ....**(01)**

(*c*) **What are the mass measurements that you take in this experiment? Give them in the order of measurements.**

(i) The mass of the (empty) calorimeter and stirrer/calorimeter with contents (m_1)

(ii)The mass of the calorimeter, stirrer and water (m_2)

(iii) The total/final mass of the system/mixture (after adding lead shots) (m_3)

..................**(03)**

[03 marks for all three correct answers in correct order; 02 mark for all three correct answers but wrong order ; 01 mark for two answers in correct order]

(*d*) (i) **What experimental steps would you take to measure the initial temperature (θ_1) of lead shots?**

Heat the water (in the bath till it boils) and measure the temperature of lead shots when it becomes steady/constant *OR* the temperature reading of *P* is steady/constant. ....**(01)**

(ii) **What are the temperature measurements that you take using thermometer *Q*? Give them in the order of measurements.**

(1)The initial temperature of water (in the calorimeter) (θ_2)...............**(01)**

(2)The highest/maximum temperature of the mixture (θ_3) ....**(01)**

(iii) **What are the experimental steps that you would take to measure temperature θ_3 given above?**

(1) Transfer/put the heated lead shots into the calorimeter instantly/quickly/as soon as possible/without splashing water ....**(01)**

(2) Stir well (continuously) and record the highest/maximum temperature of the mixture ....**(01)**

(*e*) (i) **If the specific heat capacities of water and copper are c_w and c_c respectively, write down an expression for the specific heat capacity *c* of lead in terms of the above mentioned measurements, c_w and c_c. Assume that there is no heat exchange with the surroundings.**

$(m_3 - m_2)c(\theta_2 - \theta_3) = [m_1 c_c + (m_2 - m_1](\theta_3 - \theta_1)$ ....**(02)**

(01 mark for correct L.H.S; 01 mark for correct R.H.S)

$c = \frac{[m_1 c_c + (m_2 - m_1](\theta_3 - \theta_1)}{(m_3 - m_2)(\theta_2 - \theta_3)}$ ....**(01)**

(award all 03 marks for the correct final expression)

(ii) Using the following data and neglecting the heat capacity of the calorimeter calculate the mass of lead shots (m_l) needed to raise the temperature of water by 10 °C. Assume that there is no heat loss to the surroundings.

Mass of water used = 50 g; Temperature drop of lead shots = 70 °C; specific heat capacity of lead = 125 J kg^{-1} K^{-1}; specific heat capacity of water = 4200 J kg^{-1} K^{-1}

$$m_l \times 125 \times 70 = 50 \times 10^{-3} \times 4200 \times 10$$

$$m_l = 0.24 \text{ kg}$$ ....(01)

(iii) Calculate the volume of lead shots used in (*e*) (ii) above. (Density of lead = 12×10^3 kg m^{-3})

$$\text{Volume of lead shots} = \frac{0.24}{12\times10^3}$$

$$= 2.0 \times 10^{-5} \text{ m}^3 \ (20 \text{ cm}^3)$$ ....(01)

(iv) Giving reasons state whether 100 cm^3 calorimeter is suitable or not to perform this experiment. (Density of water = 10^3 kg m^{-3})

$$\text{Volume of water} = \frac{50\times10^{-3}}{10^3}$$ ....(01)

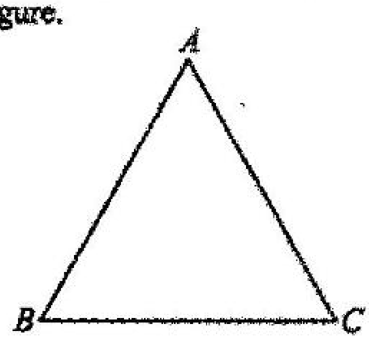
$$= 5.0 \times 10^{-5} \text{ m}^3 \ (50 \text{ cm}^3)$$

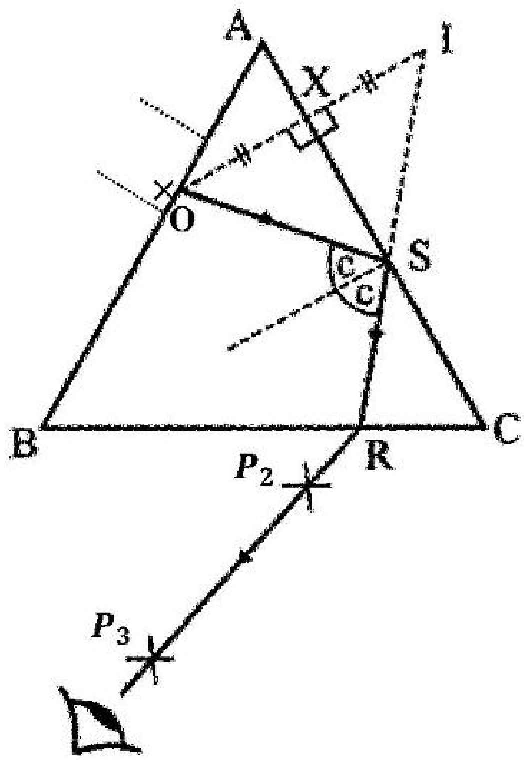
Total volume of water and lead shots = 70 cm^3

Therefore 100 cm^3 calorimeter can be used in this experiment, since water will not spill out of the calorimeter once lead shots are being inserted *OR* Total volume of lead shots and the water is less than 100 cm^3 *OR* 70 cm^3 < 100 cm^3 *OR* 100 cm^3 > 70 cm^3 ....(01)

(Do not award the mark without the correct reason)

3. You are asked to determine the refractive index of the material of a prism using the critical angle method. You are provided with an equilateral glass prism, a drawing board, drawing pins, a white sheet of paper, three optical pins, a protractor, a setsquare and a ruler. The prism ABC is shown in the figure.





(a) (i) Mark the location of the optical pin P_1 on the face AB which is used to obtain a ray of light through the prism using a cross (×).

For marking × on the face AB ....(01)

(× has to be marked within the two dotted lines)

(ii) Give two reasons for selecting the above location for P_1.

(1) To prevent refraction of light (from pin P_1) from face AB ....(01)

(2) To maximize the length of the refracting surface (AC) available for observation *OR* To maximize the length of the emergent surface (BC) available for observation *OR* If the pin is placed towards the corners of the prism the emergent ray will not be visible/cannot draw the construction line to obtain the emergent ray ....(01)

(b) (i) How do you experimentally observe and locate (using optical pins P_2 and P_3) the path of the emerging ray of light from face BC which falls on face AC at critical angle of incidence?

Looking through the face BC towards the face AC observe the image of pin P_1. ....(01)

Move the eye from end C (of the face BC) towards B until the image of the pin just begins to disappear/appearing and disappearing ....(01)

At this position, fix one pin (P_2) close to surface BC and fix the other pin (P_3) (vertically) to be in line/collinear with the disappearing image and far apart from each other. ....(01)

(ii) Drawing the ray diagram with the construction lines in the above figure, give the steps needed in the correct order to construct the ray diagram to identify the critical angle.

(Mark the edges of sides of the prism on the paper and then remove the prism)

(1) Draw the line OXI normal to AC so that $OX = XI$ and locate the image I of P_1, ...(01)

(2) Join the points where the pins P_2 and P_3 were fixed and extend the line to meet BC, at R. ....(01)

(3) Join R and I to intersect AC at S. ....(01)

(4) Join OS. ....(01)

{Steps (1) and (2) can be interchanged; Students may use different symbols. Therefore look at them carefully when awarding marks}

Construction of emerging ray ....(01)

Construction of totally reflected ray (SR) ....(01)

Construction of incident ray (OS) ....(01)

(iii) How do you determine the critical angle c?

By measuring the angle OSR/($2c$) and take the half of it ....(01)

(iv) I. Write down an expression for the refractive index n of glass in terms of c.

$$n = \frac{1}{\sin c}$$ ....(01)

II. If $c = 40°$, calculate n. Give your answer to two decimal places. (Take $\sin 40° = 0{\cdot}64$)

$$n = \frac{1}{0.64}$$

$$n = 1.56$$ ....(02)

(c) (i) If a thin layer of water is formed on the face AC, what will happen to the emerging ray from face BC? Underline the correct answer.

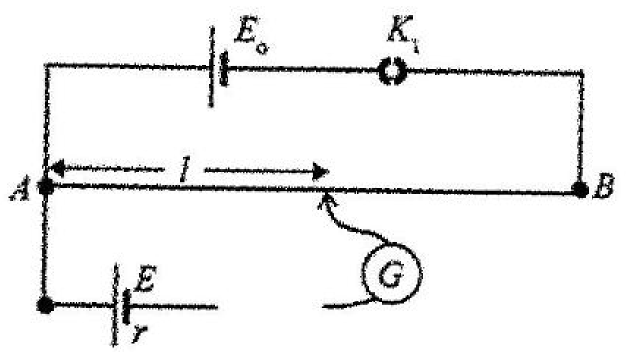
Will move towards B/will not change/<u>will move towards C</u> ....(01)

(ii) If the above water layer is replaced by a thin layer of liquid which has a refractive index higher than that of glass, giving reasons state what will happen to the ray emerged from face BC in (b) (i) above.

Emerged ray will disappear/ No emergent ray ....(01)

Incident rays will not be totally internally reflected from face AC *OR* No total internal reflection takes place at face AC *OR* Incident rays will be refracted from face AC. ....(01)

4. To determine the internal resistance (r) of a dry cell with e.m.f. E, a student uses a potentiometer and his incomplete circuit diagram is given in the figure. The following items are available to complete the circuit.



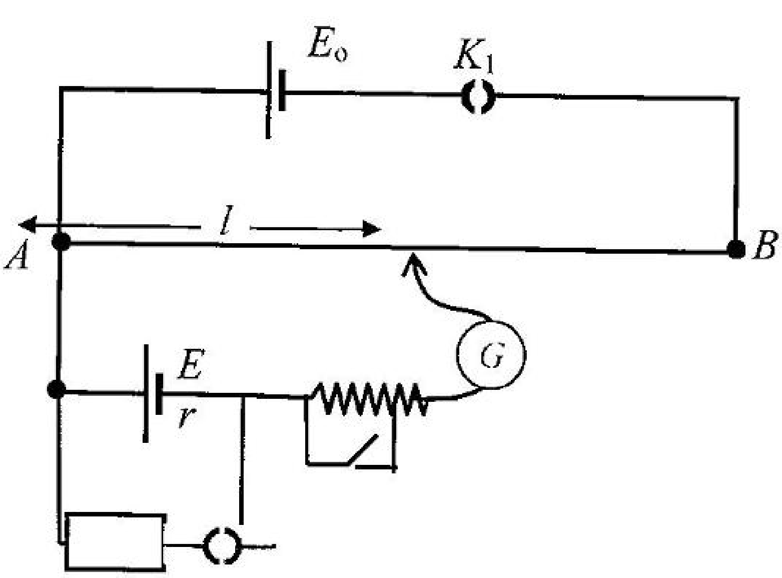
R_1 = 1 kΩ resistor

K_2 = plug key

R_2 = (0-50) Ω resistance box

K_3 = tap key

(a) Complete the circuit diagram using R_1, R_2, K_2 and K_3 in appropriate places.



For correct connection of the resistance box ....(01)

For correct connection of 1 kΩ resistor ....(01)

For connection of key K_3 at the correct place ....(01)

(Award this mark even if the keys are interchanged)

(*b*) **Write down the type and the e.m.f. of a cell suitable for obtaining E_o.**

Type of the cell: (2 V) (lead) accumulator/battery *OR* two (1.2 V) Ni-Cd cells connected in series *OR* a power supply ....(01)

Value of E_0 : 2 V (for lead accumulator). 2.4 (for Ni-Cd cells), 2 – 3 V (for power supply) ....(01)

(*c*) (i) **Write down an expression for current I through the cell with e.m.f. E at the balance position when all keys are closed in terms of E, r and the resistance value R of the resistance box.**

$I = \frac{E}{R+r}$ ....(02)

(ii) **Let k be the potential drop per metre in the wire AB. If the balance length of the potentiometer wire is l, write down an expression for the current I through R in terms of k, l and R at the balance position.**

$I = \frac{kl}{R}$ ....(02)

(iii) **Using the expressions in (*c*)(i) and (*c*)(ii) above obtain an expression to determine the internal resistance (r) of the cell by plotting an appropriate straight line graph.**

$$\frac{E}{R+r} = \frac{kl}{R}$$

$$\frac{1}{l} = \frac{kr}{E}\frac{1}{R} + \frac{k}{E}$$ ....(02)

(*d*) **In the graph identify the following.**

(i) The independent variable : $\frac{1}{R}$ ....(01)

(ii) The dependent variable: $\frac{1}{l}$ ....(01)

(e) The student plots a straight line graph and the following values are extracted.

The gradient = 0·80 (in SI units)

The intercept = 0·40 (in SI units)

(i) Calculate the internal resistance (r) of the dry cell.

$r = \frac{\text{Gradient}}{\text{Intercept}}$ (for identifying this) ....(01)

$r = \frac{0.8}{0.4}$

$r = 2\ \Omega$ ....(02)

(ii) If $k = 0{\cdot}60\ \text{V m}^{-1}$, calculate the e.m.f. E of the dry cell.

For identifying $\frac{k}{E}$ = intercept *OR* gradient = $\frac{kr}{E}$ ....(01)

$E = \frac{0.6}{0.4}$

$E = 1.5$ V ....(02)

(f) Without changing the value of E_o, if a Li-ion cell is used instead of the dry cell in the above setup it is not possible to measure the e.m.f. of it. What is the reason for this?

The e.m.f. (3.6 V – 3.7 V) of a Li-ion cell is greater than 2 V/2 V – 3 V/E_0

OR inverse argument ....(01)

Answer four questions only.
(g = 10 m s^{-2})

- **Note:** For an example the number 65210 can be written as $6{\cdot}52 \times 10^4$ in scientific notation after rounding off to two decimal places.

5. A fire has taken place on an upper floor of a residential building.

(a) As shown in figure (1), a firefighter uses a fire-hose to direct a stream of water at the burning floor to extinguish the flames. The nozzle of the hose is at height 1·0 m above the ground and 10·0 m horizontally away from the building. The stream of water is to be targeted at a height of 6·0 m above the ground. The nozzle makes an angle $\theta = 45°$ with the horizontal. The figure is not drawn to scale.

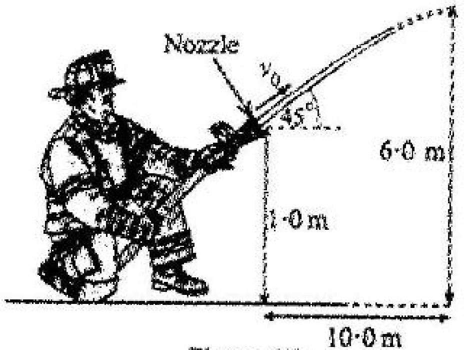


Figure (1)

(i) Calculate the initial speed v_0 of water stream ejecting from the nozzle should have, to reach the target. Neglect air resistance. Take $\sqrt{2} = 1{\cdot}4$

(ii) The internal cross-sectional area of the hose is twice that of the nozzle outlet. Calculate the speed v_1 of water inside the hose end before the nozzle assuming that water is incompressible.

(iii) If the pressure of water inside the hose before the nozzle is higher than the atmospheric pressure by a value of Δp, calculate the value of Δp. Assume that the flow is steady and water is non-viscous. Neglect the vertical height between the nozzle outlet and the hose end just before the nozzle. Density of water is $10^3\ kg\ m^{-3}$.

(iv) The internal diameter of the nozzle outlet is 2·0 cm. Calculate the volume flow rate Q of the water jet leaving the nozzle. (Take $\pi = 3$)

(b) A firefighter expects to reach the burning floor by climbing up along a ladder. As shown in figure (2), a uniform ladder of length L and mass M rests on rough ground at A with its top end against a smooth wall at B. The ladder makes an angle $\theta = 60^\circ$ with the ground. The mass of the firefighter is m.

(i) Assume that the firefighter is standing upright on the ladder at a distance x from A. Draw the free body diagram of the ladder and mark all the forces acting on the ladder taking normal reaction forces at A and B and frictional force at A acting on the ladder as R_A, R_B and F_A respectively. Draw a uniform rod for the ladder.

(ii) If the coefficient of static friction between the ground and the ladder is μ, by resolving forces and taking moments around A derive an expression for the **maximum distance** x_{max} in terms of M, m, L and μ that the firefighter can climb before the ladder begins to slip.

(iii) If $M = 20$ kg, $m = 70$ kg, $L = 6{\cdot}0$ m and $\mu = 0{\cdot}30$, calculate the value x_{max}. Give your answer to the nearest integer. (Take $\sqrt{3} = 1{\cdot}7$)

(iv) Firefighters place a special anti-slip mat under the ladder foot at A to prevent the ladder from slipping. If the firefighter must reach the top of the ladder, find the **minimum coefficient of static friction** μ_{min} between the mat and the ladder must have using the expression derived in (b) (ii) above. Give your answer to the nearest two decimal places.

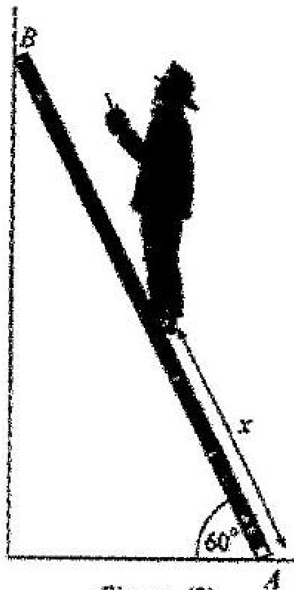


Figure (2)

(c) As shown in figure (3), another firefighter uses a rope-and-pulley to go up and rescue a person. The pulley with radius 0·10 m is fixed to the crane of the fire truck and light inextensible rope passes over it. The firefighter is attached to one end of the rope and the other end is pulled by a constant force 960·5 N by a motor in the fire truck. The mass of the firefighter with the rescue basket is 80 kg. The pulley rotates freely and the rope does not slip on it. The moment of inertia of the pulley about its rotational axis is $2{\cdot}5 \times 10^{-3}\ kg\ m^2$.

(i) Determine the linear acceleration a of the firefighter.

(ii) If the system starts from rest, calculate the angular speed ω and the rotational kinetic energy K of the pulley after 3·0 s.

Figure (3)

(a) (i) If t is the time taken for the water stream to reach the target,

Applying $\rightarrow s = ut$

$10 = v_0 \cos(45) t$ ....(01)

$t = \frac{10}{v_0 \cos(45)}$

Applying $\uparrow h = ut + \frac{1}{2}gt^2$ ....(01)

$5 = v_0 \sin(45) \frac{10}{v_0 \cos(45)} - \frac{1}{2} \times 10 \times \left(\frac{10}{v_0 \cos(45)}\right)^2$ ....(01)

(for substitution)

$5 = 10 - \frac{1}{2} \times 10 \times \left(\frac{10}{v_0 \cos(45)}\right)^2 \Rightarrow 5\left(\frac{10}{v_0 \cos(45)}\right)^2 = 5$

$\left(\frac{10}{v_0 \cos(45)}\right)^2 = 1 \Rightarrow v_0 \cos(45) = 10$

$v_0 = 10\sqrt{2}$

$v_0 = 14$ m s^{-1} ....(01)

(ii) Applying $A_1 v_1 = A_2 v_2$ ....(01)

$2v_1 = v_0$

$v_1 = 7$ m s^{-1} ....(01)

(iii) Applying Bernoulli's principle,

$P_1 + \frac{1}{2} \times 10^3 \times 7^2 = P_0 + \frac{1}{2} \times 10^3 \times 14^2$

$\Delta p + \frac{1}{2} \times 10^3 \times 7^2 = \frac{1}{2} \times 10^3 \times 14^2$ ....(01)

(for substitution)

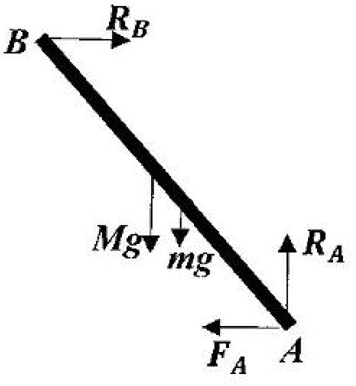
$\Delta p = 7.35 \times 10^4$ Pa ....(01)

(iv) $Q = \pi \times (10^{-2})^2 \times 14$ ....(01)

(for substitution)

$Q = 4.2 \times 10^{-3}$ m^3 s^{-1} ....(01)

(*b*) (i)



Marking forces R_A and R_B ....(01)

Marking force F_A ....(01)

Marking forces Mg and mg ....(01)

(Disregard the relative locations of Mg and mg)

(ii) At the point of slipping $F_A = \mu R_A$ ....(01)

Resolving forces horizontally

$\rightarrow R_B = \mu R_A$ ....(01)

Resolving forces vertically

$\uparrow R_A = Mg + mg$ ....(01)

Taking moment around A,

$R_B L\sin60 = Mg\frac{L}{2}\cos60 + mgx_{max}\cos60$ ....(01)

$\mu R_A L\tan60 = Mg\frac{L}{2} + mgx_{max}$

$\mu(M+m)gL\tan60 = Mg\frac{L}{2} + mgx_{max}$

$x_{max} = \frac{\mu(M+m)}{m}L\sqrt{3} - \frac{M}{m}\frac{L}{2}$ ....(01)

(iii) $x_{max} = \frac{0.3(20+70)}{70} \times 6\sqrt{3} - \frac{20}{70} \times \frac{6}{2}$

$x_{max} = 3$ m (3.1 m) ....(01)

(iv) If the firefighter must reach the top of the ladder,

$x_{max} = L$ (for identifying this) ....(01)

Substituting $x_{max} = L$ in the expression derived in (b) (ii) above,

$1 = \frac{\mu_{min}(20+70)}{70} \times \sqrt{3} - \frac{20}{70} \times \frac{1}{2}$

$\mu_{min} = 0.52\ OR\ 0.51$ ....(01)

(No mark for 0.5)

(c) $\downarrow T$ $\uparrow T$ (i) Let the tension in the right side of rope be T. Applying $F = ma$ to the firefighter

$T - 80g = 80a$ ....(1) ....(01)

If the angular acceleration of the pulley is α, then by applying $\tau = I\alpha$ to the pulley

$(960.5 - T) \times 0.1 = 2.5 \times 10^{-3} \times \alpha$ ....(01)

But, $a = R\alpha = 0.1\alpha$ ....(01)

$(960.5 - T) \times 0.1 = 2.5 \times 10^{-3} \times \frac{a}{0.1}$ ....(2)

From equations (1) and (2) $(960.5 - 80g - 80a) \times 0.1 = 2.5 \times 10^{-3} \times \frac{a}{0.1}$

$(2.5 \times 10^{-2} + 8)a = (960.5 - 800) \times 0.1 = 16.05$

$a = 2$ m s^{-2} ....(01)

(ii) $\alpha = \frac{a}{0.1}$

$\alpha = 20 \text{ rad s}^{-2}$

Applying $\omega = \omega_0 + \alpha t$ to the pulley ....(01)

$\omega = 20 \times 3 \text{ rad s}^{-1}$

$\omega = 60 \text{ rad s}^{-1}$ ....(01)

Rotational kinetic energy of the pulley $K = \frac{1}{2} I\omega^2$ ....(01)

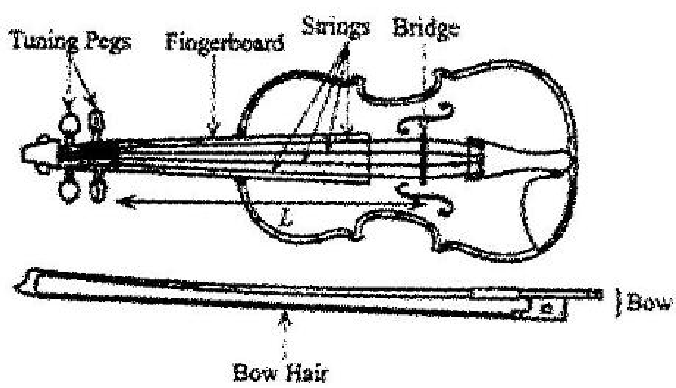
$= \frac{1}{2} \times 2.5 \times 10^{-3} \times 60^2$ ....(01)

(for substitution)

$K = 4.5 \text{ J}$ ....(01)

6. Read the following passage and answer the questions.

A diagram of a violin is shown in the figure. When a violinist draws the bow across a violin string it initiates transverse vibrations. The vibrating string can produce a motion with many harmonics. There is an important difference between plucking and bowing of a string. A plucked string very quickly loses its high harmonics and, after a short time, nearly all of the remaining energy in the string is in its fundamental note. Bowing inputs energy continuously to the string for a longer duration and thereby retains in the high harmonics for a longer period.



The frequency of a string can be changed by varying the tension in the string using the tuning pegs. The frequency also depends on the length of the string that is free to vibrate. The violinist changes the length by holding the string firmly against the fingerboard. The frequency of a string also depends on its diameter. The strings are named as *E*, *A*, *D*, and *G* (from highest to lowest pitch) based on the notes produced with their full length.

The vibrating string transmits its energy first to the bridge and then to the top wooden plate of the sound box. The top and bottom wooden plates of the sound box vibrate in complex patterns, generating both longitudinal and transverse vibrations. The sound box acts as a resonating chamber which amplifies the sound by resonating the air mass inside it, propagating longitudinal sound waves into air.

The horsehair of the bow is being coated with resin to increase friction. When the bow is drawn across a string, static friction initially causes the string to stick to the bow and move with it. As tension builds, the restoring force of the string overcomes frictional force, and the string slips back rapidly, creating a vibration. This continuous sticking and slipping process generates the vibrations of the string that lead to musical sounds.

(a) What is the main difference between plucking and bowing a string?

(b) (i) What are the three factors that determine the frequency of a violin string?

(ii) What determines the quality of sound in a sound wave?

(iii) Which string (E, A, D, or G) has the largest diameter?

(c) (i) Write down an expression for speed v of a transverse wave along a stretched violin string with tension T and mass per unit length m.

(ii) Write down an expression for the fundamental frequency f_0 of the above string in terms of its vibrating length L, T and m.

(iii) Hence, write down an expression for the frequency f_n of the n^{th} harmonic in terms of f_0.

(iv) Assuming violin string generates sinusoidal waves, draw respective standing wave patterns in the string for $n=1$ and $n=2$.

(v) Giving reasons state what will happen to the frequency of a violin string with increase of temperature.

(vi) Calculate the fundamental frequency f_0 of violin string A under a tension of 50 N. The length of the string is 30 cm and its mass per unit length is $7 \cdot 5 \times 10^{-4}$ kg m^{-1}. Take $\sqrt{\frac{20}{3}} = 2 \cdot 58$

(vii) Assuming that the above string mentioned in (c)(vi) above vibrating with its fundamental frequency performs simple harmonic motion with an amplitude 2·0 mm, calculate the energy (E) stored in the string during one vibration cycle. Take $\pi = 3$.

(d) What modes of vibrations are generated in the top and bottom wooden plates of the violin?

(e) What is the function of the sound box of a violin?

(f) (i) Why is it essential to coat horsehair with resin?

(ii) A violin string is bowed at a point where the static coefficient of friction $\mu_s = 0 \cdot 5$ and the kinetic coefficient of friction $\mu_k = 0 \cdot 3$. If the normal force applied by the bow on the string is 1·5 N determine the following.

I. The maximum friction force (F_1) before slipping.

II. The friction force (F_2) when slipping.

(iii) A violin string vibrates at 250 Hz. What is the time duration (T) of one complete stick-slip cycle?

(iv) By bowing a violin string at a point $\frac{1}{5}$ of its length from the bridge, is it possible to obtain the fifth harmonic? Give a reason for your answer.

(g) The G string of a violin is made with a denser inner core and a spiral winding around it. Give reasons for this.

(a) A plucked string very quickly loses its high harmonics and, after a short time, nearly all of the remaining energy in the string is in its fundamental note. ....(01)

Bowing inputs energy continuously to the string for a longer duration and thereby retains in the high harmonics for a longer period. ....(01)

(b) (i) Tension in the string ....(01)

Length of the string ....(01)

Diameter/Thickness (mass per unit length/linear mass density) of the string ....(01)

(ii) Superposition of harmonics/overtones (with different amplitudes) ....(01)

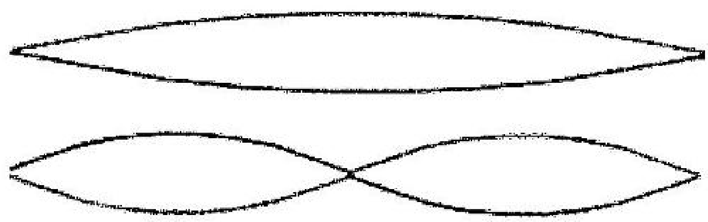
(iii) G ....(01)

(*c*) (i) $v = \sqrt{\frac{T}{m}}$ ....(01)

(ii) $f_0 = \frac{1}{2L}\sqrt{\frac{T}{m}}$ ....(01)

(iii) $f_n = nf_0$ ....(01)

(iv)



..................(01)

..................(01)

(v) The frequency decreases. ....(01)
String length will increase (slightly due to expansion) *OR* Tension tends to decrease (since string becomes loose). ....(01)

(vi) $f_0 = \frac{1}{2\times0.3}\sqrt{\frac{50}{7.5\times10^{-4}}}$ ....(01)

(for correct substitution)

$f_0 = 430 \text{ Hz}$ ....(01)

(vii) Total mass of the string, $m = 7.5 \times 10^{-4} \times 0.3$ ....(01)

(for correct substitution)

$E = \frac{1}{2}m\omega^2A^2$ ....(01)

$\omega = 2\pi f$ ....(01)

$E = \frac{1}{2} \times 7.5 \times 10^{-4} \times 0.3 \times (2 \times 3 \times 430)^2 \times (2 \times 10^{-3})^2$

$= 2.99 \times 10^{-3}$ J $(2.99 - 3.0) \times 10^{-3}$ J ....(01)

(*d*) Both longitudinal and transverse. ....(01)

(*e*) It amplifies the sound by resonating the air mass. ....(01)

(*f*) (i) To increase friction of horse hair. ....(01)

(ii) I. $F_1 = 0.5 \times 1.5$

$= 0.75 \text{ N}$ ....(01)

II. $F_2 = 0.3 \times 1.5$

$= 0.45$ N ....(01)

(iii) $T = \frac{1}{250}$ ....(01)

$= 4 \times 10^{-3}$ s (4 ms) ....(01)

(iv) No/Not possible ....(01)

Bowing at $\frac{1}{5}$ of the length produces an antinode *OR* a node is necessary at $\frac{1}{5}$ of the length for the fifth harmonic. ....(01)

(*g*) It increases linear mass density/mass per unit length without making the string too thick while keeping the string flexible and easy to bow.

OR A purel_ thick dense string would be too stiff/hard to press down/difficult to bow. ....(01)

7. (*a*) (i) Stress-strain curve for an elastic string is shown in figure (1). Name the points *P, Q, R, S* and *T*.

(ii) First a stress value between *P* and *Q* is applied to the string and then the stress is removed. Next a stress value between *Q* and *R* is applied and then this stress is also removed. Compare the end results in these two situations.

(iii) When a wire of length *L* and cross-sectional area *A* is subjected to a tensile force of *F*, the elongation is *e*. Define the Young modulus *E* of the material of the wire using the given variables.

(iv) The stress-strain curves for two types of materials I and II are shown in figure (2). What can you conclude about the elastic properties of these two materials? Also name a suitable material for each type.

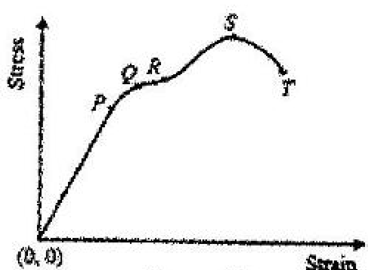


Figure (1)

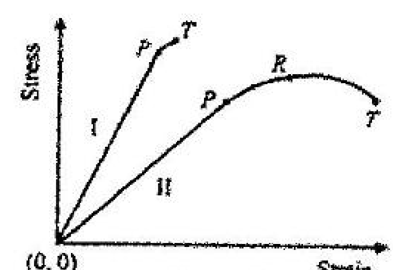


Figure (2)

(*b*) A load lifting machine has a steel cable made of a bunch of small wires each of length 20·0 m. The effective cross-sectional area of the cable is 4·00 cm^2. The Young modulus of steel is $2{\cdot}0 \times 10^{11}$ Pa. Neglect the mass of the cable. Give your answers in scientific notation.

(i) If a load of mass 1000 kg is supported by the cable, determine the elongation of the cable.

(ii) If the load is accelerated upward at 2·0 m s^{-2} by the cable, what is the additional increase in length of the cable?

(iii) What is the greatest mass that can be accelerated upward at 2·0 m s^{-2} without exceeding the stress limit of the cable, $Q = 1{\cdot}8 \times 10^8$ Pa shown in figure (1)?

(iv) After excessive usage few wires had been broken and the effective cross-sectional area of the cable reduces by 10%. The value of the limit *P* is $1{\cdot}5 \times 10^8$ Pa shown in figure (1).

I. What is the greatest mass that can be accelerated upward at 2·0 m s^{-2} in this situation without exceeding the limit *P*?

II. Also determine the total elongation of the cable in the above situation.

III. To repair the cable in (*b*) (iv) above, the broken wires are replaced by new wires made of a material having Young modulus $1{\cdot}6 \times 10^{11}$ Pa without changing the original effective cross-sectional area of the cable. What is the effective Young modulus of the composite material of the mended cable?

(*a*) (i) P – Proportional limit ....(01)

Q – Elastic limit ....(01)

R – Yield point ....(01)

S – Maximum/Breaking stress (point) ....(01)

T – Breaking point ....(01)

(ii) (When a stress value between P and Q is applied to the string and then released) the string will return to its original length *OR* the string will regain its original shape. ....(01)

(When a stress value between Q and R is applied to the string and then released) the string will not return fully to its original length *OR* the string will not regain its original shape *OR* leave a permanent elongation in the string ....(01)

(iii) $E = \frac{F}{A}\frac{L}{e}$

OR The Young modulus is defined as the ratio of (tensile) stress to the (tensile) strain within the proportional limit. ....(01)

(iv) Material I – Brittle *OR* a material which can be easily breakable/suddenly breaks (after elastic limit). ....(01)

Suitable material - Glass/Ceramics/Cast Iron/Concrete/Polystyrene ....(01)

(Accept any suitable brittle material)

Material II – Ductile *OR* a material that can be stretched or deformed (before breaking). ....(01)

Suitable material – Copper/Aluminium/Silver/Gold/Rubber/ (Pure) Iron ....(01)

(Accept any suitable ductile material)

(*b*) (i) $e = \frac{F}{A}\frac{L}{E}$

$e = \frac{10^3 \times 10 \times 20}{4 \times 10^{-4} \times 2 \times 10^{11}}$ ....(01)

(for correct substitution)

$e = 2.5 \times 10^{-3}$ m ....(02)

(ii) Additional tension in the cable $= ma = 10^3 \times 2$ ....(01)

Therefore additional increase in length = $\frac{10^3 \times 2 \times 20}{4 \times 10^{-4} \times 2 \times 10^{11}}$ ....(01)

(for correct substitution)

$= 5.0 \times 10^{-4}$ m ....(02)

{Alternative Method

Total tension in the cable $= mg + ma = 10^3 \times 10 + 10^3 \times 2$ ......(01)

Total increase in length $= \frac{12 \times 10^3 \times 20}{4 \times 10^{-4} \times 2 \times 10^{11}}$ ......(01)

(for correct substitution)

$= 3.0 \times 10^{-3}$

Therefore additional increase in length $= 3.0 \times 10^{-3} - 2.5 \times 10^{-3}$

$= 5.0 \times 10^{-4}$ m ......(02)

(iii) If m is the greatest mass that can be accelerated upward,

$\frac{m(10+2)}{4 \times 10^{-4}} = 1.8 \times 10^8$ ....(02)

(L.H.S. – 01 mark; equating to R.H.S. – 01 mark)

$m = 6.0 \times 10^3$ kg ....(01)

(iv) I. New cross-sectional area of the cable $= 0.9 \times 4 \times 10^{-4}$ ....(01)

If m' is the greatest mass that can be accelerated upward now,

$\frac{m'(10+2)}{0.9 \times 4 \times 10^{-4}} = 1.5 \times 10^8$ ....(01)

(for substitution)

$m' = 4.5 \times 10^3$ ....(01)

II. Total elongation of the cable $= \frac{4.5 \times 10^3 \times 12 \times 20}{0.9 \times 4 \times 10^{-4} \times 2 \times 10^{11}}$ ....(01)

(for substitution)

$= 1.5 \times 10^{-2}$ m ....(01)

III. For parallel wires with the same strain, if the effective Young modulus of the mended cable is E', $(E'A = E_1A_1 + E_2A_2)$

$$E' = \frac{0.9 \times A \times 2 \times 10^{11} + 0.1 \times A \times 1.6 \times 10^{11}}{A}$$ ....(01)

(for substitution)

$$E' = 1.96 \times 10^{11} \text{ Pa}$$ ....(02)

8. A satellite is an artificial object placed into orbit around earth for various purposes. Depending on their purpose and orbital characteristics, they can be classified into three main types, namely geostationary satellites, low earth orbit satellites and polar orbit satellites.

(*a*) Consider a satellite of mass m orbiting the earth in a circular path with radius r from the center of the earth. Assume that the earth is a solid uniform sphere of mass M and the satellite is a point object.

(i) Write down an expression for the gravitational force F_g acting between the satellite and the earth in terms of M, m, r and the universal gravitation constant G.

(ii) Write down an expression for the centripetal force F_c acting on the satellite in terms of m, r and its speed v.

(iii) Hence, derive an expression for v in terms of M, r and G.

(iv) Derive an expression for the orbital period T of the satellite in terms of M, r and G.

(v) Derive an expression for the total mechanical energy E of the satellite in terms of M, m, r and G.

(*b*) (i) What are the **three** conditions that a geostationary satellite should satisfy?

(ii) Write down a use of geostationary satellites.

(iii) A geostationary satellite requires 2·1 kW of continuous power for operation of its equipment. It uses solar panels with 25% efficiency and the incident solar intensity on the panels is 1200 W m^{-2}.

I. Calculate the area of solar panels needed to generate the required power above.

II. In certain times of a year, when earth comes in between sun and the satellite sunlight will not incident on to solar panels for a maximum period of 72 minutes per day. In such a situation the satellite draws electricity from rechargeable batteries to operate its equipment. Calculate the battery's output electrical energy (in kW h) needed to supply power in a day like this.

(*c*) The orbital radius of a low earth orbit satellite is less than that of a geostationary satellite. Using the expression derived in (*a*) (v) above deduce which satellite has more total mechanical energy.

(*d*) A polar satellite is a satellite that orbits the earth in a polar orbit. It passes over the north and south poles of the earth in each revolution. A polar satellite orbits earth at an altitude of 600 km above the earth surface. Radius of the earth = $6{\cdot}4 \times 10^6$ m, Mass of the earth = $6{\cdot}0 \times 10^{24}$ kg. Take $G = 7{\cdot}0 \times 10^{-11}$ N m^2 kg^{-2} and $\pi = 3$.

(i) Using the expression derived in (*a*) (iv) above, calculate the orbital period T of the satellite. Take $\sqrt{\frac{5}{3}} = 1{\cdot}3$.

(ii) How many revolutions per day will it complete? Give your answer to the nearest integer.

(iii) Explain why such a satellite can cover a large surface area of the earth.

(*e*) The Starlink satellite system is a collection of low earth orbit satellites designed to provide global broadband internet coverage. As of early August 2025, there were approximately 8075 Starlink satellites orbiting the earth at an altitude of 550 km above the earth surface. Without doing calculations state with **reasons** whether starlink satellites orbit more or less rounds around the earth per day compared to the polar satellite mentioned in (*d*) above.

(*a*) (i) $$F_g = \frac{GMm}{r^2}$$ ....(01)

(ii) $F_c = \frac{mv^2}{r}$ ....(01)

(iii) $\frac{mv^2}{r} = \frac{GMm}{r^2}$ ....(01)

$v = \sqrt{\frac{GM}{r}}$ ....(02)

(iv) $T = \frac{2\pi r}{v}$ *OR* $T = \frac{2\pi}{\omega}$ ....(01)

$T = 2\pi\sqrt{\frac{r^3}{MG}}$ ....(02)

(v) Gravitational potential energy $= -\frac{GMm}{r}$ ....(01)

Kinetic energy $= \frac{1}{2}\frac{GMm}{r}$ ....(01)

Total mechanical energy $= \frac{1}{2}\frac{GMm}{r} - \frac{GMm}{r}$ ....(01)

$E = -\frac{GMm}{2r}$ ....(02)

(*b*) (i) (1) It should have an (orbital) period of 24 hours/1 day *OR* equal to the earth's rotational period. ....(01)

(2) It should move in the equatorial plane of the earth. ....(01)

(3) It should move from west to east/ move in the same direction as the earth's rotation. ....(01)

(ii) These satellites are extensively used for telecommunication/TV broadcasting/internet coverage/weather monitoring/environmental monitoring/observation of outer space. ....(01)

(iii) I. Area of the solar panels $= \frac{2100}{0.25\times1200}$ ....(01)

(for correct substitution)

$= 7\ m^2$ ....(01)

II. Output energy $= \frac{2.1\times72}{60}$ ....(01)

(for correct substitution)

= 2.52 kW h ....(01)

(*c*) Geostationary satellite ....(01)

(*d*) (i) $r = 6.4 \times 10^6 + 0.6 \times 10^6$ ....(01)

(for addition)

$= 7.0 \times 10^6$ m

$$T = 2\pi\sqrt{\frac{r^3}{MG}}$$

$$= 2 \times 3\sqrt{\frac{7^3 \times 10^{18}}{6.0 \times 10^{24} \times 7.0 \times 10^{-11}}}$$ ....(01)

(for substitution)

$$= 2 \times 3 \times 7 \times \sqrt{\frac{5}{3}} \times 10^2$$

$$= 42 \times 1.3 \times 10^2$$

$= 5460$ s ....(01)

(ii) Number of orbits per day $= \frac{24 \times 3600}{5460}$ ....(01)

(for substitution)

$= 16$ ....(01)

(iii) It moves from pole to pole as earth rotates beneath it/ Earth rotates perpendicular to the direction of motion of the satellite. (This results in the satellite passing over different longitudes on each orbit) ....(01)

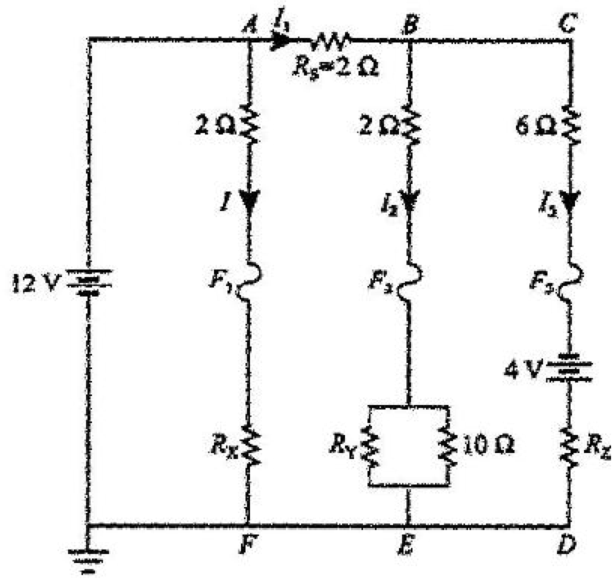
(*e*) (Orbital) period is less since the altitude is less. ....(01)

Therefore rounds around the earth is more. ....(01)

9. Answer either part (A) or part (B) only.

Part (A)

The figure shows a 12 V d.c. electrical circuit used to detect parameters, such as temperature, pressure, and concentration of flammable gases in emergency situations. It has three separate branches *AF, BE* and *CD* as shown in the figure. The *CD* branch includes another 4.0 V battery. $R_X = 10\,\Omega$, $R_Y = 15\,\Omega$ and $R_Z = 6\,\Omega$ are the resistance values of sensors used for detecting three parameters mentioned above. F_1, F_2 and F_3 represent three fuses. Assume that batteries and fuses have no internal resistance. The maximum continuous current through a fuse without burning is termed as fuse rating. The fuse ratings of F_1, F_2 and F_3 are 1 A, 5 A and 2 A respectively.



(*a*) (i) Calculate the current *I* through branch *AF*.

(ii) If the potential at junction *B* is V_B, what are the potential differences between $BE\,(V_{BE})$ and $CD\,(V_{CD})$?

(iii) Hence, write down expressions for the currents I_1, I_2 and I_3 in terms of V_B.

(iv) Considering the currents at junction *B*, calculate V_B.

(v) Calculate the potential difference across the resistor R_S.

(vi) Using your expressions in (*a*)(iii) and the value obtained for V_B in (*a*)(iv) above, calculate currents I_1, I_2 and I_3.

(vii) Calculate the power dissipated through resistors R_X, R_Y and R_Z.

(viii) Calculate the operating power of 12 V and 4 V batteries.

(*b*) Consider the following responses happen simultaneously due to an emergency fire.

Resistor R_S in the circuit is short-circuited.

Resistor R_Y in the circuit is short-circuited.

Resistor R_Z drops from 6·0 Ω to 2·0 Ω.

(i) Calculate currents I_2, and I_3 under these conditions using the expressions derived in (*a*)(iii) above.

(ii) Giving reasons state what will happen (burn/not burn) to fuses F_1, F_2 and F_3.

(*c*) State how to find experimentally that the resistor R_S in the above figure is short circuited using an ideal voltmeter.

(*a*) (i) $I = \dfrac{12}{10+2}$ ....(01)

$I = 1\text{ A}$ ....(01)

(ii) $V_{BE} = V_B$ ....(01)

$V_{CD} = V_B$ ....(01)

(iii) $I_1 = \frac{(12-V_B)}{2}$ ....(01)

Equivalent resistance of 15 Ω and 10 Ω $= \frac{15\times10}{15+10}$ ....(01)

$= 6\ \Omega$

$I_2 = \frac{V_B}{2+6}$

$I_2 = \frac{V_B}{8}$ ....(01)

$I_3 = \frac{(V_B+4)}{12}$ ....(01)

(iv) $I_1 = I_2 + I_3$ ....(01)

$\frac{(12-V_B)}{2} = \frac{V_B}{8} + \frac{(V_B+4)}{12}$

$(12 - V_B) = \frac{V_B}{4} + \frac{(V_B+4)}{6} \Rightarrow V_B + \frac{V_B}{4} + \frac{V_B}{6} = 12 - \frac{2}{3}$

$V_B = 8\ \text{V}$ ....(01)

(v) Potential difference $= 12 - 8$ ....(01)

(for the subtraction)

$= 4\ \text{V}$ ....(01)

(vi) $I_1 = \frac{(12-8)}{2}$

$I_1 = 2\ \text{A}$ ....(01)

$I_2 = \frac{8}{8}$

$I_2 = 1\ \text{A}$ ....(01)

$I_3 = \frac{(8+4)}{12}$

$I_3 = 1\ \text{A}$ ....(01)

(vii) $P_{RX} = I_X^2 R_X = 1^2 \times 10$

$= 10\ \text{W}$ ....(01)

Current through $R_Y = \frac{10}{15+10} \times 1$ ....(01)

$P_{RY} = I_Y^2 R_Y = (0.4)^2 \times 15$

$= 2.4\ \text{W}$ ....(01)

$P_{RZ} = I_Z^2 R_Z = 1^2 \times 6$

$= 6\ W$ ....(01)

(viii) Current through 12 V battery $= I + I_1 = 1 + 2$ ....(01)

(for addition)

Operating power of 12 V battery $= 12 \times 3$

$= 36\ W$ ....(01)

Operating power of 4 V battery $= 4 \times 1$

$= 4\ W$ ....(01)

(*b*) (i) When resistor R_S is short-circuited, $V_B = 12\ V$ ....(01)

When resistor R_Y is short-circuited, current through 10 Ω is zero ....(01)

Therefore $I_2 = \frac{12}{2}$

$I_2 = 6\ A$ ....(01)

$I_3 = \frac{(12+4)}{6+2}$

$I_3 = 2\ A$ ....(01)

(ii) For F_1, 1 A fuse the current flowing through is 1 A and does not exceed the rated maximum. Therefore it will not burn. ....(01)

For F_2, 5 A fuse the current flowing through is 6 A and exceeds the rated maximum. Therefore it will burn. ....(01)

For F_3, 2 A fuse the current flowing through is 2 A and does not exceed the rated maximum. Therefore it will not burn. ....(01)

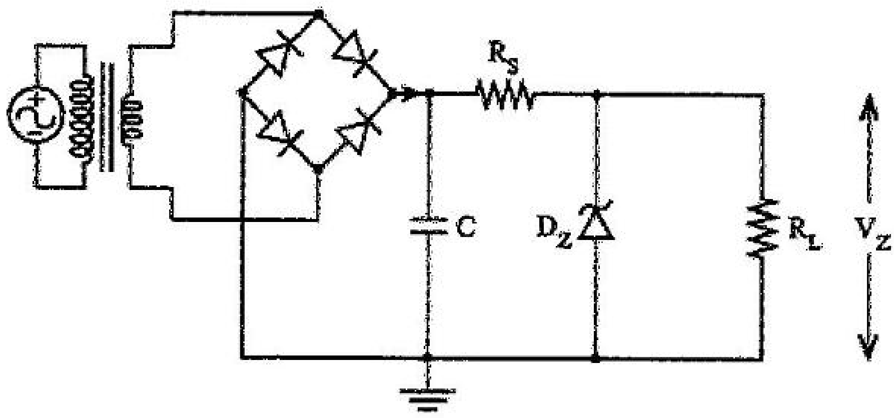
(Do not award marks without correct reasons)

(*c*) If the measured voltage difference across R_S is zero, then it is short circuited.

............(01)

Part(B)

A 200 V (r.m.s.), 50 Hz sinusoidal main power supply is connected to the primary coil of a step-down transformer with a turns ratio of 20:1. The secondary coil feeds a full-wave bridge rectifier with **ideal diodes**, followed by a smoothing capacitor C, and a Zener diode voltage regulator as shown in the circuit diagram.



(*a*) (i) Calculate the r.m.s. (V_{rms}) voltage and the peak voltage (V_p) across the secondary of the transformer. Take $\sqrt{2} = 1{\cdot}4$.

(ii) Draw the shape of the voltage waveform at the output of the full-wave bridge rectifier without the capacitor and Zener diode.

(iii) What is the frequency of the output voltage of the full-wave bridge rectifier?

(iv) How is a full-wave rectifier different from a half-wave rectifier?

(v) Calculate the mean value of d.c. voltage (V_{dc}) of the rectified signal. Take $V_{dc} = V_p \times 0{\cdot}65$

(*b*) (i) If the load resistance $R_L = 400\ \Omega$, and the Zener voltage $V_Z = 8$ V, calculate the current I_L through the load resistor.

(ii) The ripple voltage v_r is given by $v_r = \dfrac{I_L}{f_r C}$, where I_L is the load current, f_r is the ripple frequency, and C is the capacitance of the smoothing capacitor. If the capacitance of the capacitor is 200 μF, calculate the expected ripple voltage.

(iii) Draw the shape of the expected voltage waveform of the rectified output after smoothing indicating maximum and minimum voltage values.

(iv) What will be the ripple voltage if the capacitance of the capacitor is doubled?

(*c*) (i) Describe how to regulate voltage using a Zener diode.

(ii) Given the ripple voltage value obtained in (*b*) (ii) above, will the smoothed voltage drop below 8 V? If so, is regulation still effective? Give reasons for your answer.

(iii) Calculate the minimum capacitance value required to ensure smoothed voltage never drops below 8 V.

(iv) Determine the range of resistance values of the safety resistor R_S should have so that the Zener power does not exceed 1·6 W and the 8 V output stays in regulation with 400 Ω load. Take minimum Zener Current as 5 mA.

(*d*) (i) If the diodes are not ideal and forward biased voltage drop is 0·7 V what will happen to the ripple voltage? By how much will the peak value of the smoothed d.c. voltage change?

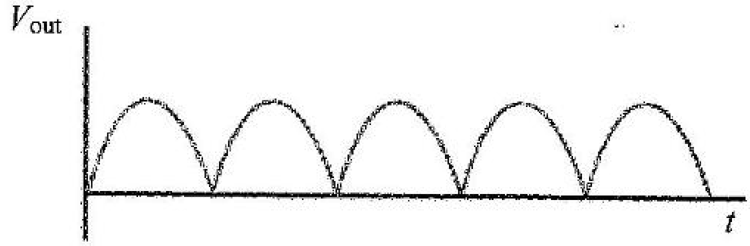
(ii) How does a Zener-regulated d.c. voltage respond when the load resistance is decreased?

(a) (i) $V s_{rms} = \dfrac{200}{20}$ ....**(01)**

$V s_{rms} = 10$ V ....**(01)**

$V_{S,pk} = V_{S_{rms}} \times 1.4 = 10 \times 1.4$

$= 14\ V$ ....(01)

(ii) 

..................(01)

(Look for the shape only; labelling axes not essential; at least three cycles should be drawn)

(iii) 100 Hz ....(01)

(iv) In a half-wave rectifier, only one half of the AC cycle appears at the output (while the other half is blocked/not present leaving gaps). ....(01)

In a full-wave rectifier, both halves of the AC input are converted to single-polarity (so that current always flows in the same direction through the load, producing a continuous single-polarity output). ....(01)

(v) $V_{dc} = V_{pk} \times 0.65 = 14 \times 0.65$

$= 9.1\ V$ ....(01)

(*b*) (i) $I_L = \frac{8}{400}$ ....(01)

$I_L = 0.02\ A\ (20\ mA)$ ....(01)

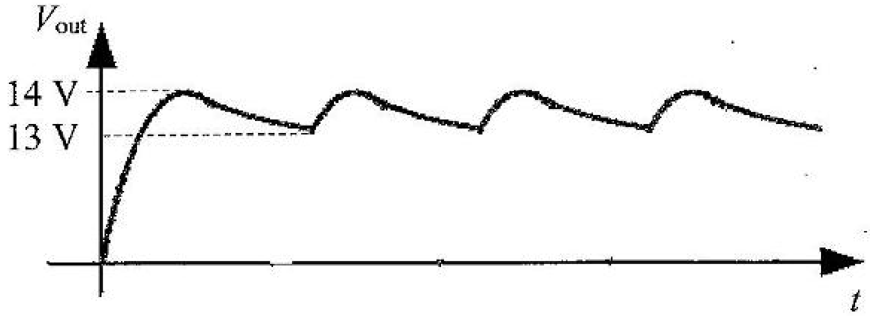
(ii) $v_r = \frac{I_L}{f_r C}$

$v_r = \frac{0.02}{100 \times 200 \times 10^{-6}}$ ....(01)

(for substitution)

$v_r = 1\ V$ ....(01)

(iii)



..................(01)

(For the shape)

Indicating 14 V at the maximum ....(01)

Indicating 13 V at the minimum ....(01)

(If a student indicate the difference of 1 V between the maximum and minimum, give both marks if either one of the maximum or minimum value is written)

(iv) If the capacitance is doubled the ripple voltage would be reduced to half. ....(01)

(*c*) (i) A Zener diode regulates/limits voltage by conducting <u>in reverse biased mode</u>. ....(01)

When the reverse voltage reaches the Zener breakdown voltage V_Z, (the diode starts to conduct heavily, but) the voltage across it <u>remains constant at Zener voltage V_Z</u>. ....(01)

(ii) No ....(01)

The minimum capacitor voltage is 13 V, so it never drops anywhere near 8 V *OR* 13 V is greater than 8 V *OR* capacitor voltage is greater than 8 V. Therefore Zener regulation remains effective. ....(01)

(iii) To ensure voltage never drops below 8 V, the maximum value allowed for the ripple voltage is = 14 – 8 ....(01)

(for the subtraction)

= 6 V

$$C_{min} = \frac{I_L}{f_r v_r}$$

$$= \frac{0.02}{100 \times 6}$$ ....(01)

(for substitution)

$= 33.3\ \mu F$ *OR* $33\ \mu F$ (3.3×10^{-5} F) ....(01)

(iv) To protect the Zener diode the maximum Zener current allowed is

$I_{Z,\max} = \frac{1.6}{8}$ ....(01)

$= 0.2$ A

$\therefore R_{S,\min} = \frac{(14-8)}{0.2}$ *OR* $\frac{(14-8)}{0.2+0.02}$

$= 30\ \Omega$ *OR* $27.3\ \Omega$ ....(01)

To keep Zener in regulation with the load, a current of $I_L + I_{Z,min}$ should pass through R_S. ....(01)

$\therefore R_{S,\max} = \frac{(14-8)}{0.02+0.005}$

$= 240\ \Omega$ ....(01)

Therefore, a value between 30 Ω and 240 Ω would work as the safety resistor

(*d*) (i) The ripple voltage will not change. ....(01)

But the peak value of the smoothed voltage goes down by 1.4 V *OR* it will be equal to 12.6 V. ....(01)

(ii) As the load resistance decreases, Zener current also decreases but the output voltage remains same at V_Z (until the Zener current reaches the minimum value below that, Zener action ceases) ....(01)

10. Answer either part (A) or part (B) only.

Part (A)

In heated buildings located in cold climates or air-conditioned buildings in hot climates, a significant amount of heat energy is transferred through glass windows, reducing the overall energy efficiency of the building. One common method of reducing heat transfer is the use of double-glazed windows instead of traditional single-glazed windows.

(*a*) (i) What are the methods of heat transfer?

(ii) What is the main method of heat transfer through a glass pane of a window?

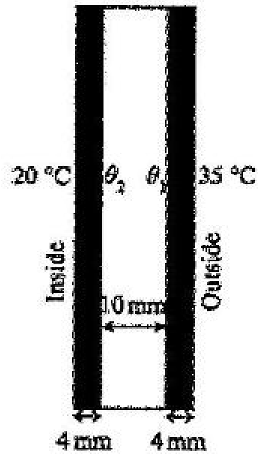
(*b*) An air-conditioned room has a window with a single glass pane of total area of $10\ m^2$. The frame of the window is fixed with an insulating rubber beading to avoid lateral heat loss. The outside temperature is 35 °C and the inside temperature of the room is 20 °C. The thickness of the glass pane is 8 mm and the thermal conductivity of glass is $0{\cdot}8\ W\ m^{-1}\ {}^{\circ}C^{-1}$.

(i) Write down the equation for rate of heat conduction through a medium and identify all the symbols.

(ii) Calculate the rate of heat transfer through the glass pane of the window at steady state condition.

(iii) What is the heat energy loss per day?

(*c*) Instead of the single glass pane mentioned in (*b*) above, a double-glazed window consisting of two glass panes each of thickness 4 mm with a sealed air gap of 10 mm in between the glass panes is used to improve energy efficiency. The inside temperature of the room is maintained at 20 °C while the outside temperature is 35 °C. Thermal conductivity of air is $0{\cdot}025\ W\ m^{-1}\ {}^{\circ}C^{-1}$.



(i) As shown in the figure, let θ_1 and θ_2 be the temperatures at the inner surface of the outer glass pane and outer surface of the inner glass pane respectively. Calculate the rate of heat transfer $\frac{Q}{t}$ through the double-glazed window at the steady state condition. Assume that there is no lateral heat loss. Give your answer to the nearest integer.

(ii) What are the temperature values of θ_1 and θ_2? Give your answers to the nearest first decimal place.

(*d*) (i) Assuming that the inside and outside temperatures remain constant throughout the day, calculate the energy saving per day in kW h when the double-glazed window is used. Give your answer to the nearest integer.

(ii) Calculate the cost saving for 30 days after replacing the single pane window with the double-glazed window if the average electricity unit (kW h) cost is rupees 30.

(*e*) (i) Modern double-glazed windows are coated with a low-emissivity transparent coating on one surface of a one glass pane. Which surface (inner/outer) of what pane (inner/outer) has to be coated like this in hot climates?

(ii) What is the purpose of applying the coating mentioned above?

(*a*) (i) conduction, convection, and radiation ....(02)

(All three correct – 02 marks; Any two correct – 01 mark)

(ii) conduction ....(01)

(*b*) (i) $\frac{Q}{t} = kA\frac{\Delta\theta}{\Delta l}$ ....(01)

A – cross-sectional area (of the object through which heat flow) ; k – thermal conductivity (of the material of the object); $\frac{\Delta\theta}{\Delta l}$ – temperature gradient [*OR* $\Delta\theta$ = temperature difference; Δl = distance between the points (where temperatures are measured)] ....(02)

(All correct 02 marks, any two correct 01 mark)

(ii) $\frac{Q}{t} = 0.8 \times 10\frac{(35-20)}{8\times10^{-3}}$ ....(02)

(for correct substitution)

Rate of heat transfer through the window = 15,000 W (15 kW) ....(02)

(iii) Heat loss for a day = $15000 \times 60 \times 60 \times 24$ ....(01)

(for multiplying by $60 \times 60 \times 24$)

$= 1.296 \times 10^9$ J (1.3×10^9 J) ....(01)

(*c*) (i) Applying heat conduction equation for the outer glass pane

$\frac{Q}{t} = 0.8 \times 10 \times \frac{(35-\theta_1)}{4\times10^{-3}}$ ....(02)

$0.0005\frac{Q}{t} = (35 - \theta_1)$.......(1)

Applying heat conduction equation for the air gap

$\frac{Q}{t} = 0.025 \times 10 \times \frac{(\theta_1-\theta_2)}{10\times10^{-3}}$ ....(02)

$0.04\frac{Q}{t} = (\theta_1 - \theta_2)$ ....(2)

Applying heat conduction equation for the inner glass pane

$\frac{Q}{t} = 0.8 \times 10 \times \frac{(\theta_2-20)}{4\times10^{-3}}$ ....(02)

$0.0005\frac{Q}{t} = (\theta_2 - 20)$ ....(3)

(1)+(2)+(3) $(0.041)\frac{Q}{t} = 15$

$\frac{Q}{t} = 366$ W ....(02)

(ii) From equation (1) $0.0005 \times 366 = (35 - \theta_1)$

$\theta_1 = 34.8\ °C$ ....(01)

From equation (2) $0.04 \times 366 = (34.8 - \theta_2)$ *OR* From equation (3) $\theta_2 = 20 + 0.18$

$\theta_2 = 20.2\ °C$ ....(01)

(*d*) (i) Power saving = 15000 – 366 ....(01)

(for the subtraction)

Energy saving per day = $\frac{14634 \times 24}{1000}$ ....(01)

(for substitution)

= 351 kW h ....(02)

(ii) Cost saving = $351 \times 30 \times 30$ ....(01)

(for multiplying by 30×30)

= Rs. 315,900 ....(01)

(*e*) (i) Coating should be applied to the inner surface of the outer pane. ....(01)

(ii) To reduce heat entering the building due to (IR) radiation. ....(01)

Part (B)

(*a*) (i) What is the value of surface emissivity of a perfect black body?

(ii) Assuming the sun as a perfect black body, find the surface temperature of the sun that emits radiation at a peak wavelength of $\lambda_{max} = 500$ nm. Take Wien's displacement constant as $3{\cdot}0 \times 10^{-3}$ m K.

(iii) Calculate the power radiated per unit area (I) of the sun. ($\sigma = 6 \times 10^{-8}$ W m^{-2} K^{-4} and take $6^4 = 1300$)

(iv) If the radius of the sun is R, write down an expression for the total power radiated (P) by the sun in terms of I and R.

(v) Assuming that the surface of the earth is at a distance d from the center of the sun, write down an expression for the radiative power received per unit area (S) at the earth's surface in terms of I, R and d.

(vi) If $d = 250R$, calculate the value of S.

(*b*) A solar sail is a spacecraft propulsion system. It uses the radiation pressure of sunlight to propel itself, similar to a sailboat using wind, without requiring fuel for that. Light photons bounce off a reflective, thin sail, transferring their momentum to the spacecraft and causing it to accelerate over time. The shape of a hexagonal solar sail is shown in the figure (1). The solar sail is made of a light material and the sun facing side is coated with a metallic material, typically aluminium.

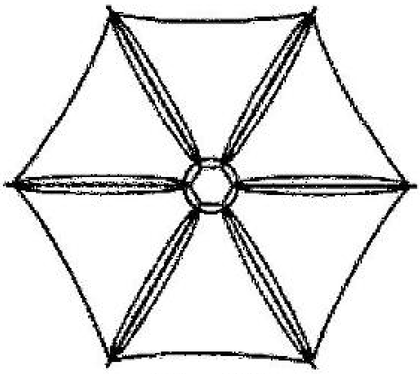


Figure (1)

(i) What do you mean by wave-particle duality?

(ii) What nature of the wave is used to explain the motion of the solar sail?

(iii) Derive an expression for the momentum (p) of a photon in terms of its energy (E) and speed of light (c) (Hint: use the relationship of energy of a photon to its wavelength and de Broglie equation).

(iv) NASA has designed a spacecraft with a solar sail of effective area $A = 500\ m^2$. The power received per unit area on the solar sail by the sun is $1200\ W\ m^{-2}$. Calculate the force exerted on the solar sail by the incident photons using the expression derived in (*b*)(iii) above. Assume that all photons have the same energy and the photons are incident perpendicular to the surface of the solar sail and recoil backwards without changing the magnitude of momentum upon incidence. (Speed of light $c = 3{\cdot}0 \times 10^8\ m\ s^{-1}$)

(v) If the total mass of the spacecraft mentioned in (*b*)(iv) above is 400 kg and starts at rest from the International Space Station how long (in days) will the spacecraft take to reach the Moon which is at a distance of $4{\cdot}05 \times 10^5$ km away from the station? Give your answer to the nearest integer. Assume that there are no other forces acting on the spacecraft and the force exerted on the solar sail is constant throughout the journey and it is equal to the value obtained in (*b*)(iv) above.

(vi) Why are sun facing side of solar sails coated with aluminium?

(vii) Figure (2) shows a cross-section of a solar sail fixed to a space craft. The direction of the incident photons is shown in the figure. Copy this diagram on to your answer sheet and draw the direction of the reflected photons and the direction of thrust on the sail exerted by photons.

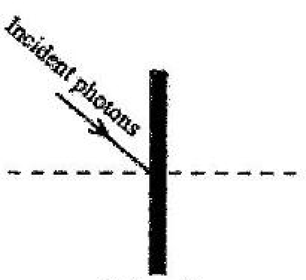


Figure (2)

(*a*) (i) Surface emissivity = 1 ....(01)

(ii) $T = \frac{3.0\times10^{-3}}{500\times10^{-9}}$ ....(01)

(for correct substitution)

$T = 6000$ K ....(01)

(iii) $I = \sigma T^4$ ....(01)

$I = 6 \times 10^{-8} \times (6000)^4$ ....(01)

(for substitution)

$I = 7.8 \times 10^7\ W\ m^{-2}$ ....(02)

(iv) $P = 4\pi R^2 I$ ....(01)

(v) $S = \frac{P}{4\pi d^2}$

$S = \frac{4\pi R^2}{4\pi d^2} I$ ....(01)

$= \left(\frac{R}{d}\right)^2 I$ ....(01)

(vi) $S = \left(\frac{1}{250}\right)^2 \times 7.8 \times 10^7$ ....(01)

(for substitution)

$S = 1248 \text{ W m}^{-2}$ ....(02)

(*b*) (i) Particles behave as waves and waves behave as particles (depending on the situation) *OR* Every particle or wave shows both wave-like and particle-like behaviour (depending on the way of observation) ....(02)

(ii) Particle nature ....(01)

(iii) Energy of a photon $E = hf = \frac{hc}{\lambda}$ (1) ....(01)

De Broglie equation $\lambda = \frac{h}{p}$ (2) ....(01)

From eq. (1) and eq. (2) $E = pc$

$p = \frac{E}{c}$ ....(01)

(iv) Change in momentum of photons = $2p$ ....(01)

Total energy incident on the solar sail = 1200×500 ....(01)

Force exerted on the solar sail by the incident photons = $\frac{2 \times 1200 \times 500}{3 \times 10^8}$

................(01)

(for substitution)

$= 0.004 \text{ N}$ ....(01)

(v) Acceleration of the spacecraft $= \frac{0.004}{400}$ ....(01)

(for substitution)

$= 0.00001 \text{ m s}^{-2}$

Applying $s = ut + \frac{1}{2}at^2$ for the spacecraft

$4.05 \times 10^8 = 0 + \frac{1}{2} \times 1 \times 10^{-5} \times t^2$ ....(01)

(for substitution)

$t = 9 \times 10^6$ s

Number of days $= \frac{9\times10^6}{24\times3600}$ ....(01)

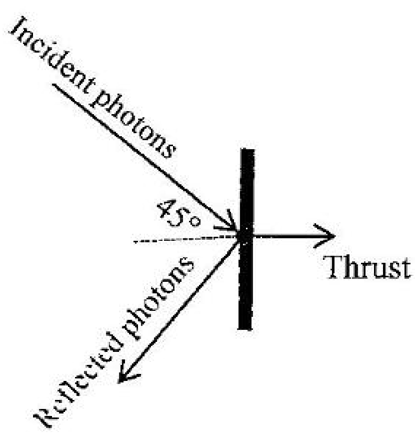
(for substitution)

$= 104$ days ....(01)

(vi) To achieve maximum reflection of the photons incident on the sail *OR* To minimise absorption of photons on the sail *OR* to achieve maximum force

................(01)

(vii)



Drawing the direction of reflected photons. ....(01)

Drawing the direction of thrust. ....(01)

(Drawing correct directions is sufficient)

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