Department of Examinations – Sri Lanka

# G.C.E. (A/L) Examination – 2021(2022)

# 01 – Physics

## Marking Scheme

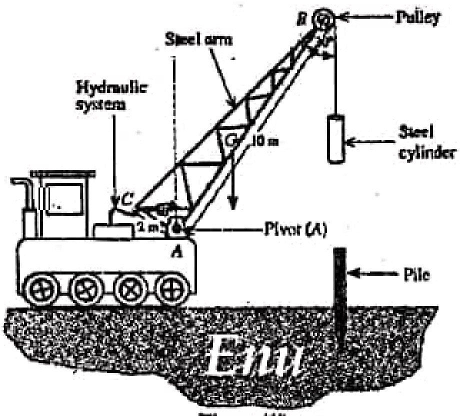



Figure (1)

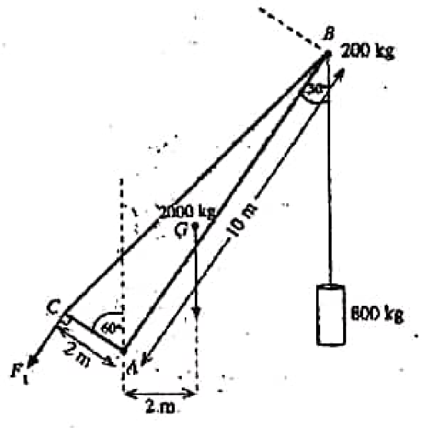
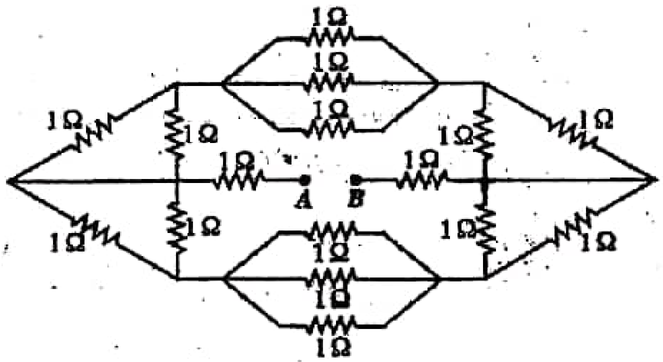



Figure (2)



# Distribution of Marks

01. Paper I – 1 × 50 = 50

02. Paper II

Part A – 20 Marks for each Question – 20 × 4 = 80

Part B – 30 Marks for each Question – 30 × 4 = $\frac{120}{200}$

Final Marks – Paper I = 50

– Paper II - $\frac{200}{4}$ = 50

Total Marks = $50+\left(\frac{200}{4}\right)$ = 100

## ශ්‍රී ලංකා විභාග දෙපාර්තමේන්තුව
## இலங்கைப் பரீட்சைத் திணைக்களம்
## අ.පො.ස (උ.පෙළ) /க.பொ.த. (உயர் தர)ப் பரீட்சை- 2021(2022)

විෂයය අංකය / பாட இலக்கம் : 01

විෂයය / பாடம் : PHYSICS



### ලකුණු දීමේ පටිපාටිය / புள்ளிவழங்கும் 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. | 2 | 11. | 4 | 21. | 3 | 31. | 3 | 41. | 4 |
| 02. | 1 | 12. | 3 | 22. | 2 | 32. | 1 | 42. | 4 |
| 03. | 4 | 13. | 1 | 23. | 1 | 33. | 1 | 43. | 1 |
| 04. | 5 | 14. | 5 | 24. | 2 | 34. | 4 | 44. | 3 |
| 05. | 4 | 15. | 3 | 25. | 2 | 35. | 3 | 45. | 2 |
| 06. | 4 | 16. | 2 | 26. | 5 | 36. | 5 | 46. | 4 |
| 07. | 4 | 17. | 1 | 27. | 2 | 37. | 1 | 47. | 2 |
| 08. | 3 | 18. | 5 | 28. | 3 | 38. | 3 | 48. | 3 |
| 09. | 2 | 19. | 5 | 29. | 1 | 39. | 2 | 49. | 5 |
| 10. | 1 | 20. | 1 | 30. | 2 | 40. | 3 | 50. | 5 |



✪ විශේෂ උපදෙස් / விசேட அறிவுறுத்தல் :

එක් පිළිතුරකට / ஒருசரியானவிடைக்கு ලකුණු 01 බැගින් / புள்ளிவீதம்

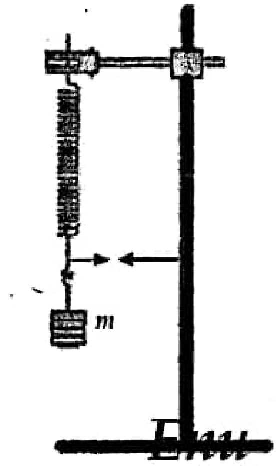
මුළු ලකුණු / மொத்தப் புள்ளிகள் 1× 50= 50

**PART A — Structured Essay**

*Answer all four questions on this paper itself.*

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

1. A mass ($m$) is suspended by a helical spring with a pointer attached at its lower end is shown in the figure. A student is asked to verify the relationship between the mass ($m$) with its periodic time ($T$) of vertical oscillations and to determine the spring constant ($k$) by using a graphical method.




(*a*) (i) Write down an expression for periodic time ($T$) of vertical oscillations of a mass ($m$) suspended by a massless spring of spring constant ($k$).

$T = 2\pi\sqrt{\frac{m}{k}}$ ..............................................(02)

(ii) Rearrange the expression written in (*a*) (i) above in order to verify the relationship between mass ($m$) and periodic time ($T$) by plotting a suitable straight line graph.

$T^2 = \left(\frac{4\pi^2}{k}\right)m$ ..............................................(01)

(*b*) (i) If the student is provided with a set of 50 g weights, what is the other essential measuring instrument that he needs to do this experiment?

(electronic/ digital) Stopwatch / Stop clock ........ ...............................(02)

(ii) It is advisable to use a locating pointer in this experiment. Draw an arrow head at the appropriate position of this pointer in the above figure.

(For drawing the locating pointer in correct position).............................(01)

[The arrow head should be reasonably close to the pointer at the same side, same level, arrow head should be clearly drawn pointing towards the pointer]

[No marks for drawing the arrow at any other position]

(iii) What is the purpose of using this locating pointer?

To accurately determine the beginning and end positions of oscillations *OR*

To determine the equilibrium position of oscillations accurately *OR*

To determine the number of oscillations accurately *OR*

To minimize the error in time measurement/to measure the time accurately

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

(c) (i) Why does the accuracy in determination of the spring constant ($k$) depends mainly on the accuracy in determination of the periodic time ($T$) of oscillation of the mass?

Small error/ uncertainty in (the measurement) $T$ would result a large error in $T^2$ *OR*

$T^2$ is used for plotting the graph ....................(01)

(ii) What is the characteristic property of the instrument mentioned in ($b$) (i) above which affect the fractional error of time measurement? (Let the value of this property be $x$.)



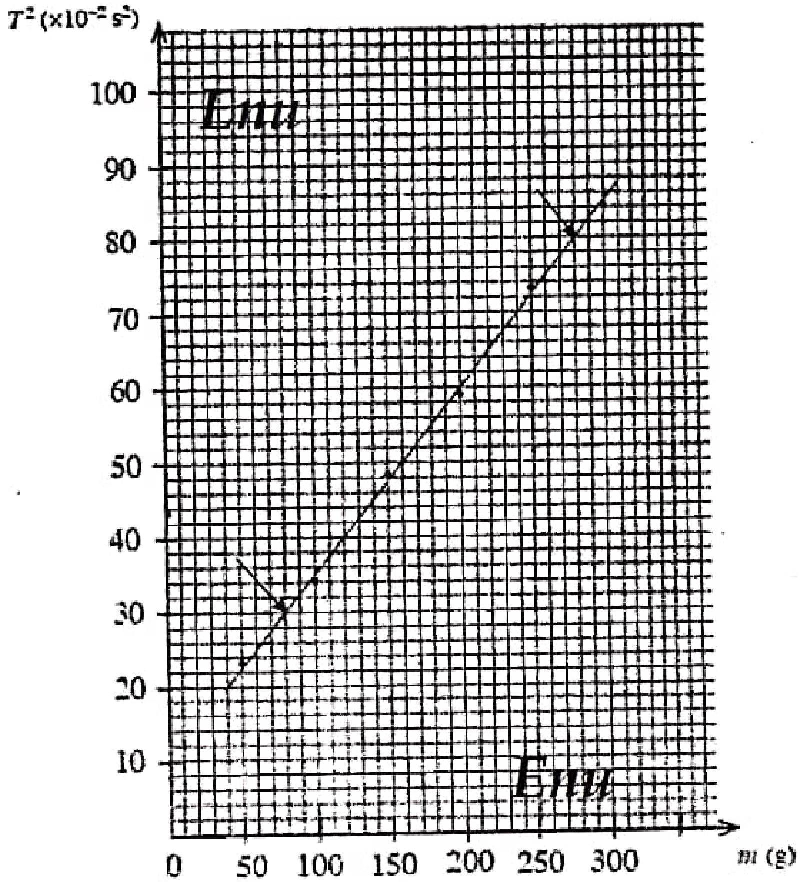
The least count of the stopwatch ....................(02)

(iii) Let the approximate time per oscillation be $t$. Write down an expression for the minimum number of oscillations ($n$) that should be taken in terms of $x$ and $t$ in order to obtain a percentage error of 1% in periodic time determination.

$\frac{1}{100} = \frac{x}{nt}$ .................... (01)

$n = \frac{100\,x}{t}$ .................... (01)

(*d*) The student obtained the following graph in order to calculate the spring constant ($k$) of the helical spring.




(i) Calculate the spring constant ($k$) of the helical spring in SI units using the above graph. (Take $\pi^2 = 10$)

Gradient ($m$) $= \frac{4\pi^2}{k}$ .........(01)

(Identify the gradient as $\frac{4\pi^2}{k}$)

Selecting points (80, 30) and (280, 80) .........(01)

(No marks for selecting any other points)

[If the student has selected any other points which lie on the line award the rest of the marks if the final answer is correct]

Gradient = $\frac{(80-30)\times10^{-2}}{(280-80)\times10^{-3}}$ (for substitution) .........(01)

$\frac{4\pi^2}{k} = \frac{50\times10^{-2}}{200\times10^{-3}}$ .........(01)

$k = \frac{4\times10\times200\times10^{-3}}{50\times10^{-2}}$

$k = 16\ \text{N m}^{-1}$ *OR* $16\ \text{kg s}^{-2}$ .........(02)

(or $160\ \text{N s}^{-2}$ or $160\ \text{kg m s}^{-4}$)

(01 mark for the correct value only)

(ii) Give the reason for obtaining a non zero intercept. (Mentioning that there are errors in data points is not an acceptable answer.)

Mass of the spring is not negligible *OR* due to mass of the spring .........(02)

2. You are asked to determine the relative humidity of air in the laboratory by measuring the dew point. You are provided a copper calorimeter with polished outer surface, a thermometer, water, a sufficient amount of small pieces of ice and a transparent glass plate. An incomplete experimental set up that can be arranged for this purpose is shown in figure (1).

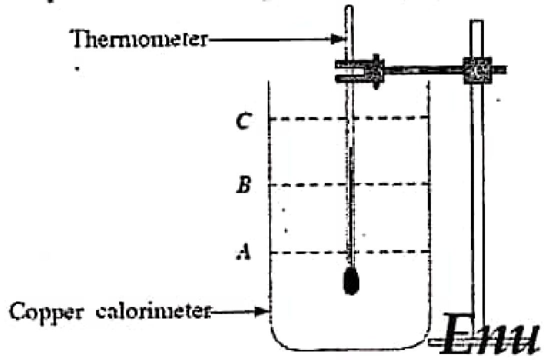



Figure (1)

(*a*) In order to perform this experiment you have to pour water into the calorimeter. Out of the three water levels *A*, *B* and *C* shown in figure (1) select the most appropriate level.

Appropriate level : *B* .......................................... **(01)**

(*b*) Three thermometers *P*, *Q* and *R* having temperature scale ranges –10 to 50 °C, –10 to 100 °C and –10 to 200 °C respectively are available in the laboratory. Select the most appropriate thermometer for this experiment.

Appropriate thermometer : *P OR* thermometer with the −10 to 50 °C range .......**(02)**

Give the reason for your selection:

The least count of *P* is smallest *OR* least count of *P* is 0.2 °C *OR* temperatures can be measured more accurately *OR* fractional/percentage error of temperature measurement is smallest/lowest/minimum *OR* sensitivity of the thermometer is high

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

(*c*) What is the other important item necessary to perform this experiment which is not given?

Stirrer *OR* stirrer with a mesh ..........................**(01)**

(*d*) In order to determine the dew point you have to measure two temperatures. Write down the experimental steps that you would follow to measure the first temperature accurately with the observation that you notice.

Experimental steps:

Add one piece of ice at a time into water ..............................(01)

Stir well until it is completely dissolved ..............................(01)

Observation: Observe the beginning of disappearing of shining of the calorimeter surface *OR* observe beginning of deposition of dew on the calorimeter surface

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

[No marks for appearance of water droplets]

(*e*) In order to measure the second temperature accurately write down the experimental steps that you would follow with the observation that you notice.



Experimental steps:

Stop adding ice ..................................(01)

Continue stirring ..................................(01)

Observation: Observe the shine of the calorimeter surface begins to reappear

*OR* observe the beginning of disappearance of dew on the calorimeter surface

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

(*f*) Write down a disadvantage of using water at 0 °C instead of ice pieces to perform this experiment.

May need a large volume of water *OR* calorimeter will fill up/water will spill before reaching the dew point *OR* temperature drop of water in the calorimeter may be insufficient *OR* heat lost by water in the calorimeter may be insufficient

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

(*g*) (i) Give two errors that can occur if the transparent glass plate is not used in this experiment. (Assume that a face mask or/and a face shield is/are not used)

(1) Temperature near the calorimeter will be changed.

(2) The relative humidity near the calorimeter will be changed.

(3) Water vapour in exhale air striking the calorimeter surface will be condensed

[Any two above – 01 mark each] ..........................(02)

(ii) If three glass plates *L*, *M* and *N* with dimensions of 5 cm × 5 cm, 20 cm × 20 cm, and 80 cm × 80 cm respectively are available, what would be the best glass plate to be used in this experiment? Give reasons for not selecting the other two plates.

The best plate: *M* ....................(02)

Reasons for not selecting other two plates:

(1) (For not selecting *L*): It does not have sufficient size/area *OR* it does not prevent exhale air reaching the calorimeter surface *OR* it does not prevent deposition of water vapour in exhale air on the calorimeter surface ...................(01)

(2) (For not selecting *N*): It obstructs stirring *OR* difficult to perform stirring with it *OR* difficult to reach the calorimeter with it (to perform stirring) ................(01)

(*h*) In this experiment the average value of the dew point and laboratory temperature are found to be 26.0 °C and 30.0 °C respectively. Determine the relative humidity of air in the laboratory, using the graphs given in figure (2). In the graph *X*-axis gives the laboratory temperature and *Y*-axis gives the dew point. In the figure straight lines represent different relative humidity values of 100%, 90%, 80% etc.

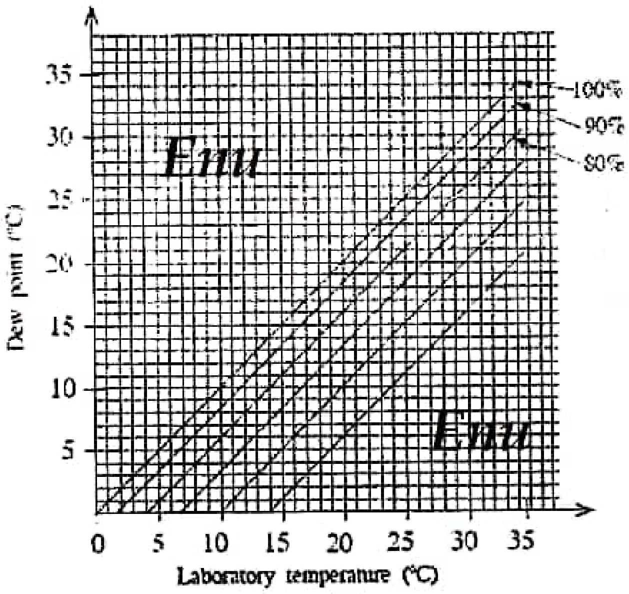



Figure (2)

Relative humidity: 80% .........................(02)

3. You are asked to determine the refractive index ($n_l$) of a transparent liquid using the apparent displacement of the image of an object. You are provided with a tall cylinder, sufficient amount of liquid, a travelling microscope, a small pin ($O$), fine plastic pieces which can float on the liquid and a large syringe.

(a) Write down an expression for the apparent displacement ($d$) produced by a transparent block made of material of refractive index ($n$) and thickness ($h$) placed in air when an object ($O$) is placed at the opposite side of the block as shown in the figure (1).

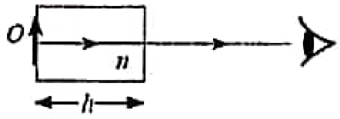


Figure (1)

$d = h\left(1 - \frac{1}{n}\right)$ .......................................... (02)

(b) As in figure (2) the small pin $O$ is placed at the bottom of the empty cylinder. The travelling microscope is focused from above to view a clear image of $O$ and the reading is taken (say $x$). Then the liquid is poured up to a certain height ($h$).

(i) What you should do to the travelling microscope to see a clear image of the pin again? Let the microscope reading be ($y$) in this situation.

Move the travelling microscope upward (until a clear image of $O$ is seen) ........ (02)

(ii) Write down the experimental steps that you follow to measure the height ($h$) of the liquid column. (Let the reading be $z$.)

Float few fine plastic pieces/powder on liquid ..........................(01)

and move the microscope (further) upward until a clear image of plastic pieces/powder are seen. (Take reading $z$) ..........................................................(01)

(No marks for stating that the travelling microscope has to be focused)

(iii) Write down expressions for height ($h$) of the liquid column and the apparent displacement ($d$) of the image using the readings $x$, $y$ and $z$.

$h = z - x$ ..........................................................................................(01)

$d = y - x$ ..........................................................................................(01)

[Award full marks if $h = x - z$ and $d = x - y$ are written; But only 01 mark if answers are mixed]

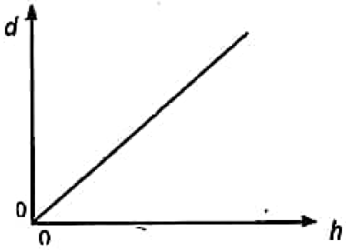
(c) (i) If the expression you have written in part (a) above is used to determine the refractive index of the liquid ($n_l$) using a graphical method what is the variable that you are going to change in it?

*h* (*OR* The height of the liquid) ..........(01)

(ii) What will be the dependent variable of the straight line graph that you going to draw?

*d* (*OR* Apparent displacement) ..........(01)

(iii) Clearly labelling the axes sketch the graph that you would expect.




.......... (02)

[02 mark for labelling *d* and *h* properly and straight line through (0, 0)/ appears as going through (0, 0)]

{Only 01 mark for labelling *d* and *h* properly and a line with positive gradient with an intercept. No marks for a line without labelling axes}

(d) Obtain an expression for the refractive index ($n_l$) in terms of the gradient ($m$) of the graph.

Gradient $m = \left(1 - \frac{1}{n_l}\right)$ ..........(01)

$\frac{1}{n_l} = 1 - m$

$n_l = \frac{1}{1-m}$ ..........(01)

(e) If the gradient $m = 0{\cdot}20$, calculate the value of refractive index ($n_l$) of the liquid.

$n_l = \frac{1}{1-0.2} \left(OR \frac{1}{0.8}\right)$ ..........(01)

$n_l = 1.25$ ..........(01)

(f) When the height of the liquid column is 5·0 cm, water is slowly poured so that the liquid floats on water. The total apparent displacement of the image of the pin is 1·5 cm and the refractive index of water is $\frac{4}{3}$. Calculate the height of the water column in the cylinder.

$d = d_l + d_w$ ................................................(01)

[For identifying total displacement is equal to the sum of two individual displacement]

$d_l = 5\left(1 - \frac{4}{5}\right) = 5 \times \frac{1}{5} = 1$ cm

$d_w = 1.5 - 1$ (for subtraction) ................................................(01)

$d_w = 0.5$

$0.5 = h_w\left(1 - \frac{3}{4}\right)$

$h_w = 2.0$ cm ................................................(02)

4. Figure (1) shows a part of an experimental set up to determine the resistivity ($\rho$) of material of a given wire with the aid of a metre bridge. The resistance value of the resistance box is $R$ and the resistance of the given wire is $S$. The length of the metre bridge wire $AB$ is 100 cm.

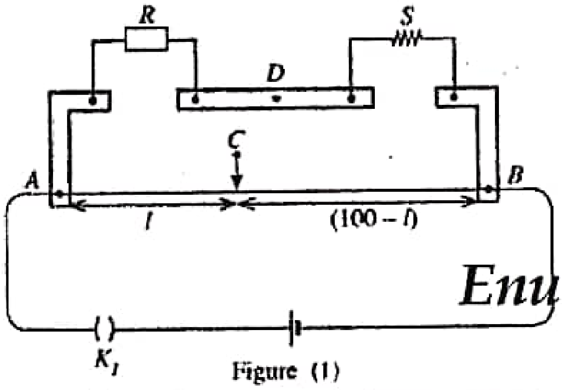



Figure (1)

(a) A centre-zero galvanometer has to be connected between points $C$ and $D$. To protect the centre-zero galvanometer the circuit in figure (2) can be used.

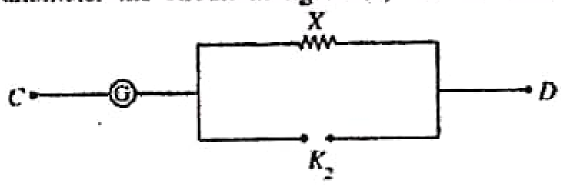



Figure (2)

(i) Name the type of key $K_2$ : ..........................................................................

Plug key ........ (01)

(ii) Select the suitable value for the resistance $X$ from resistances 1 Ω, 10 Ω, 100 Ω, and 1000 Ω.

The value of $X$ : ..........................................................................

1000 Ω ........ (01)

(b) Before taking measurements how do you check whether the circuit is connected properly?

Open $K_2$ (and close key $K_1$) ........ (01)

Touch the sliding key with both ends of the wire and check whether the deflections of the galvanometer are in opposite directions ........ (01)

(c) When the resistance value of resistance box is $R$, the balance length of the metre bridge wire is $l$ (in cm). Write down an expression for $\frac{R}{S}$ in terms of $l$. Neglect the end corrections of the metre bridge wire.

$\frac{R}{S} = \frac{l}{100-l}$ ........ (02)

(d) For $R = 9\,\Omega$, $26\,\Omega$ and $56\,\Omega$ the balance lengths are 27·0 cm, 52·0 cm and 70·0 cm respectively at 30 °C.

(i) What is the most appropriate value of resistance $R$ that must be used in order to determine the value of $S$ accurately? Give the reason.

Value : $26\,\Omega$ ........ (01)

Reason : Then balance point is in the middle of the wire which minimizes the fractional/percentage/end error of length measurements. ........ (01)



(ii) Calculate the most accurate value of $S$ using the relevant balance length and $R$.

$\frac{26}{S} = \frac{52}{100-52}$ ........ (01)

$S = 24\,\Omega$ ........ (01)

(e) The values of diameter measured in four different places in the given wire are 0·39 mm, 0·40 mm, 0·40 mm and 0·41 mm, and the length of the wire is 48·0 cm. Calculate the resistivity of the material of the wire. (Take $\pi = 3$.)

$S = \frac{\rho l}{A}$ OR $\rho = \frac{SA}{l}$ OR $\rho = \frac{S \times \pi \left(\frac{d}{2}\right)^2}{l}$ ........ (01)

Average of $d = (0.39 + 0.40 + 0.40 + 0.41)/4 = 0.40$ mm ........ (01)

$\rho = \frac{24 \times 3 \times \left(\frac{4.0 \times 10^{-4}}{2}\right)^2}{48 \times 10^{-2}}$ (for substitution) ........ (01)



$\rho = 6.0 \times 10^{-6}\,\Omega\,\text{m}$ [$(6.0 - 6.1) \times 10^{-6}\,\Omega\,\text{m}$] ........ (01)

NOTE:

[If $R = 9\,\Omega$, $\frac{9}{S} = \frac{27}{100-27}$, $S = 24.3\,\Omega$

$\rho = \frac{24.3 \times 3 \times \left(\frac{4.0\times10^{-4}}{2}\right)^2}{48\times10^{-2}} = 6.075 \times 10^{-6}\,\Omega\,\text{m}$

If $R = 56\,\Omega$, $\frac{56}{S} = \frac{70}{100-70}$, $S = 24.0\,\Omega$

$\rho = \frac{24.0 \times 3 \times \left(\frac{4.0\times10^{-4}}{2}\right)^2}{48\times10^{-2}} = 6.0 \times 10^{-6}\,\Omega\,\text{m}$ ]

(f) When the above wire is kept at constant temperature of 100 °C in an oil bath, for $R = 20\,\Omega$ in the resistance box the balance length is 40·0 cm. Calculate the temperature coefficient of resistance of the material of the wire.

$S_\theta = S_0(1 + \alpha\theta)$ ........ (01)

At the room temperature $24 = S_0(1 + \alpha \times 30)$

At 100 °C, $S = \frac{20.0\times60.0}{40.0} = 30\,\Omega$ ........ (01)

$30 = S_0(1 + \alpha \times 100)$

$\frac{24\times40.0}{20.0\times60.0} = \frac{1+30\alpha}{1+100\alpha}$ ........ (01)

$\alpha = 4.0 \times 10^{-3}\,°C^{-1}$ $[\alpha = (3.7 - 4.0) \times 10^{-3}\,°C^{-1}]$ ........ (01)

NOTE:

[At the room temperature $24.3 = S_0(1 + \alpha \times 30)$

At 100 °C, $S = \frac{20.0\times60.0}{40.0} = 30\,\Omega$

$30 = S_0(1 + \alpha \times 100)$

$\frac{24.3\times40.0}{20.0\times60.0} = \frac{1+30\alpha}{1+100\alpha}$

$\alpha = 3.7 \times 10^{-3}\,°C^{-1}$]

(g) For a certain type of material the temperature coefficient of resistance is negative around room temperature. Name the type of material.

Semiconductor material ........ (02)

5. A pile driver system is shown in figure (1). The steel arm of mass 2000 kg pivoted at point $A$ is shown in figure (2) with its dimensions. The centre of gravity of the arm is located at $G$. A pulley of mass 200 kg is attached at the upper end ($B$) of the arm and it can be rotated by an electric motor. A cable is wound around the pulley and its free end is connected to a steel cylinder of mass 800 kg. Neglect the mass of the cable. The lengths $AB$ and $AC$ are 10 m and 2 m respectively. The horizontal distance from point $A$ to the line of action of the weight of the steel arm is 2 m. The arm is operated using a hydraulic system.

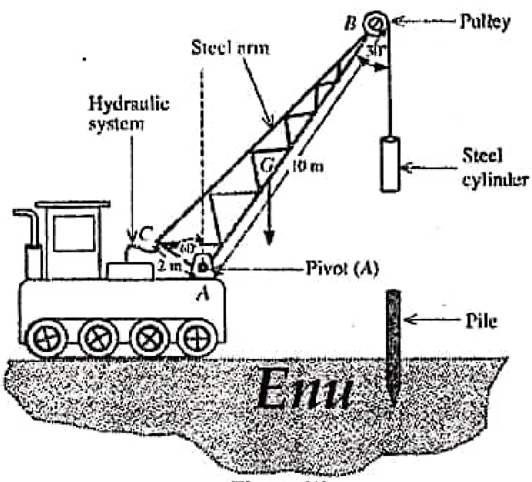



Figure (1)

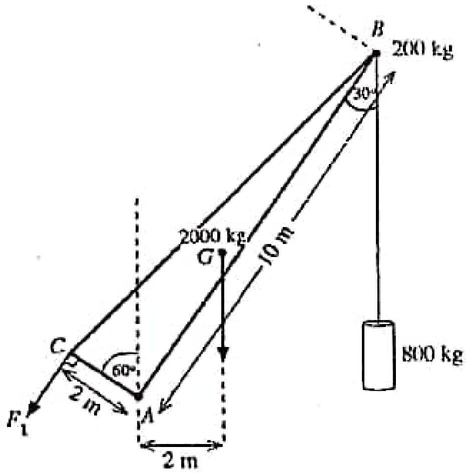



Figure (2)

(a) To keep the arm and its attachments at equilibrium position a force $F_1$ has to be applied at point $C$ using the hydraulic system as shown in figure (2). The direction of $F_1$ is perpendicular to the length $AC$. Calculate the value of this force $F_1$ by taking moments about point $A$. For this calculation neglect the size of the pulley.

(b) The force $F_1$ in (a) above is provided by compressed oil of a hydraulic pump as shown in figure (3). The cross-sectional area of the piston of the master pump is 4 cm$^2$ and the cross-sectional area of the piston at point $C$ is 60 cm$^2$. A force $F_2$ has to be applied to the piston of the master pump in order to obtain the force $F_1$.

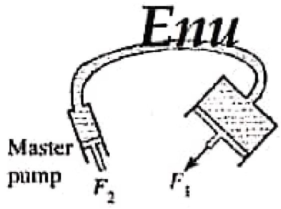



Figure (3)

(i) Name the principle that must be used to calculate force $F_2$.

(ii) Find the value of $F_2$.

(iii) What is the pressure of the compressed oil in the hydraulic pump?

(c) The radius of the pulley is 10 cm. The moment of inertia $I$ of a pulley of mass $M$ and radius $r$ about its axis of rotation can be given by $I = \frac{1}{2}Mr^2$. The cable moves without slipping.

(i) When the arm is at its maximum vertical position as shown in figure (2) the steel cylinder is moved upward at a constant linear acceleration of $0{\cdot}5\ \mathrm{m\,s^{-2}}$ by rotating the pulley. Calculate the torque that must be applied to the pulley by the motor in order to raise the cylinder.

(ii) When the cylinder has moved upward to a certain height the motor is switched off and the cylinder comes to a momentarily stop after some time. Next the cylinder attached to the cable is allowed to drop onto the pile while the pulley rotates freely. The centre of gravity of the cylinder drops from a height of $\frac{45}{8}$ m before the cylinder hits the pile. Calculate the velocity of the cylinder just before hitting the pile. For this calculation neglect frictional torques acting against rotation.

(iii) After the collision, the cylinder and the pile penetrate as a composite object into the soil without any recoil. What type of collision is this? How do you identify this type of collision in terms of loss of kinetic energy.

(iv) Calculate the velocity of the cylinder and the pile just after the collision. The mass of the pile is 480 kg.

(v) If the distance penetrated by the pile in one hit is 20 cm, calculate the average value of the resistance force produced by soil against penetration. [Take $(6{\cdot}25)^2 = 39$]

(a) Take moment about A:

(A) ; $F_1 \times 2 = 2 \times 2000 \times 10 + 10 \sin 30° \times (200 + 800) \times 10$ .................. (02)

[01 mark for identifying $10 \sin 30°$ $OR$ 5]

$F_1 = 45{,}000$ N ($OR$ 45 kN) ..............................................(02)

(b) (i) Pascal's principle. ..................................................................(01)

(ii) $\frac{F_1}{A_1} = \frac{F_2}{A_2}$ ..................................................................(01)

$\frac{45000}{60} = \frac{F_2}{4}$ (For substitution) ..............................(01)

$F_2 = 3{,}000$ N ..................................................................(01)

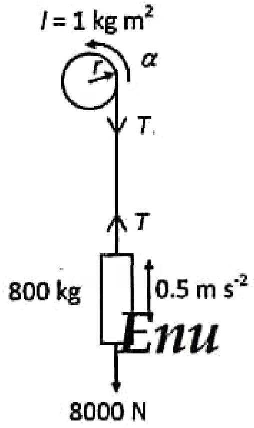
(iii) Pressure $P = \frac{F}{A}$

$F = 3000$ N and $A = 4 \times 10^{-4}\ \mathrm{m^2}$

$P = \frac{3000}{4\times10^{-4}}$ (For dividing by correct area) ...........................................(01)

$P = 7.5 \times 10^6$ Pa ( $\mathrm{N\,m^{-2}}$) ( 01 mark for value only) ..........................(02)

(c) (i) The moment of inertia of the pulley $I = \frac{1}{2} \times 200 \times 0.1^2 = 1 \text{ kg m}^2$ ................(01)




Apply $F = ma$ for the upward motion of the steel cylinder

$\uparrow$; $\quad T - 8000 = 0.5 \times 800$ ....................................(02)

$T = 8{,}400$ N

Apply $\tau = I\alpha$ for the rotational motion of the pulley

$\circlearrowleft$ B ; $\quad \tau - 8400 \times 0.1 = 1 \times \frac{0.5}{0.1}$ ....................................(02)

(01 mark for using $\alpha = \frac{a}{r}$ $\left(OR\ \frac{0.5}{0.1}\right)$ and 01 mark for the correct expression)

$\tau = 845$ N m (01 mark for value only) ..................................(02)

(ii) If the velocity of the steel cylinder is $v$ and the angular velocity of the pulley is $\omega$ then $v = r\omega$.

Using the law of conservation of mechanical energy after falling a height $h$,

$\frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 = mgh$ ..................................................................(02)

$\frac{1}{2} \times 800 \times v^2 + \frac{1}{2} \times 1 \times \frac{v^2}{(0.1)^2} = 800 \times 10 \times \frac{45}{8}$ ..........................................(01)

$450v^2 = 800 \times \frac{450}{8}$

$v^2 = 100$

$v = 10 \text{ m s}^{-1}$ ..........(02)

Alternative method:

Apply $F = ma$ for the downward motion of the steel cylinder

$\downarrow$; $8000 - T = 800a$ ---------- ① ..........(01)

Apply $\tau = I\alpha$ for the rotational motion of the pulley

(β) $T \times 0.1 = 1 \times \frac{a}{0.1}$ ..........(01)

$T = 100a$ ---------- ②

①+②; $8000 = 900a$

$a = \frac{80}{9} \text{ m s}^{-2}$ ..........(01)

$\downarrow; u = 0$, $\downarrow; a = \frac{80}{9} \text{ m s}^{-2}$ $\downarrow; s = \frac{45}{8} \text{ m}$

Apply $v^2 = u^2 + 2as$

$\downarrow; v^2 = 0 + 2 \times \frac{80}{9} \times \frac{45}{8}$

$v = 10 \text{ m s}^{-1}$ ..........(02)

(iii) Perfect inelastic collision. ..........(01)

The kinetic energy loss is maximum ..........(01)

(iv) If the velocity after the collision is $v_1$, apply the law of conservation of linear momentum for the collision;

$\downarrow$; $800 \times 10 = 1280 \times v_1$ (for substitution) ..........(01)

$v_1 = 6.25 \text{ m s}^{-1}$ ..........(01)

(v) Apply the law of conservation of energy for the combined system.

The initial kinetic energy is lost for work done against frictional force ($F$). The change in potential energy is very small and can be neglected.

$\frac{1}{2} \times 1280 \times (6.25)^2 = F \times 0.2$ ..........(01)

$F = 124{,}800 \text{ N} = 1.248 \times 10^5 \text{ N } (1.25 \times 10^5 \text{ N})$ ..........(02)

{If potential energy is considered, $\frac{1}{2} \times 1280 \times (6.25)^2 + 1280 \times 10 \times 0.2 = F \times 0.2$

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

$F = 1.376 \times 10^5 \text{ N } (1.38 \times 10^5 \text{ N})$ ..........(02)}

Alternative method:

Enu

$\downarrow; u = 6.25 \text{ m s}^{-1}$, $\downarrow; v = 0$, $\downarrow; s = 0.2 \text{ m}$

Apply $v^2 = u^2 + 2as$

$\downarrow; 0 = 6.25^2 + 2a \times 0.2$ ..........(01)

$a = -\frac{39}{0.4} \text{ m s}^{-2}$

Apply $F = ma$

$\downarrow;$ $F = -1280 \times \frac{39}{0.4}$

$F = 124{,}800 \text{ N} = 1.248 \times 10^5 \text{ N } (1.25 \times 10^5 \text{ N})$ ..........(02)

{If the weight of the combine object is considered, then

$12800 - F = 1280 \times a$

$F = 1.376 \times 10^5 \text{ N } (1.38 \times 10^5 \text{ N})$ ..........(02)}

Enu

6. Read the following passage and answer the questions.

The Doppler effect is the apparent change in the observed frequency of a wave when there is a relative motion between the source producing the waves and the observer. Here all the speeds must be measured relative to the medium in which waves propagate. Since air is assumed to be at rest relative to the earth, normally the relevant velocities are measured relative to the earth for sound waves. The change in frequency $\Delta f$ (= observed frequency − emitted frequency) as a result of the Doppler effect is known as the Doppler shift.

The Doppler effect occurs for electromagnetic waves too, such as light waves or micro waves. If the speeds of the observer and the source are very much less than the speed c of electromagnetic waves, the Doppler effect relationships derived for sound waves could be used for electromagnetic waves by substituting $c$ instead of the speed of sound.

The speeds of moving vehicles could be determined by measuring the relevant Doppler shift using electromagnetic waves. The instrument used for this purpose is known as a speed trap which consists of a radar transmitter and a radar receiver. From the transmitter microwaves are emitted in short pulses and aimed directly to a moving car as shown in figure (1).

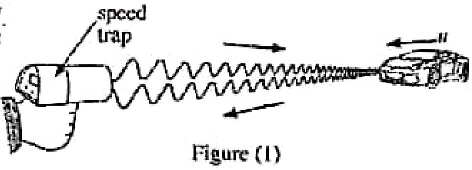



Figure (1)

The emitted microwaves reflect from the surface of speeding car and return to the receiver of the speed trap. By measuring the resulting Doppler shift, the speed at which the car moves is determined and recorded. In this type of applications, use of microwaves has an advantage over the other waves because they can penetrate fog, light rain and smoke.

(a) What is the Doppler effect?

(b) Normally the relevant velocities in Doppler effect are measured relative to the earth for sound waves. What is the reason for this?

(c) (i) The radar transmitter emits microwaves of frequency $f_0$. The car shown in the figure (1) approaches the speed trap at speed $u$. Write down an expression for the frequency $f'$ of microwaves received by the car in terms of $f_0$, $u$ and $c$ considering the transmitter of the speed trap as a stationary source and the car as a moving observer.

(ii) Now the car acts as a moving source emitting microwaves with frequency $f'$. Write down an expression for the frequency $f''$ of microwaves detected by the receiver of the speed trap in terms of $f'$, $u$ and $c$.

(iii) Combining expressions obtained in (c) (i) and (c) (ii) above, derive an expression for $f''$ in terms of $f_0$, $u$ and $c$.

(iv) Taking $u <<< c$, show that the Doppler shift $\Delta f$ observed by the speed trap is given by $\Delta f = f_0 \frac{2u}{c}$

(v) If $f_0 = 3{\cdot}0 \times 10^{10}$ Hz and $\Delta f = 7000$ Hz, calculate the speed $u$ of the car in km h$^{-1}$. (Take $c = 3{\cdot}0 \times 10^8$ m s$^{-1}$)

(d) Suppose a wind is blowing towards the speed trap from the car. Does this affect the speed measurement of the car? Give the reason for your answer.

(e) If the speed trap is not aimed directly to the car but rather at an angle to it, will the speed of the car measured be greater, equal or less than the value calculated in (c) (v) above? Give the reason for your answer.

(f) Now consider a police car with the speed trap moving at a speed $V$ is chasing behind the car moving with speed $u$ as shown in figure (2). In this situation the relationship obtained for $\Delta f$ in (c)(iv) above has to be modified as $\Delta f = f_0 \frac{2(V-u)}{c}$.

(i) Determine $\Delta f$ if $V = 100$ km h$^{-1}$. Use the value of $u$ obtained in (c) (v) above. (Give your answer to the nearest integer in Hz)

(ii) Explain why $\Delta f < 0$ in this case.

(iii) Which method is more accurate to determine the speed $u$ of the car by considering the Doppler shifts obtained in (c) and (f) above? Justify your answer.

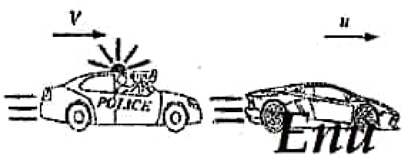



Figure (2)

(g) Write down an advantage of using microwaves in this type of applications.

($a$)The Doppler effect is the apparent change in the observed frequency/wavelength of a wave when there is relative motion between the source (producing the waves) and the observer.

.........................................(02)

($b$) The velocity of air is considered at rest relative to the earth/assumed to be zero *OR* assume that air is not blowing (moving) *OR* assume that air is still ..............................(01)



($c$) (i) $f' = f_0\left(\frac{c+u}{c}\right)$ ........................................ (02)

(ii) $f'' = f'\left(\frac{c}{c-u}\right)$ ........................................ (02)

(iii) $f'' = f_0\left(\frac{c+u}{c}\right)\left(\frac{c}{c-u}\right)$

$f'' = f_0\left(\frac{c+u}{c-u}\right)$ ........................................ (02)

(iv) $\Delta f = f'' - f_0$ ........................................ (01)

$\Delta f = f_0\left(\frac{c+u}{c-u}\right) - f_0$

$\Delta f = f_0\left[\left(\frac{c+u}{c-u}\right) - 1\right]$



$\Delta f = f_0\frac{2u}{c-u}$ .................................. (02)

$\Delta f = f_0\frac{2u}{c}$ since $u \ll c$

(v) $7000 = 3 \times 10^{10}\frac{2u}{3\times10^8}$ (for correct substitution) .................. (02)

$u = 35 \text{ m s}^{-1}$ ........................................ (01)

$u = 35 \times 3600 \times 10^{-3}$

$u = 126 \text{ km h}^{-1}$ .................................. (02)

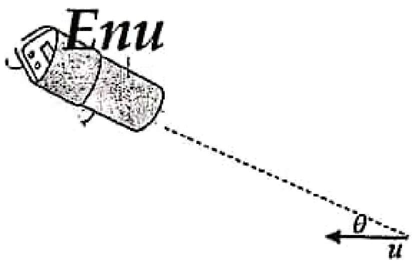
(*d*) No ................................... (01)

speed ($c$) of e.m. waves/micro waves do not depend on motion of wind

*OR* e.m. waves/micro waves do not need a medium to propagate ....................(02)

(*e*) It will be less ............................................................(01)

The measured speed towards the speed trap would be a component of the car's speed *OR* $u\cos\theta$, (where $\theta$ is the angle between the direction of the car and the line joining the speed trap) *OR* a diagram drawn as shown
............................................ (02)




(*f*) (i) $\Delta f = 3 \times 10^{10} \times \frac{2(100-126)}{3\times 10^{8}} \times \frac{10^{3}}{3600}$ (for correct substitution) ................(01)

$\Delta f = -1444$ Hz ................................... (02)

(Do not consider the negative sign)

(ii) The car is moving away relative to police car/speed trap *OR* the separation between the car and the police car/speed trap is increasing. (Therefore the observed frequency is less than $f_0$)

[Do not award marks for this part]

(iii) Method mentioned in ($c$) ............................................. (01)

Observed Doppler shift in ($c$) is large compared to the method in (*f*) ........... (01)

Therefore the speed of the car can be measured more accurately *OR* fractional/percentage error in the speed measurement is small ......................(01)

(*g*) Micro waves can penetrate fog *OR* light rain *OR* smoke. (for one advantage) ............ (01)

7. (*a*) (i) Write down an expression for the viscous force $F$ acting on a small sphere of radius $r$ moving at terminal velocity $v$ in a homogeneous fluid at rest having coefficient of viscosity $\eta$.

(ii) A small sphere of radius $r$ made of material of density $\beta$ is moving vertically downward at terminal velocity $v$ in a homogeneous fluid of density $\rho$ (where $\rho < \beta$) at rest and coefficient of viscosity $\eta$. Obtain an expression for the terminal velocity $v$ in terms of $\rho$, $\beta$, $r$, $\eta$ and $g$.

(*b*) A mixture of spherical sediment particles has to be separated depending whether their sizes are greater than or less than 2 μm using respective terminal velocities. The mixture is mixed and shaken well with small quantity of water and gently poured on to the surface of water in a beaker. After this the height of the water column in the beaker is 10 cm. The densities of material made of sediment particles and water are 1900 kg m$^{-3}$ and 1000 kg m$^{-3}$ respectively. The coefficient of viscosity of water is $1{\cdot}0 \times 10^{-3}$ Pa s. How long will it take to precipitate all particles having diameter greater than or equal to 2 μm? Assume that all particles reach their terminal velocities as soon as they are poured on to water surface.

(*c*) (i) A person without wearing a face mask or face shield releases tiny droplets of diameter 20 μm to the atmosphere at an initial horizontal velocity of 20 m s$^{-1}$ by coughing. If the density of droplets is 1080 kg m$^{-3}$ and the density of air is negligible, what is the vertical terminal velocity acquired by droplets? The coefficient of viscosity of air is $2{\cdot}0 \times 10^{-5}$ Pa s. Assume that air is still.

(ii) Sketch the velocity-time ($t$) graphs separately for

(I) the vertical component of the velocity ($v_V$) and

(II) the horizontal component of the velocity ($v_H$) of a droplet.

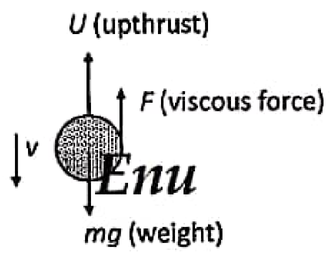
(iii) If the height to the mouth from the ground is 1·50 m, how long will the droplets suspend in still air? For this calculation assume that all droplets reach their terminal velocity as soon as they enter the atmosphere.

(iv) Practically the evaporation of exhaled droplets while they are in air has to be considered. Giving reasons, briefly explain what will happen to the horizontal displacement of the droplets as a result of evaporation during airborne time.

(v) Low atmospheric temperature or high relative humidity conditions can cause more droplets to settle on the ground. Justify this statement.

7. (*a*) (i) $F = 6\pi\eta r v$ ............................................................(02)

(ii)




Weight $(mg) = \frac{4}{3}\pi r^3 \beta g$ ............................................................(01)

Up thrust $(U) = \frac{4}{3}\pi r^3 \rho g$ ............................................................(01)

Viscous force $F = 6\pi\eta r v$

When moving at terminal velocity, there is no resultant force on the sphere

(*OR* identification of no acceleration and hence at equilibrium of forces)

*OR* $F + U = mg$ ............(01)

$6\pi\eta rv + \frac{4}{3}\pi r^3\rho g = \frac{4}{3}\pi r^3\beta g$ ............(02)

(The above 02 marks allocated for *mg* and *U* can be awarded here)

$6\pi\eta rv = \frac{4}{3}\pi r^3(\beta - \rho)g$

$v = \frac{2r^2g(\beta-\rho)}{9\eta}$ ............(02)



(Award 02 marks for (a)(ii) part if the expression is written without derivation)

(*b*) $r = 1\ \mu m = 1\times10^{-6}$ m, $\rho = 1000$ kg m$^{-3}$ $\beta = 1900$ kg m$^{-3}$ and $\eta = 1.0\times10^{-3}$ Pa s

Substitute in $v = \frac{2r^2g(\beta-\rho)}{9\eta}$

$v = \frac{2\times(1\times10^{-6})^2\times10\times(1900-1000)}{9\times1.0\times10^{-3}}$ (for substitution) ............(02)

$v = 2\times10^{-6}\ \text{m s}^{-1}$ ............(02)

Time $t = \frac{s}{v} = \frac{0.1}{2\times10^{-6}}$ s (for substitution of values) ............(01)

$t = 5\times10^4$ s ............(01)

(*c*)(i) $r = 10\ \mu m = 1\times10^{-5}$ m, $\beta = 1080$ kg m$^{-3}$ and $\eta = 2.0\times10^{-5}$ Pa s

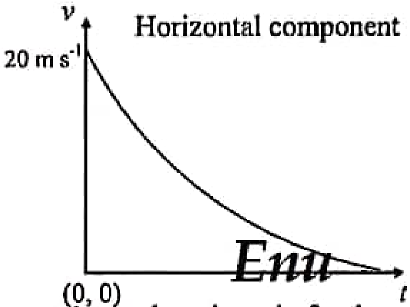


Substitute in $v = \frac{2r^2\beta g}{9\eta}$ (for identifying $\rho = 0$ in the equation) ............(01)

$v = \frac{2\times(1\times10^{-5})^2\times1080\times10}{9\times2.0\times10^{-5}}$ ............(02)

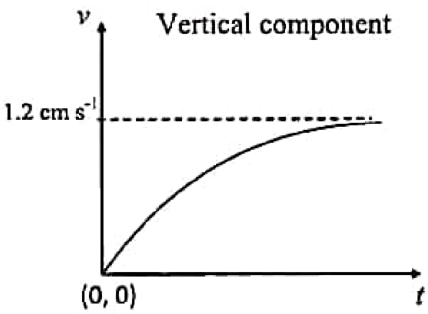
$v = 1.2\times10^{-2}\ \text{m s}^{-1}$ ............(02)

(ii)




(Award marks only for the correct shape and no terminal velocity) ........................(02)

(Do not look for the value of the velocity axis; do not consider the labeling the axis, curve does not need to touch the $t$ axis)




(A line reaching the terminal velocity) .....................(02)

(Do not look for the value of the velocity axis, do not consider the labeling the axis)

(iii) Time $t = \frac{s}{v} = \frac{1.50}{1.2\times10^{-2}}$ (for substitution of values) ......................(01)

$t = 125$ s ..................................(01)

(iv) As a result of evaporation, the radius (diameter/ size) of the droplets reduces and the terminal velocity will be reduced. ...............................(01)

Therefore, the droplets will stay a longer time in air and the horizontal distance will increase. ................................(01)

(v) Due to low atmospheric temperature or high relative humidity, the evaporation (of liquid from the surface) will be less. ..............................(01)

Therefore, the terminal velocity will not be reduced. (This cause faster settlement of droplets than in normal situation.) ............................(01)

8. (*a*) A proton of mass $m$ and charge $+q$ moving at speed $v$ enters perpendicularly to a uniform magnetic field of flux density $B$.

(i) Write down an expression for the magnitude of force $F$ acting on the proton due to the magnetic field.

(ii) Due to the above force the proton moves in a circular path. Derive an expression for radius $r$ of the path.

(iii) Obtain an expression for the time $T$ taken by the proton to complete one cycle in terms of $m$, $q$ and $B$.

(iv) Let $m = 1 \cdot 6 \times 10^{-27}$ kg, $q = 1 \cdot 6 \times 10^{-19}$ C, $v = 9 \cdot 6 \times 10^{5}$ m s$^{-1}$ and $B = 3 \cdot 0 \times 10^{-5}$ T. (Take $\pi = 3$).

(I) Determine the radius ($r$) of the circular path of the proton.

(II) What is the number of revolutions per second that the proton makes?

(*b*) Now an another proton enters with the same velocity $v$ at an angle $\theta$ with the direction of the magnetic field, as shown in figure (1).

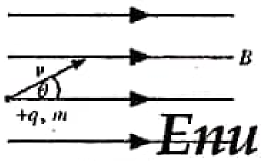


Figure (1)

(i) Name the shape of the path of the proton. Using the parallel and perpendicular components of the velocity of the proton with respect to the field explain how you arrived at the answer.

(ii) Using the values in (*a*) (iv) above calculate the time required for the proton to complete one periodic time $T$.

(iii) During this time $T$ the proton travels a distance $p$ parallel to the magnetic field. Write down an expression for the distance $p$ travelled by the proton during this time in terms of $v$, $\theta$ and $T$.

(iv) If $\theta = 30^{\circ}$ calculate the value of $p$? (Take $\sqrt{3} = 1 \cdot 7$)

(v) If the distance travelled by the proton along the direction of the magnetic field is 16320 km, what is the time taken to travel this distance?

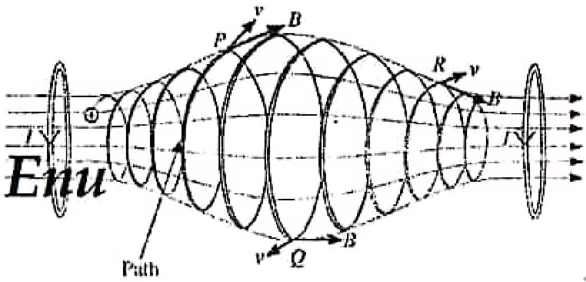


Figure (2)

(*c*) A non-uniform magnetic field can be formed using two current carrying coils as shown in figure (2). This type of magnetic field forms a "magnetic bottle" and it is an arrangement that permits to confine charged particles. The path of a positive charge particle is shown in the same figure.

(i) Explain why the radius of the path of the particle at position $P$ is smaller than that of at position $Q$.

(ii) Copy the relevant points with directions of $v$ and $B$ from figure (2) on to your answer sheet and draw the directions of the magnetic force experienced by the charge particle at each positions $P$, $Q$ and $R$ using arrows.

(iii) Giving reasons prove that the charge particle may oscillate back and forth between the two ends of the magnetic bottle.

(a) (i). $F = qvB$ ........ (02)

(ii). To move the charge particle in a circular path $F = qvB$ acts as a centripetal force towards the center

When moving in a circular path the magnitude of centripetal force is equal to that of the centrifugal force

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

$r = \frac{mv}{Bq}$ ........ (01)

(iii). Time taken to complete one circle $T = \frac{2\pi r}{v}$ ........ (01)

$T = \frac{2\pi m}{Bq}$ (01)



(iv).(I). $r = \frac{mv}{Bq}$

$r = \frac{1.6 \times 10^{-27} \times 9.6\times 10^{5}}{3.0\times 10^{-5}\times 1.6\times 10^{-19}}$ ........ (01)

$r = 3.2 \times 10^{2}$ m ........ (01)

(II). $T = \frac{2\pi m}{Bq}$

Number of revolution per unit time $f = \frac{1}{T} = \frac{Bq}{2\pi m}$



$f = \frac{3.0\times 10^{-5} \times 1.6\times 10^{-19}}{2\times 3\times 1.6 \times 10^{-27}}$ ........ (01)

$f = 500$ Hz (500 rps) ........ (01)

(b) (i).

Velocity component parallel to the direction of the magnetic field is $v\cos\theta$

Due to the magnetic field there is no effect on the parallel velocity component, therefore it pushes the charge particle to travel along the field direction ........ (01)

Velocity component perpendicular to the direction of the magnetic field is $v\sin\theta$

Velocity component/ $v\sin\theta$ is perpendicular to the magnetic field. Therefore due to $v\sin\theta$ particle moves in a circular path

........ (01)

The resultant of above two paths gives a helical path. ........ (02)

(ii). $T = \frac{2\pi m}{Bq}$

$T = \frac{2\times 3 \times 1.6\times 10^{-27}}{3\times 10^{-5}\times 1.6\times 10^{-19}}$ ........ (01)

$T = 2\times 10^{-3}$ s ........ (01)

(iii). $p$ = velocity × period of the motion

$p = Tv\cos\theta$ Enu02)

(iv). $p = 9.6\text{x}10^5 \times 2\times 10^{-3}\times \cos 30°$ ........ (01)

$p = 9.6\text{x}10^5\times 10^{-3}\times 1.7$

$p = 1632$ m ........ (01)

(v). $16320\times 10^3 = 9.6\times 10^5\times \cos 30°\times t$ ........ (01)

$OR\ t = \frac{16320\times 10^3}{1632}\times 2\times 10^{-3}$

Time taken $t = 20$ s ........ (01)

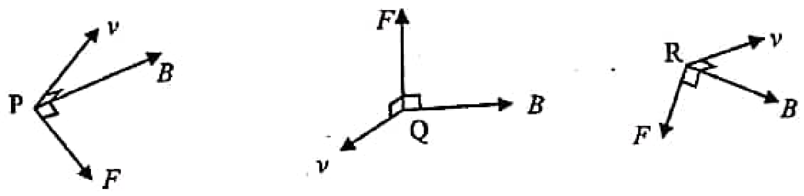
(c). (i) Since the magnetic force is perpendicular to the velocity there is no work done *OR*, kinetic energy is constant *OR* $\frac{1}{2}mv^2$ = constant *OR* speed is a constant ...... (01)

$\frac{B^2q^2r^2}{2m}$ = constant ($OR\ r = \frac{mv}{Bq}$)

$r \propto \frac{1}{B}$ ...... (01)

*B* is stronger/higher at *P* and weaker/less at *Q* ...... (01)

Therefore, at position *P* radius is smaller than that of at position *Q*




Only the correct direction of $F$ is accepatble ........ (03)

[01 mark for each correct diagram]

(iii). The components of the force $F$ at $P$ and $R$ along the direction of the axis of the bottle vary with position and always directed towards the center plane of the bottle. (Therefore, charge particle oscillates back and forth between the two ends of the magnetic bottle)

........ (02)

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

**Part (A)**

(*a*) A conducting metal wire of length $l$ and area of cross-section $A$ has $n$ number of free electrons per unit volume. Electron charge is $e$.

(i) Write down an expression for the total number of free electrons available in the wire.

(ii) When a potential difference is applied across the ends of the wire a current $I$ flows through the wire. Derive an expression for the drift velocity ($v$) of electrons in the wire in terms of $I$, $n$, $e$ and $A$.

(*b*) An electrician uses two metallic wires $X$ and $Y$ made of same material having the same length ($l$) but different cross-sectional areas $A_1$ and $A_2$. They are connected in series and then in parallel to the same constant voltage source separately.

(i) Write an expression for the ratio of respective drift velocities of electrons $\left(\frac{v_X}{v_Y}\right)$ moving in the wires $X$ and $Y$ when they are connected in series.

(ii) Write an expression for the ratio of respective drift velocities of electrons $\left(\frac{v_X}{v_Y}\right)$ moving in the wires $X$ and $Y$ when they are connected in parallel.

(iii) Plot two graphs separately to show the variation of respective drift velocities ($v_X$ and $v_Y$) along the length ($l$) of above series and parallel wire combinations. (Take $A_1 > A_2$)

(*c*) (i) A copper wire has a cross-sectional area of $2{\cdot}5 \times 10^{-7}\ m^2$. Calculate the drift velocity of electrons through the wire when the current is 4·0 A.
($e = 1{\cdot}6 \times 10^{-19}$ C; Number of free electrons per unit volume in copper $= 8{\cdot}0 \times 10^{28}\ m^{-3}$)

(ii) In a conductor, free electrons have random motion and the random speed (mean thermal speed) at a given temperature can be calculated considering the mean kinetic energy and mean thermal energy of free electrons at that temperature. The mean thermal energy of free electron at temperature $T$ is given by $\frac{3}{2}kT$ where $k$ is the Boltzmann constant. Calculate the mean thermal speed of free electrons in copper at temperature of 27 °C.
(Take mass of electron $= 9{\cdot}0 \times 10^{-31}$ kg, Boltzmann constant $= 1{\cdot}4 \times 10^{-23}\ J\ K^{-1}$)
(Take $\sqrt{1{\cdot}4} = 1{\cdot}18$)

(iii) The mean thermal speed of free electrons in a conductor is typically very large compared to the drift velocity. But why do the free electrons with their mean thermal speed in a conductor can not cause any current flow without applying an external electric field?

(*d*) The mobility ($\mu$) of charge carriers in a conductor is defined as the magnitude of the drift velocity per unit external electric field intensity that is being applied.

(i) Calculate the mobility of electrons in the copper wire mentioned in (*c*) (i) above if an electric field of intensity 50 V m$^{-1}$ is applied along the wire.

(ii) In the development of organic light emitting diodes (OLED) mobilities of charge carriers of organic materials are increased to lower the applied electric field and there by achieving a higher efficiency. What is the percentage reduction of applied electric field intensity if the mobility and drift velocity of charge carriers of an organic material are increased by 20% and 10% respectively?

(a) (i). Total free electrons in the wire = $n\,l\,A$ .........(01)

(ii).

Total charge flowing in the metallic conductor during a time $t = n\,e\,l\,A$ .........(01)

$I = \frac{n\,e\,l\,A}{t} = n\,e\,A\,v$ ..........(01)

$v = \frac{I}{neA}$ .........(01)

(b) (i). Series

$I_1 = I_2$ .........(01)

(For identifying that same current flows through both wires)

$n\,e\,A_1\,v_x = n\;e\,A_2\,v_y$ .........(01)

$\frac{Vx}{Vy} = \frac{A_2}{A_1}$ .........(01)



(ii). Parallel

$V_1 = V_2$ .........(01)

(For identifying that same voltage appear across both wires)

$I_1R_1 = I_2R_2$ .........(01)

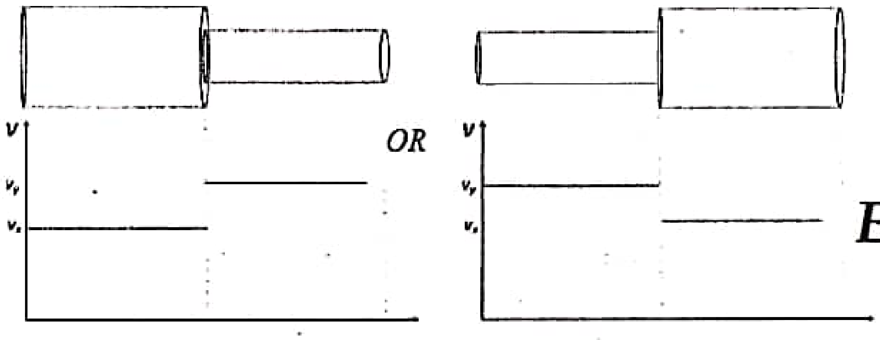


$n\,A_1\,v_x\,\rho\,\frac{l}{A_1} = n\,A_2\,v_y\,\rho\,\frac{l}{A_2}$

$\frac{Vx}{Vy} = 1$ .........(01)

[If a student argues that the electric field acting along both wires is the same and therefore the corresponding drift velocities are the same award all 03 marks]

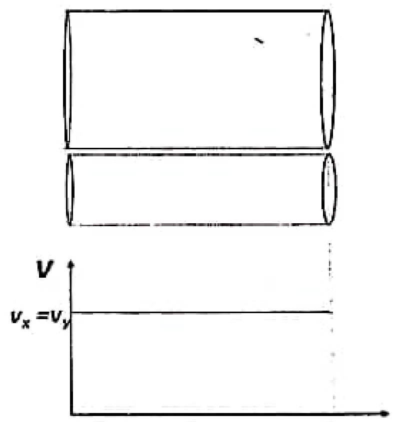
(iii) **Series**




.........(02)

[for identifying $v_y > v_x$ – 01 mark]

**Parallel**




.............................(02)

(c) (i)

$v = \frac{4}{8\times10^{28}\times1.6\times10^{-19}\times2.5\times10^{-7}}$ .........(01)

$v = \frac{1}{8\times10^{2}}$

$v = 1.25\times10^{-3}\ \text{m s}^{-1}$ .........(02)

(ii).

Kinetic Energy $= \frac{1}{2}\times 9\times 10^{-31}\times v^2$ .........(01)

Thermal Energy $= \frac{3}{2}\times 1.5\times 10^{-23}\times 300$ .........(01)

$\frac{1}{2} \times 9 \times 10^{-31} \times v^2 = \frac{3}{2} \times 1.4 \times 10^{-23} \times 300$ .........(01)

(for equating L.H.S. with R.H.S)

$v^2 = 1.4 \times 10^{10}$

$v = 1.18 \times 10^5$ m s$^{-1}$ .........(01)

(iii).

The average thermal velocity of free electrons is zero *OR* Free electrons are moving in all (random) directions *OR* Net velocity of free electrons is zero ...(02)

(d) (i).

$\mu = \frac{v}{E}$ .........(01)

$\mu = \frac{1.25\times10^{-3}}{50}$ .........(01)

$\mu = 2.5 \times 10^{-5}$ m$^2$ V$^{-1}$ s$^{-1}$ (02 marks for the correct value) .........(02)

(ii).

$\mu \rightarrow 120\ \%$ and $v \rightarrow 110\%$

New $E = \frac{v}{\mu} = \frac{110}{120}$ .........(01)

New $E$ as a percentage $= \frac{11}{12} \times 100 = 91.6\ \%$

Percentage reduction $= (1 - \frac{11}{12}) \times 100$ (for taking the difference) .........(01)

$= 8.3\ \%$ [ 8 - 9 %] .........(01)

**Part (B)**

Figure (1) shows the current ($I$) – voltage ($V$) characteristic curve for a diode.

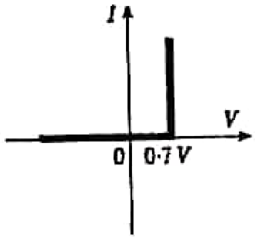



Figure (1)

(*a*) Name the diode which is represented by figure (1).

(*b*) Figures (2) and (3) show silicon diodes and two resistors with resistances $R_1$ and $R_2$. $A$ and $B$ inputs can be 0 V or 5 V. For all the calculations use the characteristic curve given in figure (1).

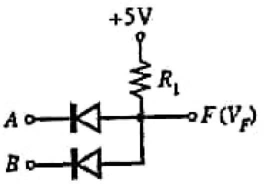



Figure (2)

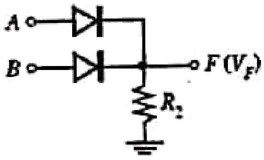



Figure (3)

(i) For different combinations of input voltages given below, determine the output voltages $V_F$ at $F$ and complete the following table for the circuits given in figure (2) and figure (3) respectively. (For this purpose copy the table twice on to your answer sheet)

| $A$(V) | $B$(V) | $V_F$(V) |
|---|---|---|
| 0 | 0 | |
| 0 | 5 | |
| 5 | 0 | |
| 5 | 5 | |

(ii) When considering the output $F$ only, if 5 V (or close to 5 V) represents binary 1 and 0 V (or close to 0 V) represents binary 0, name the respective gates corresponding to the circuits shown in figure (2) and (3) above and write down their truth tables.

(iii) Calculate the suitable values of $R_1$ and $R_2$ which limits 0·5 mA of total current flowing through both diodes in each circuit.

(c) A student wants to build a logic circuit that will ring an alarm at an office with one door and one window if the door or window or both are opened after office hours. The related logical variables are as follows.

Inputs: Time: $T = 0$ (during office hours), $T = 1$ (after office hours).

Door: $D = 0$ (door is closed), $D = 1$ (door is opened).

Window: $W = 0$ (window is closed), $W = 1$ (window is opened).

Outputs: $F = 0$ (alarm not ringing), $F = 1$ (alarm ringing)

(i) Using logical variables $T$, $D$, $W$ and $F$ mentioned above, write down a truth table that will satisfy the required conditions.

(ii) Obtain the corresponding logical expression for $F$.

(iii) Simplify the logical expression that you have written in (c) (ii) above. (You may use the identities $W+\overline{W} = 1$ and $\overline{D}W+D=D+W$).

(iv) Draw the simplest logical circuit that can be used for this purpose.

(*a*) (Hypothesized) silicon diode/(practical model of a) silicon diode ....................(02)

(*b*) (i)

| $A$(V) | $B$(V) | $V_F$(V) |
|---|---|---|
| 0 | 0 | 0.7 V |
| 0 | 5 | 0.7 V |
| 5 | 0 | 0.7 V |
| 5 | 5 | 5 V |

...................... (02)

[For any three entries correct – 01 mark]

| $A$(V) | $B$(V) | $V_F$(V) |
|---|---|---|
| 0 | 0 | 0 V |
| 0 | 5 | 4.3 V |
| 5 | 0 | 4.3 V |
| 5 | 5 | 4.3 V |

.............................. (02)

[For any three entries correct – 01 mark]

(ii) Fig. (2) AND gate .............................. (02)

Fig. (3) OR gate .............................. (02)

| $A$ | $B$ | $F$ |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

.............................. (02)

| A | B | F |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |



............................ (02)

(iii)

$$R_1 = \frac{(5 - 0.7)\ (or\ 4.3)}{0.5 \times 10^{-3}}$$ .................................... (01)

$R_1 = 8.6\ \text{k}\Omega$ *OR* $8.6 \times 10^3\ \Omega$ .................................. (01)

$$R_2 = \frac{(4.3 - 0)(or\ 4.3)}{0.5 \times 10^{-3}}$$ ................................ (01)

$R_2 = 8.6\ \text{k}\Omega$ *OR* $8.6 \times 10^3\ \Omega$ ................................ (01)

(c) (i)

| T | D | W | F |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 0 |
| 0 | 1 | 0 | 0 |
| 0 | 1 | 1 | 0 |
| 1 | 0 | 0 | 0 |
| 1 | 0 | 1 | 1 |
| 1 | 1 | 0 | 1 |
| 1 | 1 | 1 | 1 |



*OR*

| T | D | W | F |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 1 | 0 | 1 | 1 |
| 1 | 1 | 0 | 1 |
| 1 | 1 | 1 | 1 |

......................... (04)

[ 01 mark for each correct row with $T = 1$ ]

(ii)

$F = T\bar{D}W + TD\bar{W} + TDW$ ................................ (03)

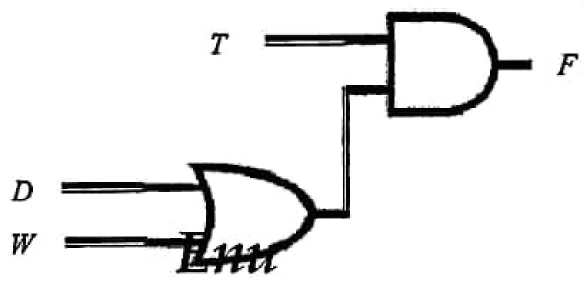
[01 mark for each correct term]

(iii) $F = T\bar{D}W + TD(\bar{W} + W)$

$F = T\bar{D}W + TD = T(\bar{D}W + D)$

$F = T(D + W)$ ................................ (02)

(iv)




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

[No marks for any other circuit]

10A

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

**Part (A)**

When exercising, human body produces energy and a high percentage of this energy is converted into heat. If this heat is not removed the body temperature will rise. In order to maintain the normal body temperature, heat is dissipated by evaporating the water in sweat. The heat of evaporation of water is provided by the body.

(*a*) When a person of mass 75 kg is riding an exercise bike the rate of energy produced is 800 W. Out of this energy 75 % is converted into heat. Neglect the loss of heat due to respiration process.

(i) What is the amount of heat produced by this person during 30 minutes of cycling?

(ii) In order to release this heat, what is the mass of water that should be evaporated? The specific heat of evaporation of water at body temperature is $2{\cdot}4 \times 10^6\ \mathrm{J\,kg^{-1}}$. (Equation $Q = mL$ can be used for this.)

(iii) What is the volume of water in millilitres which corresponds to the mass calculated in (*a*) (ii) above? The density of water is $1{\cdot}0 \times 10^3\ \mathrm{kg\,m^{-3}}$.

(iv) Calculate the temperature rise of the body during the 30 minutes period if this amount of heat is not released from his body. Average specific heat capacity of the body is $3600\ \mathrm{J\,kg^{-1}\,K^{-1}}$.

(*b*) The above person inhales a volume of $4{\cdot}5 \times 10^{-4}\ \mathrm{m^3}$ of air at atmospheric pressure and at 27 °C in each breath. The respiration rate of the person is 20 breaths per minute. At the lungs, inhaled air is heated up to 37 °C.

(i) Determine the final volume of air inhaled inside the lungs after a breath. Assume that the pressure of inhaled air inside the lungs is equal to the atmospheric pressure.

(ii) Calculate the rate of work done by the lungs in order to remove all the air inhaled while exhalation. (Atmospheric pressure = $1{\cdot}0 \times 10^5$ Pa)

(*c*) A closed gymnasium has several exercise bikes. When people are not exercising in the gymnasium, temperature of the gymnasium is 30 °C and the relative humidity is 75 %. Saturated vapour pressure of water at 30 °C is 32 mm Hg.

(i) Write down an expression for relative humidity in terms of water vapour pressures.

(ii) Determine the water vapour pressure existing in the gymnasium.

(iii) What is the mass of water vapour present in the gymnasium? At 30 °C absolute humidity of saturated water vapour is $30\ \mathrm{g\,m^{-3}}$. The volume of the gymnasium is $600\ \mathrm{m^3}$.

(iv) Suppose **four** people are riding exercise bikes in the gymnasium. Assume that the temperature of gymnasium does not change and the mass of water vapour released by each person during 30 minutes is equal which is same as the value obtained in (*a*) (ii) above. What is the new relative humidity in the gymnasium after 30 minutes?

(v) Once the riding of bikes is over the gymnasium is cooled to 20 °C and some of the water vapour is removed by an air-conditioner. The mass of water vapour removed by the air-conditioner is 6300 g. What is the final relative humidity of the gymnasium at 20 °C? Absolute humidity of saturated water vapour at 20 °C is $20\ \mathrm{g\,m^{-3}}$.

(*a*). (i).

Amount of energy produced in 1 s = 800 J

Amount of heat produced in 1 s = $800 \times \frac{75}{100}$ ........ (01)

Amount of heat produced in 30 min = $800 \times \frac{75}{100} \times 1800$

$= 1.08 \times 10^6$ J ........ (01)

(ii). Heat $Q = mL$

$1.08 \times 10^6 = m \times 2.4 \times 10^6$ ........ (01)

Enu $m = 0.45$ kg ........ (01)

(iii). Volume of 1 kg = 1000 ml

Volume of 0.45 kg = 0.45 × 1000 ml ........ (01)

Volume of water = 450 ml ........ (01)

(iv). $Mc\Delta\theta = mL$

$75 \times 3600 \times \Delta\theta = 1.08 \times 10^6$ ........ (01)

Enu

Temperature rise of the body during the 30 minutes period $\Delta\theta = 4.0$ °C ........ (01)

(*b*).(i). $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

$\frac{4.5\text{x}10^{-4}}{300} = \frac{V_2}{310}$ ........ (01)

Final volume of air inhaled inside the lungs after a breath = $4.65 \times 10^{-4}$ m$^3$ ........ (01)

(ii). $W = P\Delta V$ ........ (01)

work done by lungs = $1.0\text{x}10^5 \times 4.65 \times 10^{-4}$ ........ (01)

Rate of work done by the lungs = $\frac{46.5\text{x}20}{60}$ (award this mark for x $\frac{20}{60}$) ........ (01)

Rate of work done by the lungs = 15.5 W ........ (01)

(c).(i).

$$\text{Relative humidity} = \frac{\text{Water vapour presure at a temperature}}{\text{Saturated vapour presure at the same temperature}} \times 100$$

*OR*

$$\text{Relative humidity} = \frac{\text{Saturated water vapour presure at dew point}}{\text{Saturated water vapour presure at the room temperature}} \times 100$$

........ (02)

(ii).

$$\textit{Relative humidity} = \frac{\text{water vapour presure at a temperature}}{\text{Saturated vapour presure at the same temperature}} \times 100$$

$$75 = \frac{\textit{vapour presure}}{32}$$ ........ (01)

Vapour pressure in the room is = 24 mm Hg ........ (01)

(iii). $$\textit{Relative humidity} = \frac{\text{Absolute humidity of air inside the gymnasium}}{\text{Aabsolute humidity of saturated water vapour}} \times 100$$ ........ (01)

$$\frac{75}{100} = \frac{\text{absolute humidity of air inside the gymnasium}}{30} \times 100$$

Absolute humidity of water vapour at room temperature $= \frac{75}{100} \times 30 \text{ g m}^{-3}$ ........ (01)

The mass of water vapour in the gymnasium $= \frac{75}{100} \times 30 \times 600$ ........ (01)

$= 13500$ g (13.5 kg) ........ (01)

(iv). Evaporated mass of water $= 0.45 \times 4$ kg

Total amount of water in the room after 30 minutes = 1800 g + 13500 g = 15300 g

........ (01)

Amount of water vapour in 1 m$^3$ $= \frac{15300}{600} = 25.5$ g ........ (01)

Relative humidity $= \frac{25.5}{30.0} \times 100\%$ ........ (01)

Relative humidity = 85% ........ (01)

(v). Amount of water vapour in 1 $m^3$ $= \frac{15300-6300}{600} = 15.0$ g ........ (02)

(for subtraction 01, correct substitution 01)



Final relative humidity $= \frac{15.0}{20.0} \times 100\ \%$ (for substitution) ........ (01)

Final relative humidity of the air at 20 °C = 75% ........ (01)

**Part (B)**

Figure (1) shows a hollow cube with four different types of metal surfaces. The cube filled with hot water is used to demonstrate the intensity variation of thermal radiation emitted from different surfaces with temperature. Four thermal detectors are kept at same distance from each surface to measure the temperature of the surface.

[Let Stefan constant $\sigma = 6{\cdot}0 \times 10^{-8}$ W m$^{-2}$ K$^{-4}$,

Wien's displacement constant = 2900 μm K]

For following calculations you may use

$(300)^4 = 8 \times 10^9$, $(310)^4 = 9 \times 10^9$, $(360)^4 = 16 \times 10^9$,

and $(373)^4 = 19 \times 10^9$.

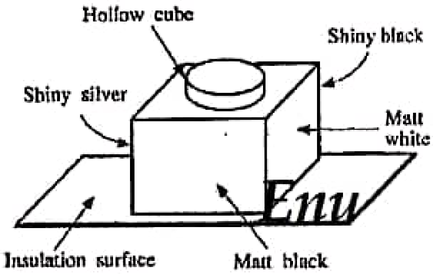



Figure (1)

(*a*) (i) What are the factors affecting absorption and emission of thermal radiation from a surface?

(ii) The measuring range of a thermal detector is from 200 K to 400 K. Calculate the peak wavelengths $\lambda_m$ (wavelength at the maximum intensity) corresponding to the minimum and the maximum temperatures of a blackbody surface that can be measured using the thermal detector.

(iii) Name the region of the electromagnetic spectrum that the peak wavelengths obtained in (*a*) (ii) above belongs to.

(*b*) The above cube consists of four different type of surfaces of matt white, matt black, shiny silver, and shiny black. Thermal detectors display the readings of (not in order) 87 °C, 72 °C, 47 °C and 37 °C corresponding to the surfaces of the cube.

(i) Identify and writedown the temperature readings corresponding to each surface.

(ii) Which surface has the maximum surface emissivity?

(iii) If the room temperature is 27 °C, assuming the emissivity of the surface identified in (*b*) (ii) above to be 1, calculate the relative emissivity of the shiny silver surface.

(*c*) Net rate of radiation heat transfer per unit area ($\dot{Q}$) between two parallel surfaces with emissivities $e_1$ and $e_2$ and temperatures $T_1$ and $T_2$ ($T_1 > T_2$) respectively is given by,

$$\dot{Q} = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\left(\frac{1}{e_1} + \frac{1}{e_2} - 1\right)}$$

A special box type Thermos flask consists of three walls *A*, *B*, and *C* as shown in figure (2). The outer surface of wall *A* and the inner surface of wall *B* are coated with silver. Walls *A* and *B* are separated by a vacuum.

(i) What is the reason for maintaining a vacuum in between walls *A* and *B*?

(ii) Why silver coated surfaces are used for walls *A* and *B*?

(iii) Calculate the net rate of radiation heat transfer per unit area between outer wall of *A* and inner wall of *B* if the emissivity of the silver coated surfaces is 0·02. Assume that the temperature of the outer wall of *A* and inner wall of *B* are 100 °C and 27 °C, respectively. (Take $\frac{1}{99} = 0{\cdot}01$)

(iv) If the heat transfer between the outer *A* and inner *B* walls is due to conduction, instead of radiation, calculate the thickness of an insulator material of thermal conductivity $6{\cdot}6 \times 10^{-3}$ Wm$^{-1}$K$^{-1}$ that must be used to obtain the same rate of heat transfer per unit area calculated in (c) (iii) above. Here assume steady state conditions.

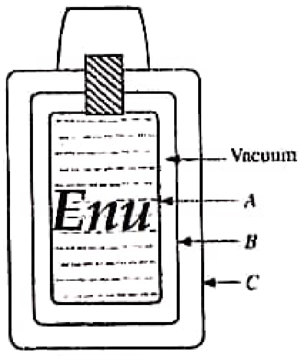



Figure (2)

. . .

(a) (i). Nature of the surface/emissivity, area of the surface, surface temperature, material

(Any two of above factors) ...... (02)

(ii).

$\lambda_m = \frac{2900}{200}$ ...... (01)

(For correct substitution)

$\lambda_m = 14.5\ \mu m$ ...... (01)

$\lambda_m = \frac{2900}{400}$ ...... (01)

(For correct substitution)

$\lambda_m = 7.25\ \mu m$ ...... (01)

(iii). Infrared / IR ...... (02)

(b) (i).



Matt black: 87 $^0$C ...... (01)

Shiny black: 72 $^0$C ...... (01)

Matt white: 47 $^0$C ...... (01)

Shiny silver: 37 $^0$C ...... (01)

(ii). Matt black ...... (02)

(iii).

Temperature of the Matt black surface= 273 +87 = 360 K



Temperature of the Shiny silver surface = 273 + 37 = 310 K

Temperature of the Room Temperature = 273+ 27 = 300 K

Relative emissivity ($e_{shiny\ silver}$) of the shiny silver surface

$= \frac{(310^4 - 300^4)}{(360^4 - 300^4)}$ ... (01)

$= \frac{(9\times10^9 - 8\times10^9)}{(16\times10^9 - 8\times10^9)}$

$= 0.125\ (0.13)$ ... (01)

(c) (i). To reduce the heat transfer by conduction and convection ... (02)

(01 mark for conduction and 01 mark for convection)

(ii). Prevent heat loss via radiation .........(02)

(iii).

$$Q = \frac{\sigma(T_1{}^4 - T_2{}^4)}{\left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1\right)}$$

$$Q = \frac{6\times10^{-8}(19\times10^{9} - 8\times10^{9})}{\left(\frac{1}{0.02} + \frac{1}{0.02} - 1\right)}$$ .........(02)

(substituting correct temperatures in Kelvin - 01 mark)



$$Q = \frac{6\times10^{-8}(11\times10^{9})}{(99)}$$ .........(01)

$= 6.6\ \mathrm{W\,m^{-2}}$ (correct value 01 mark only) .........(02)

(iv).

$$\frac{Q}{A} = k\frac{\Delta\theta}{l}$$ .........(02)

$$6.6 = 6.6 \times 10^{-2} \times \frac{73}{l}$$ .........(01)

$$l = 6.6 \times 10^{-2} \times \frac{73}{6.6}$$



$l = 73$ cm .........(02)