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இலங்கைப் பரீட்சைத் திணைக்களம்
Department of Examinations, Sri Lanka

අධ්‍යයන පොදු සහතික පත්‍ර (උසස් පෙළ) විභාගය 2021(2022)
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General Certificate of Education (Adv. Level) Examination, 2021(2022)

භෞතික විද්‍යාව II
பௌதிகவியல் II
Physics II

PART B — Essay

01 E II

Answer four questions only.
$(g = 10\,\text{m s}^{-2})$

5. A pile driver system is shown in figure (1). The steel arm of mass 2000 kg pivoted at point A is shown in figure (2) with its dimensions. The centre of gravity of the arm is located at G. A pulley of mass 200 kg is attached at the upper end (B) of the arm and it can be rotated by an electric motor. A cable is wound around the pulley and its free end is connected to a steel cylinder of mass 800 kg. Neglect the mass of the cable. The lengths AB and AC are 10 m and 2 m respectively. The horizontal distance from point A to the line of action of the weight of the steel arm is 2 m. The arm is operated using a hydraulic system.

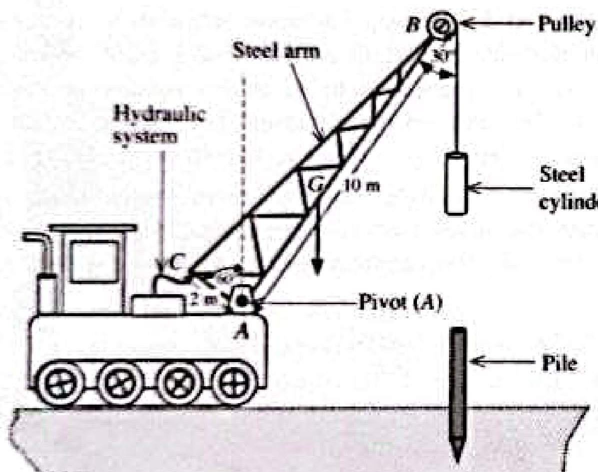

Figure (1)

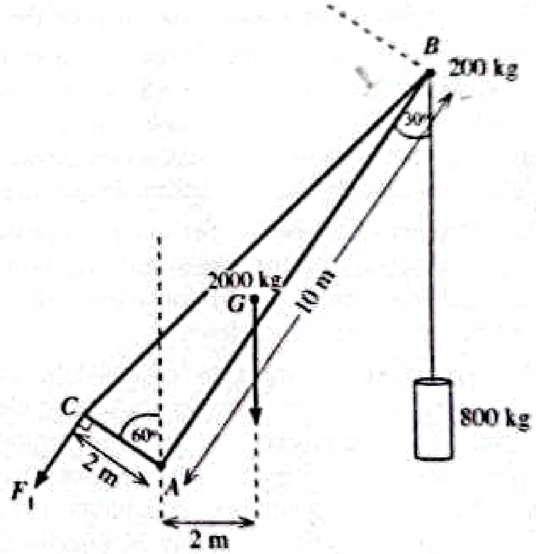

Figure (2)

(a) To keep the arm and its attachments at equilibrium position a force F_1 has to be applied at point C using the hydraulic system as shown in figure (2). The direction of F_1 is perpendicular to the length AC. Calculate the value of this force F_1 by taking moments about point A. For this calculation neglect the size of the pulley.

(b) The force F_1 in (a) above is provided by compressed oil of a hydraulic pump as shown in figure (3). The cross-sectional area of the piston of the master pump is $4\,\text{cm}^2$ and the cross-sectional area of the piston at point C is $60\,\text{cm}^2$. A force F_2 has to be applied to the piston of the master pump in order to obtain the force F_1.

(i) Name the principle that must be used to calculate force F_2.

(ii) Find the value of F_2.

(iii) What is the pressure of the compressed oil in the hydraulic pump?

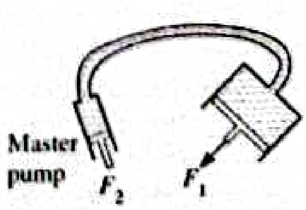

Figure (3)

[see page ten

(c) The radius of the pulley is 10 cm. The moment of inertia I of a pulley of mass M and radius r about its axis of rotation can be given by $I = \frac{1}{2}Mr^2$. The cable moves without slipping.

(i) When the arm is at its maximum vertical position as shown in figure (2) the steel cylinder is moved upward at a constant linear acceleration of $0{\cdot}5\ \mathrm{m\,s^{-2}}$ by rotating the pulley. Calculate the torque that must be applied to the pulley by the motor in order to raise the cylinder.

(ii) When the cylinder has moved upward to a certain height the motor is switched off and the cylinder comes to a momentarily stop after some time. Next the cylinder attached to the cable is allowed to drop onto the pile while the pulley rotates freely. The centre of gravity of the cylinder drops from a height of $\frac{45}{8}$ m before the cylinder hits the pile. Calculate the velocity of the cylinder just before hitting the pile. For this calculation neglect frictional torques acting against rotation.

(iii) After the collision, the cylinder and the pile penetrate as a composite object into the soil without any recoil. What type of collision is this? How do you identify this type of collision in terms of loss of kinetic energy.

(iv) Calculate the velocity of the cylinder and the pile just after the collision. The mass of the pile is 480 kg.

(v) If the distance penetrated by the pile in one hit is 20 cm, calculate the average value of the resistance force produced by soil against penetration. [Take $(6{\cdot}25)^2 = 39$]

6. Read the following passage and answer the questions.

The Doppler effect is the apparent change in the observed frequency of a wave when there is a relative motion between the source producing the waves and the observer. Here all the speeds must be measured relative to the medium in which waves propagate. Since air is assumed to be at rest relative to the earth, normally the relevant velocities are measured relative to the earth for sound waves. The change in frequency Δf (= observed frequency − emitted frequency) as a result of the Doppler effect is known as the Doppler shift.

The Doppler effect occurs for electromagnetic waves too, such as light waves or micro waves. If the speeds of the observer and the source are very much less than the speed c of electromagnetic waves, the Doppler effect relationships derived for sound waves could be used for electromagnetic waves by substituting c instead of the speed of sound.

The speeds of moving vehicles could be determined by measuring the relevant Doppler shift using electromagnetic waves. The instrument used for this purpose is known as a speed trap which consists of a radar transmitter and a radar receiver. From the transmitter microwaves are emitted in short pulses and aimed directly to a moving car as shown in figure (1).

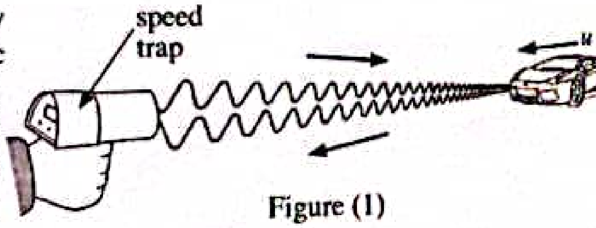

Figure (1)

The emitted microwaves reflect from the surface of speeding car and return to the receiver of the speed trap. By measuring the resulting Doppler shift, the speed at which the car moves is determined and recorded. In this type of applications, use of microwaves has an advantage over the other waves because they can penetrate fog, light rain and smoke.

(a) What is the Doppler effect?

(b) Normally the relevant velocities in Doppler effect are measured relative to the earth for sound waves. What is the reason for this?

(c) (i) The radar transmitter emits microwaves of frequency f_0. The car shown in the figure (1) approaches the speed trap at speed u. Write down an expression for the frequency f' of microwaves received by the car in terms of f_0, u and c considering the transmitter of the speed trap as a stationary source and the car as a moving observer.

(ii) Now the car acts as a moving source emitting microwaves with frequency f'. Write down an expression for the frequency f'' of microwaves detected by the receiver of the speed trap in terms of f', u and c.

(iii) Combining expressions obtained in (c) (i) and (c) (ii) above, derive an expression for f'' in terms of f_0, u and c.

[see page eleven

(iv) Taking $u<<<c$, show that the Doppler shift Δf observed by the speed trap is given by $\Delta f = f_0\frac{2u}{c}$

(v) If $f_0 = 3{\cdot}0 \times 10^{10}$ Hz and $\Delta f = 7000$ Hz, calculate the speed u of the car in $\mathrm{km\,h^{-1}}$. (Take $c = 3{\cdot}0 \times 10^8\ \mathrm{m\,s^{-1}}$)

(*d*) Suppose a wind is blowing towards the speed trap from the car. Does this affect the speed measurement of the car? Give the reason for your answer.

(*e*) If the speed trap is not aimed directly to the car but rather at an angle to it, will the speed of the car measured be greater, equal or less than the value calculated in (*c*) (v) above? Give the reason for your answer.

(*f*) Now consider a police car with the speed trap moving at a speed V is chasing behind the car moving with speed u as shown in figure (2). In this situation the relationship obtained for Δf in (*c*)(iv) above has to be modified as $\Delta f = f_0\frac{2(V-u)}{c}$.

(i) Determine Δf if $V = 100\ \mathrm{km\,h^{-1}}$. Use the value of u obtained in (*c*) (v) above. (Give your answer to the nearest integer in Hz)

(ii) Explain why $\Delta f < 0$ in this case.

(iii) Which method is more accurate to determine the speed u of the car by considering the Doppler shifts obtained in (*c*) and (*f*) above? Justify your answer.

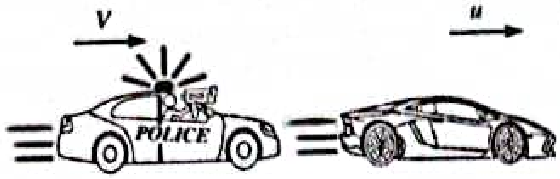

Figure (2)

(*g*) Write down an advantage of using microwaves in this type of applications.

7\. (*a*) (i) Write down an expression for the viscous force F acting on a small sphere of radius r moving at terminal velocity v in a homogeneous fluid at rest having coefficient of viscosity η.

(ii) A small sphere of radius r made of material of density β is moving vertically downward at terminal velocity v in a homogeneous fluid of density ρ (where $\rho < \beta$) at rest and coefficient of viscosity η. Obtain an expression for the terminal velocity v in terms of ρ, β, r, η and g.

(*b*) A mixture of spherical sediment particles has to be separated depending whether their sizes are greater than or less than 2 μm using respective terminal velocities. The mixture is mixed and shaken well with small quantity of water and gently poured on to the surface of water in a beaker. After this the height of the water column in the beaker is 10 cm. The densities of material made of sediment particles and water are $1900\ \mathrm{kg\,m^{-3}}$ and $1000\ \mathrm{kg\,m^{-3}}$ respectively. The coefficient of viscosity of water is $1{\cdot}0 \times 10^{-3}$ Pa s. How long will it take to precipitate all particles having diameter greater than or equal to 2 μm? Assume that all particles reach their terminal velocities as soon as they are poured on to water surface.

(*c*) (i) A person without wearing a face mask or face shield releases tiny droplets of diameter 20 μm to the atmosphere at an initial horizontal velocity of $20\ \mathrm{m\,s^{-1}}$ by coughing. If the density of droplets is $1080\ \mathrm{kg\,m^{-3}}$ and the density of air is negligible, what is the vertical terminal velocity acquired by droplets? The coefficient of viscosity of air is $2{\cdot}0 \times 10^{-5}$ Pa s. Assume that air is still.

(ii) Sketch the velocity-time (t) graphs separately for

(I) the vertical component of the velocity (v_V) and

(II) the horizontal component of the velocity (v_H) of a droplet.

(iii) If the height to the mouth from the ground is 1·50 m, how long will the droplets suspend in still air? For this calculation assume that all droplets reach their terminal velocity as soon as they enter the atmosphere.

(iv) Practically the evaporation of exhaled droplets while they are in air has to be considered. Giving reasons, briefly explain what will happen to the horizontal displacement of the droplets as a result of evaporation during airborne time.

(v) Low atmospheric temperature or high relative humidity conditions can cause more droplets to settle on the ground. Justify this statement.

[see page twelve

8. (*a*) A proton of mass m and charge $+q$ moving at speed v enters perpendicularly to a uniform magnetic field of flux density B.

(i) Write down an expression for the magnitude of force F acting on the proton due to the magnetic field.

(ii) Due to the above force the proton moves in a circular path. Derive an expression for radius r of the path.

(iii) Obtain an expression for the time T taken by the proton to complete one cycle in terms of m, q and B.

(iv) Let $m = 1{\cdot}6 \times 10^{-27}$ kg, $q = 1{\cdot}6 \times 10^{-19}$ C, $v = 9{\cdot}6 \times 10^{5}$ m s^{-1} and $B = 3{\cdot}0 \times 10^{-5}$ T. (Take $\pi = 3$).

(I) Determine the radius (r) of the circular path of the proton.

(II) What is the number of revolutions per second that the proton makes?

(*b*) Now an another proton enters with the same velocity v at an angle θ with the direction of the magnetic field, as shown in figure (1).

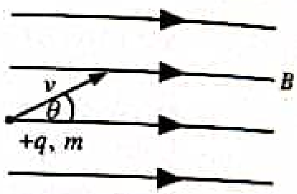

Figure (1)

(i) Name the shape of the path of the proton. Using the parallel and perpendicular components of the velocity of the proton with respect to the field explain how you arrived at the answer.

(ii) Using the values in (*a*) (iv) above calculate the time required for the proton to complete one periodic time T.

(iii) During this time T the proton travels a distance p parallel to the magnetic field. Write down an expression for the distance p travelled by the proton during this time in terms of v, θ and T.

(iv) If $\theta = 30°$ calculate the value of p? (Take $\sqrt{3} = 1{\cdot}7$)

(v) If the distance travelled by the proton along the direction of the magnetic field is 16320 km, what is the time taken to travel this distance?

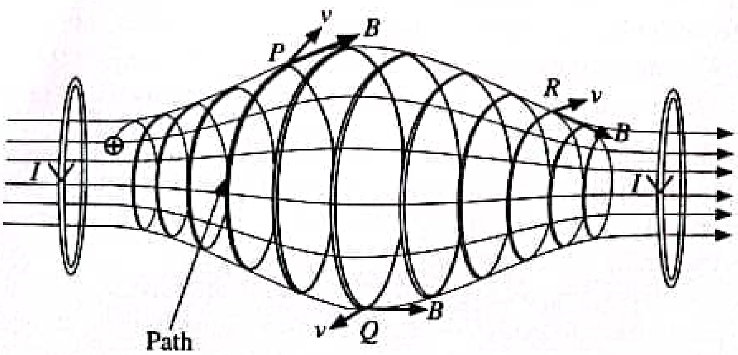

Figure (2)

(*c*) A non-uniform magnetic field can be formed using two current carrying coils as shown in figure (2). This type of magnetic field forms a "magnetic bottle" and it is an arrangement that permits to confine charged particles. The path of a positive charge particle is shown in the same figure.

(i) Explain why the radius of the path of the particle at position P is smaller than that of at position Q.

(ii) Copy the relevant points with directions of v and B from figure (2) on to your answer sheet and draw the directions of the magnetic force experienced by the charge particle at each positions P, Q and R using arrows.

(iii) Giving reasons prove that the charge particle may oscillate back and forth between the two ends of the magnetic bottle.

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

Part (A)

(*a*) A conducting metal wire of length l and area of cross-section A has n number of free electrons per unit volume. Electron charge is e.

(i) Write down an expression for the total number of free electrons available in the wire.

(ii) When a potential difference is applied across the ends of the wire a current I flows through the wire. Derive an expression for the drift velocity (v) of electrons in the wire in terms of I, n, e and A.

(*b*) An electrician uses two metallic wires X and Y made of same material having the same length (l) but different cross-sectional areas A_1 and A_2. They are connected in series and then in parallel to the same constant voltage source separately.

(i) Write an expression for the ratio of respective drift velocities of electrons $\left(\frac{v_X}{v_Y}\right)$ moving in the wires X and Y when they are connected in series.

(ii) Write an expression for the ratio of respective drift velocities of electrons $\left(\frac{v_X}{v_Y}\right)$ moving in the wires X and Y when they are connected in parallel.

(iii) Plot two graphs separately to show the variation of respective drift velocities (v_X and v_Y) along the length (l) of above series and parallel wire combinations. (Take $A_1 > A_2$)

(*c*) (i) A copper wire has a cross-sectional area of $2{\cdot}5 \times 10^{-7}\,\text{m}^2$. Calculate the drift velocity of electrons through the wire when the current is 4·0 A.
($e = 1{\cdot}6 \times 10^{-19}$ C; Number of free electrons per unit volume in copper = $8{\cdot}0 \times 10^{28}\,\text{m}^{-3}$)

(ii) In a conductor, free electrons have random motion and the random speed (mean thermal speed) at a given temperature can be calculated considering the mean kinetic energy and mean thermal energy of free electrons at that temperature. The mean thermal energy of free electron at temperature T is given by $\frac{3}{2}kT$ where k is the Boltzmann constant. Calculate the mean thermal speed of free electrons in copper at temperature of 27 °C.
(Take mass of electron = $9{\cdot}0 \times 10^{-31}$ kg, Boltzmann constant = $1{\cdot}4 \times 10^{-23}\,\text{J K}^{-1}$)
(Take $\sqrt{1{\cdot}4} = 1{\cdot}18$)

(iii) The mean thermal speed of free electrons in a conductor is typically very large compared to the drift velocity. But why do the free electrons with their mean thermal speed in a conductor can not cause any current flow without applying an external electric field?

(*d*) The mobility (μ) of charge carriers in a conductor is defined as the magnitude of the drift velocity per unit external electric field intensity that is being applied.

(i) Calculate the mobility of electrons in the copper wire mentioned in (*c*) (i) above if an electric field of intensity $50\,\text{V m}^{-1}$ is applied along the wire.

(ii) In the development of organic light emitting diodes (OLED) mobilities of charge carriers of organic materials are increased to lower the applied electric field and there by achieving a higher efficiency. What is the percentage reduction of applied electric field intensity if the mobility and drift velocity of charge carriers of an organic material are increased by 20% and 10% respectively?

[see page fourteen

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

Part (A)

When exercising, human body produces energy and a high percentage of this energy is converted into heat. If this heat is not removed the body temperature will rise. In order to maintain the normal body temperature, heat is dissipated by evaporating the water in sweat. The heat of evaporation of water is provided by the body.

(*a*) When a person of mass 75 kg is riding an exercise bike the rate of energy produced is 800 W. Out of this energy 75 % is converted into heat. Neglect the loss of heat due to respiration process.

(i) What is the amount of heat produced by this person during 30 minutes of cycling?

(ii) In order to release this heat, what is the mass of water that should be evaporated? The specific heat of evaporation of water at body temperature is $2{\cdot}4 \times 10^6\ \mathrm{J\,kg^{-1}}$. (Equation $Q = mL$ can be used for this.)

(iii) What is the volume of water in millilitres which corresponds to the mass calculated in (*a*) (ii) above? The density of water is $1{\cdot}0 \times 10^3\ \mathrm{kg\,m^{-3}}$.

(iv) Calculate the temperature rise of the body during the 30 minutes period if this amount of heat is not released from his body. Average specific heat capacity of the body is $3600\ \mathrm{J\,kg^{-1}\,K^{-1}}$.

(*b*) The above person inhales a volume of $4{\cdot}5 \times 10^{-4}\ \mathrm{m^3}$ of air at atmospheric pressure and at 27 °C in each breath. The respiration rate of the person is 20 breaths per minute. At the lungs, inhaled air is heated up to 37 °C.

(i) Determine the final volume of air inhaled inside the lungs after a breath. Assume that the pressure of inhaled air inside the lungs is equal to the atmospheric pressure.

(ii) Calculate the rate of work done by the lungs in order to remove all the air inhaled while exhalation. (Atmospheric pressure = $1{\cdot}0 \times 10^5$ Pa)

(*c*) A closed gymnasium has several exercise bikes. When people are not exercising in the gymnasium, temperature of the gymnasium is 30 °C and the relative humidity is 75 %. Saturated vapour pressure of water at 30 °C is 32 mm Hg.

(i) Write down an expression for relative humidity in terms of water vapour pressures.

(ii) Determine the water vapour pressure existing in the gymnasium.

(iii) What is the mass of water vapour present in the gymnasium? At 30 °C absolute humidity of saturated water vapour is $30\ \mathrm{g\,m^{-3}}$. The volume of the gymnasium is $600\ \mathrm{m^3}$.

(iv) Suppose **four** people are riding exercise bikes in the gymnasium. Assume that the temperature of gymnasium does not change and the mass of water vapour released by each person during 30 minutes is equal which is same as the value obtained in (*a*) (ii) above. What is the new relative humidity in the gymnasium after 30 minutes?

(v) Once the riding of bikes is over the gymnasium is cooled to 20 °C and some of the water vapour is removed by an air-conditioner. The mass of water vapour removed by the air-conditioner is 6300 g. What is the final relative humidity of the gymnasium at 20 °C? Absolute humidity of saturated water vapour at 20 °C is $20\ \mathrm{g\,m^{-3}}$.

Part (B)

Figure (1) shows a hollow cube with four different types of metal surfaces. The cube filled with hot water is used to demonstrate the intensity variation of thermal radiation emitted from different surfaces with temperature. Four thermal detectors are kept at same distance from each surface to measure the temperature of the surface.

[Let Stefan constant $\sigma = 6.0 \times 10^{-8}\ W m^{-2} K^{-4}$,

Wien's displacement constant = 2900 μm K]

For following calculations you may use

$(300)^4 = 8 \times 10^9$, $(310)^4 = 9 \times 10^9$, $(360)^4 = 16 \times 10^9$,

and $(373)^4 = 19 \times 10^9$.

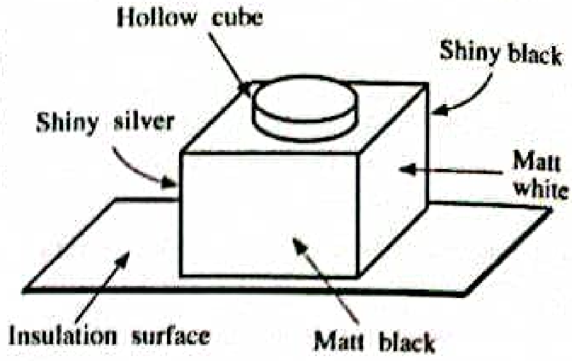

Figure (1)

(*a*) (i) What are the factors affecting absorption and emission of thermal radiation from a surface?

(ii) The measuring range of a thermal detector is from 200 K to 400 K. Calculate the peak wavelengths λ_m (wavelength at the maximum intensity) corresponding to the minimum and the maximum temperatures of a blackbody surface that can be measured using the thermal detector.

(iii) Name the region of the electromagnetic spectrum that the peak wavelengths obtained in (*a*) (ii) above belongs to.

(*b*) The above cube consists of four different type of surfaces of matt white, matt black, shiny silver, and shiny black. Thermal detectors display the readings of (not in order) 87 °C, 72 °C, 47 °C and 37 °C corresponding to the surfaces of the cube.

(i) Identify and writedown the temperature readings corresponding to each surface.

(ii) Which surface has the maximum surface emissivity?

(iii) If the room temperature is 27 °C, assuming the emissivity of the surface identified in (*b*) (ii) above to be 1, calculate the **relative** emissivity of the shiny silver surface.

(*c*) Net rate of radiation heat transfer per unit area (Q) between two parallel surfaces with emissivities e_1 and e_2 and temperatures T_1 and T_2 ($T_1 > T_2$) respectively is given by,

$$Q = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\left(\frac{1}{e_1} + \frac{1}{e_2} - 1\right)}$$

A special box type Thermos flask consists of three walls A, B, and C as shown in figure (2). The outer surface of wall A and the inner surface of wall B are coated with silver. Walls A and B are separated by a vacuum.

(i) What is the reason for maintaining a vacuum in between walls A and B?

(ii) Why silver coated surfaces are used for walls A and B?

(iii) Calculate the net rate of radiation heat transfer per unit area between outer wall of A and inner wall of B if the emissivity of the silver coated surfaces is 0·02. Assume that the temperature of the outer wall of A and inner wall of B are 100 °C and 27 °C, respectively. (Take $\frac{1}{99} = 0 \cdot 01$)

(iv) If the heat transfer between the outer A and inner B walls is due to conduction, instead of radiation, calculate the thickness of an insulator material of thermal conductivity $6 \cdot 6 \times 10^{-2}\ Wm^{-1}K^{-1}$ that must be used to obtain the same rate of heat transfer per unit area calculated in (*c*) (iii) above. Here assume steady state conditions.

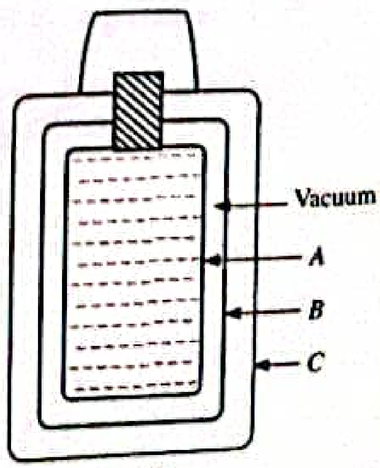

Figure (2)

* * *

Part (B)

Figure (1) shows the current (I) – voltage (V) characteristic curve for a diode.

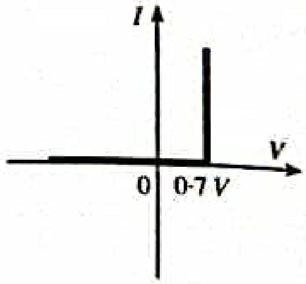

Figure (1)

(a) Name the diode which is represented by figure (1).

(b) Figures (2) and (3) show silicon diodes and two resistors with resistances R_1 and R_2. A and B inputs can be 0 V or 5 V. For all the calculations use the characteristic curve given in figure (1).

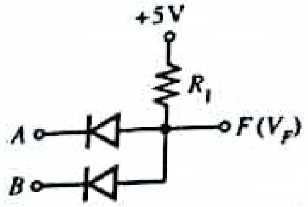

Figure (2)

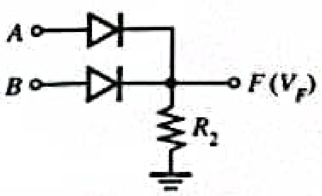

Figure (3)

(i) For different combinations of input voltages given below, determine the output voltages V_F at F and complete the following table for the circuits given in figure (2) and figure (3) respectively. (For this purpose copy the table twice on to your answer sheet)

A(V)	B(V)	V_F(V)
0	0	
0	5	
5	0	
5	5	

(ii) When considering the output F only, if 5 V (or close to 5 V) represents binary 1 and 0 V (or close to 0 V) represents binary 0, name the respective gates corresponding to the circuits shown in figure (2) and (3) above and write down their truth tables.

(iii) Calculate the suitable values of R_1 and R_2 which limits 0·5 mA of total current flowing through both diodes in each circuit.

(c) A student wants to build a logic circuit that will ring an alarm at an office with one door and one window if the door or window or both are opened after office hours. The related logical variables are as follows.

Inputs: Time: $T = 0$ (during office hours), $T = 1$ (after office hours).

Door: $D = 0$ (door is closed), $D = 1$ (door is opened).

Window: $W = 0$ (window is closed), $W = 1$ (window is opened).

Outputs: $F = 0$ (alarm not ringing), $F = 1$ (alarm ringing)

(i) Using logical variables T, D, W and F mentioned above, write down a truth table that will satisfy the required conditions.

(ii) Obtain the corresponding logical expression for F.

(iii) Simplify the logical expression that you have written in (c) (ii) above. (You may use the identities $W+\overline{W}=1$ and $\overline{D}W+D=D+W$).

(iv) Draw the **simplest** logical circuit that can be used for this purpose.

[see page fifteen