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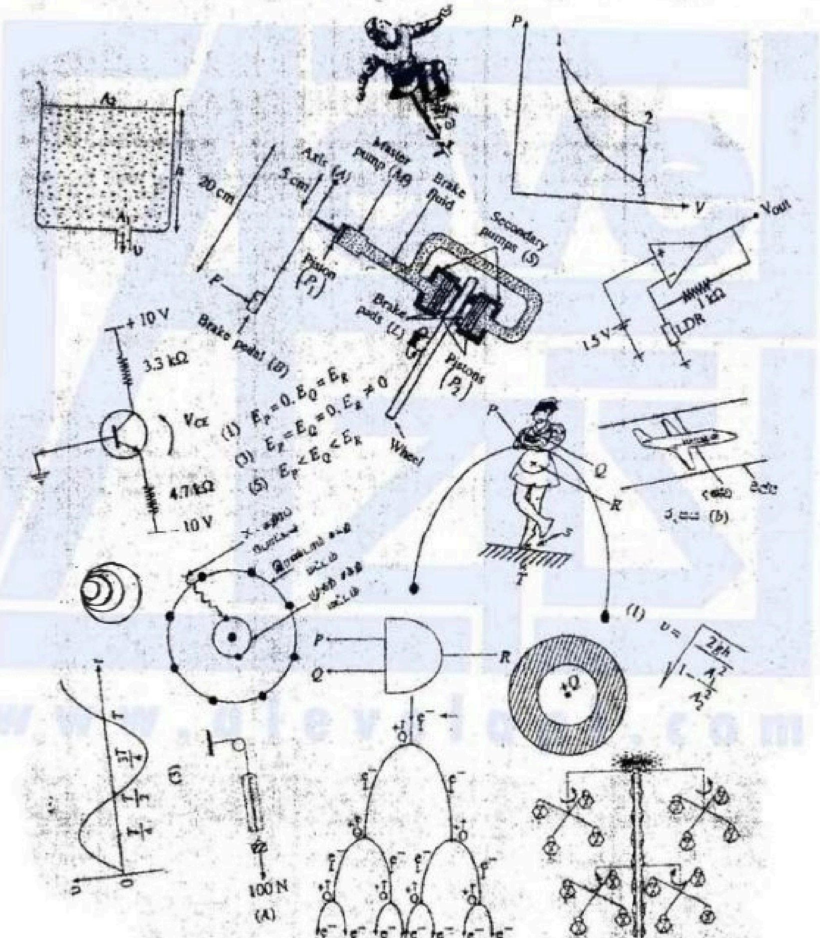
NATIONAL EVALUATION & TESTING SERVICE

DEPARTMENT OF EXAMINATIONS - SRI LANKA

G.C.E. (A/L) EXAMINATION – 2007

MARKING SCHEME



PHYSICS

STRICTLY CONFIDENTIAL

General Certificate of Education (Adv. Level) Examination
August 2007

Marking Scheme for Physics II

PART A — Structured Essay

*Answer **all four** questions on this paper itself.*

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

1. You are to determine the density of the material used to make a A-4 size (30 cm × 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?

Chemical Balance 01

(*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)	Meter Ruler / Half Meter Ruler ...01
(2) Width of the paper (say w)	Meter Ruler / Half Meter Ruler ...01
(3) Thickness of the paper (say t)	Micrometer Screw Gauge 01

(No marks for any other instrument; Do not award marks for the correct instrument written with several other 'possible' instruments;
No mark for foot ruler)

(*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.

$d = \dfrac{m}{lwt}$ 01

(*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?

The thickness may not be uniform
OR
Thickness may not have the same value everywhere
OR
Thickness can be different at various places
.... 01

(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 $\quad \frac{1}{300}\left(or \frac{0.1}{30}\right)$ ... $\frac{.05}{30}$ ... 01

(2) $t = 0.15$ mm $\quad \frac{1}{15}\left(or \frac{0.01}{0.15}\right)$ $\frac{.005}{0.15}$ 01

(Accept percentage errors as well)

(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?

20 01

(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 = $\frac{m}{lw \times 10^{-4}}$ or $\frac{m \times 10^{4}}{lw}$ 01

(Award the mark if l is taken as 30 and/or w taken as 21)

2. 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?

Chemical balance *OR* Triple beam balance *OR* Four beam balance *OR* Electronic balance... 01

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

Heat loss to the (surrounding) can be neglected
OR
No heat exchange with the (surrounding)
OR
Heat loss to the (surrounding) is minimized (*OR* prevented)

Any correct one 01

(c) List the measurements you will obtain in this experiment in the order that you perform the experiment.

1. Mass of calorimeter (with the stirrer)
2. Mass of calorimeter, (stirrer) and water
3. Initial temperature of water
4. Maximum temperature of the mixture/water
5. Mass of calorimeter, (stirrer), water and metal balls
   or mass of calorimeter and its contents
   or mass of calorimeter and the mixture

.... 02

All correct 02
Any correct three in order 01

(*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.

Should not be too small because,

Water may not cover the metal balls completely.

OR

Water may vaporize (or evaporate) (due to high temperature) it gains.

OR

Metal balls will not mix properly with water.

OR

Heat loss to the surrounding will be higher.

OR

Heat in metal balls will not completely absorbed by water

කැලරිමීටරය [illegible]

Any correct one..................... 01

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

Should not be too large because,

Water may spill over when stirring

OR

Water may spill over when balls are transferred

OR

Increase in temperature may be too small

OR Increase in temperature of water may not be detectable

Any correct one..................... 01

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

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

Calculate the specific heat capacity of the metal.

If s is the specific heat capacity of metal,
Heat lost by metal balls = $0.3 \times s \times 64$
Heat lost by metal balls = heat gained by calorimeter, stirrer and water

$0.3 \times s \times 64 = 2400$ 01

$s = 125\ J\ kg^{-1}\ {}^{0}C^{-1}$ 01

(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?

Water will be added to the mixture along with the metal balls

OR

Temperature of metal balls will be reduced when water is wiped off from the balls

OR

Dry balls cannot be obtained from this method

OR

Heat lost to the surroundings will be high while transferring the balls

Any correct one............................ 01

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

No.

1.During the transfer of metal powder to the calorimeter amount of heat lost from the powder is high because its high surface area.

OR

Temperature of metal powder will be less than 100 ^{0}C when it is transferred to the calorimeter because of higher cooling rate due to large surface area.

2. Metal powder may float in water.

3. Metal powder may stick on to the wall of the calorimeter.

Any correct two.. 01

3. 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*.

$v = f\lambda$ and $\lambda = 2l$ $\qquad v = 2fl$ 01

$v = 4fl$ ✗

(*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*.

$l = \frac{v}{2}\frac{1}{f}$ ✓ 01

$y = l$ $\qquad l = \frac{v}{4}\frac{1}{f} \rightarrow 01$

$x = \frac{1}{f}$ 01

(*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.

Step (i) First use the tuning fork with the lowest frequency and check the resonance length

Reason: To make sure that the wire is long enough to get the resonance lengths for all frequencies.

Step (ii) Start taking data with the tuning fork with highest frequency

Reason: To make sure that the fundamental mode of resonance is taken in increasing the resonance length for successively decreasing frequencies.

(Either step (i) or step (ii) can be considered as correct answer)

(Correct reason in either case) 01

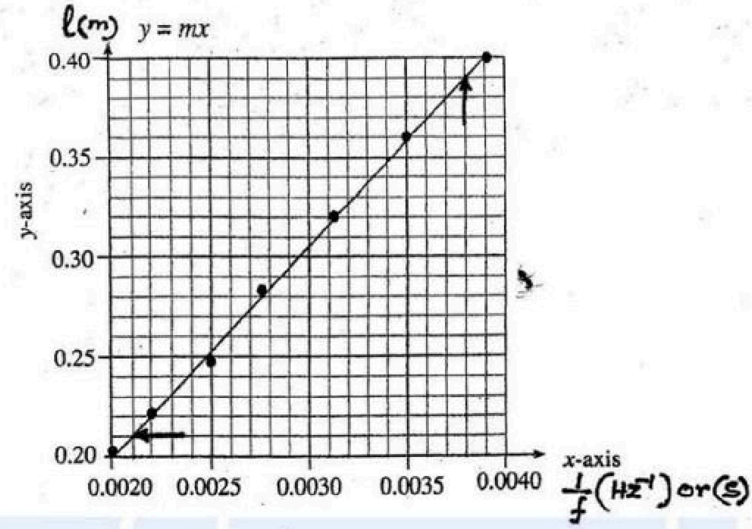
(*d*) How would you identify the tuning fork with the highest frequency from the given set of tuning forks, only considering their physical dimensions?

The shortest (smallest) tuning fork.................................. 01

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

Vibration amplitude is highest at the fundamental mode............. 01

(*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.

Y axis - l (m)

X axis - $1/f$ (Hz^{-1}) or (s)

(To award this mark both axes must be correctly labeled with units) 01

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

(Selecting the two points shown in the figure) 01

$$\text{Gradient } m = \frac{0.39-0.21}{0.0038-0.0021} = \frac{0.18}{0.0017} ms^{-1}$$

$= 105.88\ ms^{-1}$

$v = 2m = 210.76 ms^{-1}$ 211.16

211 - 212

Any value in the range (210-212 m s^{-1}) 01

(*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?

Repeat obtaining the resonance state several times by adjusting the peg (and estimate Δl_2)

OR

By slowly moving the position of the peg within the resonance region and detecting its limits

.... 01

4.

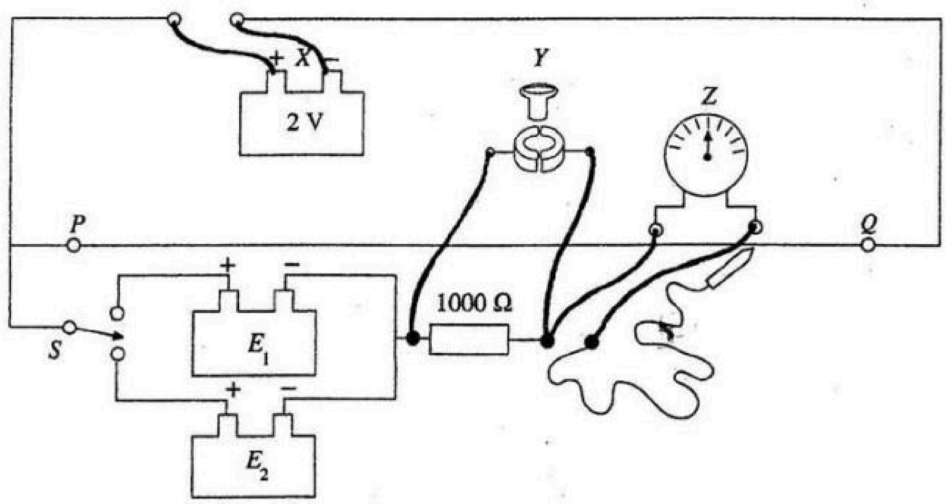


Figure shows an incomplete diagram of an experimental set-up of a potentiometer arrangement used to compare the e.m.f. E_1 and E_2 of two cells. *PQ* is a wire of length 1 m and resistance of 20 Ω. *X*, *Y* and *Z* represent a 2 V accumulator, a switch, and a centre zero galvanometer respectively. *S*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

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

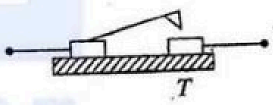
Proper connection of the 2V accumulator as shown 01
(Award this mark even if the switch Y is connected in <u>series</u> with X)

Connection of the key (Y) and Galvanometer Z 01
(Award this mark even if a student has drawn a separate key <u>across</u> the 1000 ohm resistor.)

(*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?

Magnitude of the e.m.f. of X (or accumulator) must be greater than E_1 & E_2 *OR* 2 V $>$ E_1 and E_2 01

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



T

No (or delete 'Yes')
Reasons: Wire does not come to steady state *OR*
Voltage across the wire can not be kept constant *OR*
Temperature (or the resistance) of the wire will vary.
Any reason............ 01

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

Accumulator will be discharged rapidly *OR*
E.m.f. of the accumulator can not be maintained at 2 V (constant value throughout the experiment) *OR* the potential drop per unit length of the wire will vary *OR* Wire will be heated up <u>excessively</u>
Any reason 01

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

(Select one of the cells (E_1 or E_2) with the 2-way key.
Check for proper battery connections by placing the jockey at the two ends of the wire and observing opposite deflections of the galvanometer.)

(i) Momentarily touch the wire with the jockey and find the approximate balance-point. 01

(ii) Close the switch Y and take the exact balance-point 01

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

($E_1 = kl_1$
$E_2 = kl_2$)

$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$ 01

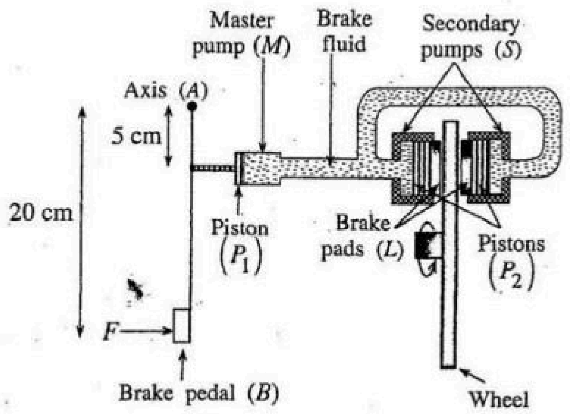
(*g*) If you want to determine the value for the ratio $\frac{E_1}{E_2}$ by plotting a suitable graph, state what modification you would propose to the circuit.

Add a resistance box in series with the potentiometer wire 01

(*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 100 cm. As a result he was unable to obtain a good set of measurements to plot a graph. How would you overcome this problem experimentally?

Replace the 2 V accumulator with another accumulator (battery) having a larger e.m.f. *OR* Connect another accumulator (battery) in series with the accumulator *OR* Connect another 2 V accumulator (battery) in series with the first. 01

1. 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 fluid is incompressible. Cross-sectional area of the master piston (P_1) is 1 cm^2, and the cross-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 5 cm, how long does it take to stop the wheel when brakes are applied with $F = 10$ N 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 $\pi = 3$)

(i) If x is the displacement of each brake pad then,

$1 \times 0.6 = 2 \times 3 \times x$
$x = 0.1$ cm 01

(ii) (a) Let F be the force on the master piston. Taking moments about A

$10 \times 20 = F \times 5$
$F = 40$ N 01

(b) Pressure on the master piston $= \dfrac{40}{10^{-4}}$
$= 4 \times 10^5$ (Pa) 01

(c) Force on a ~~slave~~ secondary piston $= 4\times10^5\times3\times10^{-4}$ 01

(correct substitution *or* the idea that the same pressure transmits throughout the liquid)

$= 120$ N 01

OR 240 N on both pads

(d) Force exerted on the wheel due to a single brake pad

$= 120\times0.5$ (*OR* application of $F=\mu R$) 01

$= 60$ N 01

(iii) Let α be the angular deceleration of the wheel. Applying

$\Gamma = I\alpha$ 01

$2\times60\times0.05 = 0.1\alpha$ 02

(01 mark – L.H.S ; 01 mark – R.H.S.)

$\alpha = -60$ rad s^{-2}

Initial angular velocity (ω_0) of the wheel

$= \omega_0 = 2\pi\times\frac{600}{60}(or\, 2\pi\times10\ or\ 20\pi\ or\ 60)$ 01

Applying $\omega = \omega_0 + \alpha t$ 01

$0 = 20\pi - 60t$

$t = 1$ s 01

Applying $\theta = \omega_0 t + \frac{1}{2}\alpha t^2$ *OR* $\omega^2 = \omega_0^2 + 2\alpha\theta$ *OR* $\theta = \frac{(\omega+\omega_0)t}{2}$

OR $\Gamma\theta = \frac{1}{2}I\omega_0^2$ 01

$\theta = 20\pi\times1 - \frac{1}{2}\times60\times1$ *OR* $0 = (20\pi)^2 - 2\times60\theta$ *OR* $\theta = \frac{20\pi\times1}{2}$

$\theta = 30$ rad

Number of revolutions $= \frac{30}{2\pi}$

$= 5$ revolutions 01

{Note: If a student takes $\pi = \frac{22}{7}$ instead of 3, then the corresponding answers will be

$t = 1.05$ s (1.04 – 1.05) 01

Number of revolutions $= 5.24$ revolutions (5.23 – 5.25)...... 01}

2. 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. 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.

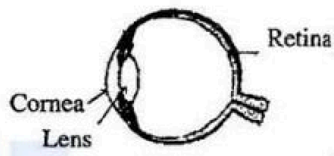


Figure (*a*)

(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*).

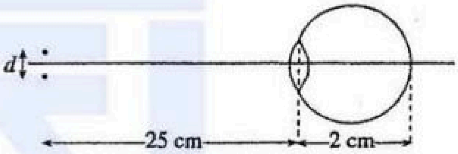


Figure (*b*)

(*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, 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 two adjacent dots must be less than a certain value s_{max}.

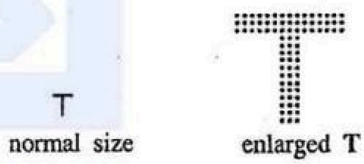


Figure (*c*)

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?

(i) (a)

(1) When focused to infinity, the focal length must be equal to the distance from the lens to the retina.
Therefore, focal length = 2 cm = 0.02 m
Power of the lens = 1/0.02 -- 01

= 50 diopters -- 01

[Alternative method:
Using lens equation, $-\frac{1}{\infty}-\frac{1}{0.02}=\frac{1}{f}$ $-\frac{1}{0.02}-\frac{1}{\infty}=\frac{1}{f}$

$f = 0.02$ m
Power of the lens = 1/0.02 ----- 01
= 50 diopters ----- 01]

(2) When focused to near point:
Using the lens formula $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$,
OR
$-\frac{1}{0.02}-\frac{1}{0.25}=\frac{1}{f}$ ------------------------------ 01

$\frac{1}{f}=-50-4$
= 54 diopters -- 01

(b) The image is real -- 01

and inverted -- 01

(c) For thin lenses in contact, $\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}$ ------------------------------ 01
$D = D_1 + D_2$

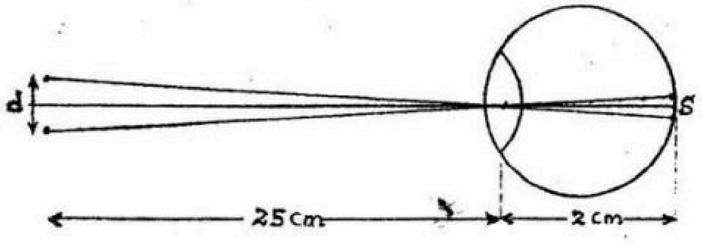
When focused to infinity, $50 = 40 + \frac{1}{f_{lens}}$

The power of the lens = 10(D) -- 01

When focused to near point, $54 = 40 + \frac{1}{f_{lens}}$

The power of the lens $= 14$ (D) -- 01

(ii) (a) $\frac{s}{d} = \frac{2}{25}$



$s = \frac{2d}{25} = 0.08d$ -- 01

(either form)

(b) When $d = 0.08$ mm, $s = 0.08 \times 0.08 = 0.0064$ mm

$= 6.4\ \mu m$ -- 01

This value is less than 8 μm. Therefore this separation is sufficient.

.... 01

(c) For 0.08 mm dot separation, the image separation is 0.0064 mm.
Using the lens, the image separation must be increased to 0.008 mm.
Therefore, the required magnification is 0.008/0.0064

$= 1.25$ -- 01

Using the lens formula,

$\frac{1}{D} - \frac{1}{u} = -\frac{1}{f}$ where D is the distance to the near point.

$M = \frac{D}{u} = 1 + \frac{D}{f}$

$1.25 = 1 + \frac{25}{f}$ -- 01

$f = 100$ cm -- 01

(*or* 1 D)

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 0.3 m. 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 600 N. Young's modulus and the breaking stress of a human bone are 1.4×10^{10} N m^{-2} and 9.0×10^{7} N m^{-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 0.02 s 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.)

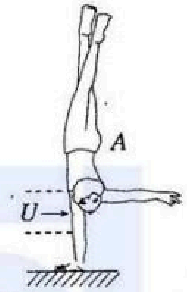


Figure (a)

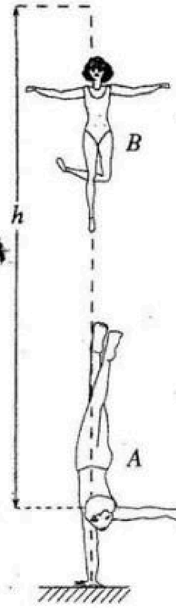


Figure (b)

(i) Compressional stress of the upper arm bone = $\dfrac{\cancel{60 \times 10}\ 600}{\pi(1-0.4^2)10^{-4}}$

..............................02

Correct area of cross section – 01
Division – 01

Using, Young's modulus = stress/ strain

Compressional strain = $\dfrac{600}{\pi(1-0.4^2)10^{-4}} \dfrac{1}{1.4 \times 10^{10}}$ 01

$= 1.6 \times 10^{-4}$ (1.60 – 1.63) 01

Compressional strain = decrease in length/initial length 01

Compression of the bone = $1.6 \times 10^{-4} \times 0.3$

$= 4.8 \times 10^{-5}$ m (4.80 – 4.79) 01

(ii) Elastic energy stored per unit volume

$= 1/2 \times \text{stress} \times \text{strain}$ 01

$= 1/2 \times \dfrac{600}{\pi(1-0.4^2)10^{-4}} \times 1.6 \times 10^{-4}$

$= 1.8 \times 10^{2}\ \text{J m}^{-3}$ (1.80 – 1.86) 01

{**Alternate Method:**

Energy stored $= ½ \times \text{force} \times \text{compression}$ 01

$= ½ \times 600 \times 4.8 \times 10^{-5}$

Energy stored per unit volume $= 1/2 \times \dfrac{600 \times 4.8\times10^{-5}}{\pi(1-0.4^2)10^{-4}\times 0.3}$

$= 1.8 \times 10^{2}\ \text{J m}^{-3}$ ....01}

(iii) (a) Using $v^2 = u^2 + 2gh$

Velocity of B when falls on to A $= \sqrt{2\times10\times h}$ $\sqrt{2gh}$......... 01

($\sqrt{20h}$ *or* $2\sqrt{5h}$ *or* $4.47\sqrt{h}$)

Change in momentum of B after falling on to A

$= (\sqrt{2\times10\times h} - 0) \times 50 = 50\sqrt{20h}$ ..$50\sqrt{2gh}$..............01

(*or* $100\sqrt{5h}$ *or* $223.5\sqrt{h}$)

(b) Average force = change in momentum/ time 01

Average force on A exerted by B

$= 50\sqrt{20h}\ /0.02 = 25\times10^{2}\ \sqrt{20h}$, $25\times10^{2}\sqrt{2gh}$.................01

(*or* $5\times10^{3}\sqrt{5h}$ *or* $111.8\times10^{2}\sqrt{h}$)

(c) Maximum stress $= 9 \times 10^{7}\ \text{N/m}^2$

Total force on the upper arm bone$= 600 + 25\times10^{2}\ \sqrt{2\times10\times h}$ .... 01 (+500+)

(*or* $600 + 5\times10^{3}\sqrt{5h}$ *or* $600 + 111.8\times10^{2}\sqrt{h}$)

to 600 OR 500 → 01 mark.

If h_{max} is the maximum height, then

$$(600 + 25\times10^2\sqrt{2\times10\times h_{max}}\ )/\ \pi \times (1-0.4^2) \times 10^{-4} = 9 \times 10^7$$

.... 01

(Award this mark even without the term 600)

h_{max} = 4.3 m 01

(3.9- 4.5)

4.

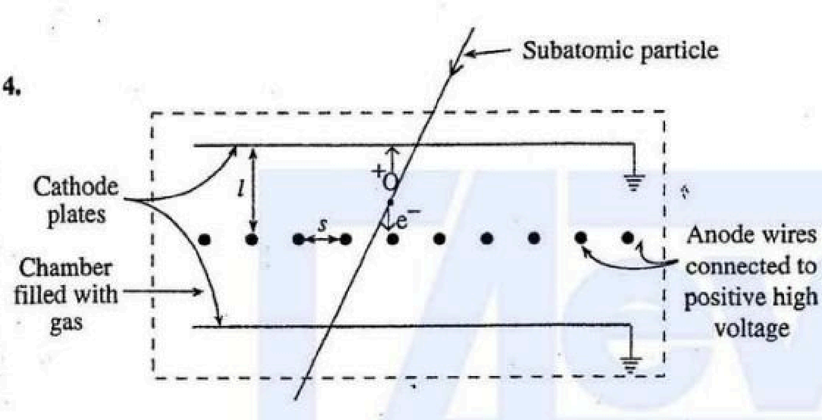


Figure (*a*)

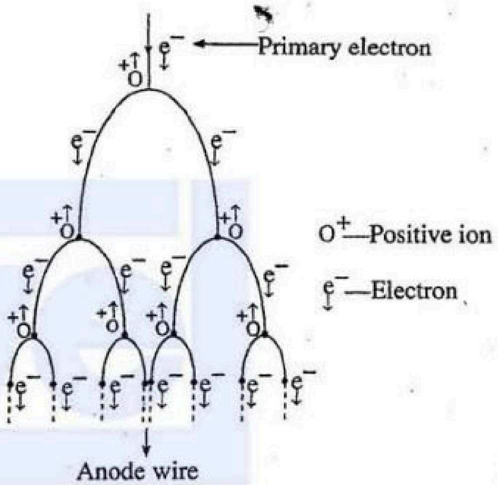


Figure (*b*)

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 μ m 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 (~2 mm). The cathodes are earthed and the anode wires are maintained at a positive high voltage (~ 3 kV) 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 30 eV 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 electron-ion 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 produced 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.

(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.

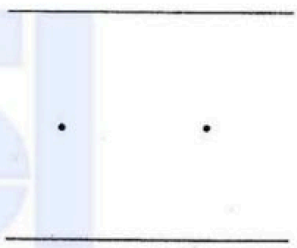


Figure (*c*)

(i) Nuclear Medicine
Protein Crystallography
Tracking detectors in high energy Physics (*or* to locate the tracks of charge particles)

(Any two).........01

(ii) Near the anode wires. 01

(iii) Due to the acceleration in the Electric field 01

(iv) Three (03) 01

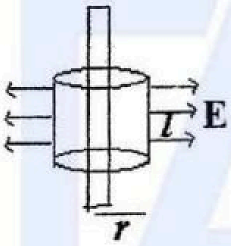
(v) Near the (anode) wire 01

(vi) Speed of the positive ions is low
Positive ions are heavier than electrons (or lower acceleration)
(Any one) 01

Positive ions have to travel a longer distance
Weaker electric field away from the wires
(Any one) 01

(vii) Gas used, anode voltage, separation between the cathode plates, separation between wires, diameter (or radius) of the wires
(Any ~~two~~ three) 01

(viii)



Consider the Cylindrical Gauss surface of length l and radius r symmetrically (~~or around the wire~~) as shown in the figure

(Correct Gauss surface in a figure or in words)
....01

Applying Gauss' law $2\pi r l E = \lambda l / \varepsilon_0$

$$E = \frac{\lambda}{2\pi \varepsilon_0 r}$$

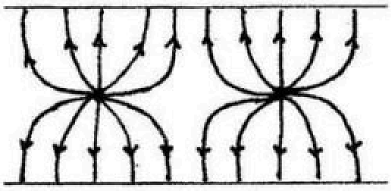
ε_0 or ε

(Correct expression) 01

(ix) Amplitude of the pulse increases.
Reason: More electrons would be collected by the anode wire
OR
More secondary ionizations being produced
OR
Stronger electric field closer to the wires.

..............01

(x)



Correct shape 01
Lines perpendicular to the cathode plates..................01
Correct direction of the field with arrows..................01

(xi) Energy of the outgoing particle:

$= 100 - \frac{100 \times 30}{1000}$

$= 97$ keV 97×10^3 eV 01

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

(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.

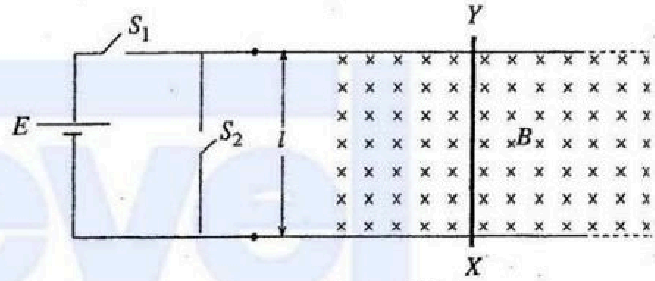


Figure (*a*)

(i) When the bar *XY* is at rest on the rails, the switch S_1 is closed, while keeping the switch S_2 opene Write down an expression using the given symbols for the force experienced by bar *XY* at this instar 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 spee

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

(*b*) Obtain expressions for the current through the bar, the force on the bar, and the power drawn fro 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 curre through the bar when it is moving at the maximum speed?

(iii) Using the Lenz's law show that the bar can be decelerated if the switch S_1 is opened and the switc S_2 is closed at any instant while it is moving. What is the mechanism through which the kinetic energ 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. Suppose the combination of the bar and the aircraft has a mass of 20 000 kg, the separation between the rails is 10 m, the magnetic flux density is 2 T, and the resistance of the bar is 100 Ω.

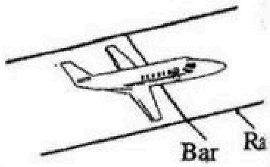


Figure (*b*)

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

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

(i) Using $F = Bil$,

$$F = \frac{BEL}{R}$$ -- 01

The direction of the force is to the <u>right</u> *or* an arrow drown to the right (→)
-- 01

(ii) (a) using $E = Blv$,

the back emf $= Blv$ -- 01

(b) Current through the bar, $i = \frac{E - Blv}{R}$ -------------------------------- 01

Using $F = Bil$,

force on the bar $= \frac{Bl(E - Bvl)}{R}$ -- 01

(Award this mark even if a wrong expression for i is substituted here)

Power delivered by the battery $= E\left(\frac{E - Bvl}{R}\right) = \frac{E^2}{R} - \frac{EBvl}{R}$ --------- 01

(Any form of the correct expression)

(c) Due to the force F, the bar is accelerated. Then, because E is constant, the force decreases. The speed v does not increase after the force becomes zero *OR* current becomes zero.

Therefore, the maximum speed is reached when $E = Bvl$ or, $v = \frac{E}{Bl}$.

(Correct argument) -- 01

When the speed is maximum, current through the bar is <u>zero</u>. -------01

(iii) When S_1 is open and S_2 is closed, the only emf present in the system is the <u>induced emf</u> due to the motion of the bar. This emf produces a <u>current which creates a force that</u> <u>opposes the motion</u> of the bar. Therefore, the bar is decelerated.

---01

The kinetic energy is converted to heat when the induced <u>current flows through the resistance</u> of the bar *OR* through i^2R type <u>heating</u> *OR* through <u>Joule heating</u>

---01

(iv) (a) Maximum speed is given by $v = \frac{E}{Bl}$. Therefore, $E = Blv$.

$\therefore$ required E is given by $2 \times 10 \times 100$ ---------------------------------- 01

$= 2000$ V ---------------------------------- 01

(b) The initial acceleration $= \frac{BlE}{mR}$ ---------------------------------- 01

$= \frac{2 \times 10 \times 2000}{20000 \times 100}$ ---------------------------------- 01

$= 0.02$ m s^{-2} ---------------------------------- 01

(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 0.7 V.

(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.

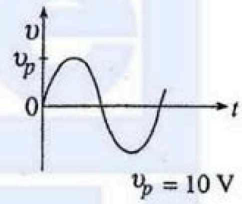


Figure (a)

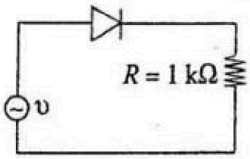


Figure (b)

(ii)

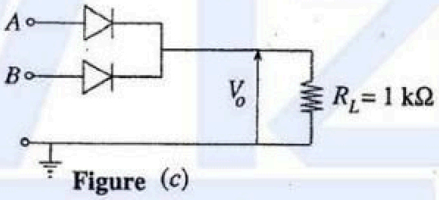


Figure (c)

V_A(V)	V_B(V)	V_o(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 5 V as shown in the table. Copy the table on to your answer script and fill in the columns for the output voltage V_o and the corresponding logic levels (1 or 0).

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

(iv)

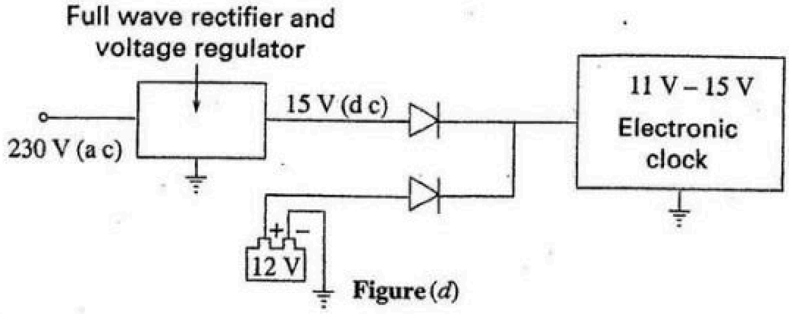


Figure (d)

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

(1) Describe the operation of the circuit when

(*a*) ac (alternating current) power is present,

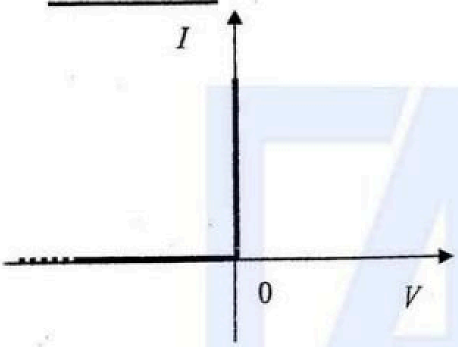
(*b*) ac power fails.

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

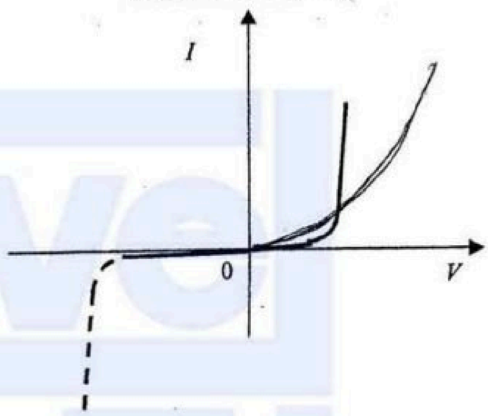
(v) Draw a suitable circuit for the full wave rectifier and voltage regulator shown in figure (*d*) above.

I-V Characteristics

Ideal Diode



Real Diode

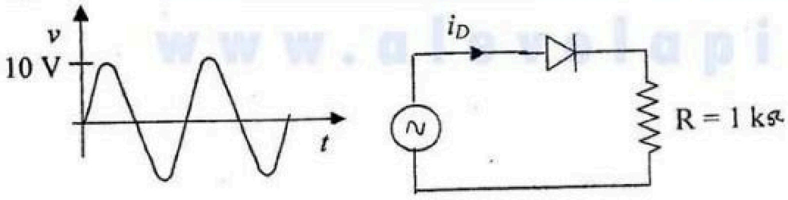


I - *V* characteristics of a real diode 01

I - *V* characteristics of an ideal diode 01

(If the axes are not labeled in both diagrams, deduct one mark. Labeling the origin is not required; Part of curve drawn with broken lines is not required)

(i)



When forward biased

Peak current of $i_D = \frac{10-0.7}{1\times10^{3}}$ 01

$= 9.3$ mA or $(9.3\times10^{-3}$ A) 01

When reverse biased, peak current of $i_D = 0$ 01

(or equal to the leakage current)

(ii)

V_A (V)	V_B (V)	V_0 (V)	Logic level
0	0	0	0
0	5	4.3	1
5	0	4.3	1
5	5	4.3	1

Correct 'V_0' column 01

Correct 'Logic level' column 01

(iii)

If V_A= 5 V and V_B= 3V,

$$I_{R_L} = \frac{5-0.7}{1\times 10^{3}}$$

$= 4.3$ mA $\quad (4.3\times10^{-3}$ A).. 01

(iv)

(1)(a) When ac power is present upper diode is forward biased and its cathode will be at 14.3 V which makes lower diode reverse biased 01

∴ clock will have 14.3 V at its supply input, and function normally 01

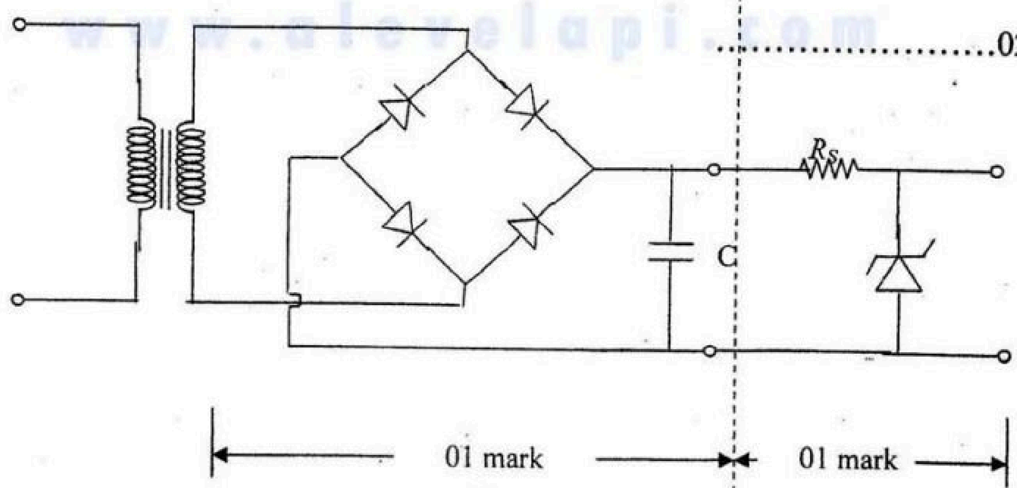
(b) When ac power fails, lower diode becomes forward biased and upper diode becomes reversed biased 01

∴ clock will have 11.3 V at its supply input, and continue to function normally 01

(2) When ac power is present the lower diode is reverse biased and therefore current drawn from the 12 V supply is zero 01

(v)

.......................02



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

(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 50 W and this heat flows out **only through the upper plate** of the casing which is a rectangular metal plate of thickness 2 mm and area 2 cm^2. The entire system is kept in a room of temperature 30 °C.

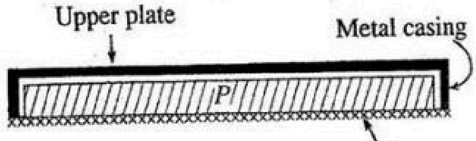


Figure (a)

(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) 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.

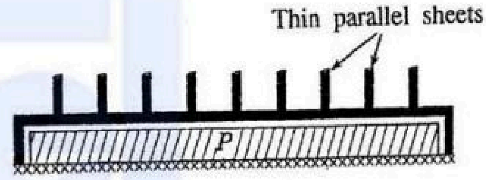


Figure (b)

(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 water flows through the jacket in kilograms per second. (Specific heat capacity of water = 4.2×10^3 J kg^{-1} °C^{-1}).

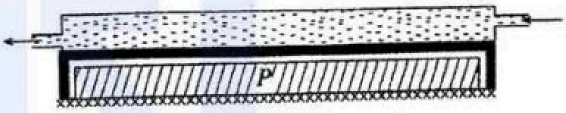


Figure (c)

(i) At the steady state, rate of heat flow through the upper plate = 50 W 01

Using rate of heat flow, $Q = kA(\theta_1 - \theta_2)/d$ 01

$$50 = \frac{k \times 2\times10^{-4}(100-98)}{2\times10^{-3}}$$ 01

(Correct substitution)

$\therefore$ Thermal conductivity, k = 250 W m^{-1} K^{-1} .... ~~01~~ 02

(ii) (a) $50 = \frac{250 \times 2 \times 10^{-4} \times (40 - \theta)}{2 \times 10^{-3}}$ 01

$\theta = 38\ ^0C$ 01

(Since rest of the factors in the expression given in (i) are the same, a student can also argue that the temperature difference must also be the same. i.e. 2 ^0C $\therefore \theta = 38\ ^0C$ .....02)

(b) From Newton's law of cooling, rate of heat loss,

$Q \ \alpha\ A\ (\theta - \theta_R)$ .... 01+01

$50\ \alpha\ A \times (38 - 30)$ 01

$50\ \alpha\ 2 \times 10^{-4} \times (98 - 30)$ 02

(Award 01mark for choosing 98 °C as one temperature and the other mark for correct substitution)

{Above proportionalities could be written as expressions using a suitable constant}

From the above proportionalities , $A = \frac{2 \times 10^{-4} \times 68}{8}$ 01

$= 17 \times 10^{-4}\ m^2$ 01

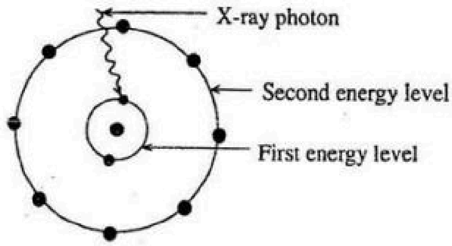
(c) Rate of heat absorbed by water = m × s × (35-30) ....~~01~~

$50 = m \times 4.2 \times 10^{3} \times 5$ ....~~01~~

01 $m = 2.3 \times 10^{-3}\ kg\ s^{-1}$.........................~~01~~

(2.3 – 2.4)

(B) When an X-ray 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 2.2 Å 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.

(*b*) Determine the threshold wavelength of incident X-rays 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 wavelength 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.

($h = 6.6\times10^{-34}$ J s, $c = 3.0\times10^{8}$ m s^{-1}, 1 Å $= 10^{-10}$m)

(i) Energy of the incident X – ray photon $= \dfrac{hc}{\lambda}$ 01

Energy of the incident X – ray photon $= \phi_1$

$\phi_1 = \dfrac{6.6\times10^{-34}\times3\times10^{8}}{2.2\times10^{-10}}$ 01

$= 9\times10^{-16}$ J 01

(ii) (a) Applying the photo-electric equation

$9\times10^{-16} - \phi_2 = 6\times10^{-16}$ 01

(Award this mark even for an incorrect value obtained for the energy of the incoming photon in (i) above)

$\phi_2 = 3\times10^{-16}$ J 01

(b) $\lambda_{th} = \dfrac{6.6\times10^{-34}\times3\times10^{8}}{3\times10^{-16}}$ 01

(Award this mark even for an incorrect value obtained for ϕ_2 in (ii)(a) above)

$\lambda_{th} = 6.6\times10^{-10}$ m (6.6 $\overset{0}{A}$).. 01

(iii) $\phi_1 - \phi_2 = 9\times10^{-16} - 3\times10^{-16}$ 01

(Award the mark for taking the difference)

$\lambda = \dfrac{6.6\times10^{-34}\times3\times10^{8}}{6\times10^{-16}}$

$\lambda = 3.3\times10^{-10}$ m (3.3 $\overset{0}{A}$).. 01

(iv) (a) $p = \dfrac{E}{c} = \dfrac{9\times10^{-16}}{3\times10^{8}}$

$= 3\times10^{-24}$ kg m s^{-1} (J s m^{-1}) 02

(Deduct 01 mark for the wrong unit)

(b) Let v be the speed of the recoiling atom, then

$6\times10^{-26}v = 3\times10^{-24}$ 01

(Award this mark even for an incorrect value of the momentum obtained above)

$v = 50$ m s^{-1} 01

(c) Kinetic energy of the atom $= \frac{1}{2} \times 6 \times 10^{-26} \times 50^2$

$= 7.5 \times 10^{-23}$ J 01

(d) Kinetic energy as a fraction $= \frac{7.5 \times 10^{-23}}{9 \times 10^{-16}}$

$= 8.3 \times 10^{-8}$ $(8.0 - 8.4)$ *OR*

indicating that 10^{-23} is very small compared to 10^{-16} 01

$\therefore$ the kinetic energy of the recoiling atom is negligibly small compared to the energy of the incident X-ray photon

1. 2
2. 3
3. 5
4. 2
5. 3
6. 2
7. 4
8. 1
9. 2
10. 1
11. 4
12. 3
13. 3
14. 2
15. 1
16. 3
17. 1
18. 4
19. 2
20. 4
21. 3
22. 5
23. 4
24. 5
25. 3
26. 5
27. 5
28. 3
29. 5
30. 3, 4
31. 4, 5
32. 5
33. 3
34. 2
35. 3
36. 1
37. 2
38. 1
39. all
40. 5
41. 1
42. 3
43. 1
44. all
45. 3
46. 2
47. 4
48. 5
49. 4
50. 3
51. 1
52. 1
53. 3
54. 4
55. 1
56. 5
57. 3
58. 5
59. 3
60. 2