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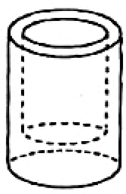
G. C. E (Advanced Level) Examination, August 2014

PHYSICS - II

Three hours

Answer all four questions. **PART A - Structured Essay** **($g = 10 N kg^{-1}$)**

01. The following measuring instruments are given to determine the density of material of a small uniform cylindrical container of the form shown in figure.
(1) A vernier calliper
(2) An electronic balance



(a) Before using a vernier calliper for taking measurements, what is the first step that you should take?

....

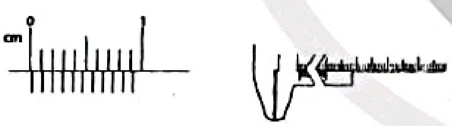
(b) Write down an expression for the density d of material of the container in terms of volume of the material V and its mass M.

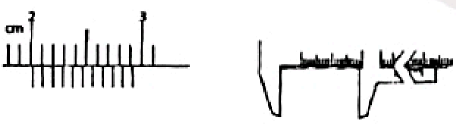
....

(c) In addition to the two measurements, the outer diameter and the inner diameter of the container, state the other measurements that you would take using the vernier calliper to determine the volume of the material.
(1) .... (2) ....
(3) ....

(d) The figures (i) to (v) below show all the relevant positions of the main and the vernier scales pertaining to one set of measurements that has been taken in order to determine the volume of the material of the container. Relevant jaws/ depth rod etc., that have been used to take each measurement are shown on the right hand side of the figure.

Nort : Height of the contairner is greater than its outer diameter.

(i)


(ii)


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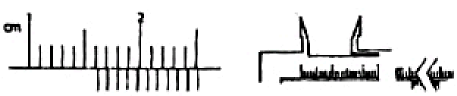
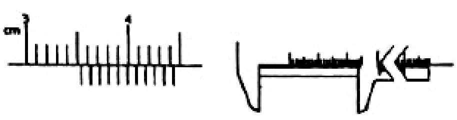


(iv)


(v)


Identify the figures correctly and relate them to the measurements that have been indicated in (c), and fill in the table given below.

Figure	Reading of the vernier calliper	Corrected reading	Name of the measurement
(i)	....		....
(ii)	....	..........(say x_1)	....
(iii)	....	..........(say x_2)	....
(iv)	....	..........(say x_3)	....
(v)	....	..........(say x_4)	....

(e) (i) Write down an expression for the volume V of the material of the container in terms of the symbols (x_1, x_2, x_3, x_4) given in the table above.

....
....
....

(ii) Using the expression written under (e) (i) above and readings that have given in the above table in (d), calculate V (Take $\pi = 3$).

....
....
....

(f) According to the reading of the electronic balance, if the mass of the container is 9.60 grams, find the density of the material of the container and give your answer in kg m^{-3}.

....
....
....

02. An experiment is to be designed and carried out to find the specific latent heat of vaporization of water using an electric method. The labelled experimental arrangement of the items to be used for this purpose is shown in figure (1).

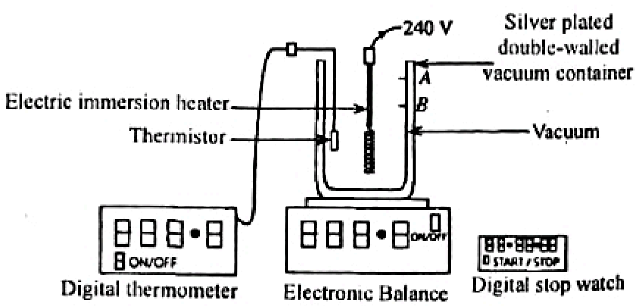


Figure (1)

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Experimental Procedure:

(1) Add a sufficient quantity of water to the silver plated double-walled vacuum container which is kept on the electronic balance.

(2) Switch on the electric immersion heater.

(3) After the water has started boiling thoroughly at the boiling point, start the digital stop watch at a certain instant (say at time t = 0) and also record the reading of the electronic balance (say M_0) at that instant.

(4) A fter a suitable time t, record the reading of the balance again (say M_1)

(5) If several readings for M_1 are needed, continue the experiment without stopping and record the successive readings of the balance at times $2t$, $3t$, $4t$, and $5t$.

(a) When the experiment is carried out according to the above procedure, suggest up to which level, A or B, marked on the diagram should the water be filled. Give **two** reasons for your choice. Assume that when boiling, water does not spill over from the container.

Level : ....

Reasons :

(i) ....

(ii) ....

(b) How does the silver plated double-walled vacuum container reduce the heat loss?

....

(c) Indicate which property of the thermistor is used to measure the temperature, and state how this property changes with the temperature.

....

(d) If P is the power of the electric heater in watts and t is the time through which the water has been boiled off as steam, write down an expression for the specific latent heat of vaporization L of water in terms of P, t and the measured quantities of M_0 and M_1 under the experimental procedure above.

(e) (i) If the least measurement of the electronic balance is 0.1 grams, what should be the minimum mass of water that has to be boiled off to ensure that the fractional error in the measured mass of water that had been boiled off as steam is $\frac{1}{100}$?

(ii) If P = 500W, calculate the minimum value for time t through which the water has to be boiled off in order to satisfy the requirement given in (*e*) (*i*) above. (For this calculation take the value of L as 2.3×10^6 J kg^{-1})

(*f*) A graph of mass m (in **grams**) of the vaporized water with time t (in **minutes**) was plotted using the data taken under the experimental procedure number (5) and the coordinates corresponding to two points on the graph were found to be (2, 26) and (8, 106). Determine the value of L.

....

....

....

....

03. You have been given a standard spectrometer, a glass prism, and a source of sodium light to determine the refractive index n of glass using a glass prism.

(a) Write down the two major components which can be rotated independent of each other, about the vertical axis passing through the centre of the prism table of the spectrometer.

(i) ....

(ii) ....

(b) Write down the major steps of the adjustments that you should do to the following items, before beginning to take measurements using the spectrometer.

(i) Eyepiece :

....

(ii) Telescope :

....

....

(iii) Collimator :

....

....

....

(c) You have been asked to use the prism PQR shown in figure 2 (a) for levelling the prism table.

Figure 2 (a)

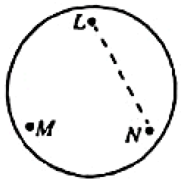


Figure 2 (b)

Draw on the figure 2(b), the way you should place the prism PQR on the prism table in order to level the prism table. In figure 2(b), L, M, N indicate the positions of the levelling screws of the table.

(d) To determine the angle of minimum deviation of a ray of light through the prism, it is necessary to take two measurements.

(i) After placing the prism on the prism table and adjusting the spectrometer to obtain the minimum deviation position, draw a ray diagram on figure (3) to show the deviation of the ray through the prism. Draw also the position of the telescope.

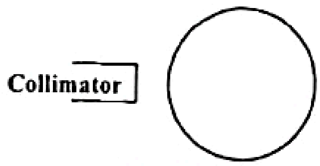


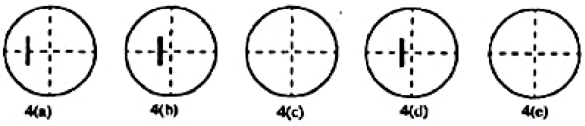
Figure (3)

(ii) If corresponding readings of one scale for the two measurements mentioned above for sodium light are 143°29' and 183°15' (Assume that the scale did not pass through 360° mark when taking the measurements.), find the angle of minimum deviation.

....

....

(e) Once you have identified and fixed the angle of minimum deviation position on the cross wires, in order to reconfirm it, you have been asked to rotate the prism table starting with a smaller angle of incidence until it passes through the minimum deviation position, while continuously observing the image of the slit. Figures 4(a), 4(b) and 4(d) show **three** of the five consecutive positions where image of the slit could be observed during this rotation.



On figure 4(c) and figure 4(e), draw the images of the slit at the position where you expect to see them.

(*f*) If A is the angle of the prism and D is the angle of minimum deviation for sodium light, write down as expression for the refractive index n of glass for the sodium light in terms of A and D.

....

....

(*g*) If $A = 60°$, find the value of n.

....

....

04. You are asked to determine the correct resistance (R) of a resistor of unknown value by measuring currents (I) and voltages (V) across it, and plotting a suitable graph. The resistance R of the unknown resistor is known to have a value around 500 Ω.

(a) A section of the circuit digaram of the electrical circuit that you would set up for this purpose is drawn in figure (1). X is a rheostat connected between points A and B.

(i) Complete the circuit diagram using circuit symbols of other components shown below. All the symbols have their usual meaning.

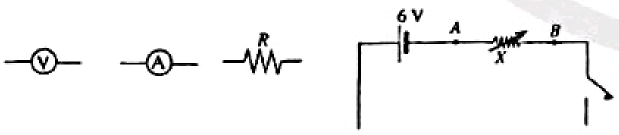


Figure (1)

(ii) Correctly mark the + and - signs on either side of circuit symbols of voltmeter and ammeter on the section of the circuit drawn by you.

(b) You have been given the rheostat shown in figure (2) to be used in this experiment. Mark the points A and B, mentioned in (a) above, at the appropriate terminals of the rheostat shown in figure (2).

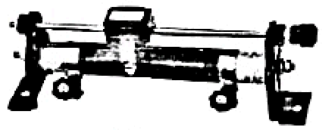


Figure (2)

(c) Following specifications are given for the rheostat.

Total resistance = 2000 Ω

Maximum current = 0.5A

When this rheostat is used in the completed circuit drawn in part (a) (i), estimate the maximum and the minimum currents that you can obtain.

Maximum current : ....

....

Minimum current : ....

....

(*d*) If you are asked to select a suitable ammeter from a collection of ammeters having full scale deflections of 0.5 mA, 15mA, 20mA, 100mA and 1 A, what would be your choice? Give reason for the choice.

Choice : ....

Reason : ....

(e) You are asked to take five different pairs of readings for I and V.

(i) Deflection of the indicator of the voltmeter corresponding to one such voltmeter reading is shown in figure (3).

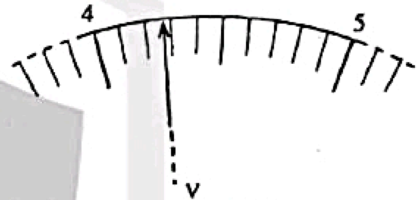


Figure (3)

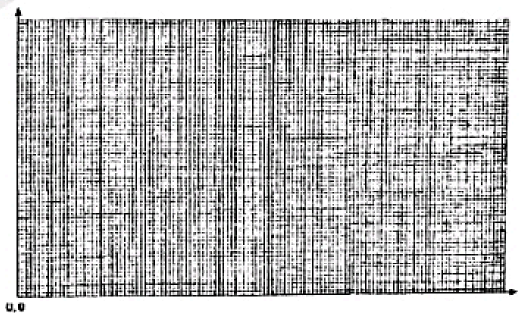
(1) Write down the value of this reading :

....

(2) What is the maximum estimated error in that measurement?

....

(ii) When this experiment was performed using the circuit completed in (a) (i) above, the corresponding voltmeter readings obtained for ammeter readings of 3 mA, 5 mA, 7 mA, 9 mA and 11 mA were 1.4V, 2.4V, 3.4V, 4.3V and 5.3V respectively. Considering the current as the independent variable mark the data points, on the grid provided, in a suitable manner to determine R.



(f) After plotting a suitable graph, suppose you have determined the value of the unknown resistance R as 480 Ω. The internal resistance (R_v) of the voltmeter that you have used in this experiment is 5000 Ω. Calculate the value you would expect from this experiment for R is R_v was infinitely large.

....

....

....

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PART B - Essay

Answer four questions only. **(g = 10N kg^{-1})**

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05. (a) When a person is changing steps while walking, at one instant the entire body weight of the person is borne only by a single leg as shown in figure (1). Front view of the relevant bone structure of this leg is shown in figure (2), and the corresponding simplified free-body diagram indicating all the forces acting on the leg is shown in figure (3). All the forces indicated in figure (3) and the weight of the body are acting in one vertical plane and the frictional force between the leg and the ground is negligible for this situation.

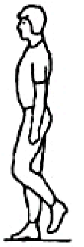


Figure (1)

Here, F_M = Resultanl force acting on the leg by the group of muscles M

F_S = Force exerted by the hip socket (S) on the leg

W_L = Weight of the leg

R = Reaction force acting on the leg by the ground

Figure (2)

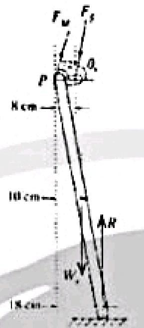


Figure (3)

(i) If the weight of the person is W, express the reaction force R in terms of W

(ii) Generally, W_L = 0.2W. By taking the moments aroud the point P or otherwise obtain a relationship between F_S, θ_S and W.

(iii) Find F_M in terms of W. (Take sin 72° = 0.9 and cos 72° = 0.3)

(iv) Find the value of θ_S.

(v) Find F_S in terms of W. (Only for this calculation, you may take sin θ_S = 1)

(b) When a person with an injured hip joint is walking, he tends to limp by leaning towards the injured side as he steps on the foot attached to the injured joint [see figure (4)]. As a result, the centre of gravity of the body shifts to the side of injured hip joint and F_M acts in the vertical upward direction. The free body diagram for the leg for this case is shown in figure (5)and corresponding forces of F_M and F_S are indicated as F'_M and F'_S respectively.

Figure (4)

(i) Find the force F'_S for this situation, in terms of W.

(ii) Calculate, as a percentage, the reduction in the magnitude of force F_S as result of the limping of the person for the reason described in (b) above.

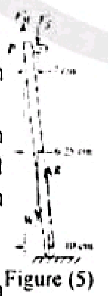


Figure (5)

(c) In the process of walking, while one leg rests on the ground the other leg moves around the hip joint. This motion can be considered as an oscillatory motion of a rod which is freely pivoted at one end as shown in figure (6). Here the leg is considered as a uniform rod of length l.

(i) If I is the moment of inertia of the rod around the axis of rotation through the point Q, obtain an expression for the angular acceleration α in terms of , θ, W_L and l, for the positionindicated in figure (6).

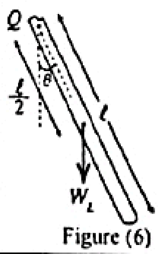


Figure (6)

(ii) The period of oscillations of the rod, T, can be obtained from $T = 2\pi\sqrt{\frac{\theta}{\alpha}}$ and it can be shown that $T = 2\pi\sqrt{\frac{2\ell}{3g}}$ for a uniform rod of length ℓ.
Clculate the value of T corresponding to a person whose length of a leg is 0.9 m. Take = 3 and $\sqrt{0.06} = 0.25$

(iii) The most effortless speed of walking for a person is the speed where his legs oscillate with period obtained in (c) (ii) above. When a person with 0.9 m long legs is walking, the distance between two successive positions where one of his legs touches the ground is 0.9m. Calculate the most effortless walking speed for him.

06. (a) Draw in **four** separate diagrams the standing wave patterns of fundamental mode and first three overtones produced by a tube of length L open at both ends. Mark nodes as N and antinodes as A in the diagram corresponding to the fundamental mode. Obtain expressions for frequencies f of these waves in terms of L and the speed of sound υ, inside the tube. Neglect end corrections.

(b) Figure 1 (a) shows a standard 6 hole-flute. According to a simple model, this flute can be consideredequivalenttoa set of tubes open at both ends. Figure 1(b) shows the corresponding effective lengths of open tubes equivalent to the flute. When all the hole of the flute are opened it is equivalent to an open tube of length L_0 as shown in figure (2). When the first hole of the flute is closed the equivalent length of the tube becomes L_1 and when the first 2 holes are closed at the **same time** the equivalent length becomes L_2 and so on [see figure (2)] L_6 is the equivalent length when all 6 holes are closed. These effective lengths are generally larger than the actual lengths of the flute due to the effects of ends and holes.

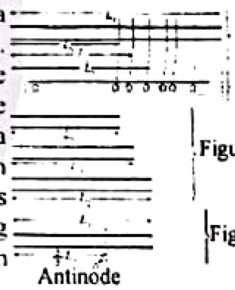


Figure 1 (b)

Figure 1(a)

Figure (2)

Figure (3)

Antinode

Table (1) shows how the holes are closed with fingers to obtain two notes, n_1 and n_2 of the flute and their correspond ing fundamental frequencies. The speed of sound in the tube is 340 ms^{-1}. Calculate the effective lengths L_6 and L_2.

(c) Certain flutes have a few small holes in addition to the standard holes. Such a small hole, when open, will produce an antinode at the location of that hole in the flute. Having such a small hole in the flute will not alter the effective length of the equivalent open tube, but produces an antinode at an appropri -ae location in the equiv- alent tube ther by mod-

Table-(1)

Note	Closed holes ⊗	Fundamental frequency Hz
n_1	⊗ ⊗ ⊗ ⊗⊗ ⊗	262.0
n_2	⊗ ⊗ O OO O	392.0

ifying the wave pattern accordinglyand produces a standing wave. If such an open small hole on the flute produces an antinode at the centre of the equivalent open tube of length L_6 when all other holes are closed, draw the first **two** new standing wave patterns produced in the tube and obtain expressions for their frequencies f in terms of υ and L_6.

(d) (i) Write down the frequencies of first four standing wave patterns in part (c) in terms of υ and L_6.

(ii) Assuming that the length L6 is equal to the length L of the open tube mentioned in (a) above, compare the frequecies that you obtain in (d) (i) with the frequencies obtained in part (a), and thereby comment on the effect of having a small hole as mentioned in part (c).

(e) An antinode is produced at a distance of $\frac{2}{3}$ L_2 in the equivalent open tube due to an open small hole located at the left of the first standard hole of the flute as shown in figure (3). Draw the wave pattern of the first standing wave in the equivalent open tube (corresponding to the lowest frequency) and calculate its frequency, when the flute is played with the small hole opened.

07. Read the passage below and answer the questions given.

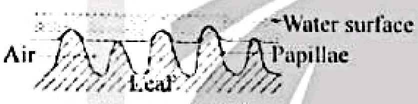


Figure (1)

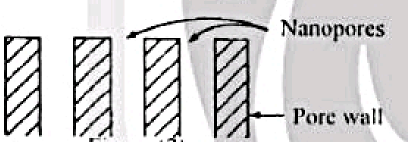
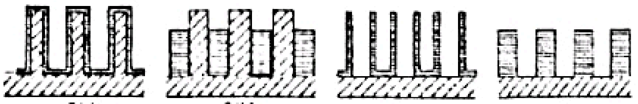


Figure (2)

The magnitude of the contact angle of water depends on the nature of the surfae with which water is in contact. Water drops can settle on certain ideally flat surfaces so that the angle of contact is less than 90°. Such a surface is known to have been wetted by water and acts as a hydrophilic surface.

However, some surfaces consisting of rough structure at micro/nano scale can act as hydrophobic surfaces showing non-wetting properties.

The lotus leaf, compared to other natural leaves, shows **superhydrophobic** properties with a contact angle of water greater than 150° and remains clean in muddy, dirty ponds and tanks. When rain drops fall on the surfaces of lotus leaves, instead of wetting the leaf, they immediately bead up like shiny spherical balls and roll off the surface even at the slightest disturbance, collecting dirt and debris away. This water repellent self cleaning property of lotus leaf is known as the 'Lotus effect'.



3(a) 3(b) 3(c) 3(d)

The lotus effect arises due to the dual scale micro/nano structures present in the lotus leaf. Covering its surface, the lotus leaf has a series of protrusions (parts that stick out like bumps) called papillae that are nearly 10μm in height. Each papilla is covered with a nano-metre scale thick superhydrophobic waxy layer. The roughness introduced by papillae allows air to be trapped under water drops as shown in figure (1) contributing to the non-wetting behaviour of the leaf. Using the lotus effect, a variety of surfaces has been patterned to produce roughened hydrophobic surfaces with high contact angles of water necessary for water repellent window glasses, self cleaning clothes and paints, and low-drag (show low resistance by water against motion) marine vessels, etc.

Wettability of a surface also depends on the nature of the liquid, some liquids wet roughened surfaces whereas, some liquids show non-wetting properties. Property of wetting of roughened surfaces by liquids is used to fabricate nano-structures such as nanotubes and nanorods by means of the techique known as 'template wetting nano fabrication'. This technique uses a solid template that contains an array of nanopores as shown in figure(2).

A non-wetting liquid does not penetrate the pores and settles on the protrusions of the template whereas, a wetting liquid penetrates into pores by wetting walls and filling the pores. When nanopores are filled with a wetting solvent that contains a desired solid and the template is heated, due to evaporation of the solvent, the solid is left behind on the Pore walls or in the nanopores asshown in figures 3(a) and 3 (d) respectively. Removal of pore walls of the template by a chemical treatment known as etching will leave behind structures with nano-tubes or nanorods as shown in figures 3(c) and 3(d), respectively.

(a) Write down **three** applications of artificially fabricated hydrophobic surfaces.

(b) How does the lotus effect help to remove dirt from the surface of a lotus leaf?

(c) How do you categorise hydrophilic, hydrophobic and superhydrophobic surfaces in terms of the contact angle of water?

(d) Show using a diagram how a wetting liquid and a nono-wetting liquid settles on an ideally flat solid surface.

(e) By copying the rough surface in figure (2) draw diagrams to show how a wetting liquid and non-wetting liquid settles on it.

(f) When dew begins to form, do you expect water molecules to condense in the pores on the surface of a lotus leaf? Give reasons for your answer.

(g) State the effect of employing roughened hydrophobic surfaces on low-drag marine vessels.

(h) Mention two nano-structures that can be fabricated using the technique 'template wetting nano fabrication'.

(i) Consider a parallel gold plate capacitor having plates consisting of gold nanorods of diameter of 100 nm and height of 50 μm with 10^{13} nanorods per square meter. Assuming that the capacitance of this capacitor increases due to the increase in the effective surface area, calculate by what factor would the capacitance increase compared to a gold plate capacitor without nanorods, but has identical dimensions. Assume that the separation between capacitor plates is much greater than the height of a nanorod.

08. Two identical planar eletrodes are placed paralle to each other with a separation of d as shown in figure (1). A magnetic field of flux density B can be established between the electrodes in the direction shown in the figure. A beam of ions enters the magnetic field region with speed υ parallel to LM as indicated in figure (1). Each ion has mass m and charge +q. The magnetic field is turned on at time $t = t_0$. Assume that the motion of the ions will not be affected by the medium through which they travel.

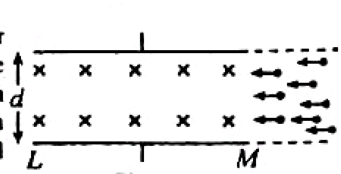


Figure (1)

(a) Obtain an expression for the radius R of the circular path followed by an ion which enters the magnetic field at time $t = t_0$ in terms of υ, B, and q.

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(b) Consider three ions which enter the magnetic field simultaneously at time $t = t_0$ from positions P (very close to the electrode), Q and R as indicated in the figure (2).

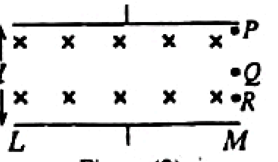


Figure (2)

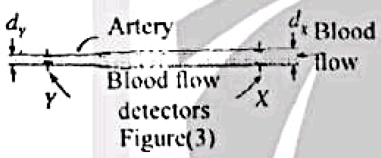
(c) Assume that the ions hitting the electrode LM get gradually and uniformly accumulated on the surface of the electrude.

(i) As the ions get accumulated on the electrode LM, what is the direction of the electric field being developed between the electrodes due to accumulated ions? Assume that the electric field is confined only to the space between the two electrodes.

(ii) Once the accumulation of the ions on the electrode has begun, the path for the ions entering the field region is not a part of a circle. What is the reason for this?

(iii) After a certain period of time has elapsed, the ions entering the field region tends to travel along a straight line without deviation. If V_0 is the the voltage across the electrodes once this state (steady state) has been reached, obtain an expression for υ in terms of V_0, B and d.

(d) As the blood contains charged ions, blood flow detectors based on the above principle can be used to find the speed of blood flow through arteries. Here the two parallel plate electrodes are placed touching the walls of the artery as shown in figure (3), and blood flow speed is determined by measuring the voltage across electrodes at the steady state.



Figure(3)

(i) If the flux density of the applied magnetic field at a certain location X of an artery is $B_x = 0.08$ T and the measured voltage across the electrodes at X is $V_x = 2.16 \times 10^{-4}$ V, determine the speed of blood flow at X using the expression obtained in (c) (iii). The internal diameter of the artery at X is $d_x = 3 \times 10^{-3}$m.

(ii) In order to investigate the possible change in diameter of the artey at another location Y, a similar device is placed at Y. When the magnetic field applied at Y is set to $B_y = 0.05$ T, the measured voltage across the electrodes at Y is $V_Y = 1.80 \times 10^{-4}$V. Find the internal diameter d_Y of the artery at Y.

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

(A) (a) A potential divider AB of total resistance R_0 is used to provide a variable voltage to a load resistance R_L. The potential divider is connected to a power supply of voltage V as shown in figure (1).

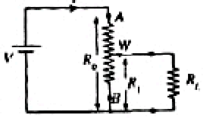


Figure (1)

(i) When the resistance of the section of the potential divider between the points B and the sliding contact (wiper) W is R_1, derive an expression for the equivalent resistance between A and B.

(ii) Through argumentation or otherwise, show that the minimum and the maximum resistances that can exist between A nd B are $\frac{R_0 R_L}{R_0 + R_L}$ and R_0 respectively.

(iii) If $R_0 = 5$ kΩ, calculate the minimum value of R_L which will permit only up to a 1% of variation in the current I of the circuit when slider W is moved from A to B.

(b) Terminals 1-9 of the potential divider shown in figure (2) are used to provide currents to 9 electrodes (not shown in the figure) of a certain device. Values of the resistors R_1, R_2 and R_3 are selected so that when electrodes are not connected to the potential divider, and a voltage (V_0) is applied to the potential divider, the voltage appearing across the resistor R_1 is 4 times that appearing across each and every R_2 resistor, and the voltage appearing across R_3 is 3 times that across R_2.

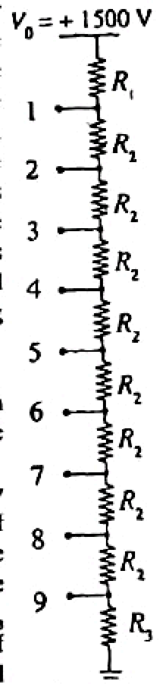


figure (2)

(i) If $V_0 = 1500$V and the current through the potential divider is 1 mA, calculate R_1, R_2 and R_3.

(ii) Consider a situation where only terminal 9 has to provide a current of 5 μA for a period of 1 μs to the electrode to which it is connected. Calculate the voltage drop appearing across R_3 during this period due to the supply of the above current from the potential divider. Assume that the current through the potential divider from terminal 1 to terminal 9 remains undhanged at 1 mA.

(iii) In situations where curents are drawn for short periods of time as in (b)(ii), the drop created in terminal voltage can be minimized by providing this current from the charges stored in the capacitor connected across R_3 as ahown in figure (3).

(1) Calculate the amount of charge ΔQ carried by 5 μA current during the period of 1μs.

(2) If this amount of charge ΔQ is provided by the capacitor of capacitance C shown in figure (3), write down an expression for the drop in voltage ΔV across the capacitor in terms of ΔQ and C.

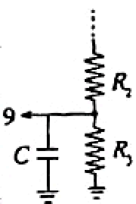


figure (3)

(3) If this drop in voltage is to be limited to 0.05V, find the value of the capacitor that has to be connected across R_3.

(B) (a) Draw the input-output voltage characterictic for a 741 operational ampilfier and label the linear and saturation regions.

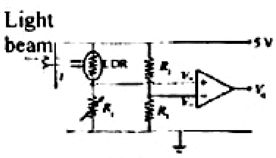


figure (1)

(b) A circuit is to be designed to detect an intruder I entering a premises at night. A part of a circuit that can be used for this purpose is shown in figure (1).

A narrow beam of light is set to incident continuously on the Light Dependent Resistor (LDR) as shown in figure (1). The operational amplifier is to operate with V_o at its saturation voltages of ±10V.

(i) If the voltage at the inverting input (V_-) is set at 3.5V, calculate the value of R_2. Take the value of R_3 as 7000 Ω.

(ii) When light falls continuously on the LDR, it is decided to maintain a voltage difference of 0.5V between the inverting input (V-) and the non inverting input (V+). What should be the value of R_1 in order to achieve a value of +10 V at the output V_o under this condition? Assume that the resistance of the LDR when light falls on it is 500 Ω.

(iii) If the light beam gets obstructed due to the movement of the intruder, what will be the value of V_o during the period of interruption? Give reasons to your answer. Take the resistance of the LDR under this condition as 10^5Ω.

(c) Suppose the output of the circuit given in figure (1) is now connected to the circuit shown in figure (2).

(i) When V_o = +10V, calculate a suitable value for R_B to provide a base current of 50μA. Take $V_D = V_{BE}$ = 0.7V.

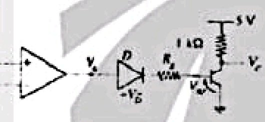


Figure (2)

(ii) If the current gain of the transistor is 100, find the value of the collector voltage V_C under the situation given in (c)(i).

(iii) When V_o = -10V,
  (1) What will be the potential difference across the diode? (Assume that the reverse breakdown voltage of the diode is 25V.)
  (2) what will be the collector voltage V_C under this condition?

(d) (i) If the transistor output V_C is connected to a S-R flip-flop as shown in figure (3), write down the input logic levels of *S* and *R* when light falls on the LDR, and when the intruder crosses the light beam.

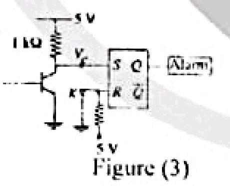


Figure (3)

(ii) If the alarm operates when Q = 1, state whether the alarm sounds continuously even after the intruder has crossed the light beam and moved away. Explain your answer. (K is a grounded switch.)

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

(A) Figure 1(a) shows a parabolic disc type solar energy collector having a circular aperture which extracts and converts solar energy to heat. Solar energy flux is concentrated to a cavity receiver placed at the focus of the parabolic disc as shown in figure 1(a). An oil passing continuously through a spiralled metal tube fixed to the inner wall of the cavity extracts the heat absorbed by the cavity. Parabolic disc is moved so that the solar flux always falls normal to the disc as shown in figure 1(b). Aperture diameter, *d* of the disc is 20 m and the intensity of the solar flux striking the earth surface is 1000W m^{-2}.

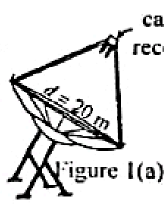


Figure 1(a)

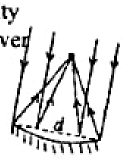


Figure 1(b)

(a) Calculate the rate at which solar energy is incident on the parabolic disc (Take π =3).

(b) Assuming that sunshine is available for 6 hours a bay and 60% of the incident solar energy is absorbed by the oil, calculate the thermal energy stored in oil per day.

When answering the parts (c) and (d) take the thrmal energy stored in oil per day as 5 x 10^9J.

(c) It is planned to store this heated oil in an insulated tank so that it can be used even during night. A cubical tank, insulated with two layers of materials of thickness d_1 (inner) and d_2 (outer) having thermal conductivities k_1 and K_2 respectively is used for this purpose [see figure 2]. Such a storage of thermal energy is called a thermal battery.

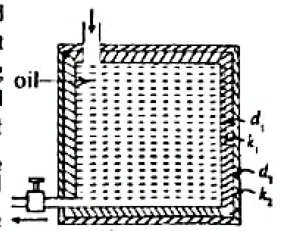


Figure (2)

(i) If the effective total surface area of cross-section of the inner and outer insulation layers are A_1 and A_2 respectively, write down expressions for the rate of flow of heat through the insulation layers, $\left(\frac{\Delta Q}{\Delta t}\right)$, at the steady state in terms of d_1, d_2, k_1, k_2, A_1, A_2, θ_1, θ_2, and θ_3, where θ_1 = temperature of the oil; θ_2 = temperature at the interface between the two layers; θ_3 = room temperature. Assume that the tank is completely filled with oil and heat flow is normal to the surfaces every where.

(ii) Find the thickness d_2 that the outer insulation layer must have in order to limit the heat loss from oil to the environment in a period of 10 hours to 1 % of the total thermal energy stored per day. Perform your calculation assuming that the temperature of oil, remains at θ_1 = 330 °C during the 10 hour period. Take k_1 = 0.2J m^{-1} K^{-1}; k_2 = 0.03J m^{-1} K^{-1}; A_1 = 16m²; A_2 = 17m²; d_1 = 0.2m; θ_3 = 30°C.

(iii) If the d_2 value calculated under the assumption in part (c) (ii) above is used to construct the thermal battery, will the heat from the battery be less than or greater than the planned limit of 1%? Explain your answer.

(d) 25% of the thermal energy stored per day in the thermal battery is to be used to produce distilled water by sending water at 30 °C through a metallic spiral tube dipped in the tank as shown in figure (3) and producing steam at 100°C. The steam is condensed using a heat exchanger. Calculate the number of litres of distilled water that can be produced per bay if the efficiency of this process is 50%. Specific latent heat of vaporization of water is 2.25 × 106 Jkg⁻¹. Specific

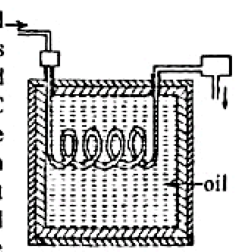


Figure (3)

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heat capacity of water is 4200 J kg^{-1} K^{-1}
(1 kg of water ≡ 1 liter)

(B) Write down the expression for the Stefan-Boltzmann law of blackbody radiation. Identify each quantity of the above expression.

(a) (i) The sun behaves like an idealized black body. The distance from the Sun to the surface of the earth is 1.5×10^8 km. If the intensity of solar radiation flux received on the earth from the Sun is 1000 W m^{-2}, find the temperature of the Sun's surface. Neglect the temperature of the earth compared to the surface temperature of the Sun. Take the mean radius of the Sun as 7.0×10^5 km. Stefan - Boltzmann constant is 5.67×10^{-8} W m^{-2} K^{-4}.

(ii) Hence, calculate the wavelength of the peak emission of radiation from the Sun at the above temperature. The Wien's displacement constant is 2.9×10^{-3} m K.

(iii) A satellite orbiting the earth found that the more accurate temperature of the surface of the Sun to be 5800 K. Explain briefly the reason for the deviation of your answer from this value.

(b) The sunspots are irregularly shaped small dark regions of the surface of the Sun. The dark centre of a sunspot is known as the umbra and it emits 30% of radiation compared to an equal area without sunspots on the surface of the Sun.

(i) Assuming that a sunspot also behaves as an idealized black body, calculate the temperature of the umbra of a sunspot.

(ii) Calculate the shift in the wavelength of the peak emission of radiation from the umbra compared to the wavelength of peak emission of radiation from the normal surface of the Sun.

(c) What changes in appearance would you expect to observe in the Sun if the number of sunspots per unit area of the Sun's surface increases **significantly?** Explain your answer using the blackbody radiation spectrum.

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