PART A — Structured Essay

Answer all four questions on this paper itself.

($g = 10\,N\ kg^{-1}$)

In an experiment to find the density of coconut oil you are provided with the following:

(1) U-tube mounted on to a vertical frame with appropriate scales
(2) Water and sufficient amount of coconut oil
(3) Funnels.

(*a*) (i) Draw a labelled diagram of the experimental setup, clearly showing the levels of wat and coconut oil columns and their common interface.

(ii) On the diagram drawn above mark, as h_1 and h_2, the two measurements that you have to take.

(*b*) If the densities of coconut oil and water are given by d_1 and d_2 respectively, write down an expression for d_1 in terms of d_2, h_1 and h_2.

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(*c*) (i) Select the correct procedure out of the following in order to draw a graph in determining d_1

(1) Adding more water to the respective arm.
(2) Adding more coconut oil to the respective arm.

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(ii) Give the correct reason for not selecting the other procedure.

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(iii) In such a graph the gradient is found to be 0·87. Determine the density of coconut oil (density of water = $10^3\ kg\ m^{-3}$).

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(*d*) In this experiment, which liquid should be poured into the U-tube **first**. Give reasons for your answer.

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(*e*) If you want to determine the density of coconut oil with a fractional error of 0·1, what should be the minimum height possessed by a liquid column? Assume that the height of a liquid column can be measured with an accuracy of 1 mm.

[**Hint:** Fractional error of density $\left(\frac{\Delta d}{d}\right)$ = 2 × fractional error of height of a liquid column $\left(\frac{\Delta h}{h}\right)$]

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(*f*) What is the experimental **disadvantage** of using mercury instead of water in this experiment?

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11. You are asked to determine the dew point inside the laboratory using a polished calorimeter.

(*a*) What is the experimental procedure that you would follow in this experiment to form dew on the calorimeter surface?

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(*b*) Two temperature readings are to be taken in this experiment. What are they?

(1) .....

(2) .....

(c) In this experiment water is stirred to achieve a uniform temperature throughout the volume of water. Why is this important?

oil

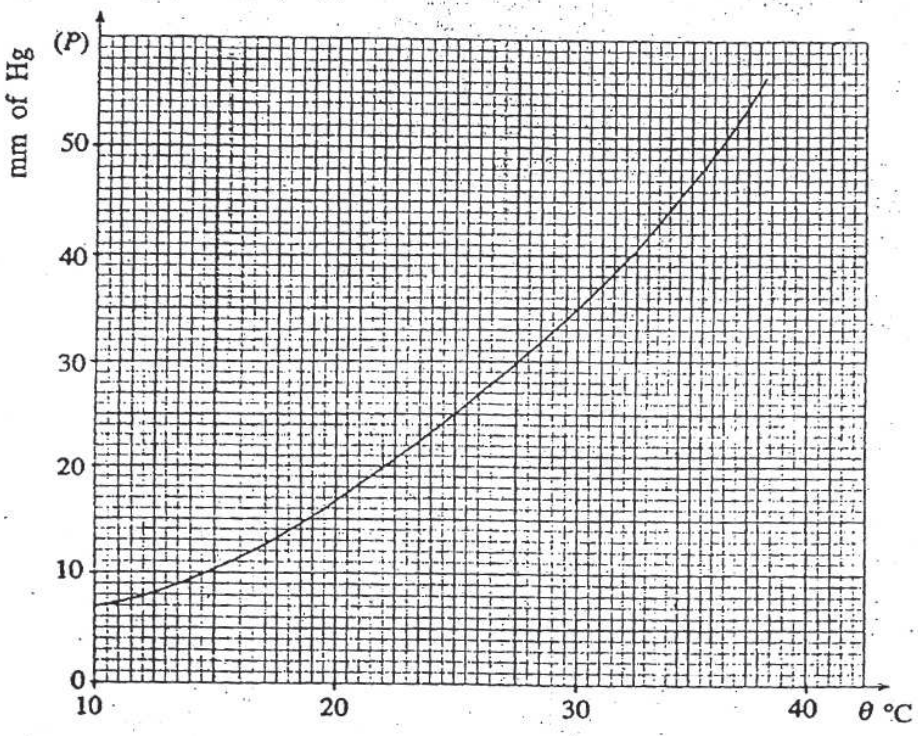
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(d) If the two temperatures obtained in (*b*) are 23·2 °C and 23·6 °C, then what is the dew point?

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(e) In a certain day when the room temperature is 30 °C the dew point is 25 °C. You are supposed to calculate the relative humidity using the following graph, which shows the variation of saturated vapour pressure (P) with temperature (θ).



(i) Write down the **relevant formula** that you use in order to calculate the relative humidity.

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(ii) Hence, find the relative humidity.

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(f) When you blow your breath on a polished metal surface you can observe that the surface brightness is being reduced. Explain the reason for this.

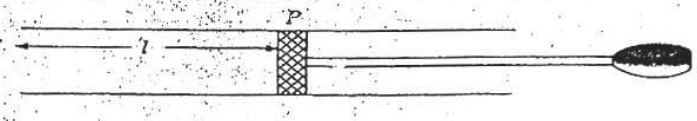
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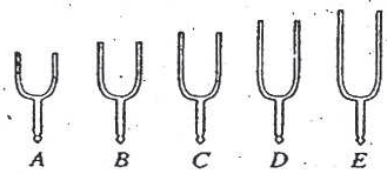
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3. To study the resonance phenomenon in sound you are asked to use a glass tube with a piston (P), and a set of tuning forks (A, B, C, D and E) found in your laboratory (see figure). The piston can be moved smoothly inside the glass tube.





(a) All the tuning forks are made of the same material and prongs have the same area of cross section. If it is known that the set of tuning forks has the frequencies, 256 Hz, 384 Hz, 512 Hz, 420 Hz and 320 Hz, what is the frequency of the tuning fork B?

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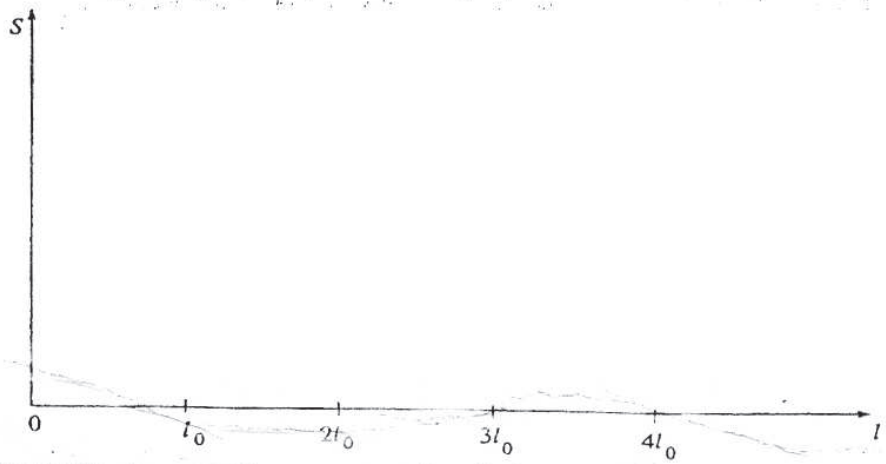
(b) (i) For a given tuning fork, briefly describe how you would obtain a resonance length l_0 corresponding to the fundamental tone.

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(ii) Instead of the ear, a sound measuring instrument is kept close to the open end of the tube to record the intensity levels (S) of the sound when l (shown in the above figure) is varying in order to obtain l_0 in (b) (i). Sketch below the expected variation of S with l in, and around l_0.



(iii) What is the corresponding resonance length for the first overtone in terms of l_0? (Assume that the end correction is negligible.)

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(iv) Sketch also on the same diagram above, the expected variation of S with l corresponding to the first overtone.

(c) Suppose now you wish to find the velocity of sound in air using **all** the tuning forks in the above set.

(i) In order to use a graphical method to find the velocity of sound in air, which tuning fork from the above set is most desirable to use first.

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(ii) There is another important physical quantity that you should record during the experiment in order to report your result meaningfully. What is this physical quantity?

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(d) In (b) (ii) it was observed that the value of S for one instant was 60 dB. Find the corresponding intensity of sound given that the threshold of audibility is 10^{-12} W m^{-2}.

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4. The potential divider shown in Figure (1) provides a variable potential difference (V_{XY}) across the terminals X and Y. R is a 5 kΩ variable resistor with the sliding contact P. E is a 6 V battery with negligible internal resistance.

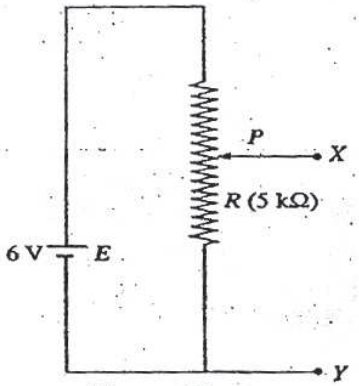


Figure (1)

(a) Following items are provided for you to plan an experiment to verify Ohm's law by using the above potential divider.

An ammeter with negligible internal resistance —Ⓐ—

A voltmeter with 10 MΩ internal resistance —Ⓥ—

A 60 Ω resistor —WW—

(i) Complete the circuit diagram in figure (1), using these items in order to obtain the circuit employed for this experiment.

(ii) Mark the positive terminals of ammeter and the voltmeter in the above circuit using the "+" sign.

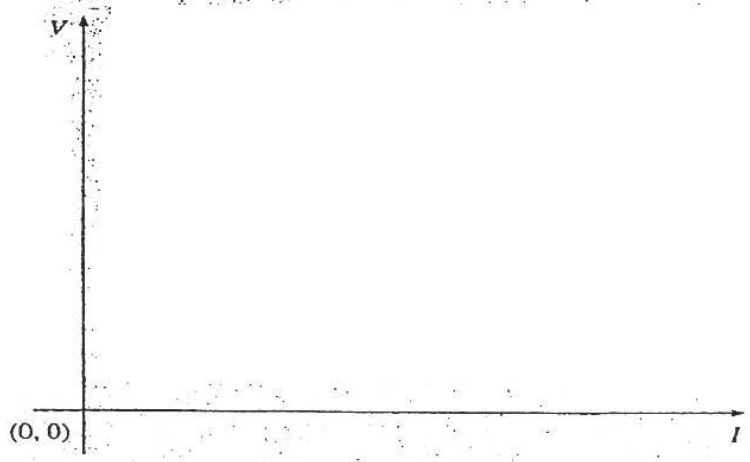
(iii) Suggest a suitable value for the full scale deflection of the ammeter.

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(iv) What is the advantage of using an ammeter with a full scale deflection suggested in (iii) above?

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(v) Draw a rough sketch of the graph that you would expect from this experiment.



(*b*) The 60 Ω resistor was then replaced by a torch bulb and the *V* versus *I* graph in figure (2) was obtained.

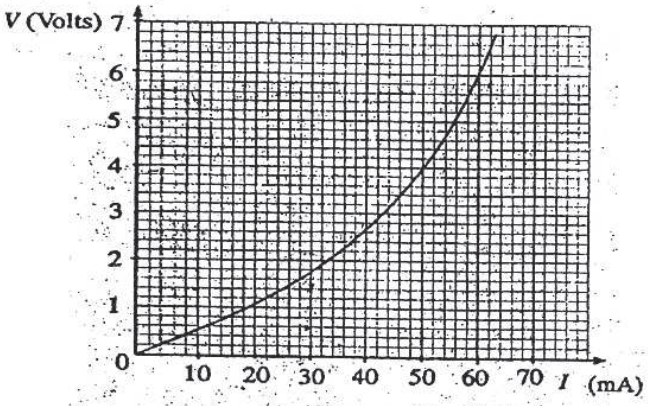


Figure (2)

(i) What is the reason for the deviation of the *I* - *V* characteristic of the filament from the Ohms law?

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(ii) Rating of the torch bulb is given as 6 V, 0·36 W.
Calculate the resistance of the filament of the bulb when operating at the above recommended rating.

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(iii) Mark the operating point of the bulb on the above curve with '×' sign when it glows with its recommended rating.

(c) A 6 V torch bulb produced by another manufacturer requires 360 mA to produce similar brightness to the bulb mentioned under (*b*) (ii).

(i) Which bulb would you prefer in your torch?

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(ii) What is the advantage of your selection?

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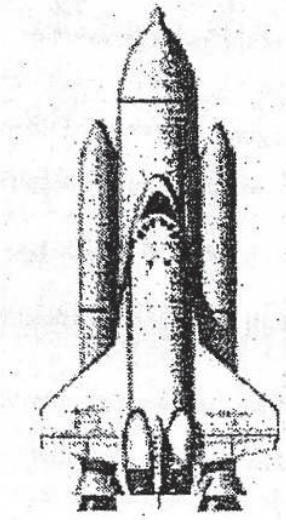
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கல்விப் பொதுத் தராதரப்பத்திர(உயர் தர)ப் பரீட்சை, 2003 ஏப்பிரல்
General Certificate of Education (Advanced Level) Examination, April 2003

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பௌதிகவியல் II
Physics II

PART B — Essay

Answer four questions only.

(g = 10 N kg^{-1})



A space shuttle, when it stands on the launching pad, has a mass of $2{\cdot}0 \times 10^6$ kg. The upward thrust needed to move the shuttle is $3{\cdot}0 \times 10^7$ N, which is achieved by burning $3{\cdot}0 \times 10^3$ kg of fuel per second and expelling the hot gas thus produced, through the nozzle at the bottom. The force of upward thrust is given by the product of the rate (M) at which fuel is burnt and the exhaust velocity (u) of the gas **relative to the shuttle.**

(i) Show that the product, Mu, has the dimensions of force.

(ii) (*a*) What is the initial acceleration of the shuttle just as it begins leaving the launching pad?

(*b*) Assuming that the acceleration of the shuttle is constant, determine the velocity of the shuttle 30 s after take off.

(iii) (*a*) Calculate the exhaust velocity (u) of the gas **relative to the shuttle.**

(*b*) What is the exhaust velocity of the gas **relative to the earth** 30 s after take off?

(iv) A student states that the shuttle cannot accelerate if there is no atmosphere outside. Is this statement correct? Explain your answer.

(v) (*a*) In reality the acceleration of the shuttle increases as it burns fuel, even though the upward thrust on the shuttle is constant. Explain this statement.

(*b*) Sketch the velocity (v)-time (t) curve for the shuttle corresponding to the situation in (v)(*a*) above.

(vi)

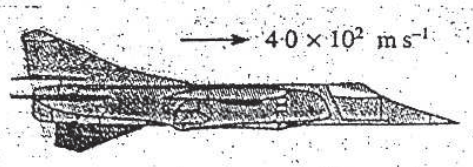


Figure (*A*)

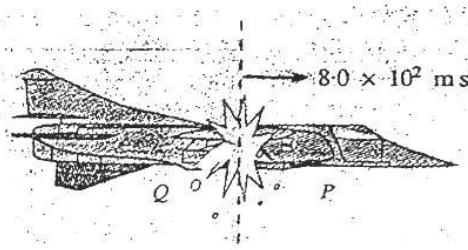


Figure (*B*)

(*a*) Consider a situation where the shuttle is moving horizontally close to the earth surface as shown in figure (*A*) with a velocity of $4{\cdot}0 \times 10^2$ m s^{-1}. The mass of the shuttle at this instant is $1{\cdot}0 \times 10^5$ kg. Unfortunately, due to an internal explosion the shuttle breaks into two pieces (*P* and *Q*) with equal masses. If the piece *P* moves forward horizontally with a velocity of $8{\cdot}0 \times 10^2$ m s^{-1} (relative to the earth) as shown in figure (*B*), determine the velocity of piece *Q* relative to the earth. What is the velocity of *Q* relative to *P*? Assume that there is no loss in the mass of the shuttle due to explosion.

(*b*) Briefly state the subsequent motion of pieces *P* and *Q* after the explosion as seen by an observer on the earth.

(*c*) If the explosion lasts for 0·2 s what is the average value of the force exerted on each piece due to the explosion?

2. The angular magnification (m) of a telescope is given by $m = \frac{\alpha'}{\alpha}$. Identify α' and α.

With a **suitable diagram/diagrams,** show that a higher angular magnification will produce a larger image on the eye.

An astronomical telescope is made with an objective of focal length 100 cm and an eyepiece of focal length 5 cm.

(i) Draw a ray diagram for the telescope when it is in normal adjustment. Clearly label the objective and the eyepiece.

(ii) Use the ray diagram drawn in (i) to calculate the angular magnification of the telescope.

(iii) The telescope is used to observe the moon. Its eyepiece was adjusted to form the final image at the near point of the eye. The moon subtends an angle 0·25° at the unaided eye. Using first principles calculate the angle subtended by the image of the moon at the eye. You can assume that the near point of the eye is at a distance of 25 cm and the distance between the eye and the eyepiece is negligible.
(You may use 1° = 0·018 radians.)

(iv) The objective of the telescope in the above adjustment has to be moved by 10 cm in order to focus an object at a closer distance. Find the distance to the object from the objective of the telescope.

3. A space lab is in a circular orbit of 1700 km above the earth surface.

(i) What is the speed of the space lab? Radius of the earth is 6400 km and gravitational acceleration (g) on the earth surface = 10 m s^{-2}.

(ii) Calculate the **minimum** energy that has to be supplied to a space vehicle of mass 10^4 kg including cargo to just reach the orbit of the space lab from the earth. Neglect air resistance.

(iii) What **additional** energy is required for the space vehicle to link with the space lab without changing its orbit?

(iv) After the linkage, the cargo in the space vehicle is transferred to the space lab. Will the speed of the orbiting space lab change due to loading this cargo? Explain your answer.

4. (i) Three glass capillary tubes are immersed partially in three liquids A, B and C, in which the angles of contact with glass are 30°, 90° and 130°, respectively. If the tubes are immersed vertically, in each of the above cases, draw the liquid level outside the tube, liquid level inside the tube and the shape of the liquid meniscus in the tube. Clearly indicate the directions of surface tension forces acting on the liquid in the tube and mark the angles of contact.

(ii) A glass tube of inner radius (r) 0·5 mm is immersed vertically in a container of mercury such that the lower end of the tube remains 10 cm below the surface of mercury in the container. The surface tension (T) and the density of mercury (ρ) are 0·465 N m^{-1} and 13·6 × 10^3 kg m^{-3}, respectively and the angle of contact, (θ) between mercury and glass is 140°. The atmospheric pressure is 1·0 × 10^5 N m^{-2}. Gravitational acceleration (g) is 10 m s^{-2}.

(a) Derive an expression for the difference (h) between mercury levels of the tube and the container in terms of r, T, ρ, θ, and g. Hence calculate h. [cos 40° = 0·766]

(b) What must be the pressure of air in the tube in order to form a hemispherical meniscus at the lower end of the tube?

(iii) Oil in a hot cup of soup floats in little oil bubbles on the surface of the soup, but when the soup cools the oil spreads over the surface of the soup. Explain the above observations in considering the variation of surface tension of water and oil with temperature.

5. **Answer either part (a) or part (b).**

(a) How does a real voltmeter differ from ideal voltmeter concept?

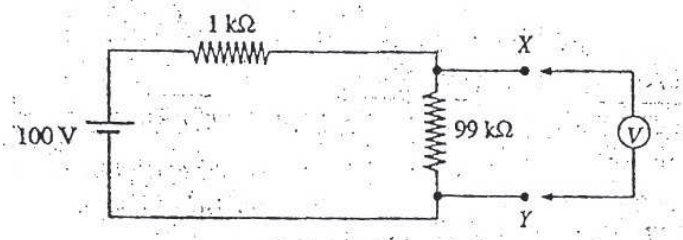


Figure (1)

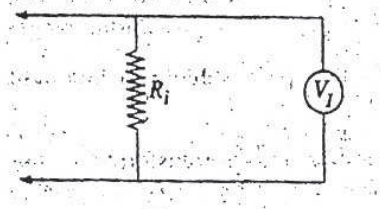
(i) Voltage across the terminals XY of the above circuit is measured

(a) with a voltmeter (V) having an internal resistance very much greater than 99 kΩ.

(b) with a voltmeter (V) having an internal resistance of the order of 1 kΩ.

Estimate the approximate values of voltmeter readings in (a) and (b). Neglect the internal resistance of the cell.

(ii) If the voltmeter (V) in figure (1) above has an internal resistance R_i, give reasons to justify that the voltmeter V is equivalent to the following combination, where V_I represents an ideal voltmeter.



(iii) Figure (2) shows a potentiometer arrangement.

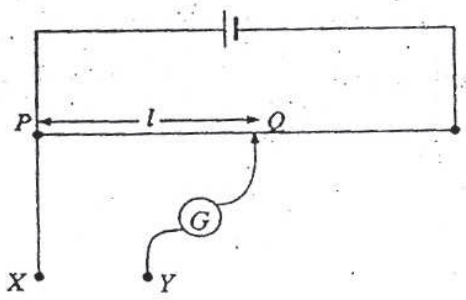


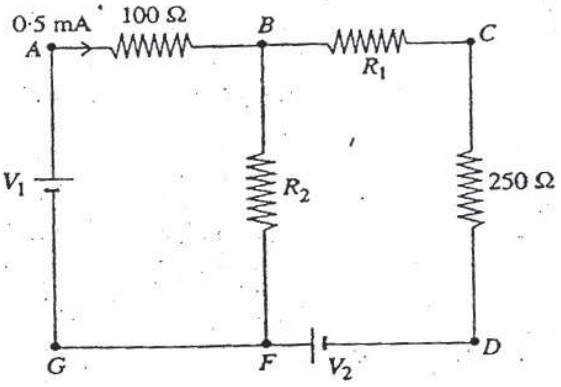
Figure (2)

Terminals XY can be connected to a suitable electrical circuit.

'Under the balanced condition, the terminals XY of the above arrangement act as the terminals of an ideal voltmeter.'

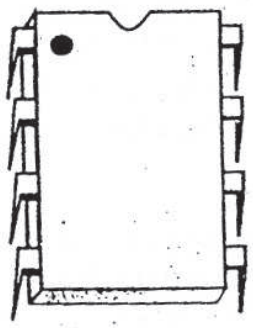
Would you agree with this statement? Give reasons to justify your answer.

(iv) In the circuit shown, current through the 100 Ω resistor is 0·5 mA. When the terminals XY of the above potentiometer arrangement are conntected across AB, CD and BF, the balanced lengths obtained are 40 cm, 20 cm and 64 cm respectively. Find the resistance of R_2.



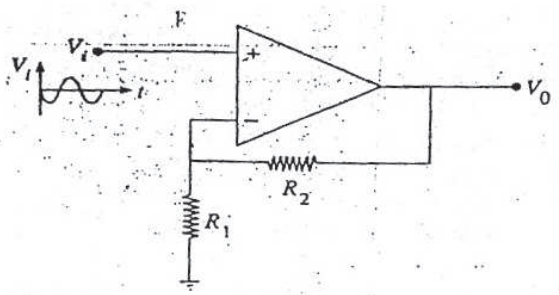
(i). (*a*) State **two** advantages of integrated circuits (IC) over electronic circuits constructed of discrete elements.

(*b*) Top view of an operational amplifier IC is shown below.



Copy the diagram onto your answer script in a suitable manner and number the pins.

(ii)



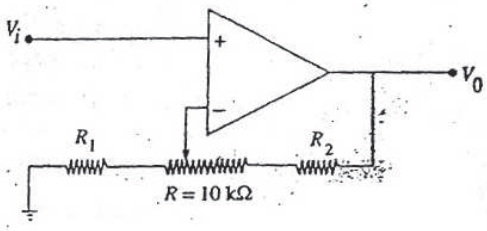
(*a*) Identify the above circuit and write down an expression relating V_0 and V_i interms of R_1 and R_2.

(*b*) Draw a rough sketch of the output waveform for the input waveform shown in figure.

(*c*) What will be the voltage gain of the circuit when R_1 is made very large relative to R_2?

(iii) The circuit in (ii) above is modified as shown below to form an amplifier with a variable voltage gain.

R_1 and R_2 are fixed resistors and R is a variable resistor. The operational amplifier operates with two voltage supplies of +15 V and −15 V.



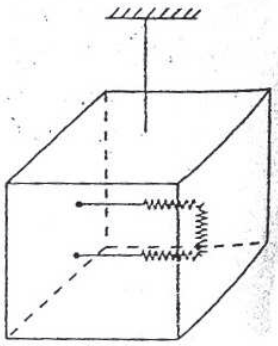
(*a*) Calculate suitable values for R_1 and R_2 in order to obtain a variable voltage gain between 10 and 100.

(*b*) What would be the range of input voltages (V_i) that can be amplified properly with this amplifier?

(*c*) What is the gain of the amplifier when R_1 is disconnected from the ground?

6. **Answer either part (a) or part (b).**

(a) A hollow closed cube of side 0·5 m is made of thin metal sheets of specific heat capacity 200 J kg^{-1} K^{-1}. A heating element of electrical resistance 23 Ω at its operating temperature, and heat capacity 100 J K^{-1} is placed inside the cube. The cube is hung by an insulated string in a room at temperature 27 °C.



(i) Assuming that the cube is filled with an ideal gas at atmospheric pressure and room temperature, find the number of gas moles in the cube. The atmospheric pressure and the gas constant (R) are $1{\cdot}0 \times 10^5$ N m^{-2} and 8·31 J mol^{-1} K^{-1}, respectively. Neglect the volume of the heating element.

(ii) The heating element which is connected to a house-hold power supply of 230 V is switched on at time $t = 0$. At $t = 5$ minutes, the temperature of the cube and the air inside the cube is found to be 177 °C. Assume that the heating element attains its operating temperature of 827 °C as soon as the switch is turned on.

During the five minute period, find

(*a*) the total energy supplied by the power source.

(*b*) the energy absorbed by the walls of the cube and the heating element. Total mass of the walls of the cube is 6·0 kg.

(*c*) the energy absorbed by the gas within the cube. The molar heat capacity of the gas is 20 J mol^{-1} K^{-1}.

(*d*) the percentage energy lost from the system.

(iii) When the system reached the steady state find the temperature of the outer surface of the cube. Neglect the heat loss due to convection and conduction, and assume that the room temperature remained unchanged. Stefan constant (σ) is $5{\cdot}67 \times 10^{-8}$ W m^{-2} K^{-4} and the emissivity of the surface is 0·7.

(b) Read the following passage carefully and answer the questions given below.

Not all atomic nuclei are stable. Unstable nuclei transform themselves into other nuclei by spontaneous emission of α particles, β particles and γ-rays. Such unstable nuclei are said to be radioactive nuclei. This phenomenon was discovered in 1896 by a French scientist named Henri Becquerel.

The rate of decay which is called the activity (A) of a given radioactive sample is directly proportional to the number of unstable nuclei (N) in the sample. This radioactivity law can be expressed as $A = \lambda N$, where λ ($= 0{\cdot}693/T$) is the decay constant and T is the half-life. One important application of radioactivity is the radiocarbon dating which is a technique used for the determination of the age of fossils.

Radioactive carbon $^{14}_{6}C$ is being produced continuously in the Earth's atmosphere as a result of a nuclear reaction between a nitrogen $^{14}_{7}N$ atom in air and a cosmic ray neutron with the emission of a proton. Subsequently $^{14}_{6}C$ atom decays into nitrogen by emitting a β^- particle with a half-life of 5730 years ($= 1{\cdot}8 \times 10^{11}$ s). Because of these two processes there exist an equilibrium between the rate at which $^{14}_{6}C$ is produced in the atmosphere and the rate at which it decays. As the composition of the Earth's atmosphere and the flux of cosmic rays have not been changed significantly in the last few thousand years, the ratio, $\frac{\text{number of } ^{14}_{6}C \text{ atoms}}{\text{number of } ^{12}_{6}C \text{ atoms}}$ which is 10^{-12} in atmospheric carbon dioxide (CO_2) can be considered to be constant throughout this period.

Living plants and animals take carbon from the atmosphere and hence the percentage of $^{14}_{6}C$ in plants and animals remains constant as long as they are alive. When a plant or an animal dies, the $^{14}_{6}C$ continues to decay without being replaced. As a result the percentage of $^{14}_{6}C$ decreases with time.

In radioactive carbon dating the number of β^- particles given off in a certain period of time by a fixed volume of CO_2 gas in the atmosphere at a given temperature and pressure is first measured using a particle counter. Hence the activity of $^{14}_{6}C$ in the atmospheric CO_2 volume can be calculated. Then a small piece of the fossil is burnt and an equal volume of CO_2 under the same conditions is prepared. The activity of $^{14}_{6}C$ in the fossil sample can be calculated by measuring the number of β^- particles emitted from this CO_2 volume. Using the above data the age of the fossil can be determined.

(i) What is the SI unit of activity?

(ii) Write down the law of radioactivity in words.

(iii) Define the half-life of a radioactive sample.

(iv) What is the reason for the radioactive decay of certain nuclei?

(v) Write down the nuclear reaction corresponding to the production of $^{14}_{6}C$ in the atmosphere.

(vi) Write down the decay reaction of $^{14}_{6}C$.

(vii) What are β^- and β^+ particles? What is an α particle?

(viii) Explain how the percentage of $^{14}_{6}C$ in the atmosphere remains constant.

(ix) Find the decay constant λ of $^{14}_{6}C$.

(x) There are 5.0×10^{22} atoms of $^{12}_{6}C$ in 1 g of carbon. If all the β^- particles emitted by a sample of 1 g of carbon of a living plant are counted, how many counts would be accumulated in one hour.

(xi) Radiocarbon dating has been used to find the age of a piece of fossil. Number of β^- counts obtained in one hour from 1 g of carbon in the fossil is found to be 347. Find the age of the fossil.