All Rights Reserved

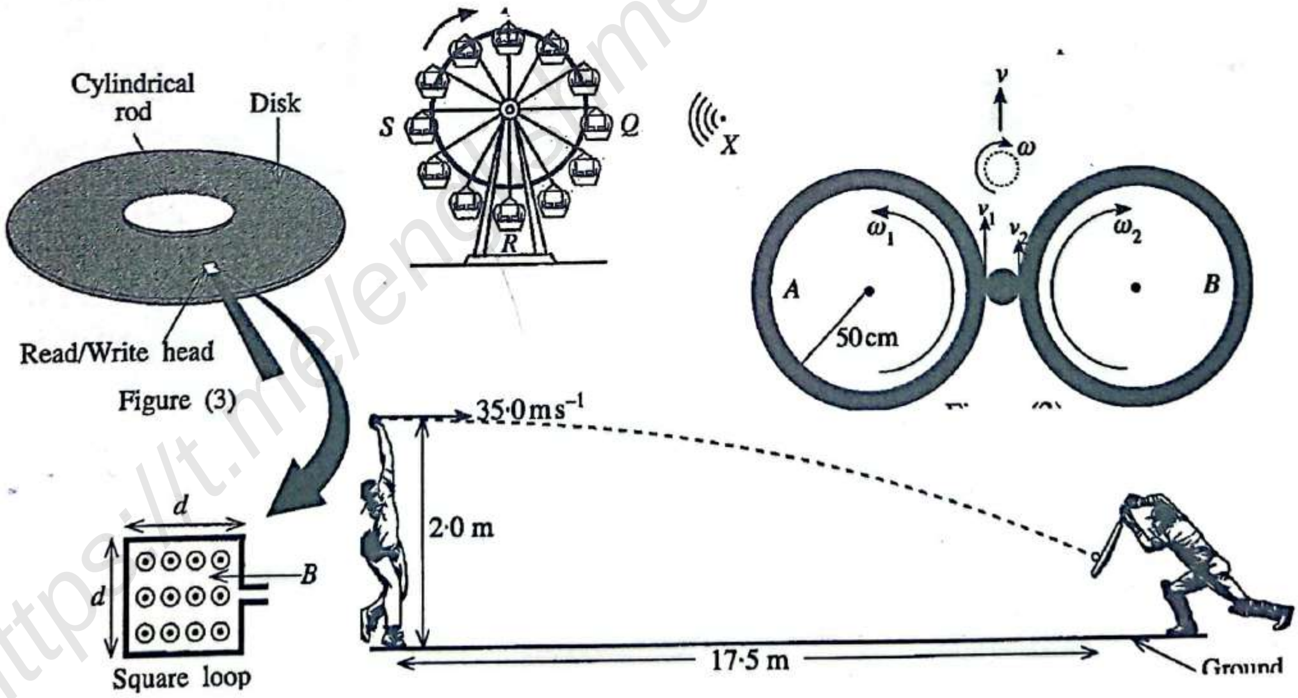
Confidential

Department of Examinations – Sri Lanka

G.C.E. (A/L) Examination – 2023(2024)

01 – Physics

Marking Scheme



https://t.me/englishmediumadvancelevel

This has been prepared for the use of marking examiners

15150000188110017

ශ්‍රී ලංකා විභාග දෙපාර්තමේන්තුව

இலங்கைப் பரீட்சைத் திணைக்களம்

අ.පො.ස. (උ.පෙළ) විභාගය/ க.பொ.த. (உயர் தர)ப் பரீட்சை - 2023(2024)

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

✪ විශේෂ උපදෙස් / விசேட அறிவுறுத்தல் :

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

මුළු ලකුණු / மொத்தப் புள்ளிகள் 1 × 50 = 50

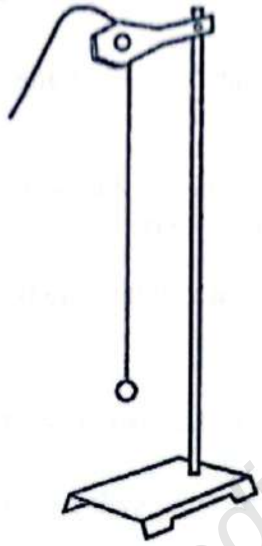
https://t.me/englishmediumadvancelevel

PART A – Structured Essay

Answer all four questions on this paper itself.

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

1. You are asked to determine the acceleration due to gravity (g) using the simple pendulum shown in the figure. The oscillating length of the pendulum could be adjusted.



(*a*) Name the additional measuring instruments and items necessary for carrying out this experiment.

Additional measuring instruments: Stopwatch/Stop-clock, Meter ruler ....(02)

(01 mark for each)

Additional items: Indicator/Pointer/Locating pin/Reference pin/Pin and a stand ....(01)

(No marks for pin only)

(*b*) (i) Write down an expression for the period of oscillation (T) of a simple pendulum in terms of oscillating length (l) and the acceleration due to gravity (g).

$$T = 2\pi\sqrt{\frac{l}{g}}$$ ....(02)

(ii) What is the exact oscillating length (l) in this experiment?

Distance between point of suspension and the centre of gravity of the pendulum bob /*OR* centre of the pendulum bob/sphere

OR any value of l between 40 cm to 1 m ....(01)

30

https://t.me/englishmediumadvancelevel

(*c*) (i) Underline the correct angle of inclination at which you release the pendulum bob before it starts to oscillate.

1^0 / $\underline{5^0}$ / 10^0 ....(01)

(ii) How can you avoid error in counting the number of oscillations when starting the stop watch?

(Counting in descending order and) start the stopwatch when counting 0 as the bob passes the locating pin/reference pin

OR start counting (from 3, 2, 1) when the bob passes the locating pin/reference pin/ and start the stopwatch when counting 0 ....(02)

(No marks for start the stopwatch when the bob passes the locating pin)

(iii) How do you verify that the oscillations of the pendulum occur in a vertical plane?

Ensuring the pendulum bob/string swings without sideways motion

OR without to and fro motion of the bob/string sideways

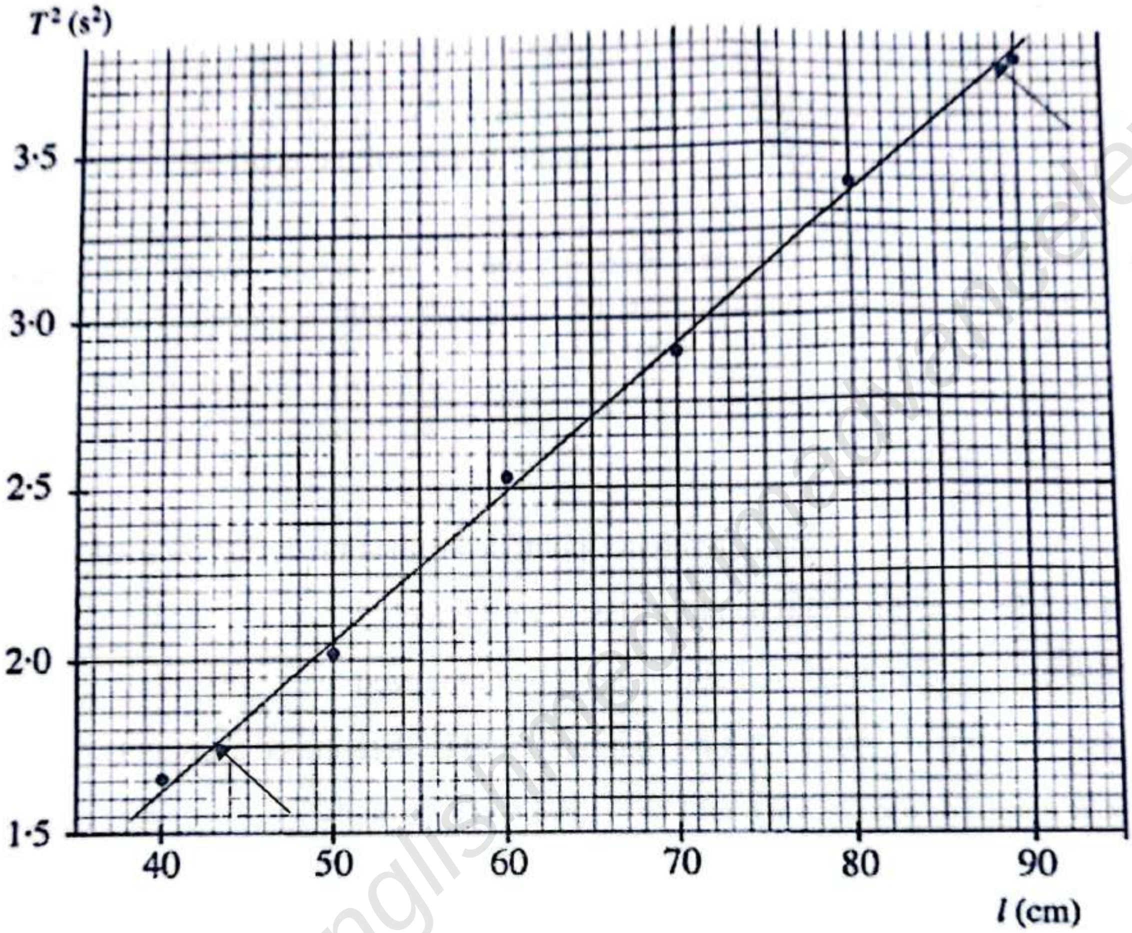
OR look at the motion by directing the eye on the plane on oscillation...............(01)

(*d*) (i) Rearrange the expression written in (*b*) (i) above in order to determine acceleration due to gravity (*g*) by plotting a suitable straight line graph.

$T^2 = \left(\frac{4\pi^2}{g}\right) l$ ....(02)

https://t.me/englishmediumadvancelevel

(ii) Calculate the acceleration due to gravity (g) using the following graph. Give your answer in SI units. (Take $\pi^2 = 10$). [Hint: Do not simplify the value of the gradient]



https://t.me/englishmediumalevel

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

(Identifying $\frac{4\pi^2}{g}$ as the gradient)

Selecting the lower point as (43, 1.75) ....(01)

Selecting the higher point as (89, 3.75) ....(01)

(No marks for any other points)

Gradient $= \frac{3.75-1.75}{(89-43)\times10^{-2}}$ (for gradient calculation) ....(01)

$\frac{4\pi^2}{g} = \frac{2\times10^2}{46}$

06150000188110017

$g = \frac{4\times10\times46}{2\times10^2}$

$g = 9.2 \text{ m s}^{-2}/\text{N kg}^{-1}$ (9.07 – 9.20) ....(02)

(Do not look for unit)

{If a student has obtained the correct/accepted answer for g selecting different points for gradient calculation, award 04 marks only. i.e. for identification of the gradient, gradient calculation and the final answer}

(*e*) **Consider the conical-shaped mass shown in the figure. Write down one advantage and one disadvantage of using this conical-shaped mass as the bob instead of a spherical mass.**

Advantage: Easy/accurate reference point determination during oscillation

OR reference pin could be pointed easily/accurately

OR error in counting oscillations could be minimized

OR counting the number of oscillations could be determined accurately

OR period of oscillation could be determined accurately ....(01)

Disadvantage: Complex center of gravity determination

OR position of center of gravity is unknown

OR exact oscillation length cannot be determined

OR higher drag force acting on it due to air

OR oscillations will cease quickly ....(01)

2. You are asked to determine the specific latent heat of fusion (L) of ice using the method of mixtures. You are provided with a copper calorimeter, three thermometers (you have to select the most appropriate one), water at room temperature, block of ice at 0 °C and filter papers.

(*a*) What are the other measuring instrument and the item that you need to do this experiment?

Measuring instrument: Four/three-beam balance *OR* (laboratory) electronic balance (No marks for just stating balance) ....(01)

Item : Square – net stirrer / Stirrer with net ....(01)

https://t.me/englishmediumadvancelevel

(b) It is advisable to determine the dew point of the atmosphere approximately before adding ice. What is the reason for this?

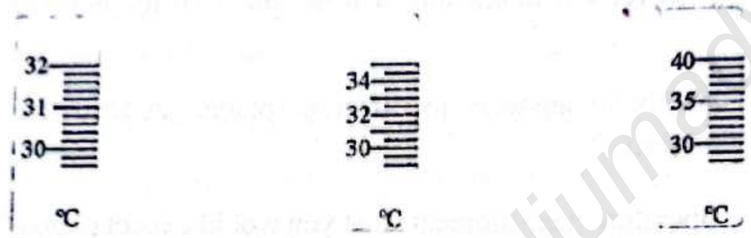
The error caused due to depositing of dew on the calorimeter surface can be avoided

OR the drop of minimum temperature of the mixture going below the dew point can be avoided

OR gaining/exchanging of heat with the surroundings can be minimized

OR compensation of heat can be done accurately ....(02)

(c) Parts of the enlarged scales and their ranges of three thermometers (*P*, *Q*, *R*) available in the laboratory are shown in the figure.



−10 °C to 60 °C	−10 °C to 110 °C	−10 °C to 250 °C
P	*Q*	*R*

(i) If the room temperature is 30 °C and the dew point of air is 24 °C, select the most appropriate thermometer that should be used to perform this experiment.

Most appropriate thermometer: *P* ....(01)

(ii) What is the least count of the thermometer selected in (*c*) (i) above?

$0.2\ ^{0}C$ ....(01)

[If a student has selected *Q* in (c) (i) above, then the least count is $0.5\ ^{0}C$ *OR* If a student has selected *R* in (c) (i) above, then the least count is $1\ ^{0}C$. Award this mark appropriately]

(iii) What should be the initial temperature of water?

$35.0\ ^{0}C$ (Also accept $35.2\ ^{0}C/35.4\ ^{0}C/35.6\ ^{0}C/35.8\ ^{0}C$)

OR $5\ ^{0}C$ above the room temperature ....(01)

https://t.me/englishmediumadvancelevel

(*d*) When preparing ice, adding ice into water and mixing ice what steps would you take to ensure proper procedure in order to determine *L*?

Preparing ice : Break the block of ice into small pieces and ....(01)

dry the pieces/wipe out water using the filter papers. ....(01)

Adding ice : Add one piece by one /add one piece at a time (using a pincer) into the water in the calorimeter ....(01)

while stirring, taking care to insert one piece after the previous one has dissolved. ....(01)

Mixing : Stir with net stirrer OR and make sure that the piece of ice is inside water/not floating ....(01)

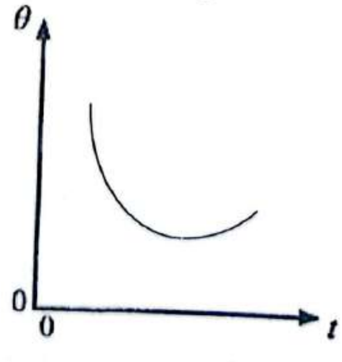
(Students might write above answers at different places. Award the marks accordingly considering underlying terms)

(*e*) (i) What are the temperature measurements that you would expect to take in this experiment? Give them in order of measurements.

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

(2) The minimum/lowest temperature of the mixture/water/system ....(01)

(ii) In order to measure the second temperature mentioned in (*e*) (i) above accurately you could plot the variation of temperature (θ) of water with time (t). Sketch the curve that you would expect using the given axes.



Temperature falling part ....(01)

Temperature rising part ....(01)

(Deduct 01 mark if the curve touches the $\theta = 0$ time axis)

https://t.me/englishmediumadvancelevel

(*f*) **Apart from the temperature measurements mentioned in (*e*) (i) above and the required mass measurements what data would you need to determine *L*?**

(1) Specific heat capacity of water ....(01)

(2) Specific heat capacity of copper/material of the calorimeter ....(01)

(*g*) (i) **If the added ice contained water at 0 °C with it, would the experimental value of *L* be higher or lower than the standard value?**

Higher/lower (underline the correct word) ....(01)

(ii) **Give reasons for your answer.**

A higher mass than the correct mass of ice is taken into the calculation

OR melted ice has already absorbed heat from air

OR the initial temperature of the water in the calorimeter will not drop as far.

OR the final temperature of the mixture will be higher. ....(01)

3. A student plans an experiment to determine the focal length of a convex lens by measuring the distance to the real image of an object pin.

(*a*) **Before choosing suitable values for the object distance the student should know the approximate value of the focal length of the lens. How does he find the approximate focal length?**

By adjusting the lens in front of a wall, obtain a clear image of a distant object on the wall

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

and measure the distance between the lens and the wall by (keeping a meter ruler perpendicular to the wall). (Also accept screen instead of wall) ....(01)

(*b*) **Taking objective distance = u, image distance = v and focal length = f, write down the equation that the student is going to use in this experiment.**

$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ *OR* $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$ ....(01)

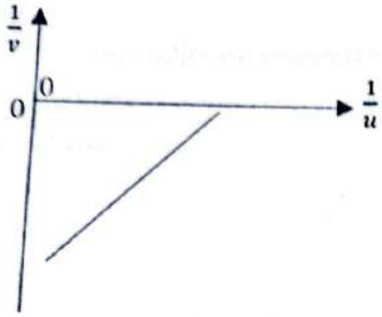
https://t.me/englishmediumadvancelevel

04150000188110017

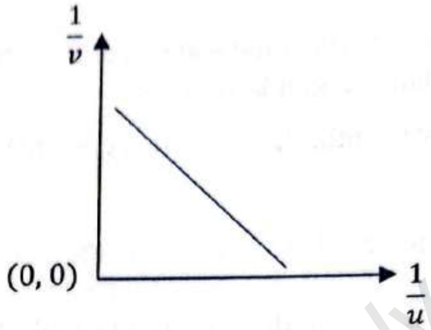
(*c*) Rearrange the equation in (*b*) above to obtain a straight line graph.

$\frac{1}{v} = \frac{1}{u} + \frac{1}{f}$ *OR* $\frac{1}{v} = -\frac{1}{u} + \frac{1}{f}$ ....(01)

(*d*) If the readings of the experiment are plotted using the sign convention, with proper labelling of independent and dependent variables draw the expected graph in the space given below.



OR



Identification of X-axis as $\frac{1}{u}$ ....(01)

Identification of Y-axis as $\frac{1}{v}$ ....(01)

Identification of origin as (0, 0) ....(01)

Straight line with positive/negative gradient ....(01)

(*e*) If the approximate focal length of the lens is 12 cm, taking 16·7 cm as the minimum object distance and 100 cm as the maximum object distance, write down **four** (4) suitable object distances in between the minimum and maximum. The length of the laboratory table is 200 cm. (You may use $0{\cdot}167 \times 6 = 1{\cdot}0$)

Corresponding *u* values are 20 cm, 25 cm, 33.3 cm (*OR* 33.4) and 50 cm (*OR* 50.1)......**(04)**

(01 mark for each correct value)

[Explanation: Since $\frac{1}{16.7} = 0.06$ and $\frac{1}{100} = 0.01$, intermediate $\frac{1}{u}$ values should be 0.05, 0.04, 0.03 and 0.02]

(*f*) Another student took $u = 12{\cdot}5$ cm as the object distance and he could not measure an image distance. Give the reason for it with proper explanation.

The image distance is too far from the lens

OR image distance is even more than the length of the table

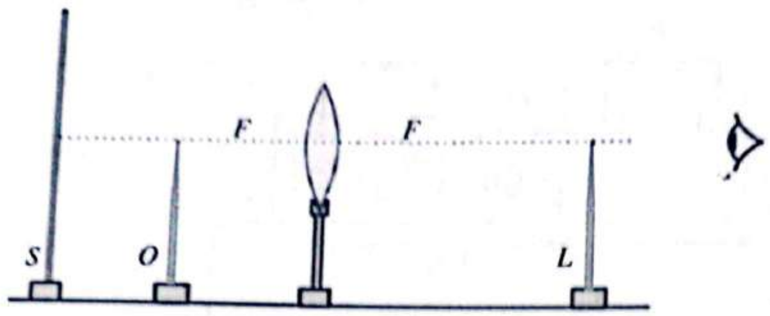
OR the image distance is about 300 cm (*or* larger than 200 cm)

OR the image pin cannot be placed on the table.

(No marks for the image will be formed at infinity) ....(01)

https://t.me/englishmediumadvancelevel

(g) **Complete the following diagram of the experimental setup indicating both focal points, object pin *O*, locating pin *L*, the position of the eye and the other important item.**



Both focal points *F* ....(01)

Correct sides of *O* and *L* including supports and labelling ....(01)

Tips of *O* and *L* just touching the axis ....(01)

(Tips of *O* and *L* could be represented by arrows)

Position of the eye on the axis ....(01)

Position of the screen *S* ....(01)

(h) **One student plotted a graph with 6 points by measuring three *u* values only. State the procedure that he has adopted to plot the graph and give the reason.**

Procedure: The *v* values corresponding to the three *u* values can be taken as another three *u* values

OR the *v* values corresponding to the three *u* values can be interchanged as *u* values thereby six data points can be obtained

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

Reason: The real images of a convex lens can be interchanged with respective objects

OR real image distances/*v* of a convex lens can be interchanged with respective object distances/*u*

OR object distances/*u* and real image distances/*v* form a conjugate pair

OR any pair of object distance/*u* and real image distance/*v* can be considered as another pair of image distance/*v* and object distance/*u*

OR since the path of the light rays are reversible the object distance/*u* and the relevant real image distance/*v* can be interchanged. ....(01)

https://t.me/englishmediumadvancelevel

4. (*a*) The meter bridge circuit shown in figure (1) is used to determine the resistivity of the material of a given uniform wire and its length. A known resistance R is connected across the first gap of the bridge. Let unknown resistance connected across the second gap of the bridge be S. If the balance length is l write down an expression for S in terms of R and l neglecting end corrections of the meter bridge wire.

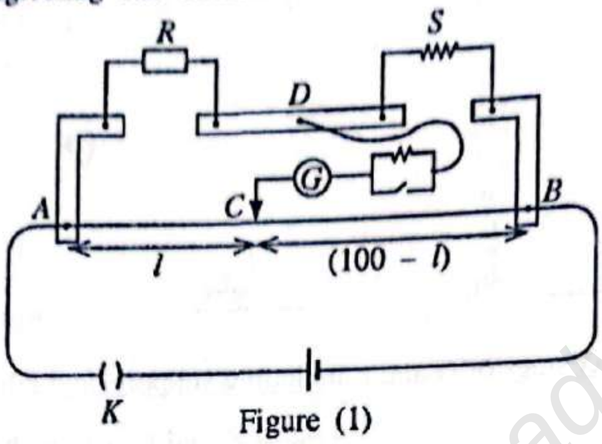


Figure (1)

$S = R\frac{(100-l)}{l}$ (l is in cm) *OR* $S = R\frac{(1-l)}{l}$ (l is in m) ....(02)

(*b*) The part (*XZ*) of the wire is covered in a box and the part (*XY*) is outside the box as shown in the figure (2). Unknown resistance S is obtained from the length *XZ* and a part of the wire *XY*.

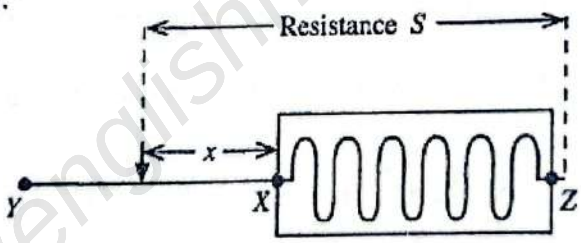


Figure (2)

(i) The covered length of the wire *XZ* is L. If the length of the part of the wire measured from X is x and resistance per unit length of the wire is k write down an expression for resistance S across the second gap in terms of L, x, and k.

$S = k(L + x)$ ....(02)

(ii) By varying the length x, the respective balance length l is measured. When $x = 10$ cm, $l = 50$ cm and when $x = 30$ cm, $l = 40$ cm. Substituting the expression obtained for S in (*b*) (i) above into the expression written in (*a*) above and using the given values of x and l, determine L.

https://t.me/englishmediumadvancelevel

$k(L+x) = R\frac{(100-l)}{l}$

$k(L+10) = R\frac{(100-50)}{50}$......(1) (for correct substitution) ....(01)

$OR\ k(L+0.1) = R\frac{(1-0.5)}{0.5}$

$k(L+30) = R\frac{(100-40)}{40}$......(2) (for correct substitution) ....(01)

$OR\ k(L+0.3) = R\frac{(1-0.4)}{0.4}$

$\frac{(1)}{(2)} \Rightarrow \frac{L+10}{L+30} = \frac{2}{3}$

$L = 30$ cm (OR 0.3 m) ....(02)

(iii) If $R = 10\,\Omega$ determine the value of k.

Substituting the value of L in equation (1)

$40k = R$

$k = \frac{10}{40}$

$k = 0.25\ \Omega\ \text{cm}^{-1}$ (OR 25 $\Omega\ \text{m}^{-1}$) (Do not look for unit) ....(02)

(c) Using a suitable measuring instrument the diameter of the uncovered part of the wire was measured at different locations and the readings obtained were 1·60 mm, 1·62 mm, 1·60 mm and 1·58 mm.

(i) What was the measuring instrument used in these measurements?

Micrometer screw gauge ....(02)

(ii) What is the least count of above instrument in mm?

0.01 mm ....(01)

(iii) Calculate the mean cross-sectional area (in m^2) of the wire using the above readings. Take $\pi = 3$.

Mean diameter = 1.60 mm

Mean cross-sectional area (A) $= 3 \times (0.8 \times 10^{-3})^2$ ....(01)

(for correct substitution)

$A = 1.92 \times 10^{-6}\ \text{m}^2$ ....(01)

https://t.me/englishmediumadvancelevel

02150000188110017

(iv) Calculate the resistivity ρ of the material of the wire.

Since k is the resistance per unit length

$$k = \frac{\rho}{A}$$ ....(01)

$$\rho = 25 \times 1.92 \times 10^{-6}$$

$$\rho = 4.8 \times 10^{-5}\ \Omega\,\text{m}\ \ (OR\ \ 4.8 \times 10^{-7}\ \ \Omega\,\text{cm})$$ ....(02)

(Deduct 01 mark for incorrect unit)

(*d*) What is the essential parameter that must be given when expressing the resistivity of a material?

Temperature ....(02)

https://t.me/englishmediumadvancelevel

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*) In a cricket match, a fast bowler delivers a ball without hitting the ground (full toss ball) with horizontal velocity of $35{\cdot}0\,m\,s^{-1}$ at a height of 2·0 m from the ground level as show in the figure (1). The ball travels a horizontal distance of 17·5 m before touching the bat. Assume there is no air resistance.

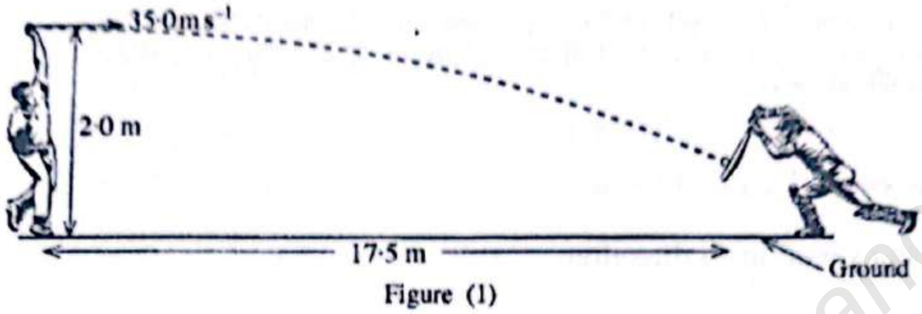


Figure (1)

(i) How long will it take for the ball to touch the bat?

(ii) At what height from the ground will the ball touch the bat?

(iii) Calculate the speed of the ball just before touching the bat. Give your answer to the nearest first decimal place in $m\,s^{-1}$. You may take $\sqrt{2} = 1{\cdot}41$.

(iv) The ball approaching perpendicular to the bat is successfully hit by the batsman so that it rebounds and returns in the same incoming line with the same speed as it approached the bat. If the mass of the ball is 0·16 kg and time of contact with the bat is 0·2 s calculate the force exerted on the ball by the bat. Give your answer to the nearest first decimal place in N.

(*b*) Cricket batsmen use mechanical bowling machines to practise in the net for improving their skills. A certain bowling machine consists of two identical heavy wheels *A* and *B* fitted with rubber tyres. The radius *R* of wheels with tyres is 50 cm. The top view of the setup is shown in the figure (2). Each wheel is driven by its own electric motor but in opposite directions. They are mounted in a **horizontal plane** with a gap in between two wheels. The gap is slightly less than the diameter of a specially designed uniform ball.

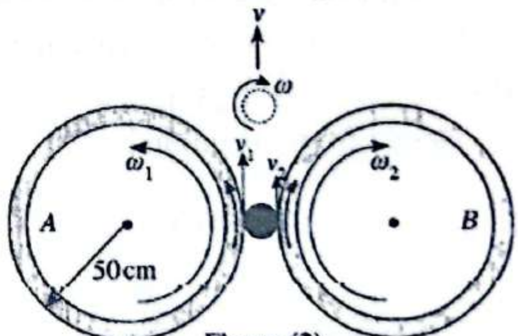


Figure (2)

(i) For sending a spinning ball, the rotational speed of wheels *A* and *B* are set at $\omega_1 = 640$ rpm and $\omega_2 = 560$ rpm respectively while keeping the plane of the wheels horizontally. rpm denotes number of rotations per minute. The linear velocity v of the centre of mass (CM) of the ball is given by $v = \frac{(v_1 + v_2)}{2}$. The angular velocity ω of the ball is given by $\omega = \frac{(v_1 - v_2)}{2r}$ where r is the radius of the ball. v_1 and v_2 are the velocities of the surface of the ball at contact points. The radius of the ball $r = 4{\cdot}0$ cm. Take $\pi = 3$.

I. Calculate the angular velocities (ω_1 and ω_2) of wheels in rad s^{-1}.

II. Calculate the linear velocity (v) of the CM of the ball when ejects.

III. Calculate the angular velocity (ω) of the ball in rpm when ejects.

https://t.me/englishmedumadvancelevel
011500001881100017

IV. If the mass of the ball is m, write down an expression for the total kinetic energy of the ball when ejects in terms of m, r, v and ω. The moment of inertia I of a uniform ball of radius r about an axis through the centre is given by $I = \frac{2}{5}mr^2$.

V. When the ball ejects calculate the **maximum** speed that a point on the surface of the ball can have.

(ii) For sending a fast ball without spin the angular speeds of the wheels are set equal so that $\omega_1 = \omega_2 = \omega_o$. To eject a fast ball at velocity of $35\ \text{m s}^{-1}$ what should be the angular speed ω_o of each wheel in rpm?

(a) (i) $\rightarrow u = 35\ \text{m s}^{-1}$, $\rightarrow s = 17.5\ \text{m}$

Applying $s = ut$ in $\rightarrow$ direction

$t = \frac{17.5}{35}$ ....(01)

$= 0.5\ \text{s}$ ....(01)

(ii) $\downarrow u = 0$, $\downarrow a = 10\ \text{m s}^{-2}$ and $\downarrow t = 0.5\ \text{s}$

Applying $s = ut + \frac{1}{2}at^2$ in $\downarrow$ direction

$h = 0 + \frac{1}{2} \times 10 \times 0.5^2$ ....(01)

$h = 1.25\ \text{m}$

Height from the ground = (2.0 - 1.25) m (for subtraction) ....(01)

= 0.75 m ....(01)

(iii) $\downarrow u = 0$, $\downarrow a = 10\ \text{m s}^{-2}$, $\downarrow t = 0.5\ \text{s}$ and $\downarrow v = v_y$

Applying $v = u + at$ in $\downarrow$ direction

$v_y = 0 + 10 \times 0.5$ ....(01)

$\downarrow v_y = 5\ \text{m s}^{-1}$

and $\rightarrow v_x = 35\ \text{m s}^{-1}$

Since $v^2 = v_x^2 + v_y^2$ ....(01)

$v^2 = 35^2 + 5^2 = 1250$

$= 625 \times 2$

$v = 25 \times \sqrt{2} = 25 \times 1.41$

$v = 35.3\ \text{m s}^{-1}$ (35.25 - 35.40) m s^{-1} ....(02)

https://t.me/englishmediumadvancelevel

(iv) In the direction perpendicularly away from the bat $\Delta p = m(2v)$ ……………(01)

$F = \frac{\Delta p}{\Delta t}$

$F = \frac{0.16\times2\times35.3}{0.2}$ ……………(01)

(for the substitution)

$F = 56.5$ N (56.4 – 56.6) N ……………(02)

(If a student has considered the component of weight of the ball along perpendicular to the bat award marks/disregard it)

(b) (i) I. $\omega_1 = 640$ rpm

$= \frac{640\times6}{60}$ rad s^{-1} ……………(01)

(for dividing by 60 and multiplying by 2π)

$= 64$ rad s^{-1} ……………(01)

$\omega_2 = 560$ rpm

$= \frac{560\times6}{60}$ rad s^{-1}

$= 56$ rad s^{-1} ……………(01)

II. Applying $v = R\omega$ to wheels

$v_1 = R\omega_1$, $v_2 = R\omega_2$ and $R = 0.5$ m

$v = \frac{(V_1+V_2)}{2} = \frac{0.5}{2}(64+56)$

$v = 30$ m s^{-1} ……………(02)

III. $r = 4$ cm $= 0.04$ m

$\omega = \frac{(V_1-V_2)}{2r} = \frac{0.5}{2\times0.04}(64-56)$

$\omega = 50$ rad s^{-1}

$= 500$ rpm (*OR* 50 rad s^{-1}) ……………(02)

https://t.me/englishmediumadvancelevel

IV. Total K. E. $= \frac{1}{2}mv^2 + \frac{1}{2}(\frac{2}{5}mr^2)\omega^2$

Total $K.E. = \frac{1}{2}mv^2 + \frac{1}{5}mr^2\omega^2$ ....(02)

[01 mark for linear K.E. and 01 mark for rotational K.E.]

V. The rotational speed v_r of the surface is given by $v_r = r\omega$

$$v_r = 0.04 \times 50$$ ....(02)

[01 mark for the identifying $r = 4$ cm and 01 mark for multiplication of r by ω]

$$= 2 \text{ m s}^{-1}$$

The maximum speed is on the left surface of the ball

The maximum speed $= 30 + 2$ ....(01)

(for the addition)

$$= 32 \text{ m s}^{-1}$$ ....(02)

(ii) $v = 35 \text{ m s}^{-1}$ and $R = 0.5$ m

Applying $v = R\omega_o$ to the wheel

$35 = 0.5\ \omega_o$ ....(01)

$\omega_o = 70 \text{ rad s}^{-1}$

$\omega_o = 700$ rpm (OR 70 rad s^{-1}) ....(02)

https://t.me/englishmediumadvancelevel

6. Read the following passage and answer the questions.

Audible range of human ear extends from 20 Hz to 20 kHz. Ultrasound waves are also sound waves but differ from audible sound only in its frequency. Ultrasound is used in many different areas such as in industry, medicine, navigation, imaging, cleaning, mixing, communication and testing.

An ultrasound transducer converts electrical signals into ultrasound waves and ultrasound waves into electrical signals. The key component of the transducer is a piezoelectric crystal which works on the principle of piezoelectric effect. When a high frequency alternating voltage is applied across such a piezoelectric crystal, it expands and contracts along one axis producing ultrasound waves. Similarly if ultrasound waves produce a variable pressure in the crystal, a small potential difference develops across the crystal. Therefore the same transducer is used to generate ultrasound waves and to detect the reflected ultrasound waves.

When ultrasound waves are incident on a boundary between two different mediums, a part of the ultrasound waves will be reflected and a part will be transmitted. The amount of reflection or transmission depends on a property called acoustic impedance (Z) of each medium and it is given by the relationship $Z = \rho v$. Here ρ is the density of the medium and v is the speed of ultrasound waves in that medium. For normal incidence, the ratio of the reflected intensity (I_r) to the incident intensity (I_i) is given by $\frac{I_r}{I_i} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$.

Here Z_1 and Z_2 are acoustic impedances of the first medium and the second medium respectively.

Since the Z value of skin is large compared to that of air, when an ultrasound transducer is placed directly on to a patient's skin, 99·9% of the incident ultrasound intensity is reflected and only 0·1% is transmitted into the body. In order to ensure that most of the ultrasound is transmitted into the patient, a special gel layer is applied in between the patient's skin and the transducer. Since the Z value of the gel is almost the same as that of the skin, very little ultrasound will be reflected and this ensures effective imaging of internal structures.

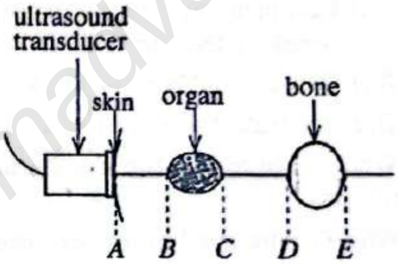


Figure (1)

Figure (1) shows a cross-section through a part of a patient's body. Ultrasound is pulsed through the center of the section so that it passes first through an organ and then through a bone. Figure (2) shows an oscilloscope trace of the reflected ultrasound signal received from the gel-skin boundary and then from the front and back surfaces first the organ and then the bone.

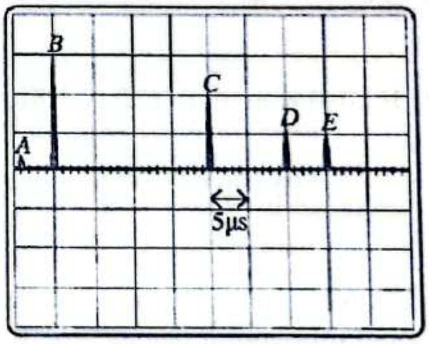


Figure (2)

(*a*) What is the audible range of human ear?

(*b*) Name **three** areas where ultrasound waves are used.

(*c*) What are the functions of an ultrasound transducer?

(*d*) (i) Briefly explain how ultrasound waves are produced in an ultrasound transducer.

(ii) If the natural frequency of the piezoelectric crystal in an ultrasound transducer is 48 kHz, what is the most appropriate frequency of the alternating voltage that should be applied across the crystal? Give the reason for your answer.

(*e*) Is it possible to apply the same equation that is used to find out the speed of sound in a medium to determine the speed of ultrasound waves propagating in that medium? Give the reason to your answer.

https://t.me/englishmediumadvancedlevel

(*f*) (i) In the expression $\frac{I_r}{I_i} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$, show that the dimension of I_r is not equal to that of $(Z_2 - Z_1)^2$.

(ii) What will be the value $\frac{I_r}{I_i}$, if $Z_2 = Z_1$?

(iii) What will be the value $\frac{I_r}{I_i}$, if $Z_2 >> Z_1$?

(*g*) What is the reason for applying a special gel between the patient's skin and the transducer?

(*h*) (i) What is the acoustic impedance Z of human skull with density $1600\ \text{kg m}^{-3}$ if ultrasound waves travel through the human skull at a speed of $3750\ \text{m s}^{-1}$?

(ii) The average acoustic impedance of the material that the brain made of is $4{\cdot}0 \times 10^6\ \text{kg m}^{-2}\ \text{s}^{-1}$.

Calculate the percentage of $\frac{I_r}{I_i}$, when ultrasound waves incident on the boundary of skull and brain.

(*i*) (i) Using the information given in figure (2), determine the total time interval during which the ultrasound waves travel in the organ.

(ii) Calculate the total distance travelled by ultrasound waves through the organ. Ultrasound wave speed in the organ is $1600\ \text{m s}^{-1}$.

(iii) Hence, calculate the thickness of the organ.

(iv) Calculate the thickness of the bone. Ultrasound wave speed in the bone is $4100\ \text{m s}^{-1}$.

(*j*) What is the reason for sending ultrasound pulses instead of a continuous beam of ultrasound in medical imaging?

(*k*) Why is ultrasound scan safer over X-rays to examine a foetus in a womb?

(a) 20 Hz to 20 kHz ....(01)

(b) Industry, medicine, navigation, imaging, cleaning, mixing, communication, testing.

(Any three 02 marks, any two 01 mark) ....(02)

(c) An ultrasound transducer converts electrical signals into ultrasound waves ....(01)
and ultrasound waves into electrical signals. ....(01)

Generate and recieve

(d) (i) When a high frequency alternating voltage is applied across (a piezoelectric crystal in) an ultrasound transducer it expands and contracts along one axis. (These crystal vibrations produce ultrasound waves.) ....(01)

https://t.me/englishmediumadvancedlevel

(ii) 48 kHz ....(01)

The piezoelectric crystal resonates

OR The piezoelectric crystal vibrates with maximum amplitude. ....(02)

(e) Yes/possible ....(01)

Ultrasound waves are merely sound waves but differ from audible sound only in its frequency. ....(01)

(f) (i) Dimension of intensity $= \frac{[\text{Power}]}{L^2} = \frac{MLT^{-2}L}{L^2T}$

$= MT^{-3}$ ....(01)

Dimension of $Z^2 = (ML^{-3}LT^{-1})^2$

$= M^2L^{-4}T^{-2}$ ....(01)

Therefore dimension of I_r is not same as $(Z_2 - Z_1)^2$.

(ii) Ultrasound waves will not be reflected

OR $I_r = 0$

OR all incident ultrasound waves will be transmitted. ....(01)

(iii) All/most ultrasound waves will be reflected

OR $I_r = I_i$

OR nothing/very little will be transmitted. ....(01)

(g) To match acoustic impedances

OR Z value of the gel is same as that of the skin

OR to allow very little ultrasound reflection

OR to allow more ultrasound transmission

OR to ensure effective imaging of internal structures ....(01)

https://t.me/englishmediumadvancelevel

(h) (i) $Z = 1600 \times 3750$ ....(01)

$= 6.0 \times 10^6\ kg\ m^{-2}\ s^{-1}$ ....(01)

(ii) $\frac{I_r}{I_i} = \frac{(6-4)^2}{(6+4)^2}$ ....(01)

(correct substituting)

$= \frac{2^2}{10^2} \times 100$

$= 4\%$ ....(02)

(i) (i) 20 μs ....(01)

(ii) $20 \times 10^{-6} \times 1600$

0.032 m (3.2 cm) ....(01)

(iii) $\frac{0.032}{2}$ (for dividing by 2) ....(01)

0.016 m (1.6 cm) ....(01)

(iv) $\frac{5 \times 10^{-6} \times 4100}{2}$

0.0125 m (1.25 cm) ....(02)

(j) Ultrasound waves must be emitted in pulses in order measure the time interval between the signal to reach the target of interest and be reflected back to the transducer before the next pulse is emitted. ....(01)

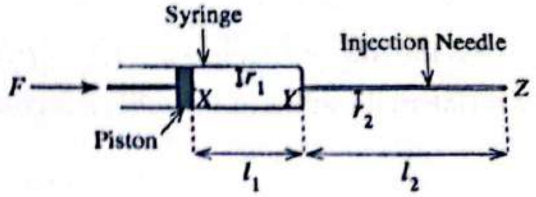
(k) X-rays are ionizing radiations which could harm the foetus, ...(01)

whereas ultrasound waves are sound waves and they do not harm the foetus.

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

https://t.me/englishmediumadvancelevel

7. As shown in the figure a cylindrical syringe is attached to a cylindrical injection needle which is used to inject a liquid medicine into a vein of a patient. Both the syringe and the needle are kept horizontally and completely filled with the medicine. The internal radius of the syringe is r_1 and the length between points X and Y is l_1. The internal radius of the needle is r_2 and the length of the needle is l_2. The coefficient of viscosity of the medicine is η. When a force F is applied to the piston of the syringe, the rate of volume flow of the medicine through the system is Q. The end Z of the needle is inserted into the vein.



(*a*) Write down the Poiseuille equation for the rate of volume flow Q of a viscous liquid passing through a horizontal narrow tube. Identify each symbol in the equation.

(*b*) (i) Write down an expression for the pressure P at point X due to the applied force in terms of F and r_1. Assume that the force F is uniformly distributed over the cross-sectional area of the piston.

(ii) If the atmospheric pressure is P_0 what is the total pressure P_1 at point X.

(iii) If the pressure at point Y is P_2, write down an expression for $(P_0 - P_2)$ in terms of Q, r_1, l_1, η and F.

(iv) If the pressure at point Z (inside the vein) is P_3, write down an expression for $(P_2 - P_3)$ in terms of Q, r_2, l_2 and η.

(v) Using the expressions written in (*b*) (iii) and (*b*) (iv) above, write down an expression for $(P_0 - P_3)$ in terms of Q, r_1, l_1, η, r_2, l_2 and F.

(vi) Hence write down an expression for F in terms of Q, r_1, l_1, η, r_2, l_2, P_3 and P_0.

(*c*) The pressure P_3 in the vein is 10 mmHg higher than the atmospheric pressure.

(i) Determine $(P_3 - P_0)$ in Pa. Density of mercury (Hg) is $1{\cdot}36 \times 10^4\ \text{kg m}^{-3}$.

(ii) If $r_1 = 2{\cdot}5$ mm, $l_1 = 50$ mm, $r_2 = 0{\cdot}10$ mm, $l_2 = 60$ mm and $\eta = 2{\cdot}0 \times 10^{-3}$ Pa s determine the magnitude of the force F needed to inject a volume flow rate of $3{\cdot}0 \times 10^{-7}\ \text{m}^3\,\text{s}^{-1}$ liquid medicine into the vein. Take $\pi = 3$. [Hint: In the determination of F, two terms having small values can be neglected].

(iii) What is the flow speed of the liquid medication inside the needle? Take $\pi = 3$.

(*d*) In a modern jet injection method (needle free) liquid medicine is delivered into the body using a high-pressure nozzle just touching the skin. A narrow stream of liquid medicine penetrates the skin and delivers the medicine into the tissue. The inner radius of the opening of the nozzle is 4 μm. When the liquid medicine is filled in the horizontal syringe, the liquid starts to release from the opening of the nozzle at a certain pressure.

(i) Write down an expression for the excess pressure (Δp) across a spherical meniscus of radius r of a liquid of surface tension T.

(ii) Calculate the pressure P' needed to be in the liquid medicine near the nozzle when a liquid drop is just detached from the opening of the nozzle. Surface tension of the liquid medicine is $8{\cdot}0 \times 10^{-2}\ \text{N m}^{-1}$ and atmospheric pressure is $1{\cdot}0 \times 10^5$ Pa.

https://t.me/englishmediumadvancelevel

(a) $Q = \frac{\Delta P \pi r^4}{8\eta l}$ *OR* $Q = \frac{(P_1 - P_2)\pi r^4}{8\eta l}$ ....(02)

ΔP = Pressure difference *or* $(P_1 - P_2)$ = pressure difference *or* $\frac{\Delta P (P_1 - P_2)}{l}$ = pressure gradient; r = (internal) radius of the tube; η = coefficient of viscosity (of the liquid); l = length of the tube ....(02)

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

(b) (i) $P = \frac{F}{\pi r_1^2}$ ....(02)

(ii) $P_1 = P_0 + \frac{F}{\pi r_1^2}$ *OR* $P_1 = P_0 + P$ ....(02)

(iii) $Q = \frac{\left[\left(P_0 + \frac{F}{\pi r_1^2}\right) - P_2\right]\pi r_1^4}{8\eta l_1}$ *OR* $Q = \frac{[(P_0 + P) - P_2]\pi r_1^4}{8\eta l_1}$

$$P_0 - P_2 = \frac{Q 8\eta l_1}{\pi r_1^4} - \frac{F}{\pi r_1^2}$$ ....(02)

(iv) $P_2 - P_3 = \frac{Q 8\eta l_2}{\pi r_2^4}$ ....(02)

(v) By adding the expressions in (b) (iii) and (b)(iv)

$$P_0 - P_3 = \frac{Q 8\eta l_1}{\pi r_1^4} + \frac{Q 8\eta l_2}{\pi r_2^4} - \frac{F}{\pi r_1^2}$$ ....(02)

https://t.me/englishmediumadvancelevel

(vi) $\frac{F}{\pi r_1^2} = \frac{Q8\eta}{\pi}\left[\frac{l_1}{r_1^4} + \frac{l_2}{r_2^4}\right] + P_3 - P_0$

$F = Q8\eta\left[\frac{l_1}{r_1^2} + \frac{l_2 r_1^2}{r_2^4}\right] + \pi r_1^2(P_3 - P_0)$ OR $F = Q8\eta r_1^2\left[\frac{l_1}{r_1^4} + \frac{l_2}{r_2^4}\right] + \pi r_1^2(P_3 - P_0)$

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

(c) (i) $(P_3 - P_0) = 10 \times 10^{-3} \times 13.6 \times 10^3 \times 10$ ....(01)

(Correct substitution)

$(P_3 - P_0) = 1360$ Pa ....(02)

(ii) $\frac{l_1}{r_1^2}$ term: $\frac{50\times10^{-3}}{2.5^2\times10^{-6}} = 8 \times 10^3$

$\frac{l_2 r_1^2}{r_2^4}$ term: $\frac{60\times10^{-3}\times2.5^2\times10^{-6}}{10^{-16}} = 3.75 \times 10^9$

$\pi r_1^2(P_3 - P_0)$ term: $3 \times 2.5^2 \times 10^{-6} \times 1360 = 2.55 \times 10^{-2}$

First and the third term could be neglected in comparison with the second term.

$\therefore F = Q8\eta\frac{l_2 r_1^2}{r_2^4}$

$F = 3.0 \times 10^{-7} \times 8 \times 2.0 \times 10^{-3} \times 3.75 \times 10^9$

$F = 18$ N ....(02)

(iii) $\pi r_2^2 v = Q$

$v = \frac{Q}{\pi r_2^2}$ ....(01)

$v = \frac{3.0\times10^{-7}}{3\times10^{-8}}$ ....(01)

(Correct substitution)

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

https://t.me/englishmediumadvancelevel

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

(d) (i) $\Delta p = \frac{2T}{r}$ ....(01)

(ii) $P' - 1.0 \times 10^5 = \frac{2 \times 8.0 \times 10^{-2}}{4 \times 10^{-6}}$

(Correct substitution) ....(02)

$P' = 1.4 \times 10^5$ Pa

https://t.me/englishmediumadvancelevel

8. (a) As shown in figure (1) electrons emitting from a hot filament S, pass through an aperture A and then move along the axis of a metallic, open ended hollow cylinder. The system is kept in vacuum. A potential difference V is applied across the cylinder and the aperture so that the cylinder is kept at positive potential and the aperture is kept at negative potential.

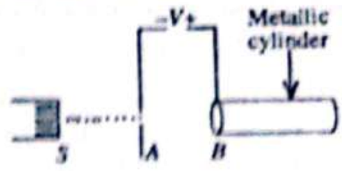


Figure (1)

(i) If the velocity of the electrons passing through the aperture A is negligible write down an expression for the kinetic energy K_1 of electrons at B in terms of V and electron charge e after crossing the gap between the cylinder and the aperture.

(ii) Hence write down an expression for the velocity v_1 of the electrons at B in terms of e, V and mass of the electron m.

(b) The setup shown in figure (1) can be modified to accelerate electrons to a higher kinetic energy by placing a series of coaxial metallic cylinders in line. This type of arrangement is known as a linear accelerator (LINAC). Electrons leaving the aperture A move along the axis of a series of coaxial metallic cylinders 1, 2, 3, 4 etc. known as drift tubes as shown in figure (2). The drift tubes are connected to an a.c. voltage source of $V_{rms} = V$ and high frequency f. The alternate tubes have potentials of opposite polarities so that during one-half cycle of the a.c. source the tubes 1 and 3 are positive while 2 and 4 are negative. In the next half cycle the polarities are reversed, that is tubes 1 and 3 will be negative and tubes 2 and 4 will be positive.

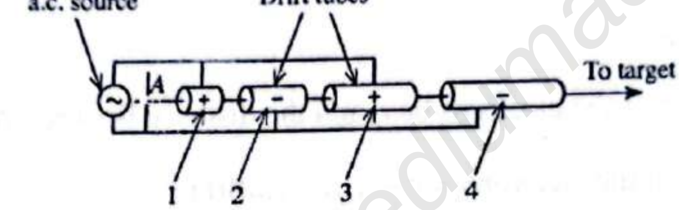


Figure (2)

Electrons leaving A accelerate during the half cycle when the drift tube 1 is positive with respect to A. Then the velocity v_1 of the electrons reaching the tube 1 is given by the expression you have written in (a) (ii) above. The length of the tube 1 is designed so that as the electrons come out of it, the potential of the tube 1 turns to negative and the potential of tube 2 turns to positive. Therefore electrons are again accelerated in the gap between the tubes 1 and 2. The electrons accelerate in the gaps between the tubes but travel with constant velocities within the tubes.

(i) What is the reason for electrons to travel with constant velocities inside the tubes?

(ii) Derive an expression for velocity v_2 of electrons reaching the tube 2 in terms of v_1.

(iii) Write down an expression for kinetic energy K_2 of electrons reaching the tube 2 in terms of e and V.

(c) Similarly the length of the tube 2 is designed so that as the electrons come out of it, the potential of the tube 2 turns positive to negative and the potential of tube 3 turns negative to a positive. Therefore electrons are again accelerated in the gap between the tubes 2 and 3.

(i) Derive an expression for velocity v_3 of electrons reaching the tube 3 in terms of v_1.

(ii) Write down an expression for kinetic energy K_3 of electrons reaching the tube 3 in terms of e and V.

(iii) If there are n number of tubes, looking at the answers in (a) (i), (b) (iii) and (c) (ii) above or otherwise, write down an expression for the kinetic energy K_n of electrons leaving the n^{th} tube.

https://t.me/englishmediumadvancedlevel

(*d*) As electrons are accelerated in the gap between two consecutive tubes, the time taken by electrons to travel through tubes should be equal to half of the periodic time of the high frequency a.c. voltage.

(i) Write down an expression for time t taken by electrons to travel through in each of drift tubes in terms of the frequency f of the a.c. voltage.

(ii) Hence show that the length L_n of n^{th} tube is given by $L_n = \frac{1}{f}\sqrt{\frac{neV}{2m}}$.

(*e*) A medical linear accelerator (medical LINAC) is the device most commonly used for external beam radiation treatments for patients with cancer. Accelerated electrons are allowed to collide with a heavy metal target like tungsten to produce high energy X-rays. These high energy X-rays are used to destroy cancer cells. The accelerated electrons coming out from a medical LINAC have a kinetic energy of 10 MeV. Determine the minimum wavelength of X-rays emitted.

($hc = 1{\cdot}24 \times 10^{-3}$ MeV nm)

(a) (i) $K_1 = eV$ ....(02)

(ii) $\frac{1}{2}mv_1^2 = eV$ ....(02)

$v_1 = \sqrt{\frac{2eV}{m}}$ ....(02)

{Alternative method:

Let the acceleration of the electrons be a and the distance between A to B is d.

The electric force on the electrons $= e\frac{V}{d}$ ....(01)

Then applying $F = ma$ to electrons,

$e\frac{V}{d} = ma$ ....(01)

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

$v_1^2 = 2\frac{eV}{md}d$

$v_1 = \sqrt{\frac{2eV}{m}}$ ....(02)

$K_1 = \frac{1}{2}mv_1^2$

$K_1 = eV$ ....(02) }

https://t.me/englishmediumadvancelevel

(b) (i) In a metallic tube net charge lie on the outer surface of the tube *OR* electric filed/intensity is zero inside a metallic tube. ....(02)

(ii) $\frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2 = eV$ ....(01)

$\frac{1}{2}mv_2^2 = 2eV$ ....(01)

$v_2 = \sqrt{2}v_1$ ....(02)

(iii) $K_2 = 2eV$ ....(02)

{Accept similar alternative method given in (a) above}

(c) (i) $\frac{1}{2}mv_3^2 - \frac{1}{2}mv_2^2 = eV$ ....(01)

$v_3 = \sqrt{3}v_1$ ....(02)

(ii) $K_3 = 3eV$ ....(01)

{Accept similar alternative method given in (a) above}

(iii) $K_n = neV$ ....(01)

(d) (i) $t = \frac{1}{2f}$ ....(02)

(ii) $L_n = v_n t$ ....(02)

But, $v_n = \sqrt{n}\sqrt{\frac{2eV}{m}}$ *OR* $v_n = \sqrt{n}v_1$ ....(02)

$\therefore \; L_n = \sqrt{\frac{n2eV}{m}}\frac{1}{2f}$

(e) $\frac{hc}{\lambda} = K$ ....(02)

$\lambda = \frac{1.24\times10^{-3}}{10}$ ....(01)

$\lambda = 1.24 \times 10^{-4}$ nm ....(02)

https://t.me/englishmediumadvancelevel

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

Part (A)

A source X with zero internal resistance is shown in figure (1). The voltage of X is linearly dependant on temperature and it produces a current (I) from 0 to 20 mA for temperatures ranging from 0 °C to 100 °C. The current is linearly converted into a voltage between 0 - 5 V range and is measured across the resistance R as a output voltage (V).

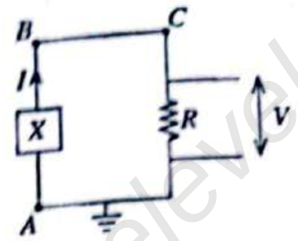


Figure (1)

(*a*) (i) If R is an ohmic resistance, sketch the $I-V$ characteristic of R.

(ii) What should be the value of the resistance R?

(iii) Calculate the values of voltage and current across the resistor when the temperature of X is 25 °C. Hence find the power dissipation in the resistor.

(*b*) Suppose that resistance R_1 is connected parallel to X and the wire segment BC in the circuit shown in figure (1) is replaced by resistor R_2 as shown in figure (2). Let R remains constant at the value calculated in (*a*) (ii) above.

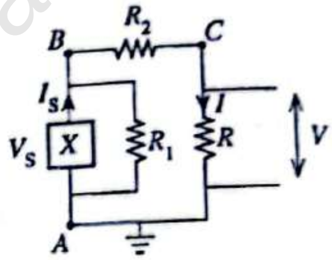


Figure (2)

(i) When the source produces a voltage (V_S), write down an expression for the current (I) passing through resistance R.

(ii) Hence write down an expression for the source current (I_S).

(iii) Using the expressions in (*b*) (i) and (*b*) (ii) above, state what will happen to the ratio $\frac{I_s}{I}$ if $R_1 >> (R + R_2)$. What is the physical significance of this?

(*c*) In a computer hard disk drive (HDD), data is stored by magnetizing tiny regions of a thin film deposited on a flat, circular disk. As shown in figure (3), a cylindrical rod passing through the axis of the disk is used to spin the disk. When the disk spins, the information stored in the disk is read as an induced e.m.f. generated in the read/write head which is a conducting horizontal square loop of side length d placed just above the disk. The disk is spinning with constant angular velocity ω. When the disk spins, an isolated magnetic region of the same size as the loop located at mean distance r from the center of the disk passes under the conducting loop, where $r >>> d$. The magnetic region produces a uniform magnetic field of flux density B pointing upwards. An enlarged picture of the square loop seen from above is shown in figure (4). When the magnetic region is completely underneath the loop, the magnetic field produced by the magnetic region is directed out of the plane of the loop.

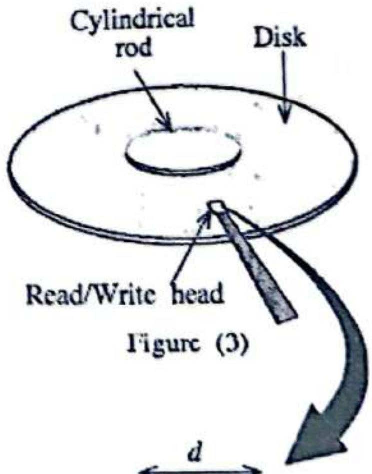
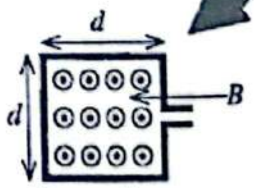


Figure (3)



Square loop

Figure (4)

(i) Sketch the variation of the induced e.m.f. ξ with time t, as follows.

t_1 as the time when the field just enters the loop,

t_2 as the time when the loop is fully inside the field, and

t_3 as the time when the field just completely leaves the loop.

https://t.me/englishmediumadvancelevel

(ii) Write down an expression for the magnetic flux (ϕ) through the square loop in terms of B and d, when the loop is completely within the magnetic region.

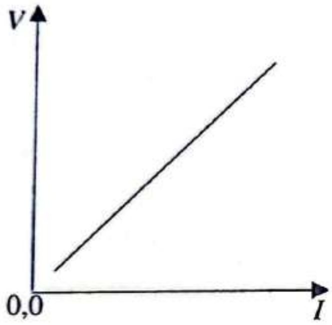
(iii) Write down an expression for the time (Δt) taken for the magnetic region to pass the loop in terms of d, r and ω. Assume that the magnetic region is at a mean distance r from the centre of the disk.

(iv) Using your answers to part (c) (ii) and (c) (iii) above or otherwise, write down an expression for the magnitude of the induced e.m.f. (ξ) in the loop in terms of B, d, r and ω.

(v) The area of the circular disk with a radius of 62·5 mm is half filled with $1{\cdot}0\times10^{13}$ isolated uniformly distributed square magnetic regions. There are no magnetic regions in the cylindrical rod of radius 12·5 mm. Calculate the side length d of a single magnetic region. Take $\pi = 3$ and $\sqrt{562\cdot5} = 24$.

(vi) If $B = 1{\cdot}0\times10^{-3}$ T and the angular speed of the spinning disk is 540 rad s^{-1}, calculate the induced e.m.f. ξ on the loop when a magnetic region situated at the circumference (r = 62·5 mm) of the disk passes under the loop.

(a) (i)



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

(01 mark for labeling the axis and 0,0)

(01 mark for straight line going through zero or seems to go through zero) {V and I could be interchanged}

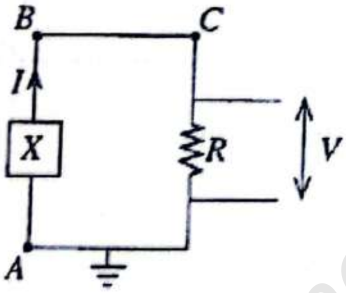


Figure (1)

(ii) $R = \frac{V}{I}$ ....(01)

$R = \frac{5}{20\times10^{-3}}$ ....(01)

(correct substitution)

$R = 250\ \Omega$ ....(01)

https://t.me/englishmediumadvancelevel

(iii) Since 25 °C is one fourth of 100 °C

$V = \frac{5}{4}$ ....(01)

$V = 1.25$ V

$I = \frac{20}{4}$ (OR 1.25 / 250 = 5 mA) ....(01)

I = 5 mA (OR 5×10^{-3} A)

$P = I^2R = (5 \times 10^{-3})^2 \times 250$ ....(02)

$= 6.25 \times 10^{-3}$ W (OR 6.25 mW)

(Deduct 01 mark for incorrect unit)

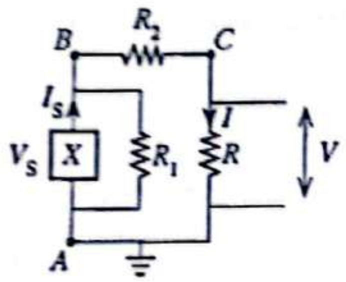


Figure (2)

(b) (i)

$I = \frac{V_S}{250+R_2}$ OR $\frac{V_S}{R+R_2}$ ....(02)

(ii) $I_S = \frac{V_S}{R_1} + \frac{V_S}{250+R_2}$ OR $\frac{V_S}{R_1} + \frac{V_S}{R+R_2}$ ....(02)

[01 mark for V_S/R_1 term, 01 mark for summation]

(iii) $\frac{I}{I_S} = \frac{V_S}{R+R_2} \times \frac{R_1(R+R_2)}{(R_1+R+R_2)V_S} = \frac{R_1}{(R_1+R+R_2)}$

If $R_1 \gg (R_2 + R)$,

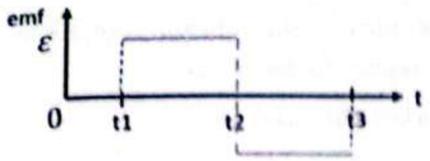
$\frac{I_S}{I} = 1$ ....(02)

The current produced by the source is fully converted to voltage
OR the total current produced by the source pass through R (or 250 Ω)
OR none of the current pass through R_1 ....(01)

0001006

https://t.me/englishmediumadvancelevel

(c) (i)



OR inverse ....(03)

(01 mark for correct times)
(01 mark for opposite polarity)
(01 mark for correct shape with equal magnitudes)
[Drawing dash lines are not essential; time t_1 could start at 0]

(ii) $\Delta\varphi = Bd^2$ ....(02)

(iii) $\Delta t = \frac{d}{v}$, where v is the mean speed of the magnetic domain.

$\Delta t = \frac{d}{r\omega}$ ....(01)

(iv) $\varepsilon = \frac{\Delta\varphi}{\Delta t}$ ....(01)

$\varepsilon = \frac{Bd^2 r\omega}{d}$

$\varepsilon = Bdr\omega$ ....(02)

{Alternative method:
$\varepsilon = vdB$ .... (01)
$\varepsilon = Bdr\omega$ ....(02)}

(v) Total area of the magnetic regions $= 1\times10^{13}d^2$ ....(01)

Area of the disk without the rod $= \pi\times(62.5^2 - 12.5^2)$ ....(01)
$(OR\ \pi\times(62.5^2 - 12.5^2)\times10^{-6})$

Area over which the magnetic regions are distributed $= \frac{\pi\times(62.5^2-12.5^2)}{2}$
$[OR\ \frac{\pi\times(62.5^2-12.5^2)\times10^{-6}}{2}]$

$1\times10^{13}\,d^2 = \frac{\pi\times(62.5^2-12.5^2)}{2}$
$d = \sqrt{562.5}\times10^{-6}$
$= 24$ nm (OR 24×10^{-6} mm, 24×10^{-9} m) ....(01)

(vi) $\varepsilon = Bdr\omega$
$= (1\times10^{-3})\times(24\times10^{-9})\times(62.5\times10^{-3})\times540$ ....(01)
(for substitution)

$= 0.81$ nV (OR 8.1×10^{-10} V) ....(01)

https://t.me/englishmediumadvancelevel

Part(B)

(*a*) Considering the properties of a silicon p-n junction diode, answer the following questions,

(i) What is the reason for the formation of a depletion region in the diode?

(ii) What happens to the width of the depletion region when the diode is

(I) forward biased and

(II) reverse biased?

(iii) What is the reason for generating a very small reverse-biased leakage current in the diode?

(*b*) If the diode current of a forward biased silicon diode is kept constant, the voltage linearly drops with temperature. The circuit with a silicon transistor (V_{BE} = 0·7 V) and a Zener diode (*Z*) can be used to keep a constant I_D current through the diode (*D*) when the transistor is operating in active mode as shown in figure (1).

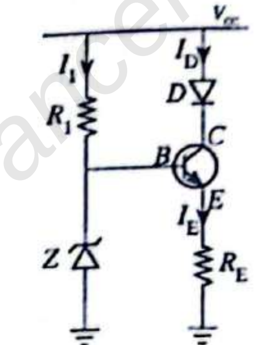


Figure (1)

(i) What is the purpose of the Zener diode in the circuit?

(ii) If the Zener voltage is V_Z, write down an expression for R_E in terms of I_E, V_Z and V_{BE}.

(iii) If the circuit needs to produce a constant current of I_D = 20 mA, calculate a suitable value for R_E. Take V_Z = 5·7 V. Write down the assumption you made during the calculation with regard to I_E.

(iv) Show that the circuit works as a constant current source if V_{CC} = +12 V and V_Z = 5·7 V. The forward biased voltage drop across the silicon diode is 0·7 V.

(*c*) The operational amplifier circuit shown in figure (2) can be used to amplify a small voltage similar to the diode voltage given in (*b*) above.

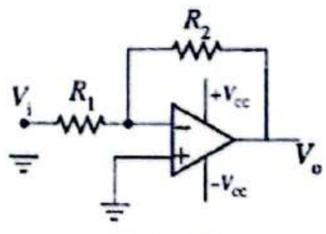


Figure (2)

(i) What is the op-amp configuration shown in figure (2)?

(ii) The golden rule-one states that no current flows into the input terminals of an op-amp. What is the reason for this?

(iii) The golden rule-two states that the voltage difference between the input terminals of an op-amp is zero. How is it achieved in practice?

(iv) Applying the two golden rules, derive an expression for the output voltage V_o in terms of the small input voltage V_i, R_1 and R_2.

(v) If small input voltages between 0 and 0·7 V need to be converted to values between 0 V and 3·5 V output range, determine the voltage gain of the op-amp.

(vi) The small input voltage at 0·7 V linearly drops with temperature by 2 mV per 1 °C. Calculate the output voltage of the op-amp corresponding to 10 °C increase in temperature in V_i.

(vii) The voltage gain of the op-amp circuit can be set by choosing R_1 and R_2 values in ohm range. However, in practice resistor values in kΩ or larger range are used in the op-amp circuit. What is the reason for using large resistor values in the circuit?

https://t.me/englishmediumadvancelevel

(a) (i) Majority carriers diffuse across the junction and recombine ....(01)

(ii) (I) decreases ....(01)

(II) increases ....(01)

(iii) Minority carriers in the depletion region, diffuse and drift across the depletion region.

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

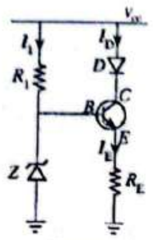


Figure (1)

(b) (i) Eliminate fluctuations in current (I_B and/or I_D) caused by the changes in V_{CC}
OR keep I_B and/or I_D constant
OR keep V_B constant ....(02)

(ii) $V_Z - V_{BE} - I_E R_E = 0$ ....(01)

$R_E = \frac{(V_Z - V_{BE})}{I_E}$ ....(01)

(iii) $R_E = \frac{(V_Z - V_{BE})}{I_E}$

$R_E = \frac{(V_Z - V_{BE})}{I_D}$

$= \frac{5.7 - 0.7}{20 \times 10^{-3}}$ (for substitution) ....(01)

$R_E = 250\ \Omega$ ....(01)

Assumption: $I_E = I_D$ ....(01)

(iv) For constant current operation the transistor should be in the active region as given in the problem.

Therefore, $V_C - V_E = (V_{CC} - V_D) - (V_Z - V_{BE})$

Since $V_D = V_{BE}$

$V_C - V_E = V_{CC} - V_Z = 12 - 5.7$

$= 6.3$ V ....(01)

Since $12 > 6.3 > 0.1$ (*or* 0), the transistor is in active region ....(01)

and therefore the circuit operates as a constant current source.

https://t.me/englishmediumadvancelevel

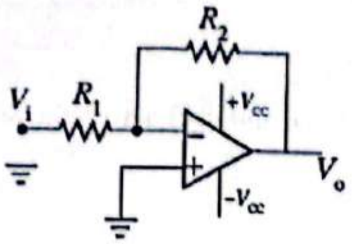


Figure (2)

(c) (i) Inverting amplifier ....(02)

(ii) Op-amp has a very large input resistance/impedance ....(02)

(iii) By using negative feedback ....(02)

(iv) $V_O = -\frac{V_i R_2}{R_1}$ ....(02)

(v) Voltage gain $= \frac{3.5}{0.7}$ ....(01)

$= 5$ ....(01)

(vi) Voltage drop $= 2 \times 10$ mV ....(01)

(for multiplication)

$V_i = (0.7 - 0.02)$ ....(01)

(for subtraction)

$V_O = (0.7 - 0.02) \times 5$ ....(01)

(for multiplying by 5)

$V_O = 3.4$ V ....(01)

(vii) Input devices with large resistance can be connected to the circuit

OR to increase the input resistance/impedance of the circuit ....(02)

https://t.me/englishmediumadvancelevel

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

Part (A)

As a solution to scarcity of drinking water, United Arab Emirates (UAE) planned to introduce the iceberg project. The concept of the project is to bring a massive iceberg from Antarctica to the sea of Persian Gulf at UAE and to produce drinking water. A huge cubical iceberg of volume $1{\cdot}0\times10^7\,m^3$ in Antarctica has to be pulled with the help of a massive tugboat. Assume that the average density of sea water and ice are $1000\,kg\,m^{-3}$ and $900\,kg\,m^{-3}$ respectively at Antarctica and Persian Gulf.

(a) (i) What is the total initial mass of the iceberg?

(ii) Calculate the volume percentage of part of the iceberg submerged below the surface of the sea.

(iii) If 80 % of initial mass remains as ice when the iceberg is at the Persian Gulf, how many cubic metres (m^3) of water can be produced using this iceberg?

(b) The iceberg brought to the sea of Persian Gulf is completely wrapped with an insulating material *A* of thickness 4·0 cm. The part of the iceberg above the sea water level is covered with an additional insulating material *B* with thickness 4·0 cm. Assume that the average temperature of sea water below the water level is 20 °C and air temperature is 30 °C. Thermal conductivity of insulating material *A* is $0{\cdot}2\,W\,m^{-1}\,K^{-1}$ and that of *B* is $0{\cdot}1\,W\,m^{-1}\,K^{-1}$. Assume that the iceberg has cubical shape and the temperature of the outer layer of the iceberg is at 0 °C. Neglect the mass of insulating material. Assume that there are no edge effects and heat flows perpendicular to all the surfaces.

(i) Write down an expression for rate of heat flow (Q) at steady state through a material and identify all the symbols you used.

(ii) Find the side length (l) of the ice cube in *(a)* (iii) above.

- Round off your answers of parts (iii), (iv), (v) and (vi) below to two decimal places in scientific notation. See the note given at the beginning of page 9.

(iii) Calculate the surface area of the cubical iceberg

(I) above the water level

(II) below the water level

(iv) Calculate the rate of heat absorbed by the part of the iceberg from sea water below the water level.

(v) Calculate the rate of heat absorbed by the part of the iceberg from air above the water level.

(vi) Water produced by melting of ice in the iceberg is used to distribute for consumption. Initially how many m^3 of water at 0 °C is produced during one day? Take specific latent heat of fusion of ice as $3{\cdot}0\times10^5\,J\,kg^{-1}$ and 1 day = $9{\cdot}0\times10^4$ s.

(a) (i) Mass of the iceberg = $1\times10^7\times900$ ....(01)

$= 9\times10^9$ kg ....(01)

(ii) Let v be the volume of the iceberg and v' be the volume submerged,

$v\times900 = 1000\times v'$ ....(01)

The percentage of iceberg which is below the ocean = 90 % ....(01)

(Award both marks to the correct final answer)

https://t.me/englishmediumadvancelevel

(iii) Amount of water that can be produced in $m^3 = \frac{80}{100} \times \frac{9\times 10^9}{1000}$ ....(02)

(01 mark for taking 80%, 01 mark for dividing by 1000)

$v = 7.2 \times 10^6\ m^3$ ....(01)

(b) (i) $\frac{Q}{t} = kA\frac{\Delta\theta}{\Delta l}$ ....(02)

$\frac{Q}{t}$ - rate of heat flow; 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) Initial volume of the ice cube = $1.0 \times 10^7 m^3$

Volume of the iceberg at the Persian Gulf = $\frac{80}{100} \times 1.0 \times 10^7$

$= 8 \times 10^6\ m^3$

If l is the side length of the iceberg, then $l^3 = 8 \times 10^6$

$l = 200$ m ....(02)

(iii) (I) Area of the iceberg above the water = $(0.1 \times 4 + 1) \times 200 \times 200$ ....(01)

$= 5.60 \times 10^4\ m^2$ ....(01)

(II) Area of the iceberg below the water = $(0.9 \times 4 + 1) \times 200 \times 200$ .... (01)

$= (3.6 + 1) \times 200 \times 200$

$= 1.84 \times 10^5\ m^2$ ....(01)

https://t.me/englishmediumadvancelevel

(iv) Let the rate of heat flow below water level be $\frac{Q_1}{t}$.

$\frac{Q_1}{t} = 0.2 \times 1.84 \times 10^5 \times \frac{20}{4\times10^{-2}}$ ....(02)

(for substitution)

$\frac{Q_1}{t} = 1.84 \times 10^7$ W ....(02)

(v) Let the rate of heat flow above water level be $\frac{Q_2}{t}$ and the temperature at the boundary be θ. For the inner layer

$\frac{Q_2}{t} = 0.2 \times 5.6 \times 10^4 \times \frac{\theta - 0}{4\times10^{-2}}$ ....(02)

(for substitution)

$\frac{Q_2}{t} \times (4 \times 10^{-2}) = 0.2 \times 5.6 \times 10^4 \times (\theta - 0)$

$\frac{\frac{Q_2}{t}\times(4\times10^{-2})}{0.2\times5.6\times10^4} = (\theta - 0)$ .... (A)

For the outer layer

$\frac{Q_2}{t} = 0.1 \times 5.6 \times 10^4 \times \frac{30-\theta}{4\times10^{-2}}$ ....(02)

(for substitution)

$\frac{\frac{Q_2}{t}\times(4\times10^{-2})}{0.1\times5.6\times10^4} = (30 - \theta)$ .... (B)

(A)+(B)⇒ $\frac{\frac{Q_2}{t}\times(4\times10^{-2})}{0.2\times5.6\times10^4} + \frac{\frac{Q_2}{t}\times(4\times10^{-2})}{0.1\times5.6\times10^4} = 30$

$$\frac{Q_2}{t} = \frac{30}{\left(\frac{4\times10^{-2}}{1.12\times10^4} + \frac{4\times10^{-2}}{0.56\times10^4}\right)}$$

$$\frac{Q_2}{t} = \frac{30\times10^6}{\left(\frac{1}{0.28} + \frac{1}{0.14}\right)}$$

$$\frac{Q_2}{t} = \frac{30\times10^6\times0.28\times0.14}{0.42+0.14}$$

$$\frac{Q_2}{t} = \frac{30\times10^6\times0.28\times0.14}{0.42}$$

$\frac{Q_2}{t} = 2.80 \times 10^6$ W ....(01)

https://t.me/englishmediumadvancelevel

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

(vi). Total rate = $2.80 \times 10^6 + 1.84 \times 10^7$

(for adding the two rates)

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

Total rate for a day $Q = (2.80 \times 10^6 + 18.4 \times 10^6) \times 9 \times 10^4$

(for multiplying by number of seconds in a day or multiplying by 24×3600)

Let m be the mass of water produced,

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

$(2.8 \times 10^6 + 18.4 \times 10^6) \times 9 \times 10^4 = m \times (3.0 \times 10^5)$

(for multiplying or dividing by L)

$$21.2 \times 10^6 \times 9 \times 10^4 = m \times (3.0 \times 10^5)$$

$$m = \frac{21.2 \times 10^6 \times 9 \times 10^4}{3.0 \times 10^5}$$

$$m = 6.36 \times 10^6 \text{ kg}$$

Volume of water produced during one day = $\frac{6.36 \times 10^6}{1000}$

$= 6.36 \times 10^3 \text{ m}^3$ $(6.10 - 6.36) \text{ m}^3$ ....(01)

https://t.me/englishmediumadvancelevel

Part (B)

(a) The amount of radiation energy absorbed per unit mass of tissue is used to measure the radiation dose. Write down the dimension of radiation dose.

(b) What is meant by activity of a radioactive sample?

(c) Write down the radioactive decay (disintegration) law **in words**.

(d) The symbolic notation of nucleus of atom X is given by $^{A}_{Z}X$.

(i) What is meant by Z?

(ii) What is meant by A?

(e) The fission reaction of U-235 nucleus capturing slow neutron can be written as follows.

$$^{235}_{92}U + n \rightarrow ^{148}_{x}La + ^{85}_{35}Br + yn$$

Relevant Atomic masses are given below.

$^{235}U = 235{\cdot}124\ u$ $\quad$ $^{148}La = 147{\cdot}961\ u$ $\quad$ $^{85}Br = 84{\cdot}930\ u$

$p = 1{\cdot}007\ u$ $\quad$ $n = 1{\cdot}009\ u$ $\quad$ $1\ u = 932\ MeV/c^2$

Take Avogadro number as $N_A = 6{\cdot}0 \times 10^{23}\ mol^{-1}$, $1\ MeV = 1{\cdot}6 \times 10^{-13}\ J$ and $c = 3{\cdot}0 \times 10^8\ m\,s^{-1}$.

(i) What are the values of x and y in the above nuclear reaction?

(ii) Calculate the binding energy of U-235 nucleus. Give your answer to the nearest integer in MeV.

(iii) Calculate the energy released from the above nuclear reaction. Give your answer to the nearest integer in MeV.

(f) It has been proposed to generate electricity by using a floating nuclear power plant when electricity generated by hydropower is insufficient. One of the advantage of a floating nuclear power plant is that it can be assembled in highly advanced factories with well-trained experts and brought to the place where energy need is acute.
Such an offshore nuclear power plant has been designed to provide 400 MW electricity to the main electricity supply using U-235 as the reactor material. The nuclear power plant converts 75 % of the nuclear energy into electricity and generates electricity for 10 years continuously. Take the mean energy released per U-235 nucleus is equal to the value obtained in part (*e*) (iii).
Take 1 year = $3{\cdot}3 \times 10^7$ s.

(i) Write down Einstein's mass-energy equivalence equation and define the symbols used.

(ii) Calculate the corresponding **equivalent** mass to the nuclear energy generated during 10 years. Give your answer in grams (g) to the nearest integer.

(iii) Calculate the mass of U-235 consumed in the nuclear power plant to produce electricity during 10 years. Give your answer in kilograms (kg) to the nearest integer.

(iv) Why is **not** essential to consider the decay of U-235 in the above calculation? Half-life of U-235 is $7{\cdot}0 \times 10^8$ years. Avoid doing any calculation.

(a) $$[\text{dose}] = \frac{[\text{energy}]}{[\text{mass}]} = \frac{M\,L^2T^{-2}}{M}$$

$$= L^2T^{-2}$$ ……………...(02)

https://t.me/englishmediumadvancelevel

(b) The activity of a radioactive sample is the number of disintegrations (decays) of radioactive nuclei/atoms per unit time/per sec

OR the rate of disintegration/decay of radioactive nuclei/atoms in a sample ....(02)

OR Activity = $\frac{dN}{dt}\left(or\ \frac{\Delta N}{\Delta t}\right)$, where N is the number of radioactive nuclei/atoms.

(c) The rate of disintegration /decay *OR* activity of a given sample of radioactive elements at any moment is (directly) proportional to the number of radioactive nuclei/atoms present at that moment. ....(02)

(d) (i) Z = Atomic number ....(01)

(ii) A = Mass number ....(01)

(e) $^{235}_{92}U + n \rightarrow {}^{148}_{x}La + {}^{85}_{35}Br + yn$

$^{235}U = 235.124$ u $\quad$ $^{148}La = 147.961$ u $\quad$ $^{85}Br = 84.930$ u

p = 1.007 u $\quad$ n = 1.009 u $\quad$ $1\text{ u} = 932\ \text{MeV}/c^2$

(i) $x = 57$ ....(01)

$y = 3$ ....(01)

(ii) 143n + 92p = 144.287 + 92.644 = 236.931 u ....(02)

(for the addition)

B. E. = mass of nucleons − mass of U nucleus = 236.931 − 235.124 = 1.807 u

$B = 1.807 \times 932$ ....(01)

(for multiplying by 932)

= 1684 MeV (1684.1) MeV ....(01)

(iii) Mass of nuclear products = $^{148}La + {}^{85}Br + 3n$

= 147.961+84.930+3.027 ....(01)

(for the addition of right hand side masses)

https://t.me/englishmediumadvancelevel

$= 235.918$ u

Mass of initial nuclei $= 235.124 + 1.009 = 236.133$

$\Delta m = 236.133 - 235.918$ ....(01)

(for subtraction)

$= 0.215$ u

$\Delta E = 0.215 \times 932$

$= 200$ MeV (200.4 MeV) ....(02)

{Alternative method:

Mass of nuclear products with 2n = ^{148}La + ^{85}Br+ 2n

= 147.961+84.930+2.018..................(01)

(for the addition of right hand side masses)

= 234.909 u

$\Delta m = 235.124 - 234.909$ ....(01)

(for subtraction)

$= 0.215$ u

$\Delta E = 0.215 \times 932$

$= 200$ MeV (200.4 MeV)..................(02)}

https://t.me/englishmediumadvancelevel

(f) (i) Write down the Einstein's mass-energy equation and define the symbols used.

$\Delta E = \Delta mc^2$ *OR* $E = mc^2$ ....(01)

where ΔE = energy released *OR* E = energy

Δm = mass converted into energy (*OR* loss as energy) *OR* m = mass ....(01)

c = speed of light (in free space)

(ii) Total electrical energy produced in 10 years $= 400 \times 10^6 \times 3.3 \times 10^7 \times 10$ ....(01)

(for correct substitution; number of seconds in a year can be taken as $365 \times 24 \times 3600$)

Total nuclear energy in 10 years $= 400 \times 10^6 \times 3.3 \times 10^7 \times 10 \times \frac{4}{3}$ ....(01)

[for multiplying by $\frac{100}{75}\left(or\ \frac{4}{3}\right)$]

$= 1.76 \times 10^{17}$ J

$= \frac{1.76\times10^{17}}{9\times10^{16}}$ kg ....(01)

(for dividing by c^2)

= 1956 g (1869 – 1956) g *or* (1.87 - 1.96) kg ....(01)

(iii) Energy released per U-235 nucleus = 200 MeV

$= 200 \times 1.6 \times 10^{-13}$ J ....(01)

(for converting MeV to J)

$= 3.2 \times 10^{-11}$ J

The number of U-235 nuclei needed for 10 years $= \frac{1.76\times10^{17}}{3.2\times10^{-11}}$ ....(01)

(for the division)

$= 5.5 \times 10^{27}$

Mass of U-235 needed $= \frac{5.5\times10^{27}}{6.0\times10^{23}} \times 0.235$ ....(02)

[01 mark for dividing by Avogadro number, 01 mark for multiplying by 0.235 *or* 235]

= 2154 kg (2058 – 2154) kg ....(01)

(iv) Compared to 10 years, half-life of U-235 is extremely large

OR 10 years is very small compared to half-life of U-235

OR $7.0 \times 10^8 \gg 10$

OR $10 \ll 7.0 \times 10^8$ ....(01)

Therefore decay of U -235 can be neglected.

https://t.me/englishmediumadvancelevel