G.C.E. (Advanced Level) Examination - August 2007
PHYSICS - II
Three hours

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

01. You are to determine the density of the material used to make a A-4 size (30 cm x 21 cm) photocopy paper.

(a) You are provided with a spring balance, a triple-beam balance and a chemical balance which are available in a school laboratory. What is the most suitable measuring instrument that you would select to determine the mass (m) of the sheet of paper?

....

(b) In order to determine the volume of the paper you have to take three measurements. Indicate below the most suitable and appropriate measuring instrument you would use to measure each of them.

Measurement	**Instrument**
(1) Length of the paper (say l)	....
(2) Width of the paper (say w)	....
(3) Thickness of the paper (say t)	....

(c) Write down an expression for the density (d) of the material used to make the paper, in terms of m, l, w and t.

d = ...

(d) When measuring the thickness, it is more appropriate to take several readings at different places of the paper. What is the reason for this?

....

(e) (i) Once the most appropriate measuring instruments are used by a student to measure l and t, the values he obtained are given below. Determine the fractional error of each of the measurements l and t. (It is **not** necessary to simplify your answers.)

	Fractional error
(1) l = 30.0 cm	....
(2) t = 0.15 mm	....

(ii) In order to achieve the fractional error of t same as that of l, a student suggested to measure the thickness of a bundle of papers. How many papers does he need to make the bundle?

....

(f) In practice, a unit called gsm is used to measure the thickness of papers. gsm stands for grams per square metre, i.e. the mass of 1 m^2 area of a given paper.
Assuming that in (a) and (b) above, m was measured in grams and the l and w were measured in centimetres, write down an expression for the gsm value of the paper.
gsm value = ...

02. You are asked to design and perform an experiment in the school laboratory to determine the specific heat capacity of a metal using the method of mixtures. Water, a thermally insulated calorimeter with a stirrer, a thermometer and small metal balls heated to 100 °C are provided.

(a) What is the other instrument you need in this experiment?

....

(b) What is the advantage of using a thermally insulated calorimeter?

....

(c) List the measurements you will obtain in this experiment in the order that you perform the experiment.
(1) ....
(2) ....
(3) ....
(4) ....
(5) ....

(d) The amount of water used in the calorimeter should not be too small or too large.

(i) Give a reason as to why it should **not** be too small.

....

(ii) Give a reason as to why it should **not** be too large.

....

(e) Suppose the following values were calculated from your experimental results.

Heat gained by calorimeter, stirrer and water	= 2400 J
Mass of metal balls	= 0.3kg
Decrease in temperature of metal balls	= 64°C

Calculate the specific heat capacity of the metal.

....
....

(f) Why is it **not suitable** to heat the metal balls in a water bath at 100 °C in order to obtain the 'metal balls heated to 100 °C required for this experiment?

....
....

(g) Instead of small metal balls, is it possible to use metal powder in this experiment? (Yes/No) Give **two** reasons for your answer.
(1) ....
(2) ....

03 A student is asked to design an experiment using the resonance phenomenon to determine the speed (υ) of transverse waves in a sonometer wire being kept under constant tension. The student is supposed to use a graphical method. A set of tuning forks is provided for this purpose.

(a) If resonance at the fundamental mode was obtained with a tuning fork of frequency f, write down an expression for υ in terms of resonance length l, and f.

υ = ...

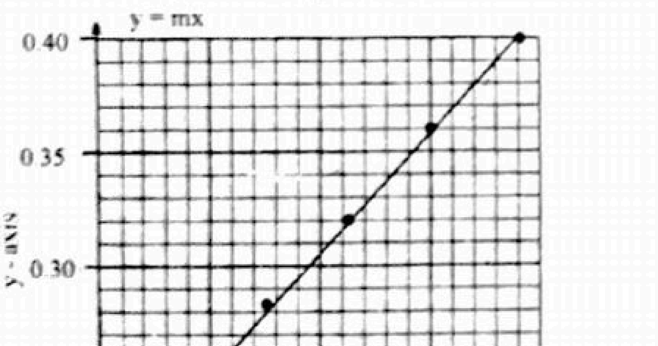
(b) Rearrange the expression in (a) above to take the form $y = mx$, where y is the dependent variable. In this experiment choose y in such a way that it is not a reciprocal of a measurement. Identify x.

(c) State whether you would start the experiment with the tuning fork having the highest frequency or with the tuning fork having the lowest frequency first. Give the reason for your answer.

(d) How would you identify the tuning fork with the highest frequency from the given set of tuning forks, only considering their physical dimensions?

(e) why is it easier to observe the resonance state of the wire at its fundamental mode of vibration than at an overtone?

(f) The graph, y against x, obtained by the student is shown below. All quantities are given in SI units.



(i) Label the axes of the graph with units.

(ii) Calculate υ from the graph. Clearly indicate the **two** points which you have used to calculate υ.

(g) The error Δl of the resonance length l has two components; i.e. the reading error (Δl_1) of the instrument used to measure l, and the error due to the uncertainty in obtaining the resonance state (Δl_2). How would you experimentally determine Δl_2?

04.

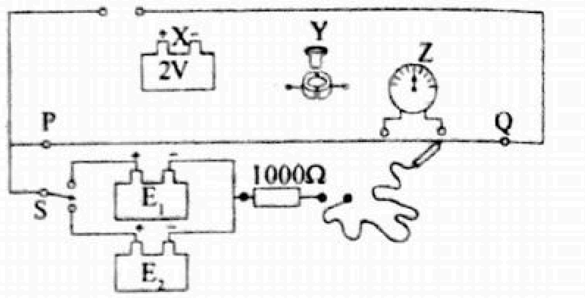
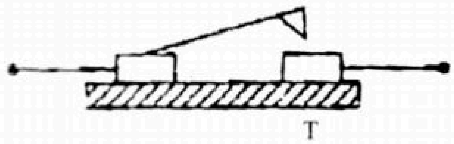


Figure shows an incomplete diagram of an experimental set-up of a potentiometer arrangement used to compare the e.m.f E_1 and E_2 of two cells. PQ is a wire of length 1 m and resistance of 20 Ω. X, Y and Z represent a 2V accumlator, a switch, and a centre zero galvanometer respectively. S is a two-way key.

(a) Complete the arrangement by connecting the items X, Y and Z to the circuit with lines.

(b) In order to perform this experiment the magnitudes of E_1 and E_2 must satisfy a certain requirement with e.m.f. of X. What is it?

(c) Do you suggest a tap-key (T) shown in the figure to the accumulator circuit? (yes/ No). State the reason.



(d) Give a reason as to why a much thicker wire of the same material should **not** be used as the potentiometer wire.

(e) List the essential steps that you would perform when obtaining a balanced length.

(f) Write down an expression relating E_1, E_2 and their corresponding balanced lengths l_1 and l_2.

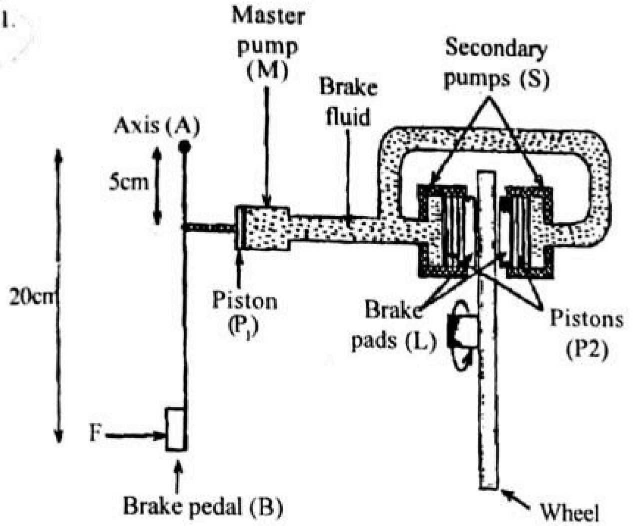
(g) If you want to determine the value for the ratio $\frac{E_1}{E_2}$ by plotting a suitable graph, state what modification you would propose to the circuit.

(h) When a student began to perform the experiment as mentioned in (g) above, he found that the lowest pair of values that he could obtain for l_1 and l_2 were closer to 100cm. As a result he was unable to obtain a good set of measurements to plot a graph. How would you overcome this problem experimentally?

Physics II PART B

Answer four questions only. $[g = 10\ N\ kg^{-1}]$

01.



The figure shows a hydraulic braking system which could be used to stop a rotating wheel. A force F is applied perpendicular to the brake pedal (B). The pedal rotates freely about a fixed axis through (A) and perpendicular to the plane of the paper as shown in the figure, and causes a force to be applied perpendicularly to the piston (P_1) of the master pump (M). The resulting pressure is transmitted by the brake fluid to the two identical pistons (P_2) of the secondary pumps (S). Then the brake pads (L) attached to the pistons move a little distance and press against both sides of the rotating wheel. Assume that the brake fluld is incompressible. Cross-sectional area of the master pistion (P_1) is 1 cm^2, and the croos-sectional area of the secondary piston (P_2) is 3 cm^2.

(i) When a certain force is applied to the master piston it moves a distance of 0.6 cm to the right in this process. How far does a single brake pad (L) move?

(ii) If F = 10 N,

(a) what is the force applied on the piston (P_1) of the master pump? The required distances are marked in the figure.

(b) Calculate the pressure exerted by master piston (P_1) on the brake fluid in pascal.

(c) Calculate the force exerted on the brake pads due to the pressure created on the secondary pistons (P_2).

(d) If the coefficient of dynamic friction between the brake pads and the wheel is 0.5, calculate the frictional force acting on the wheel due to each pad when they are pressed against the wheel.

(iii) Before applying the brakes, the wheel was rotating freely at 600 revolutions per minute. If the distance from the rotating axis of the wheel to the line of action of the frictional force is 5cm, how long does it take to stop the wheel when brakes are applied with $F = 10N$ as above? The moment of inertia of the wheel about its axis of rotation is 0.1 kg m^2. Assume that the frictional force remains constant throughout the motion.

How many revolutions does the wheel make before coming to rest? (Take $\pi = 3$)

02. Figure (a) shows a cross section of a human eye. Although it is normally considered that the eye lens is responsible for the formation of the image on the retina, actually it is the combination of the cornea and the eye lens that forms the image.

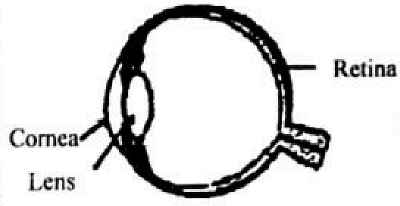


Figure (a)

The cornea can be considered as a convex lens with a fixed focal length while the focal length of the eye lens can be adjusted through muscle movements.

(i) Assume that the cornea and the eye lens can be considered as a composite lens consisting of two thin lenses in contact. The distance from the composite lens to the retina is 2 cm.

(a) Calculate the power in dioptres, of the composite lens when it is adjusted for (1) far point (infinity) (2) near point (25 cm.) (Take the power of a convex lens as positive.)

(b) Is the image on the retina real or virtual, and erect or inverted?

(c) If the power of the cornea is 40 dioptres, calculate the power of the eye lens for the two cases mentioned in part (a) above.

(ii) Consider two tiny dots, with a small separation d, on a paper placed at the near point of the eye as shown in figure (b).

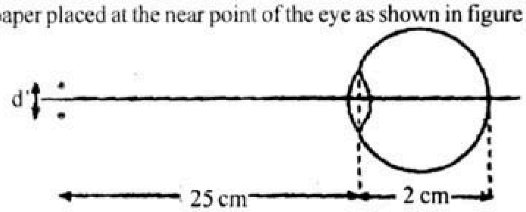


Figure (b)

(a) Obtain an expression for the distance s between the two images formed by the two dots on the retina in terms of d.

(b) Letters and images printed by some computer printers consist of many closely spaced tiny dots which are not visible to normal eye. For example,

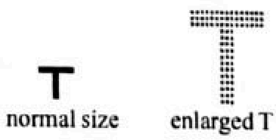


Figure (c)

the enlarged letter **T** in figure (c), formed by many dots, appears without dots when viewed at normal size. For this to happen, the separation of the images on the retina formed by any tow adjacent dots must be less than a certain value S_{max}.

If the value for S_{max} is 8 μm, show that a dot separation of 0.08 mm (300 dots per inch) is sufficient for a letter to be seen without dots.

(c) If it is necessary to see the dots contained in a letter printed with 0.08 mm dot separation with a magnifying glass, what is the maximum focal length of the magnifying glass that should be used?

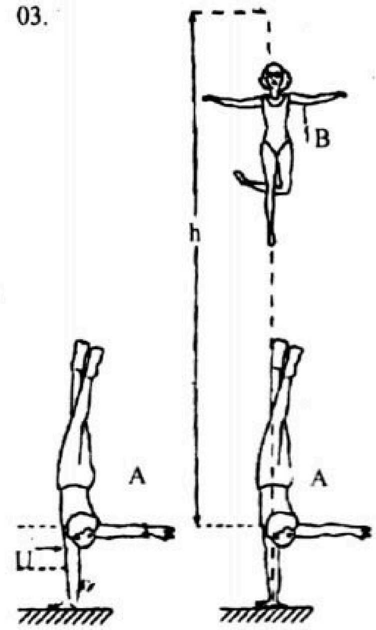
03. 

Figure (a) Figure (b)

An acrobat A stands on one hand as shown in figure (*a*). Assume that the bone of the upper arm *U* of the acrobat is a solid cylinder with an inner cylindrical cavity. When not subjected to stress the length of this cylinder is 0.3m. Its outer radius and that of the inner cylindrical cavity are 10^{-2} m and 4×10^{-3} m respectively. The weight of the acrobat excluding the arm is 600N. Young's modulus and the breaking stress of a human bone are 1.4×10^{10} Nm and 9.0×10^{7} Nm^{-2} respectively.

(i) What is the compressional strain of the upper arm bone when he is standing as shown in figure (*a*)? By how much is the bone compressed?

(ii) What is the elastic energy stored in a unit volume of the bone?

(iii) Starting from rest, another acrobat *B* of mass 50 kg now jumps vertically on to A from a height h as shown in figure (*b*). After landing on the shoulder of *A*, which is right above his upper arm bone, *B* takes a time of 0.02s to come to rest.

(a) Once landed on A and came to rest, what is the change in momentum of *B* in terms of *h*?

(b) Find the average value of the force in terms of *h* exerted on *A* by *B* due to the change in momentum.

(c) Calculate the maximum height from which *B* can jump on to *A* without breaking the upper arm bone of *A*. (Assume that Hooke's law is applicable until the breaking stress is applied.)

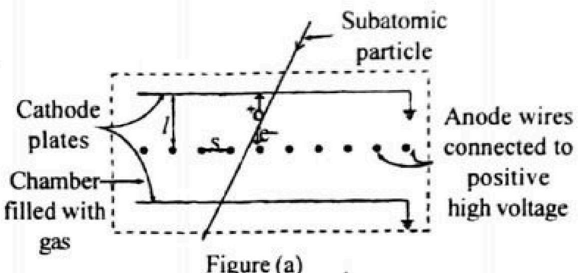
04. 

Figure (a)

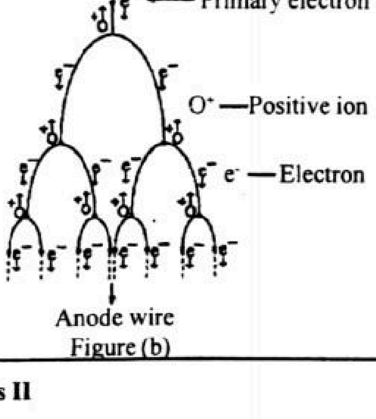


Figure (b)

Detection of photons and other subatomic particles is important in high energy particle physics. The multiwire proportional chamber (MWPC) is one of the detectors that is used for such purposes. Applications of MWPC can be found in a variety of fields such as nuclear medicine, protein crystallography, and particle track detection in high energy physics experiments. In its basic configuration, an MWPC consists of thin (~20 μm diameter) parallel and equally spaced anode wires symmetrically placed between two thin metallic cathode plates as shown in figure (a). For proper operation, the gap *l* is normally three or four times larger than the wire spacing s (~2mm). The cathodes are earthed and the anode wires are maintained at a positive high voltage (~3kV) to produce an extremely large electric field around the wires. The chamber is filled with a gas mixture of 90% argon and 10% of molecular gas such as CO_2 or CH_4.

When a high energy charged subatomic particle passes through the detector it collides and ionizes the gas molecules (mainly argon atoms) along its path in the chamber producing a certain number of electron-positive ion pairs. This ionization is called the primary ionization. In the process of creating one electron-ion pair, the high energy particle loses about 30eV from its kinetic energy. The primary electrons thus created move towards the anode wires and the positive ions to cathode Plates due to the electric field present inside the chamber. when these Primary electrons move closer to anode wires, the strong electric field that exists around the wires will accelerate them increasing their kinetic energies. Such energetic electrons, while moving towards the anode wires will collide with argon atoms producing more electron-ion pairs close to the wires. This process, called secondary ionization, is repeated many times producing a large number of electron-ion pairs. This will continue until all the electrons are collected by the anode wires. Figure (*b*) shows how a single primary electron will give rise to a large number of secondary electronion pairs through secondary ionization. This number is 10^3 in pure argon and its value can be about 10^6 in a mixture of argon and CO_2. The anode wires will finally collect all the electrons in a very short time leaving a cloud of positive ions around the wires, which slowly migrates towards the cathodes.

Electrons collected by anode wires can be observed as a current pulse which can later be converted to a voltage pulse. The pulse amplitude by MWPC is a measure of the energy loss by the particle during its passage through the detector. In addition the amplitude of the pulse depends on the detector properties such as the gas used, voltage applied to anode wires, the gap between cathode plates, wire spacing and wire diameter.

(i) Give **two** areas in which MWPC finds applications.

(ii) Which region of the detector has the highest electric field?

(iii) How does a primary electron acquire energy to produce a secondary electron-positive ion pair?

(iv) If the secondary ionization takes place according to the diagram given in figure (*b*) how many electron-atom collisions are necessary for one primary electron to produce 4 secondary electrons (including the primary electron)?

(v) Where in the detector are the majority of positive ions being produced?

(vi) Give **two** reasons as to why positive ion cloud takes a longer time to migrate to the cathode.

(vii) Give **three** properties of the detector that determine the amplitude of the pulse.

(viii) Use Gauss' theorem to find an expression for the electric field intensity E at a distance r $(r > a)$ from the axis of a long straight wire of radius 'a' carrying a charge per unit length λ.

(ix) What would happen to the amplitude of the pulse if the radius of the anode wires is reduced? Give reasons for your answer.

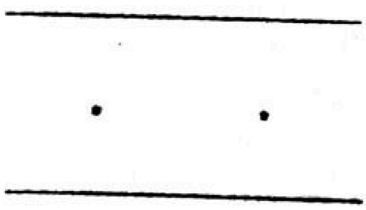


Figure (c)

(x) The figure (c) shows a section of an MWPC with two anode wires. Copy this diagram on to your answer sheet and draw the pattern of electric field lines inside this section.

(xi) If a high energy charged particle entering the detector with a kinetic energy of 100 keV passes through the detector creating 100 primary electron-ion pairs, calculate the energy of the particle when it leaves the detector.

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

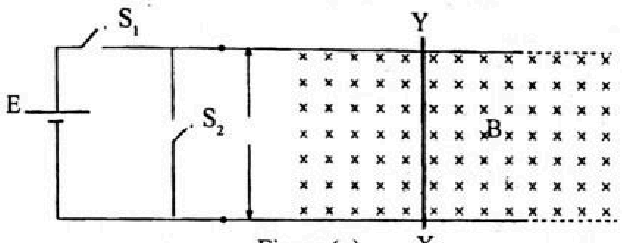


Figure (a)

(A) The figure (a) shows an arrangement that consists of a bar XY of mass m and resistance R placed on two parallel smooth horizontal conducting rails with negligible resistance, separated by a distance l. A uniform magnetic field with a flux density B is applied perpendicular to the plane of the rails (into the paper) and throughout the region between the rails. A battery of e.m.f. E with negligible internal resistance connected to the rails produces a current through the bar.

(i) When the bar XY is at rest on the rails, the switch S_1 is closed, while keeping the switch S_2 opened. Write down an expression using the given symbols for the force experienced by bar XY at this instant, due to the magnetic field. What is the direction of this force?

(ii) Consider an instant at which the bar is moving at a speed υ which is less than its maximum speed.

(a) Write down an expression for the magnitude of the back e.m.f. induced across the bar at this instant.

(b) Obtain expressions for the current through the bar, the force on the bar, and the power drawn from the battery at this instant.

(c) Hence show that the maximum speed that the bar XY can attain is given by $\frac{E}{Bl}$. What is the current through the bar when it is moving at the maximum speed?

(iii) Using the Lenz's law show that the bar can be decelerated it the switch S_1 is opened and the switch S_2 is closed at any instant while it is moving. What is the mechanism through which the kinetic energy of the bar is converted to heat during this process?

(iv) The above principle is used in the device known as linear motor which has many applications. One such application is launching of an aircraft from a ship. As shown in figure (b), the aircraft is mounted on the moving bar and when it reaches the required speed, the aircraft is detached from the bar and allowed to take-off. The bar is then decelerated as mentioned in part (iii) above.

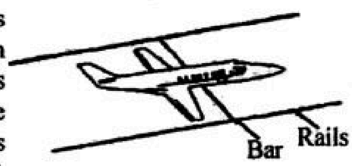


Figure (b)

Suppose the combination of the bar and the aircraft has a mass of 20 000kg, the separation between the rails is 10m, the magnetic flux density is 2T, and the resistance of the bar is 100Ω.

(a) Calculate the e.m.f. that should be provided by the battery to achieve a maximum speed of 100ms^{-1}.

(b) Hence calculate the initial acceleration of the aircraft.

(B) Draw the I-V characteristics of an ideal diode and a real diode.

In answering the following questions assume that the voltage across the diodes, when conducting is 0.7V.

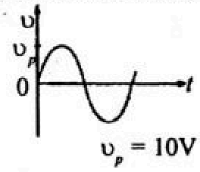


Figure (a)

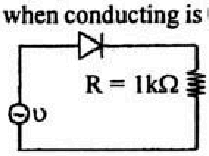


Figure (b)

(i) Input signal (υ) to the circuit given in figure (b) is shown in figure (a). Calculate the values of positive and negative peak currents in the circuit.

(ii)

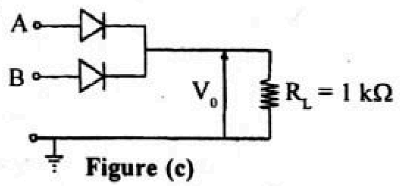


Figure (c)

V_A(V)	V_B(V)	V_0(V)	Logic Level
0	0		
0	5		
5	0		
5	5		

In the given table V_A and V_B are voltages applied to inputs A and B of the circuit shown in figure (c). Inputs A and B are connected to combinations of 0 and 5V as shown in the table. Copy the table on to your answer script and fill in the columns for the output voltage V_0 and the corresponding logic levels (1 or 0).

(iii) In the circuit shown in figure (c) above if $V_A = 5V$ and $V_B = 3V$, calculate the current through R_L.

(iv)

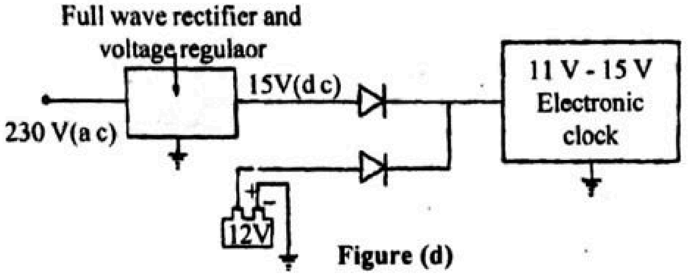


Figure (d)

Figure (*d*) shows the power connection to an electronic clock which needs a dc (direct current) voltage in the range 11V - 15V for proper operation.

(1) Describe the operation of the circuit when
 (a) ac (alternating current) power is present,
 (b) ac power fails.

(2) What is the current drawn from the 12V battery when the ac power is present?

(v) Draw a suitable circuit for the full wave rectifier and voltage regulator shown in figure (*d*) above.

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

Figure (a)

(A) An electronic device P is mounted on a thermally insulated base of a metal casing as shown in the figure (a). The device dissipates heat at the rate of 50W and this heat flows out **only through the upper plate of** the casing which is a rectangular metal plate of thickness 2mm and area 2cm². The entire system is kept in a room of temperature 30 °C.

(i) At the steady state, the temperatures of the inner and outer surfaces of the upper plate of the casing are 100 °C and 98°C respectively. Calculate the thermal conductivity of the material of the casing.

(ii)

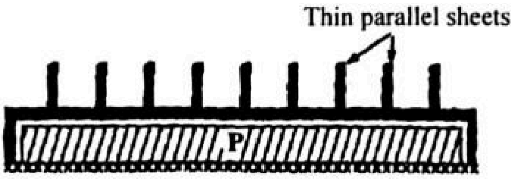


Figure (b)

For efficient and safe operation of the device the temperature of the **inner surface** of the upper plate of the casing should be maintained at 40 °C by means of a suitable mechanism.

(a) Under this condition, what should be the temperature of the **outer surface** of the upper plate?

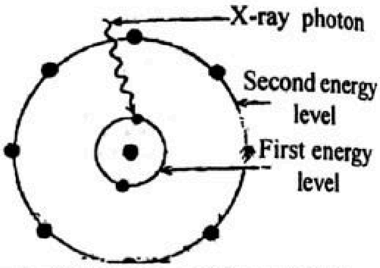
(b) As a mechanism to remove heat efficiently, the effective outer surface area of the upper plate is increased by mounting thin parallel sheets, made of casing material, perpendicular to the outer surface of the upper plate as shown in the figure (b). Assuming that the temperature of the entire outer surface including the thin parallel sheets is maintained at the value calculated in part (ii) (a) above, calculate the new effective surface area of the upper plate using the Newton's Law of cooling. The room temperature is given above.

(c)

Figure (c)

As an alternate method, the outer surface of the upper plate of the casing is cooled by passing water through a metal jacket which is in contact with the outer surface of the upper plate as shown in the figure (c). At the steady state the temperature of the water at the inlet and the outlet of the jacket are 30 °C and 35 °C respectively. If heat is not lost to the surrounding, calculate the rate at which watch water flows through the jacket in kilograms per second. (Specific heat capacity of water = 4.2×10^3 J kg^{-1} °C^{-1}).

(B) When an X-rey photon collides with an inner electron of an atom, (see the figure) the electron could be detached from the atom by absorbing the energy of the X-ray photon.



This process of removal of electrons could be studied using the usual **photoelectric equation.** The minimum energy needed to remove an electron can be taken as the work function appearing in the photoelectric equation. At the threshold wavelength of the incident X-ray photon, the electron is just removed without imparting any kinetic energy to it.

(i) An X-ray photon of wavelength 2.2Å could barely remove an electron at the first energy level in a Ca atom. Determine the minimum energy required (ϕ_1) to remove an electron at the first energy level in a Ca atom.

(ii) (a) When another X-ray photon with the same wavelength as in (i) collides with an electron at the second energy level in a Ca atom and gives all its energy to it, the electron is ejected with a kinetic energy of 6.0×10^{-16}J. Calculate the minimum energy (ϕ_2) required to remove an electron at the second energy level in a Ca atom.

(iii) Consider the situation described in (i) above. Following the removal of an electron at the first energy level, a vacancy is created in it. An electron from the second energy level drops to the first energy level to occupy this vacancy. This transition yields a photon with energy equal to the difference between ϕ_1 and ϕ_2. Determine the wave length of this photon. (Detection of such X-rays is used to identify heavy elements).

(iv) The energy (E) of a photon is related to its momentum (p) by the equation $E = pc$, where c is the velocity of light.
 (a) Determine the momentum of the incident X-ray photon mentioned in (i) above.
 (b) Since the electron is just removed without any momentum in (i) above, the Ca atom should recoil to conserve linear momentum. Calculate the speed of the recoiling Ca atom. (The mass of Ca atom is 6.0×10^{-26} kg).
 (c) Calculate the kinetic energy of the recoiling Ca atom.
 (d) Hence show that this kinetic energy is negligibly small compared to the energy of the incident X-ray photon.

($h = 6.6\ 10^{-34}$ Js, $c = 3.0 \times 10^8$ ms^{-1}, 1 Å = 10^{-10}m)