



Dr. Bbosa Science

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List of physical constants to be used

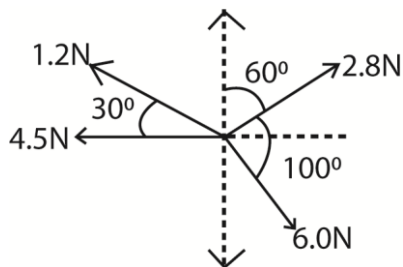
Acceleration due to gravity, g	9.81ms^{-2}
Electron charge, e	$1.6 \times 10^{-19}\text{C}$
Electron mass	$9.11 \times 10^{-31}\text{kg}$
Mass of the earth	$5.97 \times 10^{24}\text{kg}$
Plank's constant, h	$6.6 \times 10^{-34}\text{Js}$
Stefan's-Boltzmann's constant, σ	$5.67 \times 10^{-8}\text{Wm}^{-2}\text{K}^{-1}$
Radius of the earth	$6.4 \times 10^6\text{m}$
Radius of the sun	$7 \times 10^8\text{m}$
Radius of the earth's orbit about the sun	$1.5 \times 10^{11}\text{m}$
Speed of light in the vacuum, c	$3.0 \times 10^8\text{ms}^{-1}$
Thermal conductivity of copper	$390\text{Wm}^{-1}\text{K}^{-1}$
Thermal conductivity of aluminium	$210\text{Wm}^{-1}\text{K}^{-1}$
Specific heat capacity of water	$4.200\text{Jkg}^{-1}\text{K}^{-1}$
Universal gravitational constant	$6.67 \times 10^{-11}\text{Nm}^2\text{Kg}^{-2}$
Avogadro's number, N_A	$6.02 \times 10^{23}\text{mol}^{-1}$
Surface tension of water	$7.0 \times 10^{-2}\text{Nm}^{-1}$
Density of water	1000kgm^{-3}
Gas constant, R	$8.31\text{Jmol}^{-1}\text{K}^{-1}$
Charge to mass ratio, e/m	$1.8 \times 10^{11}\text{Ckg}^{-1}$
The constant, $\frac{1}{4\pi\epsilon_0}$	$9.0 \times 10^9\text{F}^{-1}\text{m}$
Faraday's constant, F	$9.65 \times 10^4\text{Cmol}^{-1}$
Thermal conductivity of Iron	$75\text{Wm}^{-1}\text{K}^{-1}$
Specific latent heat of fusion of Ice =	$3.3 \times 10^5\text{Jkg}^{-1}$

Permittivity of free space, μ_0	$4.0\pi \times 10^{-7} \text{Hm}^{-1}$
Permittivity of free space, ϵ_0	$8.85 \times 10^{-12} \text{Fm}^{-1}$
One electron volt	$1.6 \times 10^{-19} \text{J}$
Resistivity of Nichrome wire at 250C	$1.2 \times 10^{-6} \Omega \text{m}$
Specific heat capacity of copper	$400 \text{Jkg}^{-1} \text{K}^{-1}$

1. (a) (i) Distinguish between scalar and vector quantity. (01 mark)

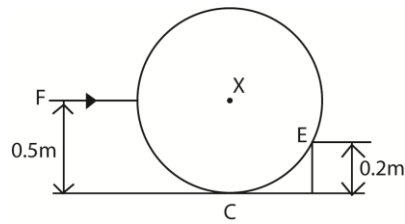
(ii) Give two examples of each type of quantity. (02marks)

(b) A body of mass 0.2kg at rest is acted on by four forces of 2.8N, 6.0N, 4.5N and 1.2N as shown in the figure below.



Calculate

- (i) Resultant force on the body (04marks)
 - (ii) Distance moved in 4s (02marks)
- (c) State Newton's law of motion and use them to derive the law of conservation of momentum. (06marks)
- (d) A body of mass 800kg moving at 30ms^{-1} collides with another of mass 400kg moving in the same direction at 25ms^{-1} . The two bodies stick together after collision. Calculate the
- (i) common velocity just after collision (02marks)
 - (ii) kinetic energy lost during collision (03marks)
2. (a) Define moment of force and give its SI unit. (02marks)
- (b) Explain briefly how to locate the centre of gravity of an irregular sheet of cardboard. (04marks)
- (c) State the conditions necessary for equilibrium of a rigid body under action of a system of forces. (02marks)
- (d) A wheel of radius 0.5m rests on a level surface at point C and makes contact with edge E of a block height 0.2m as shown in the figure below.



A force F is applied horizontally through the axle of the wheel at X to just move the wheel over the block. If the weight of the wheel is 180N , find the

- (i) Force exerted at point E (02marks)
- (ii) Force F (04marks)

(e) State the laws of friction and explain each of them (06marks)

3. (a) Define the following as applied to circular motion:

- (i) Centripetal acceleration (01mark)
- (ii) Period (01mark)

(b) (i) Explain why a cyclist bends inward while going round a curved path. (03marks)

(ii) Show that if θ is the angle of inclination of the cyclist to the vertical and μ is the coefficient of limiting friction between the ground and the bicycle tyres, then for safe riding $\tan \theta \leq \mu$. (04marks)

(iii) A body of mass 1.5kg moves once round a circular path to cover 44.0cm in 5s . Calculate the centripetal force acting on the body. (04marks)

(c) Define simple harmonic motion (01mark)

(d) A body executes simple harmonic motion with amplitude A and angular velocity, ω .

(i) Write down the equation for velocity of the body at a displacement x from the mean position (01mark)

(ii) Sketch the velocity-displacement graph for the body in (d)(i) for $\omega < 1$. (02marks)

(iii) If the body moves with amplitude 14.142 cm , at what distance from the mean position will be kinetic energy equal to potential energy? (03marks)

4. (a) State and illustrate Archimedes' principle. (05marks)

(b)(i) State the law of flotation (01 marks)

(ii) Describe an experiment to verify the law in (b)(i). (05marks)

(c) (i) Write Bernoulli's equation and define each term in the equation. (02marks)

(ii) Explain the origin of lift force on the wings of a plane. (03marks)

(iii) Air flows over the upper surfaces of the wings of an aeroplane at a speed of 120ms^{-1} , and past the lower surface of the wings at 110ms^{-1} . Calculate the lift force on the aeroplane if it has a total wing area of 20m^2 . Density of air = 1.29kgm^{-3})

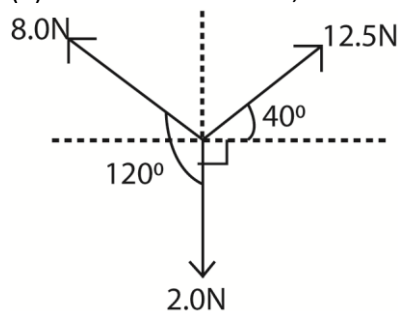
5. (a) What is meant by relative velocity? (01mark)

(b) A ship is heading due to north at a speed of 30ms^{-1} . Water in the lake is moving in the north-east direction at an average speed of 5kmh^{-1} . Calculate

(i) relative velocity of the ship (04 marks)

(ii) distance off course the ship will be after 40 minutes. (02marks)

- (c) (i) Explain why a passenger in a car jerks forward when the brakes are suddenly applied. (03marks)
 (ii) Use Newton's second law to define the Newton. (04marks)
 (d) Three forces of 8.0N, 12.5N and 2.0N act on a body of mass 0.7kg as shown below



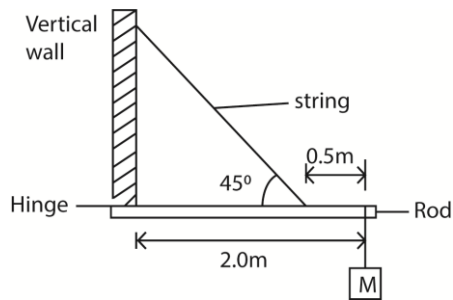
Calculate the acceleration of the body

6. (a) what is meant by the centre of the mass? (01mark)
 (b) Explain why a long spanner is preferred to a short one in undoing a tight bolt. (03marks)
 (c) A uniform ladder of length 10m and weight 400N, leans against a smooth wall and its foot rests on rough ground. The ladder makes an angle of 60° with the horizontal. If the ladder just slips when a person of weight 800N climbs 6m up the ladder, calculate the
 (i) reaction on the wall and the ground (05marks)
 (ii) distance another person of weight 600N can climb up the ladder so that the same reaction are exerted as in (c)(i). (02marks)
 (d) (i) State the principle of conservation of energy. (01mark)
 (ii) How does the principle in (d)(i) apply to a child sliding down an incline? (02marks)
 (e) A pump with power output of 147.1W can raise 2kg of water per second through a height of 5m and deliver it into a tank. Calculate the speed with which the water is delivered into the tank. (03marks)
 (f) Explain the effect of a **couple** on a rigid body. (03marks)
7. (a) What is meant by a
 (i) Brittle material (01mark)
 (ii) Ductile material (01marks)
 (b) Give one example of each of the materials in (a) (01mark)
 (c) Explain why bicycle frames are hollow (02marks)
 (d) (i) Sketch a labelled graph of stress against strain for a ductile material (02marks)
 (ii) Explain the main features of the graph in (d)(i) (04marks)
 (e) Derive the expression for the energy stored per unit volume in a rod of length, L , Young's Modulus, Y , when stretched through distance, e . (04marks)
 (f) A load of 5kg is placed on top of a vertical brass rod of radius 10mm and length 50cm. if
 (i) decrease in length (03marks)
 (ii) energy stored in the rod. (02marks)
8. (a) Define the following:
 (i) Angular velocity
 (ii) Period

- (b) An object moves in a circular path of radius, r , with a constant velocity, V . Derive an expression for its acceleration. (04marks)
- (c) (i) State two factors on which the rate of flow of a fluid through a tube depends. (02marks)
- (ii) Describe an experiment to measure the coefficient of viscosity of a liquid using Poiseuille's formula
- (d) Find the time take for an oil drop of diameter 6.0×10^{-3} mm to fall through a distance of 4.0 cm in air of coefficient of viscosity 1.8×10^{-5} Pa.
- [The density of oil and air are $8.0 \times 10^3 \text{ kg m}^{-3}$ and 1 kg m^{-3} respectively]
9. (a) (i) State Newton's laws of motion. (03marks)
- (ii) A molecule of a gas contained in a cube of side L strikes the wall of the cube repeatedly with a velocity u . Show that the average force F on the wall is given by $F = \frac{mu^2}{L}$; where m is the mass of the molecule (04marks)
- (b) (i) Define linear momentum and state the law of conservation of linear momentum. (02marks)
- (ii) A body of mass m_1 moving with velocity u , collides with another body of mass m_2 at rest. If they stick together after collision, find the common velocity with which they move (04marks)
- (c) A bullet of mass 10g is fired horizontally with a velocity of 300 ms^{-1} into a block of wood of mass 290g which rests on a rough horizontal floor. After impact, the block and the bullet move together and come to rest when the block has travelled a distance of 15m. Calculate the coefficient of sliding friction between the block and the floor. (07marks)
10. (a) State Kepler's laws of planetary motion. (03marks)
- (b) Use Newton's law of gravity to derive the dimension of the universal gravitational constant (03marks)
- (c) A satellite is revolving at a height, h , above the surface of the earth with period T .
- (i) Show that the acceleration due to gravity, g , on the earth's surface is given by $g = \frac{4\pi^2(r_e+h)^3}{T^2 r_e^2}$ where r_e is the radius of the earth. (06marks)
- (ii) What is meant by parking orbit? (02marks)
- (d) A satellite revolves in a circular orbit at a height of 600km above the earth's surface. Calculate the
- (i) speed of the satellite. (03marks)
- (ii) period of the satellite. (03marks)
11. (a)(i) Define Simple harmonic motion. (01mark)
- (ii) Sketch a displacement-time graph for a body performing simple harmonic motion. (01mark)
- (b) A uniform cylindrical rod of length 16cm and density 920 kg m^{-3} floats vertically in a liquid of density 1000 kg m^{-3} . The rod is depressed through a distance of 7mm and then released.
- (i) Show that the rod performs simple harmonic motion (06marks)
- (ii) Find the frequency of the resultant oscillations. (04marks)

- (iii) Find the velocity of the rod when it is at a distance of 5mm above the equilibrium position (03marks)
- (c) What is meant by potential energy? (01mark)
- (d) Describe the energy changes which occur when a
- (i) ball thrown upwards in air (03marks)
 - (ii) loud speaker vibrating (01mark)
12. (a)(i) Define elastic deformation and plastic deformation (02marks)
- (ii) Explain what is meant by work hardening. (02marks)
- (b) (i) Sketch using the same axes, stress-strain curves for ductile material and for rubber (03marks)
- (ii) Explain the features of the curve for rubber. (03marks)
- (c) A capillary tube is held in a vertical position with one end dipping in a liquid of surface tension γ and density ρ . If the liquid rises to a height, h , derive an expression for h in terms of γ , ρ and radius r of the tube assuming the angle of contact is zero. (04marks)
- (d) A mercury drop of radius 2mm falls vertically and on hitting the ground, it splits into two drops each of radius 0.5mm. Calculate the change in surface energy given that the surface tension of mercury is 0.52Nm^{-1} . (05marks)
- (e) State the effect of temperature on surface tension of a liquid. (01mark)
13. (a) (i) Define dimensions of a physical quantity. (01mark)
- (ii) In the gas equation
$$\left(P + \frac{a}{V^2}\right)(V - b) = RT$$
Where P = pressure, V = volume, T = absolute temperature and R = gas constant, what are the dimensions of the constants a and b ? (04mark)
- (b) A particle is projected from a point on horizontal plane with a velocity, u , at an angle, θ , above the horizontal. Show that the maximum horizontal range $R_{\max}$ is given by,
$$R_{\max} = \frac{u^2}{g}$$
where, g , is the acceleration due to gravity. (04marks)
- (c) (i) Define elastic limit of a material. (01marks)
- (ii) Describe an experiment to determine Young's Modulus of a steel wire. (06marks)
- (d) Explain why tyres of a vehicle travelling on a hard surfaced road may burst. (04marks)
14. (a) (i) What is meant by efficiency of a machine? (01mark)
- (ii) A car of mass $1.2 \times 10^3\text{kg}$ moves up an incline at a steady velocity of 15ms^{-1} against a frictional force of $6.0 \times 10^3\text{N}$. The incline is such that the car rises 1.0m for every 10m along the incline. Calculate the output power of the car engine. (04marks)
- (b) (i) Define the impulse and momentum. (02marks)
- (ii) An engine pumps water such that the velocity of the water leaving the nozzle is 15ms^{-1} . If the water jet is directed perpendicularly on a wall and comes to a stop at the wall, calculate the pressure exerted on the wall. (03marks)
- (c) (i) Define inertia. (01mark)
- (ii) Explain why a body placed on a rough plane will slide when the angle of inclination is increased. (04marks)
- (d) (i) State the conditions for a body to be in equilibrium under action of coplanar forces. (02marks)
- (ii) Briefly explain the three states of equilibrium (03marks)

15. (a) (i) What is meant by conservative forces? (01mark)
(ii) Give two examples of conservative forces (02marks)
(b) Explain the following
(i) damped oscillations (02marks)
(ii) Forced oscillations (02marks)
(c) (i) State Newton's law of gravitation (01mark)
(ii) Show that Newton's law of gravitation is consistent with Kepler's third law. (05marks)
(d) If the earth takes 365 days to make one revolution around the sun, calculate the mass of the sun (04marks)
(e) Explain briefly how satellites are used in world-wide radio or television communication. (04marks)
16. (a) (i) What is meant by fluid element and flow line as applied to fluid flow? (02mark)
(ii) Explain why some fluids flow more easily than others (03marks)
(b) (i) state Bernoulli's Principle. (01mark)
(ii) Explain how a Pilot-static tube works (04marks)
(c) Air flowing over the upper surface of an air craft's wing causes a lift force of $6.4 \times 10^5 \text{N}$. The air flows under the wing at a speed of 120ms^{-1} over an area of 28m^2 . Find the speed of air flow over an equal area of the upper surface of the air craft's wings. [Assume density of air = 1.2kgm^{-3}] (04marks)
(d) (i) What is meant by surface tension and angle of contact of a liquid? (02marks)
(ii) A water drop of radius 0.5cm is broken up into other drops of water each of radius 1mm. assuming isothermal conditions, find the total work done to break up the water drop. (04marks)
17. (a) (i) what is meant by conservative force? (01mark)
(ii) Give two examples of conservative forces. (01mark)
(b) (i) State the law of conservation of mechanical energy. (01mark)
(ii) A body of mass, m , is projected vertically upwards with speed, u . show that the law of conservation of mechanical energy is obeyed throughout its motion. (05marks)
(iii) Sketch a graph showing variation of kinetic energy by the body with time. (01 mark)
(c) (i) Describe an experiment to measure the coefficient of static friction. (04marks)
(ii) State two disadvantages of friction. (01mark)
(d) A bullet of mass 20g moving horizontally strikes and get embedded in a wooden block of mass 500g resting on a horizontal table. The block slides through a distance of 2.3m before coming to rest. If the coefficient of kinetic friction between the block and table is 0.3, calculate
(i) friction force between the block and the table. (02marks)
(ii) velocity of the bullet just before it strikes the block. (04marks)
18. (a) (i) State the principle of moments. (01mark)
(ii) Define the terms centre of gravity and uniform body. (02marks)
(b) Figure below shows a body, M of mass 20kg supported by a rod of negligible mass horizontally hinged to a vertical wall and supported by a string fixed at 0.5m from the other end of the rod.



Calculate the

- (i) Tension in the string (03marks)
- (ii) Reaction of the hinge (03marks)
- (iii) Maximum additional mass which can be added to the mass of 20kg before the string can break given that the string cannot support a tension of more than 500N. (02marks)

(c) (i) Define Young's modulus. (01marks)

(ii) Explain the precautions taken in determinations of Young's modulus of a wire. (06marks)

(iii) Explain why a piece of rubber stretches much more than a metal wire of the same length and cross section (02marks)

19. (a) State Kepler's laws of planetary motion (03marks)

(b) (i) what is a parking orbit? (01mark)

(ii) Derive an expression for the period, T , of a satellite in a circular orbit of radius, r , above the earth in terms of mass of earth, m , gravitational constant, G and r . (04marks)

(c) (i) A satellite of mass 200kg is launched in a circular orbit at a height of 3.59×10^7 m above the earth's surface. Find the mechanical energy of the satellite. (03marks)

(ii) Explain what will happen to the satellite if its mechanical energy was reduced. (03marks)

(d) Describe laboratory method of determining the universal gravitational constant, G . (06marks)

20. (a) (i) Distinguish between surface tension and surface energy (01mark)

(ii) Show the surface energy and surface tension are numerically equal. (03marks)

(iii) Explain why water dripping out of a tap does so in spherical shapes. (03marks)

(b) Two soap bubbles of radius 2.0cm and 4.0cm respectively coalesce under isothermal conditions. If the surface tension of the soap solution is $2.5 \times 10^{-2} \text{Nm}^{-1}$, calculate the excess pressure inside the resulting soap bubble. (04marks)

(c) (i) State Bernoulli's principle (0marks)

(ii) Explain how wind at a high speed over the roof of a building can cause the roof to be ripped off the building. (03marks)

(iii) An aeroplane has a mass of 8,000kg and wing area of 8.0m^2 . When moving through still air, the ratio of its velocity to that of the air above its wings is 0.25. At what velocity will the aeroplane be able to just lift off the ground? (Density of air = 1.3kgm^{-3})

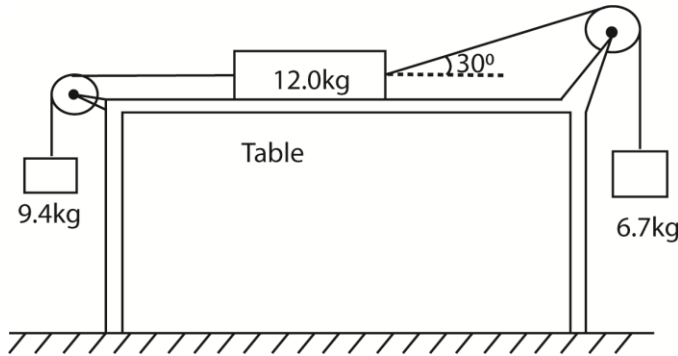
21. (a)(i) What is projectile motion? (01 marks)

(ii) A bomb is dropped from an aeroplane when it is directly above a target at a height of 1402.5m. The aeroplane is moving horizontally with a speed of 500kmh^{-1} . Determine whether the bomb will hit the target. (05marks)

(b) (i) Define angular velocity. (01mark)

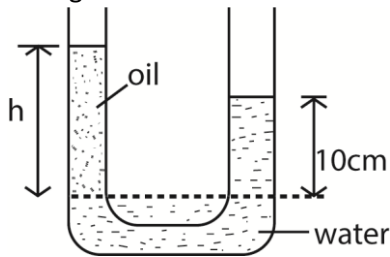
- (ii) a satellite is revolving around the earth in a circular orbit at an altitude of $6 \times 10^5 \text{m}$ where the acceleration due to gravity is 9.4 ms^{-2} . Assuming that the earth is spherical, calculate the period of the satellite. (03marks)
 - (c) (i) State Newton's laws of motion (03marks)
 - (ii) Explain how a rocket is kept in motion. (04marks)
 - (iv) Explain why passengers in a bus are thrown backwards when the bus suddenly start moving (03marks)
22. (a) (i) What is meant by Young's modulus? (03marks)
- (ii) State Hooke's law (01mark)
 - (iii) Derive an expression for energy released in a unit volume a stretched wire in terms of stress and strain. (04marks)
- (b) A steel wire of length 0.6m and cross-section area $1.5 \times 10^{-6} \text{m}^2$ is attached at B to a copper wire BC of length 0.39m and cross section area $3.0 \times 10^{-6} \text{m}^2$. The combination is suspended vertically from a fixed point at A and supports a weight of 250N at C. find the extension in each of the wires, given that Young's Modulus for steel is $2.0 \times 10^{11} \text{Nm}^{-2}$ and that of copper is $1.3 \times 10^{11} \text{Nm}^{-2}$. (05marks)
- (c) With the aid of a labelled diagram, describe an experiment to determine the Young's Modulus of a steel wire (07marks)
- (d) Explain the term plastic deformation in metals (02marks)
23. (a) Define work and energy (02marks)
- (b) Explain whether a person carrying a bucket of water does any work on the bucket while walking on a levelled road. (03marks)
- (c) A pump discharges water through a nozzle of diameter 4.5cm with speed of 62ms^{-1} into a tank 16m above the intake.
- (i) Calculate the work done per second by the pump in raising the water if the pump is ideal. (04marks)
 - (ii) Find the power wasted if the efficiency of the pump is 73% (02marks)
 - (iii) Account for the power loss in (c)(ii) (02marks)
- (d) (i) State work-energy theorem. (01mark)
- (ii) Prove the work-energy theorem for a body moving with constant acceleration. (03marks)
- (e) Explain briefly what is meant by internal energy of a substance. (03marks)
24. (a) Define coefficient of viscosity and state its units. (02marks)
- (b) Explain the origin of viscosity in air and account for the effect of temperature on it. (05marks)
- (c) Describe, stating the necessary precautions an experiment to measure the coefficient of viscosity of a liquid using Stoke's law. (07marks)
- (d) A steel ball bearing of diameter 8.0mm falls steadily through oil and covers a vertical height of 20.0cm in 0.56s. If the density of steel is 7800kgm^{-3} and that of oil is 900kgm^{-3} , calculate the
- (i) up thrust on the ball (03marks)
 - (ii) viscosity of the oil (03marks)
25. (a) Using the molecular theory, explain the laws of friction between solid surfaces. (06marks)

- (b) With the aid of a labelled diagram, describe how the coefficient of static friction for an interface between a rectangular block of wood and a plane surface can be determined. (06marks)
- (c) The diagram below shows three masses connected by inextensible strings which pass over smooth pulleys. The coefficient of friction between the table and the 12.0kg mass is 0.25.



- If the system is released from rest, determine the
- Acceleration of the 12.0kg mass (05marks)
 - Tension in each string (03marks)
26. (a) Define terminal velocity (01mark)
- (b) Explain laminar flow and turbulent flow (03marks)
- (c) Describe an experiment to measure the coefficient of viscosity of water using Ponselle's formula. (07marks)
- (d) (i) State Bernoulli's principle (01 mark)
- (ii) Explain why a person standing near a railway line is sucked towards the railway line when a fast moving train passes. (03marks)
- (e) A horizontal pipe of cross sectional area 0.4m^2 , tapers to a cross section area of 0.2m^2 . The pressure at the large section of the pipe is $8.0 \times 10^4 \text{Nm}^{-2}$ and the velocity of water through the pipe is 11.2ms^{-1} . If the atmospheric pressure is $1.01 \times 10^5 \text{Nm}^{-2}$, find the pressure at the small section of the pipe. (05marks)
27. (a) (i) State the law of conservation of linear momentum (01mark)
- (ii) A body explodes and produces two fragments of mass m and M . If the velocities of the fragments are u and v respectively. Show that the ratio of the kinetic energies of the fragments is
- $$\frac{E_1}{E_2} = \frac{M}{m} \text{ where } E_1 \text{ is the kinetic energy of } m \text{ and } E_2 \text{ is the kinetic energy of } M$$
- (b) Show that the centripetal acceleration of an object moving with constant velocity, v , in a circle of radius, r is $\frac{v^2}{r}$. (04marks)
- (c) A car of mass 1000kg moves round a banked track at constant speed of 108kmh^{-1} . Assuming the total reaction at the wheels is normal to the track, and the radius of curvature of the track is 100m , calculate the:
- angle of inclination of the track to the horizontal (04marks)
 - reaction at the wheels (02marks)
- (d) (i) Define uniformly accelerated motion (01mark)

- (ii) A train starts from rest at station A and accelerates at 1.25ms^{-2} until it reaches a speed of 20ms^{-1} . It then travels at this steady speed for a distance of 1.56km and then decelerates at 2ms^{-2} to come to rest at station B. Find the distance from A to B. (04marks)
28. (a)(i) State Kepler's laws of planetary motion. (03marks)
- (ii) Estimate the mass of the sun, if the orbit of the earth around the sun is circular. (04marks)
- (b) Explain Brownian motion (03marks)
- (c) Explain the energy changes which occur when a pendulum is set into motion. (03marks)
- (d) A simple pendulum of length 1m has a bob of mass 100g . It is displaced from mean position A to position B so that the string makes an angle of 45° with the vertical. Calculate the
- (i) maximum potential energy of the bob. (03marks)
- (ii) velocity of the bob when the string makes an angle of 30° with the vertical. [Neglect air resistance]
29. (a) State Hooke's law. (01mark)
- (b) A copper wire is stretched until it breaks.
- (i) Sketch a stress- strain graph for the wire and explain the main features of the graph. (04marks)
- (ii) Explain what happens to the energy used to stretch the wire at each stage. (04marks)
- (iii) Derive the expression for the work done to stretch a spring of force constant, k , by a distance, x . (03marks)
- (c)(i) Define Young's Modulus. (01mark)
- (ii) Two identical steel bars A and B of radius 2.0mm are suspended from the ceiling. A mass of 2.0kg is attached to the free end of bar A. Calculate the temperature to which B should be raised so that the bars are again equal in length.
[Young's Modulus of steel = $1.0 \times 10^{11}\text{Nm}^{-2}$]
[Linear expansivity of steel = $1.2 \times 10^{-5}\text{K}^{-1}$] (05mark)
- (d) Why does an iron roof make cracking sound at night? (02marks)
30. (a) Define the following terms as applied to oscillatory motion
- (i) Amplitude (01mark)
- (ii) Period (01mark)
- (b) State four characteristics of simple harmonic motion. (02marks)
- (c) A mass, m is suspended from a rigid support by a straight string of length L . the mass is pulled aside so that the string makes an angle, θ , with the vertical and then released.
- (i) Show that the mass executes simple harmonic motion with a period $T = 2\pi \sqrt{\frac{L}{g}}$.
- (ii) Explain why this mass comes to a stop after a short time. (02marks)

- (d) A piston in a car engine performs a simple harmonic motion of frequency 12.5Hz. If the mass of the piston is 0.50kg and its amplitude of vibration is 45mm, find the maximum force on the piston. (03marks)
- (e) Describe an experiment to determine the acceleration due to gravity, g , using a spiral spring, of known constant. (06marks)
31. (a) Explain what is meant by centripetal force. (02marks)
- (b)(i) Derive an expression for centripetal force acting on a body of mass, M , moving in a circular path of radius, r . (06marks)
- (ii) A body moving in a circular path of radius 0.5m makes 40 revolutions per second. Find the centripetal force if the mass is 1kg (03marks)
- (c) Explain the following
- (i) A mass attached to a string rotating at constant speed in a horizontal circle will fly off at a tangent of the string breaks. (02marks)
- (ii) A cosmonaut in a satellite which is in a free circular orbit around the earth experiences the sensation of weightlessness even though there is influence of gravitational field on earth. (03marks)
- (d) (i) Derive an expression for maximum horizontal distance travelled by a projectile in terms of the initial speed, u , and the angle of projection, θ , to the horizontal. (02marks)
- (ii) Sketch a graph to show the relationship between kinetic energy and height above the ground in a projectile. (02marks)
32. (a)(i) What is meant by the following terms, steady flow and viscosity? (02marks)
- (ii) Explain the effect of increase in temperature on viscosity of a liquid. (03marks)
- (b) (i) Show that the pressure, P , exerted at a depth, h , below the free surface of a liquid of density, ρ , is given by $P = h\rho g$. (03marks)
- (ii) Define relative density. (01mark)
- (iii) A U-tube whose ends are open to atmosphere, contains water and oil as shown in the figure below
- 
- Given the density of oil is 300kgm^{-3} , find the value of h .
- (c) A metal ball of diameter 10mm is timed as it falls through oil at a steady speed. It takes 0.5s to fall through a vertical distance of 0.3m. Assuming that the density of metal is 7500kgm^{-3} and that of oil is 900kgm^{-3} , find
- (i) the weight of the ball (02marks)
- (ii) the up thrust on the ball (02marks)
- (iii) the coefficient of viscosity of the oil (03marks)

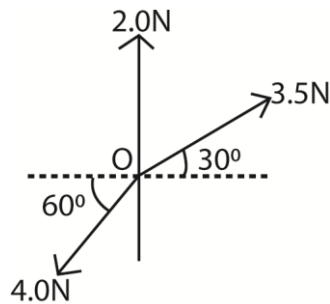
[Assume the viscous force = $6\pi\eta rv_0$ where η is the coefficient of viscosity, r is the radius of the ball, v_0 is the terminal velocity]

33. (a) Define the following terms
- (i) Uniform acceleration (01mark)
 - (ii) Angular velocity (01mark)
- (b) (i) What is meant by banking a track? (01mark)
- (ii) Derive an expression for the angle of banking θ for a car of mass, m , moving at speed, v , round a banked track of radius, r . (04marks)
- (c) A body of mass, m is tied to an inelastic thread of length, L , and whirled with constant speed in a vertical circle
- (i) With the aid of a sketch diagram, explain the variation of tension in the string along the circle. (05 marks)
 - (ii) If the string breaks at one point along the circle, state the most likely position and explain the subsequent motion of the bob.
- (d) A body of mass 15kg is moved from earth's surface to a point $1.8 \times 10^6\text{m}$ above the earth. If the radius of the earth is $6.4 \times 10^6\text{m}$ and the mass of the earth is $6.0 \times 10^{24}\text{kg}$; calculate the work done in taking the body to that point (06marks)
34. (a) State Newton's laws of motion. (03marks)
- (b) Use Newton's laws of motion to show that when two bodies collide their momentum is conserved. (04marks)
- (c) Two balls P and Q travelling in the same line in opposite directions with speeds of 6ms^{-1} and 15ms^{-1} respectively make a perfect collision. If the masses of P and Q are 8kg and 5kg respectively, find the
- (i) final velocity of P, (04marks)
 - (ii) change in kinetic energy. (04marks)
- (d) (i) What is an impulse of a force? (01marks)
- (ii) Explain why a long jumper should normally land on sand. (04marks)
35. (a) (i) What is meant by viscosity. (01mark)
- (ii) Explain the effect of temperature on viscosity of a liquid. (03marks)
- (b) Derive an expression for terminal velocity of a sphere of radius, a , falling in a liquid of viscosity, η . (04marks)
- (c) Explain why velocity of a liquid at a wide part of a tube is less than that at a narrow part. (02marks)
- (d) A solid weighs 237.5g in air and 12.5g when totally immersed in a fluid of density $9.0 \times 10^2\text{kgm}^{-3}$. Calculate the density of the liquid in which the solid would float with one fifth of its volume exposed above the liquid surface.
- (e) Describe an experiment to measure the coefficient of static friction between a rectangular block of wood and a plane surface. (04marks)
36. (a) (i) What is meant by simple harmonic motion? (01mark)
- (ii) State two practical examples of simple harmonic motion. (01mark)

- (iii) Using graphical illustrations, distinguish between under damped and critically damped oscillations (04marks)
- (b) (i) Describe an experiment to measure acceleration due to gravity using a spiral spring (06marks)
- (ii) State two limitations to the accuracy of the value obtained in (b)(i).
- (c) A horizontal spring of force constant 200Nm^{-1} fixed at one end has a mass of 2kg attached to the free end and resting on a smooth horizontal surface. The mass is pulled through a distance of 40.0cm and released.
- Calculate the
- (i) Angular speed
- (ii) Maximum velocity attained by a vibrating body. (02marks)
- (iii) Acceleration when the body is half way towards the centre from its initial position (02marks)
37. (a) (i) State the law of conservation of linear momentum. (01mark)
- (ii) Use Newton's law to derive the law in (a) (i) (04marks)
- (b) Distinguish between elastic and inelastic collision (01mark)
- (c) An object X of mass M , moving with a velocity of 10ms^{-1} collides with a stationary object Y of equal mass. After collision, X moves with a speed u at an angle 30° to the initial direction, while Y, moves with a speed V at angle 90° to the new direction of X.
- (i) Calculate the speeds U and V (05marks)
- (ii) Determine whether the collision is elastic or not. (03marks)
- (d) (i) Define uniform acceleration. (01mark)
- (ii) With the aid of a velocity-time graph, describe the motion of a body projected vertically upwards. (03marks)
- (iii) Calculate the range of a projectile which is fired at an angle of 45° to the horizontal with a speed of 20ms^{-1} . (02marks)
38. (a)(i) State Archimedes' principle. (01mark)
- (ii) A solid weighs 20.0g in air, 15.0g in water and 16.0g in a liquid, R. Find the density of R (03marks)
- (b) (i) What is meant by simple harmonic motion? (01 mark)
- (ii) Distinguish between damped and forced oscillations (02marks)
- (c) A cylinder of length, L , and cross section area A and density σ floats in a liquid of density, ρ . The cylinder is pushed down slightly and released.
- (i) show that it performs simple harmonic motion. (05marks)
- (ii) Derive the expression for period of the oscillation. (02marks)
- (d) A spring of force constant 40Nm^{-1} is suspended vertically. A mass of 0.1kg suspended from the spring is pulled down a distance of 5mm and released. Find the
- (i) period of the oscillation (02marks)
- (ii) maximum acceleration of the mass (02marks)
- (iii) net force acting on the mass when it is 2mm below the centre of oscillation. (02marks)

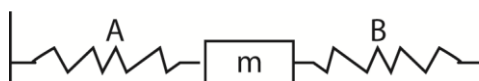
39. (a) Define viscosity of a fluid (01mark)
- (b) (i) Derive an expression for terminal velocity attained by a sphere of density, σ , and radius, a , falling through a fluid of density, ρ and viscosity, η . (05marks)
- (ii) Explain the variation of viscosity of a liquid with temperature. (02marks)
- (c) (i) State the laws of friction. (02marks)
- (ii) With the aid of a well labelled diagram, describe an experiment to determine the coefficient of kinetic friction between two surfaces. (05marks)
- (d) A body slides down a rough plane inclined at 30° to horizontal. If the coefficient of kinetic friction between the body and the plane is 0.4, find the velocity after it has travelled 6m along the plane. (05marks)
40. (a) (i) Describe the terms tensile stress and kinetic strain as applied to a stretched wire. (02marks)
- (ii) Distinguish between elastic limit and proportional limit. (02marks)
- (b) With the aid of a labelled diagram, describe an experiment to investigate the relationship between tensile stress and tensile strains of a steel wire. (07marks)
- (c)(i) A load of 60N is applied to a steel wire of length 2.5m and cross sectional area of 0.22mm^2 . If Young's Modulus for steel is 120GPa, find the expansion produced. (03marks)
- (ii) If the temperature rise of 1K causes a fractional increase of 0.001%, find the change in length of a steel wire of length 2.5 when the temperature increases by 4K. (03marks)
- (d) The velocity, V , of a wave in a material of Young's Modulus, E and density, ρ , is given by $V = \sqrt{\frac{E}{\rho}}$. Show that the relationship is dimensionally correct. (03marks)
41. (a) (i) Define the term impulse (01mark)
- (ii) State Newton's laws of motion (03marks)
- (b) A bullet of mass 10g travelling horizontally at a speed of 100ms^{-1} strikes a block of wood of mass 900g suspended by a light vertical string and is embedded in the block which subsequently swings freely. Find the
- (i) vertical height through which the block rises. (04marks)
- (ii) Kinetic energy lost by the bullet (03marks)
- (c) Explain the terms time of flight and range as applied to projectile motion. (02marks)
- (d) A stone is projected at an angle of 20° in horizontal and just clears a wall which is 10m high and 30m from the point of projection. Find the
- (i) speed of projection. (04marks)
- (ii) Angle which the stone makes with the horizontal as it clears the wall. (03marks)
42. (a) Define the following terms
- (i) Velocity
- (ii) Moment of a force
- (b) (i) A ball is projected vertically up wards with a speed of 50ms^{-1} . on return it passes a point of projection, and falls 78m below. Calculate the total time taken. (05marks)
- (ii) State energy changes that occurred during the motion of the ball in (b)(i) above. (03marks)
- (c) (i) State the conditions required for mechanical equilibrium to be attained. (02marks)

- (ii) A uniform ladder of mass 400kg length 5m, rests with its upper end against a smooth vertical wall and with its lower end at 3m from the wall on a rough ground. Find the magnitude and direction of the force exerted at the bottom of the ladder. (06marks)
- (d) State four instances where increasing friction is useful. (02marks)
43. (a) What is meant by simple harmonic motion? (01mark)
- (b) A cylindrical vessel of cross-section area A, contains air of volume V, at pressure, P, trapped by frictionless air tight piston of mass, M. the piston is pushed down and released.
- (i) If the piston oscillates with simple harmonic motion, show that its frequency, f, is given by
- $$f = \frac{A}{2\pi} \sqrt{\frac{P}{MV}} \text{ (06marks)}$$
- (ii) Show that the expression for f, in (b)(i) is dimensionally correct. (03marks)
- (c) A particle executing simple harmonic motion vibrates in a straight line. Given that the speeds of the particle are 4ms^{-1} and 2ms^{-1} when the particle is 3cm and 6cm respectively from the equilibrium, calculate the
- (i) amplitude of oscillation. (03marks)
- (ii) frequency of the particle. (03marks)
- (d) Give two examples of oscillatory motion which approximate to simple harmonic motion and state the assumption made in each case. (04marks)
44. (a) (i) State Archimedes' Principle. (01mark)
- (ii) Use Archimedes' Principle to derive an expression for resultant force on a body of weight, W, and density, σ , totally immersed in a fluid of density, ρ . (04marks)
- (b) A tube of uniform cross sectional area of $4 \times 10^{-3}\text{m}^2$ and mass 0.2kg is separately floated vertically in water of density $1.0 \times 10^3\text{kgm}^{-3}$ and in oil of density $8.0 \times 10^2\text{kgm}^{-3}$. Calculate the difference in the lengths immersed (04marks)
- (c) (i) Define surface tension in terms of work (01mark)
- (ii) Use the molecular theory to account for surface tension of a liquid. (04marks)
- (iii) Explain the effect of increasing temperature of a liquid on its surface tension. (04marks)
- (iv) Calculate the excess pressure inside a soap bubble of diameter 3.0cm if the surface tension of the soap solution is $2.5 \times 10^{-2}\text{Nm}^{-1}$. (02marks)
45. (a) (i) Define the term velocity and displacement. (02marks)
- (ii) Sketch velocity against time for an object thrown vertically upwards. (02marks)
- (b)



Three forces of 3.5N, 4.0N and 2.0N, act at O as shown in the figure above. Find the resultant force. (04marks)

- (c) (i) What is meant by saying that a body is moving with velocity relative to another? (01marks)
- (ii) A ship, A is travelling due north at 20kmh^{-1} and ship B is travelling due east at 15kmh^{-1} . Find the velocity of A relative to B. (03marks)
- (iii) If the ship B in (c)(ii) is 10km due west of A at noon. Find the shortest distance apart and when it occurs. (05marks)
- (d) (i) What is meant by a couple in mechanics? (01mark)
- (ii) State the conditions for equilibrium of a system of coplanar forces
46. (a) (i) State the laws of friction between solid surfaces (03marks)
- (ii) Explain the origin of friction force between two solid surfaces in contact. (03marks)
- (iii) Describe an experiment to measure the coefficient of kinetic friction between two solid surfaces. (03marks)
- (b) (i) A car of mass 1000kg moves along a straight surface with speed of 20ms^{-1} . When brakes are applied steadily, the car comes to rest after travelling 50m. Calculate the coefficient of friction between the surface and the tyre. (04marks)
- (ii) State the energy changes which occur from the time brakes are applied to the time the car comes to rest. (02marks)
- (c) (i) State two disadvantages of friction (01mark)
- (ii) Give one method of reducing friction between solid surfaces. (01mark)
- (d) Explain what happens when a small steel ball is dropped centrally in a tall jar containing oil. (03marks)
47. (a) (i) Define simple harmonic motion. (01mark)
- (ii) A particle of mass m executes simple harmonic motion between two points A and B about equilibrium position O. sketch a graph of the restoring force acting on the particle as a function of distance, r , moved by the particle. (02marks)
- (b)



Two springs A and B of spring constant K_A and K_B respectively are connected to mass m as shown in the figure above. The surface on which the mass slides is frictionless.

(i) Show that when the mass is displaced slightly, it oscillates with simple harmonic

motion of frequency, f given by $f = \frac{1}{2\pi} \sqrt{\frac{K_A + K_B}{m}}$ (04marks)

(ii) If the two springs in the figure above are identical such that $K_A = K_B = 5.0 \text{ Nm}^{-1}$ and mass $m = 50 \text{ g}$, calculate the period of oscillation (03marks)

(c) (i) With the aid of a diagram, describe an experiment to determine the universal gravitational constant, G . (0marks)

(ii) If the moon moves round the earth in a circular orbit of radius $= 4.0 \times 10^8 \text{ m}$ and takes exactly 27.3 days to go round once, calculate the value of acceleration due to gravity, g , at the earth's surface. (04marks)

48. (a) State

(i) Newton's laws of motion (03marks)

(ii) The principle of conservation of momentum (01mark)

(b) A body A of mass m_1 moves with velocity u_1 and collides head on elastically with another body B of mass m_2 which is at rest. If the velocities of A and B are v_1 and v_2 respectively and given that $X = \frac{m_1}{m_2}$, show that

(i) $\frac{u_1}{v_1} = \frac{X+1}{X-1}$ (04marks)

(ii) $\frac{v_2}{v_1} = \frac{2X}{X-1}$ (03marks)

(c) Distinguish between conservative and non-conservative forces. (02marks)

(d) A bullet of mass 40g is fired from a gun at 200 ms^{-1} and hit a block of wood of mass 2kg which is suspended by a light vertical string 2m long. If the bullet gets embedded in the wooden block,

(i) Calculate the maximum angle the string makes with the vertical. (06marks)

(ii) State a factor on which the angle of swing depends. (01mark)

49. (a) Define simple harmonic motion (SHM). (01mark)

(b) Sketch a graph of:

(i) velocity against displacement for a body executing SHM. (03marks)

(c) A glass U-tube containing a liquid is tilted slightly and then released.

(i) Show that the liquid oscillates with simple harmonic motion. (04mark)

(ii) Explain why the oscillations ultimately come to rest. (03marks)

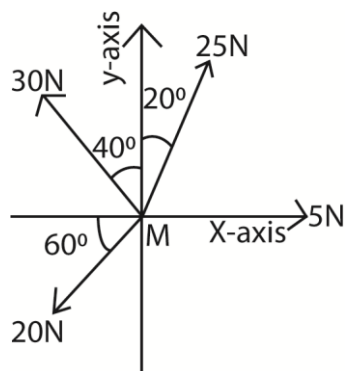
(d) Explain why maximum speed of a car on a banked road is higher than on an unbanked road. (04marks)

(e) A small bob of mass 0.2kg is suspended by an inextensible string of length 0.8m. The bob is then rotated in a horizontal circle of radius 0.4m. Find

(i) linear speed of the bob (03marks)

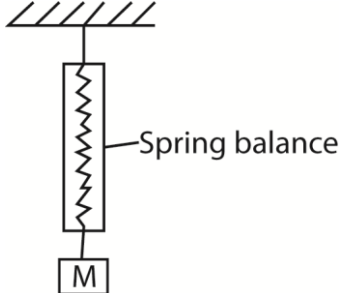
(ii) tension in the string. (02marks)

50. (a) State Kepler's laws of planetary motion. (03marks)
- (b) (i) A satellite moves in a circular orbit of radius, R , about a planet of mass, M , with period T . Show that $R^3 = \frac{GMT^2}{4\pi^2}$, where G is the universal gravitational constant. (04marks)
- (ii) The period of the moon around the earth is 27.3 days. If the distance of the moon from the Earth is $3.83 \times 10^5 \text{ km}$, calculate the acceleration due to gravity at the surface of the Earth. (04marks)
- (iii) Explain why any resistance to forward motion of an artificial satellite results into an increase in its speed. (04marks)
- (c) (i) What is meant by weightlessness? (02marks)
- (ii) Why does acceleration due to gravity vary with location on the surface of the earth? (03marks)
51. (a) (i) State the laws of solid friction. (03marks)
- (ii) Using molecular theory, explain the laws stated in (a)(i) (03marks)
- (b) Describe an experiment to determine the coefficient of static friction for an interface between a rectangular block of wood and plane surface. (04marks)
- (c) (i) State the difference between conservative and non-conservative forces, give one example each. (03marks)
- (ii) State the work-energy theorem. (01mark)
- (iii) A block of mass 6.0 kg is projected with a velocity of 12 ms^{-1} up a rough plane inclined at 45° to horizontal. If it travels 5.0 m up the plane, find the friction force. (04marks)
- (d) Explain the effect of temperature on the viscosity of a liquid.
52. (a) (i) Define vector and scalar quantities and give one example of each. (03marks)
- (ii)



A body, M , of mass 6 kg is acted on by forces of 5 N , 20 N , 25 N and 30 N as shown in the figure above. Find the acceleration of M (05marks)

- (b) (i) What is meant by acceleration due to gravity? (01mark)
- (ii) Describe how you would use a spiral spring, a retort stand with a clamp, a pointer, seven 50 g masses, a meter rule and a stop clock to determine the acceleration due to gravity. (06marks)
- (iii) State any two sources of error in the experiment in (b)(ii) above. (01marks)

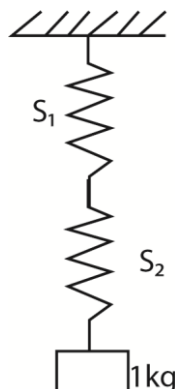
- (iv) A body of mass 1kg moving with simple harmonic motion has speeds of 5ms^{-1} and 3ms^{-1} when it is at distances of 0.10m and 0.2m respectively from equilibrium point. Find the amplitude of the motion. (04marks)
53. (a)(i) What is meant by uniformly accelerated motion? (01marks)
- (ii) Sketch the speed against time graph for a uniformly accelerated body. (01mark)
- (iii) Derive the expression: $S = ut + \frac{1}{2}at^2$, for the distance, S, moved by a body which is initially travelling with speed u and is uniformly accelerated for time t.
- (b) A projectile is fired horizontally from the top of a cliff 250m high. The projectile lands $1.414 \times 10^3\text{m}$ from the bottom of the cliff. Find the
- (i) initial speed of the projectile. (05marks)
- (ii) velocity of the projectile just before it hits the ground. (05marks)
- (c) Describe an experiment to determine the centre of gravity of a plane sheet of material having irregular shape (04marks)
54. (a) (i) Define force and power. (02marks)
- (ii) Explain why more energy is required to push a wheel barrow uphill than on a level ground. (03mark)
- (b)
- 
- A mass, M, is suspended from a spring balance as shown in the figure above. Explain what happens to the reading of the spring balance when the setup is raised slowly to a very high height above the ground. (02marks)
- (c) (i) State the work-energy theorem (01mark)
- (ii) A bullet of mass 0.1kg moving horizontally with a speed of 420ms^{-1} strikes a block of mass 2.0kg at rest on a smooth table and becomes embedded in it. Find the kinetic energy lost if they move together. (04marks)
- (d) State the condition for equilibrium of a rigid body under the action of coplanar forces. (02marks)
- (e) A 3m long ladder rests at an angle 60° to the horizontal against a smooth vertical wall on a rough ground. The ladder weighs 5kg and its centre of gravity is one-third from the bottom of the ladder.
- (i) Draw a sketch diagram to show the forces acting on the ladder. (02marks)
- (ii) Find the reaction of the ground on the ladder (04marks)
55. (a) (i) Define stress and strain (02marks)
- (ii) Determine the dimensions of Young's modulus. (03marks)

- (b) Sketch a graph of stress versus strain for a ductile material and explain its features. (06marks)
- (c) A steel wire of cross section area 1mm^2 is cooled from a temperature of 60°C to 15°C . Find the:
- (i) strain (02marks)
 - (ii) force needed to prevent it from contracting. (03marks)
- [Young's Modulus = $2.0 \times 10^{11}\text{Pa}$, Coefficient of linear expansion of steel = $1.1 \times 10^{-5}\text{K}^{-1}$]
- (d) Explain the energy changes which occur during plastic deformation (04marks)
56. (a) (i) State Archimedes' Principle. (01mark)
- (ii) Describe an experiment to determine the relative density of an irregular solid which floats in water
 - (iii) A block of wood floats at an interface between water and oil with 0.25 of its volume submerged in oil. If the density of the wood is $7.3 \times 10^2\text{kgm}^{-3}$, find the density of oil. (04marks)
- (b) (i) State Bernoulli's Principle. (04marks)
- (ii) Explain the origin of the lift force on the wings of an aeroplane at take-off. (04marks)
- (c) Water flowing in a pipe on the ground with a velocity of 8ms^{-1} and at gauge pressure of $2.0 \times 10^3\text{Pa}$ is pumped into a water tank 10m above the ground. The water enters the tank at a pressure of $1.0 \times 10^5\text{Pa}$. Calculate the velocity with which the water enters the tank. (03marks)
- (d) Describe how terminal velocity can be measured. (04marks)
57. (a) Distinguish between scalar and vector quantities giving two example each. (03marks)
- (b) The equation for volume, V , of a liquid flowing through a pipe in time t , under steady flow is given by $\frac{V}{t} = \frac{\pi r^4 P}{8\eta L}$ where
- r = radius of the pipe
 - P = pressure difference between two point of the pipe
 - L = length of the pipe
 - η = coefficient of viscosity of the liquid
- If the dimensions of η are $\text{ML}^{-1}\text{T}^{-1}$, show that the above equation is dimensionally consistent.
- (c) (i) define linear momentum. (01mark)
- (ii) State the law of conservation of linear momentum. (01mark)
 - (iii) Show the law in (c)(ii) above follows from Newton's law of motion. (03marks)
 - (iv) Explain why, when catching a fast moving ball, the hands are drawn back while the ball is being brought to rest. (02marks)
- (d) A car of mass 100kg travelling at uniform velocity of 20ms^{-1} collides perfectly inelastically with a stationary car of mass 1500kg . Calculate the loss in kinetic energy of the car as a result of the collision. (04marks)
- (e) (i) What is meant by conservation of energy? (01mark)
- (ii) Explain how conservation of energy applies to an object falling from rest in a vacuum. (02marks)

58. (a) Explain the term
- (i) Ductility (01mark)
 - (ii) Stiffness (01mark)
- (b) A copper wire and steel wire each of length 1.0m and diameter 1.0mm are joined end to end to form a composite wire 2.0m long. Find the strain in each when the composite stretches by 2.0×10^{-3} m.
- [Young's Modulus for copper and steel are 1.2×10^{11} Pa and 2.0×10^{11} Pa respectively]
(07marks)
- (c) (i) Define centre of gravity (01mark)
- (ii) Describe an experiment to find the centre of gravity of a flat irregular piece of cardboard. (03marks)
- (d) Explain the laws of solid friction using molecular theory (07marks)
59. (a) What is meant by the following terms?
- (i) Velocity gradient. (01mark)
 - (ii) Coefficient of viscosity (01mark)
- (b) Derive an expression for terminal velocity of a steel ball-bearing of radius, r , and density, ρ , falling through a liquid of density, σ , and coefficient of viscosity, η . (05marks)
- (c) (i) Define surface tension (01mark)
- (ii) Explain the origin of surface tension. (03marks)
- (iii) Describe an experiment to measure surface tension of a liquid by capillary method. (06marks)
- (d) Explain, with the aid of a diagram why air-flow over the wings of an aircraft at take-off cause a lift. (03marks)
60. (a) (i) Define angular velocity. (01marks)
- (ii) Derive an expression for the force, F , on a particle of mass, m , moving with angular velocity, ω , in a circle of radius, r . (03marks)
- (b) A stone of mass 0.5kg is attached to a string of length 0.5m which will break if the tension in it exceeds 20N. The stone is whirled in a vertical circle, the axis of rotation being at a vertical height of 1.0m above ground. The angular speed is gradually increased until the string breaks.
- (i) In what position is the string most likely to break? (02marks)
 - (ii) At what angular speed will the string break? (03marks)
 - (iii) Find the position where the stone hits the ground when the string breaks. (03marks)
- (c) Explain briefly the action of a centrifuge. (03marks)
- (d) Describe how the acceleration due to gravity can be measured using helical spring of unknown force constant, and the other relevant apparatus. (05marks)

61. (a) State the laws of friction (04marks)
- (b) A block of mass 5.0kg resting on the floor is given a horizontal velocity of 5.0ms^{-1} and comes to rest in a distance of 7.0m. Find the kinetic friction between the block and the floor. (04marks)
- (c) (i) State the law of conservation of linear momentum (01mark)
- (ii) What are perfectly inelastic collision? (01mark)
- (d) A car of 1500kg rolls from rest down a road inclined to the horizontal at an angle 35° , through 50m. The car collides with another car of identical mass at the bottom of the incline. If the two cars interlock on collision, and the coefficient of kinetic friction is 0.20, find the common velocity of the vehicles. (08marks)
- (e) Discuss briefly the energy transformation which occur in (d) above
62. (a) Define angular velocity (01mark)
- (b) A car of mass, m , travels round a circular track of radius, r , with velocity, V .
- (i) Sketch a diagram to show the forces acting on the car. (02marks)
- (ii) Show that the car does not overturn if $V^2 < \frac{arg}{2h}$, where a is the distance between the wheels, h , is the height of the centre of gravity above the ground and g is acceleration due to gravity. (05marks)
- (c) A pendulum bob of mass 0.2kg is attached to one end of an inelastic string of length 1.2m. The bob moves in a horizontal circle with the string inclined at 30° to the vertical. Calculate
- (i) the tension in the string (02marks)
- (ii) the period of motion (04marks)
- (d) Explain and sketch the variation of acceleration due to gravity with distance from the centre of the earth (06marks)
63. (a) (i) What is meant by simple harmonic motion? (01mark)
- (ii) Show with the aid of a suitable sketch graph how kinetic energy of a mass attached at the end of an oscillating light spring changes with distance from equilibrium position. (04marks)

(b)



A mass of 1.0kg is hang from two springs S_1 and S_2 connected in series as shown above.

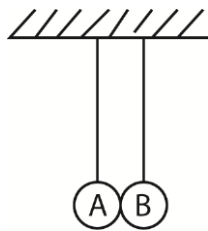
The force constant of the springs are 100Nm^{-1} and 200Nm^{-1} respectively. Find

- (i) The extension produced in combination. (04marks)
 - (ii) The frequency of oscillation of the mass if it is pulled downwards through a small distance and released. (06marks)
- (c) Explain with the aid of a sketch graph, what would happen to the oscillations in (b)(ii) above if the mass was immersed in a liquid such as water. (04marks)
64. (a) (i) Define gravitational field strength. (01mark)
- (ii) Draw a sketch graph to show how the gravitational field strength varies with height, h , above the earth's surface. (02marks)
- (b) The period of simple pendulum is measured at different locations along a given longitude. Explain what is observed. (06marks)
- (c) Derive the expression for the escape velocity of a rocket fired from earth. (03marks)
- (d) The rings of the planet Saturn consist of a vast number of small particles, each in a circular orbit about the planet. Calculate the speed of the particles nearest to Saturn if its mass is $6.0 \times 10^{26}\text{kg}$ (04marks)
- (e) The moon moves in a circular orbit of radius $3.84 \times 10^8\text{m}$ around the earth with a period of $2.36 \times 10^5\text{s}$. Calculate the gravitational field of the earth at the moon. (04marks)
65. (a) Distinguish between fundamental and derived physical quantities. Give two examples of each. (04marks)
- (b) (i) What is meant by scalar and vector quantities? (02marks)
- (ii) A ball is thrown vertically upwards with a velocity 10m s^{-1} from a point 3.0m above ground. Describe with the aid of a velocity-time sketch graph, the subsequent motion of the ball. (10marks)
- (c) A boat crosses a river 3km wide flowing at 4ms^{-1} to reach a point on the opposite bank 5km upstream. The boat's speed in still water is 12ms^{-1} . Find the direction in which the boat must be headed. (04marks)
66. (a) Define the following terms:
- (i) Angular velocity (01mark)
 - (ii) Centripetal acceleration (01mark)
- (b) (i) Explain why a racing car can travel faster on a banked road than on flat track of the same curvature. (04marks)
- (ii) Derive an expression for the speed with which a car can negotiate a bend on a banked track without skidding. (03marks)
- (c) a Show how to estimate the mass of the sun if the period and radius of one of its planets are known. (03marks)
- (d) The gravitational potential, U , at the surface of a planet of mass M and radius R is given by $U = -\frac{GM}{R}$, where G is gravitational constant.
- Derive an expression for the lowest velocity, V , which an object of mass, m , must have at the surface of the planet if it is to escape from the planet. (04marks)
- (e) Communication satellites orbit the earth in synchronous orbits. Calculate the height of communication satellite above the earth. (04marks)

67. (a) State the law of floatation. (01mark)
- (b) With the aid of a diagram, describe how to measure the relative density of a liquid using Archimedes' Principle of moments (06marks)
- (c) A cross sectional area of a ferry at its water-line is 720m^2 . If sixteen cars of average mass 1100kg are placed on board, to what extra depth will the boat sink in the water? (04marks)
- (d) (i) Define longitudinal stress and Young's Modulus of elasticity. (02marks)
- (ii) Describe how to determine Young's Modulus for steel wire. (07marks)
68. (a) A mass of 0.1kg is suspended from a light spring of force constant 24.5Nm^{-1} . Calculate the potential energy of the mass. (04marks)
- (b) (i) State four characteristics of simple harmonic motion. (04marks)
- (ii) Show that the speed of a body moving with simple harmonic motion of angular velocity, ω , is given by $V = \omega(A^2 - x^2)^{1/2}$, where A is the amplitude and x is the displacement from equilibrium position. (04marks)
- (iii) Sketch graphs to show the variation with displacement, of kinetic and potential energies of a body moving with simple harmonic motion (02marks)
- (c) A mass of 0.1kg suspended from a spring of force constant 24.5Nm^{-1} is pulled vertically downwards through a distance 5.0cm and released. Find the
- (i) period of acceleration (02marks)
- (ii) position of the mass 0.3s after release. (04marks)
69. (a) (i) What is meant by the dimensions of a physical quantity? (01mark)
- (ii) For stream line flow of non-viscous, incompressible fluid, the pressure, P , at a point is related to height, h , and the velocity, V by the equation $(P-a) = \rho g(h-b) + \frac{1}{2}(\rho v^2 - d)$ where a , b , and d , are constants and ρ is the density of the fluid and g is the acceleration due to gravity. Given that the equation is dimensionally consistent, find the dimensions of a , b and d . (03marks)
- (b) Define simple harmonic motion. (01marks)
- (c) Sketch the following graphs for a body performing simple harmonic motion:
- (i) velocity against displacement (01mark)
- (ii) displacement against time (01mark)
- (d) The period of oscillation of a conical pendulum is 2.0s . If the string makes 60° to the vertical at the point of suspension, calculate the
- (i) vertical height of the point of suspension above the circle. (03marks)
- (ii) length of the string (01 mark)
- (iii) Velocity of the mass attached to the string (03marks)
- (e) (i) Give one example of an oscillatory motion which approximates simple harmonic motion
- (ii) What approximation is made in (e)(i) above? (01mark)
- (f) Explain why the acceleration of a ball bearing falling through a liquid decreases continuously until it becomes zero. (04marks).
70. (a) (i) State Newton's law of universal gravitation. (01mark)
- (ii) Show that this law is consistent with Kepler's third law. (03marks)

- (iii) Two alternative units for gravitational field strength are Nkg^{-1} and ms^{-1} . Use the method of dimensions to show that the two units are equivalent. (03marks)
- (b) (i) Derive an expression for speed of a body moving uniformly in a circular path. (03marks)
- (ii) Explain why a force is necessary to maintain a body moving with constant speed in a circular path. (02marks)
- (c) A small mass attached to a string suspended from a fixed point moves in a circular path at constant speed in horizontal plane.
- (i) Draw a diagram showing the force acting on the mass. (01mark)
- (ii) Derive an equation showing the angle of inclination of the string depends on the speed of the mass and radius of the circular path. (03marks)
- (d) (i) Define moment of force. (01mark)
- (ii) A wheel of radius 0.6m is pivoted at its centre. A tangential force of 4.0N acts on the wheel so that the wheel rotates with uniform velocity. Find the work done by the force to turn the wheel through 10 revolutions. (03marks)
71. (a) (i) Show that the weight of a fluid displaced by an object is equal to up thrust on the object. (05marks)
- (ii) A piece of metal of mass $2.60 \times 10^{-3}\text{kg}$ and density $8.4 \times 10^3\text{kgm}^{-3}$ is attached to a block of wax of mass $1.0 \times 10^{-2}\text{kg}$ and density $9.2 \times 10^2\text{kgm}^{-3}$. When the system is placed in a liquid, it floats with wax just submerged. Find the density of the fluid. (04marks)
- (b) Explain the
- (i) term laminar flow and turbulent flow. (04marks)
- (ii) effects of temperature on viscosity of liquids and gases. (03marks)
- (c) (i) distinguish between static pressure and dynamic pressure. (02marks)
- (ii) A pitot-static tube fitted with a pressure gauge is used to measure the speed of a boat at sea. Given that the speed of the boat does not exceed 10mms^{-1} and the density of water is 1000kgm^{-3} , calculate the minimum pressure on the gauge. (02marks)
72. (a) Define the terms surface tension and surface energy. (01mark)
- (b) (i) Calculate the work done against surface tension in blowing a soap bubble of diameter 15mm, if the surface tension of soap solution is $3.0 \times 10^{-2}\text{Nm}$. (03marks)
- (ii) A soap bubble of radius r_1 is attached to another bubble of radius r_2 . If r_1 is less than r_2 . Show that the radius of curvature of the common interface is $\frac{r_1 r_2}{r_2 - r_1}$. (05marks)
- (c) (i) Define coefficient of viscosity of a liquid. (01mark)
- (ii) Describe an experiment to demonstrate streamline and turbulent flow in liquids. (06marks)
- (d) (i) Sketch a graph of potential energy against separation of two molecules of a substance. (01mark)
- (ii) Explain the main features of the graph in (d)(i). (03marks)
73. (a) (i) State the principle of conservation of mechanical energy. (01mark)
- (ii) Show that a stone thrown vertically upwards obeys the principle in (a)(i) above throughout its upward motion. (04marks)

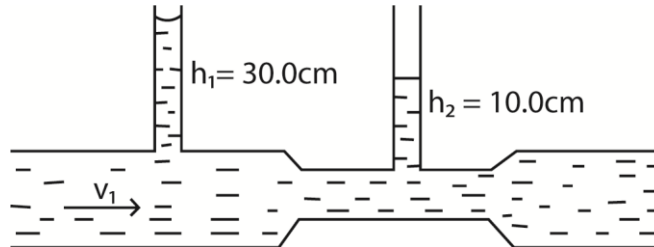
- (b)(i) A wind turbine made of a blade of radius, r , is driven by wind of speed, V . If σ is the density of air, derive an expression for minimum power, P , which can be developed by the turbine in terms of σ , r and V . (03marks)
- (ii) Explain why the power attained is less than the maximum value in (b)(i) above. (02marks)
- (c) State the conditions under which the following will be conserved in collision between two bodies
- (i) linear momentum (10mark)
- (ii) kinetic energy (01mark)
- (d) Two pendulum bobs A and B of equal length L , and masses $3M$ and M respectively. The pendula are hung with bobs in contact as shown below



The bob A is displaced such that the string makes an angle θ with the vertical and released. If A makes a perfectly inelastic collision with B, find the height to which B rises. (08marks)

74. (a) Define the following terms
- (i) Stress (01mark)
- (ii) Strain (01mark)
- (b) The velocity, V , of sound travelling along a rod made of a material of Young's Modulus, Y , and density, ρ is given by $V = \sqrt{\frac{Y}{\rho}}$.
- Show that the formula is dimensionally consistent. (03marks)
- (c) State the measurement necessary in the determination of Young's Modulus of a metal wire. (02marks)
- (d) Explain why the following precautions are taken during an experiment to determine Young's Modulus of a metal wire.
- (i) two long, thin wires of the same material are suspended from a common support. (02marks)
- (ii) the readings of the vernier are also taken when the loads are gradually removed in steps. (01marks)
- (e) The ends of a uniform wire of length 2.00m are fixed to points A and B which are 2.00m apart in the same horizontal line. When a 5kg mass is attached to the mid-point C of the wire, the equilibrium position of C is 7.5 below the line AB. Given that Young's Modulus for the material of the wire is $2.0 \times 10^{11} \text{Pa}$, find

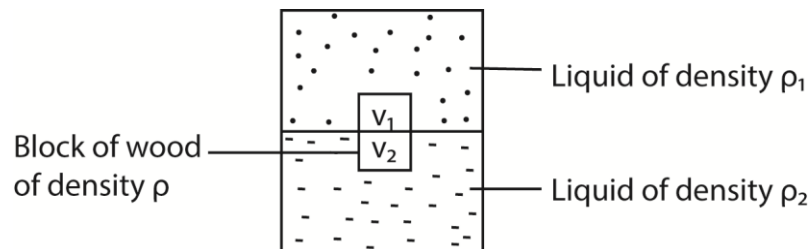
- (i) the strain in the wire (03marks)
 - (ii) the stress in the wire, (02marks)
 - (iii) The energy stored in the wire (04marks)
 - (iv) State any assumptions made. (01mark)
75. (a) Define surface tension and derive its dimensions (03marks)
- (b) Explain using the molecular theory the occurrence of surface tension. (04 marks)
 - (c) Derive an experiment to measure surface tension of a liquid by the capillary tube method. (06marks)
 - (d) (i) Show that the excess pressure in a soap bubble is given by $P = \frac{4\gamma}{r}$, (03marks)
 - (ii) Calculate the total pressure within a bubble of air of radius 0.1mm in water if the bubble is formed 10cm below the water surface and surface tension of water is $7.27 \times 10^{-2} \text{Nm}^{-1}$. [Atmospheric pressure = $1.01 \times 10^5 \text{Pa}$] (05marks)
76. (a) (i) Define coefficient of viscosity and determine its dimensions. (04marks)
- (ii) The resistive force on a steel ball bearing of radius, r , falling with speed, V , in a liquid of viscosity, η is given by $F = K\eta rV$, where K is a constant. Show that K is dimensionless. (04marks)
- (b) Write down Bernoulli's equation for fluid flow, defining all symbols used (03marks)
- (c) A venturi meter consists of a horizontal tube with a constriction which replaces part of the piping system as shown below



If the cross-sectional area of the main pipe is $5.81 \times 10^{-3} \text{m}^2$ and that of the constriction is $2.58 \times 10^{-3} \text{m}^2$, find the velocity v_1 of the liquid in the main pipe. (5marks)

- (d) Explain the origin of the lift on an aeroplane at take-off. (04marks)
77. (a) (i) State Newton's laws of motion (03marks)
- (ii) Define impulse and derive its relation to linear momentum of the body on which it acts. (03marks)
- (b) A body of mass m_1 and velocity, u_1 collides head on with a body of mass, m_2 having velocity, u_2 in the same direction as u_1 . Use Newton's laws to show that the quantity $m_1u_1 + m_2u_2$ is conserved. (5marks)
- (c) A ball of mass 0.5kg is allowed to drop from rest, from a point a distance of 5.0m above a horizontal concrete floor. When the ball first hits the floor, it rebounds to a height of 3.0m.
- (i) What is the speed of the ball just after the first collision with the floor? (3marks)
 - (ii) If the collision lasted 0.01s, find the average force which the floor exerts on the ball. (02marks)

78. (a) (i) state Archimedes' Principle. (01mark)
 (ii) What is simple harmonic motion? (02marks)
 (b) A uniform cylindrical rod of length 0.08m, cross sectional area 0.02m^2 and density 900kgm^{-3} floats vertically in a liquid of density 1000kgm^{-3} . The rod is displaced through a distance of 0.005m and released.
 (i) Show that the rod performs simple harmonic motion. (05marks)
 (ii) Find the frequency of the resultant oscillation. (04marks)
 (iii) Find the velocity of the rod when it is a distance of 0.004m above the equilibrium position. (03marks)
 (c)



A block of wood of density ρ floats at the interface between immiscible liquids of densities ρ_1 and ρ_2 as shown in the figure above.

- (i) Show that the ratio of volumes v_1 to v_2 of the block in the two liquids is given by $\frac{v_1}{v_2} = \frac{\rho_2 - \rho}{\rho - \rho_1}$ (04marks)
 (ii) What happens when this block of wood is replaced with a denser one? (01mark)
79. (a) Distinguish between scalar and vector quantities. Give two examples each. (03marks)
 (b) (i) Define the time of flight and range as applied to projectile motion. (02 marks)
 (ii) A projectile is fired in air with a speed $u \text{ ms}^{-1}$ at an angle θ to the horizontal. Find the time of flight of the projectile (02marks)
 (c) State the conditions for equilibrium of a rigid body under action of coplanar forces. (02marks)
 (d) A mass of 5.0kg is suspended from the end A of a uniform beam of mass 1kg and length 1.0m. The end B of the beam is hinged in a wall. The beam is kept horizontal by a rope attached to A and a point C, in the wall at a height 0.75m above B.
 (i) Draw a sketch diagram to show the forces acting on the beam. (02marks)
 (ii) Calculate the tension in the rope. (04marks)
 (iii) What is the force exerted by the hinge on the beam? (05marks)
80. (a) State Kepler's laws of gravitation (03marks)
 (b) (i) Show that the period of a satellite in a circular orbit of radius r about the earth is given by $T = \left(\frac{4\pi^2}{GM_s} \right)^{\frac{1}{2}} r^{\frac{3}{2}}$ where G is the universal constant and M_s is the mass of the earth. (05marks)
 (ii) Explain briefly how world-wide radio or television communication can be achieved with the help of satellites. (04marks)
 (c) A satellite of mass 100kg is in a circular orbit at height of $3.39 \times 10^7\text{m}$ above the earth's surface.
 (i) Find the mechanical energy of the satellite (04marks)
 (ii) Explain what would happen if the mechanical energy was decreased. (04marks)



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List of physical constants to be used

Acceleration due to gravity, g	9.81ms^{-2}
Electron charge, e	$1.6 \times 10^{-19}\text{C}$
Electron mass	$9.11 \times 10^{-31}\text{kg}$
Mass of the earth	$5.97 \times 10^{24}\text{kg}$
Plank's constant, h	$6.6 \times 10^{-34}\text{Js}$
Stefan's-Boltzmann's constant, σ	$5.67 \times 10^{-8}\text{Wm}^{-2}\text{K}^{-1}$
Radius of the earth	$6.4 \times 10^6\text{m}$
Radius of the sun	$7 \times 10^8\text{m}$
Radius of the earth's orbit about the sun	$1.5 \times 10^{11}\text{m}$
Speed of light in the vacuum, c	$3.0 \times 10^8\text{ms}^{-1}$
Thermal conductivity of copper	$390\text{Wm}^{-1}\text{K}^{-1}$
Thermal conductivity of aluminium	$210\text{Wm}^{-1}\text{K}^{-1}$
Specific heat capacity of water	$4.200\text{Jkg}^{-1}\text{K}^{-1}$
Universal gravitational constant	$6.67 \times 10^{-11}\text{Nm}^2\text{Kg}^{-2}$
Avogadro's number, N_A	$6.02 \times 10^{23}\text{mol}^{-1}$
Surface tension of water	$7.0 \times 10^{-2}\text{Nm}^{-1}$
Density of water	1000kgm^{-3}
Gas constant, R	$8.31\text{Jmol}^{-1}\text{K}^{-1}$
Charge to mass ratio, e/m	$1.8 \times 10^{11}\text{Ckg}^{-1}$
The constant, $\frac{1}{4\pi\epsilon_0}$	$9.0 \times 10^9\text{F}^{-1}\text{m}$
Faraday's constant, F	$9.65 \times 10^4\text{Cmol}^{-1}$
Thermal conductivity of Iron	$75\text{Wm}^{-1}\text{K}^{-1}$
Specific latent heat of fusion of Ice =	$3.3 \times 10^5\text{Jkg}^{-1}$

Permittivity of free space, μ_0	$4.0\pi \times 10^{-7} \text{Hm}^{-1}$
Permittivity of free space, ϵ_0	$8.85 \times 10^{-12} \text{Fm}^{-1}$
One electron volt	$1.6 \times 10^{-19} \text{J}$
Resistivity of Nichrome wire at 250C	$1.2 \times 10^{-6} \Omega \text{m}$
Specific heat capacity of copper	$400 \text{Jkg}^{-1} \text{K}^{-1}$

1. (a) (i) Distinguish between scalar and vector quantity. (01 mark)

A scalar quantity is a physical quantity with magnitude but no direction

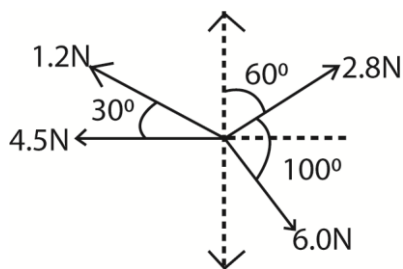
A vector quantity is a physical quantity with both magnitude and direction

- (ii) Give two examples of each type of quantity. (02marks)

Examples of scalar quantities: volume area, distance speed

Examples of vector quantities: force, displacement, impulse, momentum, acceleration

- (b) A body of mass 0.2kg at rest is acted on by four forces of 2.8N, 6.0N, 4.5N and 1.2N as shown in the figure below.



Calculate

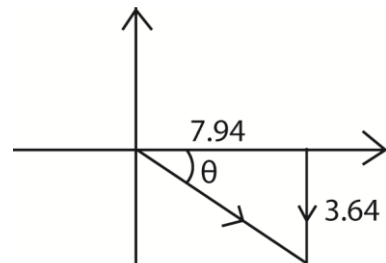
- (i) Resultant force on the body (04marks)

$$F_x = 4.5 + 6\cos 70 + 2.8\cos 30 - 1.2\cos 30 = 7.94\text{N}$$

$$F_y = 0 - 6\sin 70 + 2.8\sin 30 + 1.2\sin 30 = -3.64\text{N}$$

$$\text{Magnitude of the resultant force} = \sqrt{7.94^2 + (-3.64)^2} = 8.73\text{N}$$

Direction



$$\tan \theta = \frac{3.64}{7.94}; \theta = 24.6^\circ$$

The resultant force is 8.73N in a direction 24.60 below the horizontal axis.

(ii) Distance moved in 4s (02marks)

Using $F = ma$

$$8.73 = 0.2a$$

$$a = 43.65 \text{ms}^{-1}$$

$$s = ut + \frac{1}{2} at^2$$

$$= 0 \times 4 + \frac{1}{2} \times 43.65 \times 4^2$$

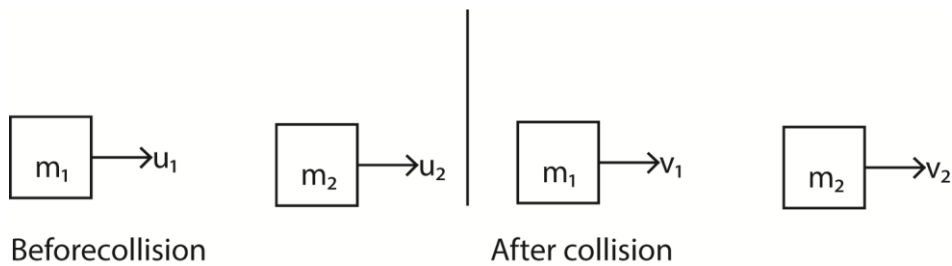
$$= 349.2\text{m}$$

(c) State Newton's law of motion and use them to derive the law of conservation of momentum. (06marks)

- A body continues in its state of rest or uniform motion in a straight line unless acted upon by an external force
- The rate of change of momentum of a body is directly proportional to applied force and takes place in the direction of the force
- For every action, there is an equal and opposite reaction

Derivation of the law of conservation of momentum

Let m_1, m_2 be the masses of two bodies initially moving in the same direction with velocities u_1 and u_2 which collide after time t , and gain velocities v_1 and v_2 respectively when $u_1 > u_2$.



During collision, each body exerts a force of impact on each other according to Newton's second law of motion.

Let I be the impulse on A, then the impulse on B = $-I$.

$$I = M_1 v_1 - m_1 u_1 \dots\dots\dots (i)$$

$$-I = m_2 v_2 - m_2 u_2 \dots\dots\dots (ii)$$

Equation (i) + equation (ii)

$$0 = M_1 v_1 - m_1 u_1 + m_2 v_2 - m_2 u_2$$

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

Alternatively

$$\text{From } F = ma = \frac{m(v-u)}{t}$$

Force exerted by body of m_1 on body of mass $m_2 = F_1 = \frac{m_1(v_1 - u_1)}{t}$

Force exerted by body of m_2 on body of mass $m_1 = F_2 = \frac{m_1(v_1 - u_1)}{t}$

Using Newton's third law, the forces are equal and opposite

$$F_1 = F_2$$

$$\frac{m_1(v_1 - u_1)}{t} = \frac{m_2(v_2 - u_2)}{t}$$

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

(d) A body of mass 800kg moving at 30ms^{-1} collides with another of mass 400kg moving in the same direction at 25ms^{-1} . The two bodies stick together after collision. Calculate the

(i) common velocity just after collision (02marks)

$$m_1u_1 + m_2u_2 = (m_1 + m_2)v$$

$$(800 \times 30) + (400 \times 25) = (800 + 400)V$$

$$v = 28.3\text{ms}^{-1}$$

(ii) kinetic energy lost during collision (03marks)

Kinetic energy lost = kinetic energy before – kinetic energy after

$$= \frac{1}{2} \times 800 \times 30^2 + \frac{1}{2} \times 400 \times 25^2 - \frac{1}{2} \times 1200 \times 28.3^2$$

$$= 4,466\text{J}$$

2. (a) Define moment of force and give its SI unit. (02marks)

Moment of force is the product of force and perpendicular distance from the line of action of the force to the pivot. S.I units Nm.

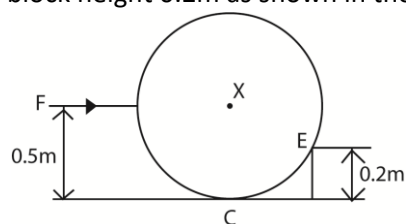
(b) Explain briefly how to locate the centre of gravity of an irregular sheet of cardboard. (04marks)

- three holes are drilled around the edge of the cardboard.
- The cardboard is suspended from a pin through one of the holes. When the cardboard is freely suspended, a plumb line is suspended from the same pin.
- A line is drawn to mark the line where the plumb line passes.
- The procedure is repeated for the other two holes.
- The point of intersection of the three line is the centre of gravity

(c) State the conditions necessary for equilibrium of a rigid body under action of a system of forces. (02marks)

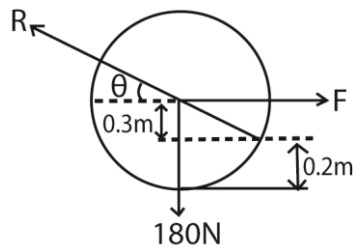
- The sum of clock wise moments about a fixed point is equal to the sum of anticlockwise moments about the same point.

(d) A wheel of radius 0.5m rests on a level surface at point C and makes contact with edge E of a block height 0.2m as shown in the figure below.



A force F is applied horizontally through the axle of the wheel at X to just move the wheel over the block. If the weight of the wheel is 180N , find the

- (i) Force exerted at point E (02marks)



$$R \sin \theta = 180$$

$$R \times \frac{3}{5} = 180$$

$$R = 300\text{N}$$

The force exerted = 300N

- (ii) Force F (04marks)

$$F - R \cos \theta = 300 \cos 69.9^\circ = 240\text{N}$$

- (e) State the laws of friction and explain each of them (06marks)

- Friction force oppose relative motion between surfaces in contact.

Explanation; surfaces have projections with small area. When in contact, the surfaces rest on each other's projection. Because of the actual area of contact being small, high pressures exist at the points of contact and a force which opposes motion is developed.

- Friction force is independent of area of contact provided normal reaction is constant.

Explanation; When the object is turned over so that different surfaces are presented, the actual area of contact is approximately the same

- The friction force is directly proportional to the normal reaction.

Explanation; when the load increases, the pressure at points of contact increases the actual area of contact producing stronger bonds and increases the degree of interlocks. A greater force is therefore required for motion to take place.

3. (a) Define the following as applied to circular motion:

- (i) Centripetal acceleration (01mark)

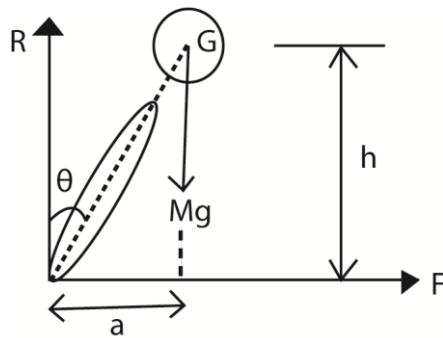
Centripetal acceleration is the rate of change of velocity of a body moving in a circular path.

- (ii) Period (01mark)

A period is the time taken to move once round a circular path

- (b) (i) Explain why a cyclist bends inward while going round a curved path. (03marks)

- (ii) Show that if θ is the angle of inclination of the cyclist to the vertical and μ is the coefficient of limiting friction between the ground and the bicycle tyres, then for safe riding $\tan \theta \leq \mu$. (04marks)



Taking moment about G,

$$F \times h = R \times a$$

$$\begin{aligned} - \quad \tan \theta &= \frac{a}{h} = \frac{F}{R} \\ - \quad F &= R \tan \theta \end{aligned}$$

For safe riding, $F \leq F_1$ (limiting friction)

$$\text{But } F_1 = \mu R$$

$$\therefore R \tan \theta \leq \mu R$$

$$- \quad \tan \theta = \mu$$

- (iii) A body of mass 1.5kg moves once round a circular path to cover 44.0cm in 5s. Calculate the centripetal force acting on the body. (04marks)

Radius of circular path, r

$$\text{Circumference} = 2\pi r = 44\text{cm}$$

$$r = \frac{44}{2\pi} = 7\text{cm}$$

$$\text{Linear velocity, } v = \frac{0.44}{5\text{s}} = 0.088\text{ms}^{-1}$$

$$\text{Centripetal force, } F = \frac{mv^2}{r} = \frac{1.5 \times 0.088^2}{7 \times 10^{-2}} = 0.166\text{N}$$

- (c) Define simple harmonic motion (01mark)

Simple harmonic motion is the motion of a body whose acceleration is directed towards a fixed point and is directly proportional to the displacement of the body from a fixed point.

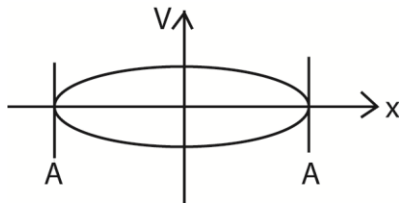
- (d) A body executes simple harmonic motion with amplitude A and angular velocity, ω .

- (i) Write down the equation for velocity of the body at a displacement x from the mean position (01mark)

$$v^2 = \omega^2(A^2 - x^2)$$

$$v = \omega\sqrt{(A^2 - x^2)}$$

- (ii) Sketch the velocity-displacement graph for the body in (d)(i) for $\omega < 1$. (02marks)



- (iii) If the body moves with amplitude 14.142 cm, at what distance from the mean position will be kinetic energy equal to potential energy? (03marks)

Kinetic energy = half of total energy

$$= \frac{1}{2} m \omega^2 (A^2 - x^2)$$

$$\text{Total energy} = \frac{1}{2} m \omega^2 A^2$$

$$- \frac{1}{2} m \omega^2 (A^2 - x^2) = \frac{1}{2} \left(\frac{1}{2} m \omega^2 A^2 \right)$$

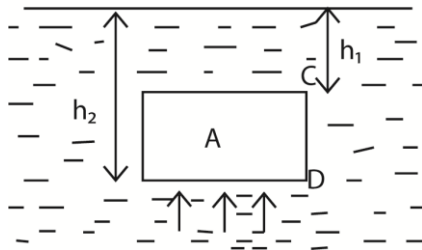
$$A^2 - x^2 = \frac{A^2}{2}$$

$$x = \frac{A}{\sqrt{2}} = \frac{14.142}{\sqrt{2}} = 10 \text{ cm}$$

4. (a) State and illustrate Archimedes' principle. (05marks)

Archimedes' Principle: when a body is wholly or partially immersed in a fluid, it experiences an up thrust force equal to the weight of the fluid displaced.

Illustrating diagram



$$F_c = h_1 \rho g A, F_D = h_2 \rho g A$$

$$\text{Net force (up thrust)} = (h_2 - h_1) \rho g A$$

$$\text{Volume of liquid displaced} = (h_2 - h_1) A$$

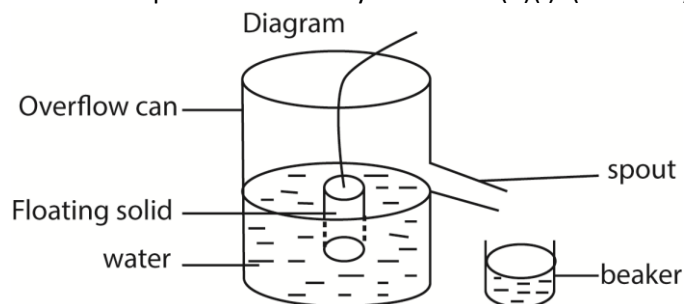
$$\text{Weight of liquid displaced} = (h_2 - h_1) \rho g A$$

Hence up thrust = weight of liquid displaced

- (b)(i) State the law of flotation (01 marks)

A floating body displaces its own weight of fluid in which it floats.

- (ii) Describe an experiment to verify the law in (b)(i). (05marks)



- Overflow can is filled with water up to spout level
- An object is lowered in the can until it floats.
- The displaced water is collected in the beaker.

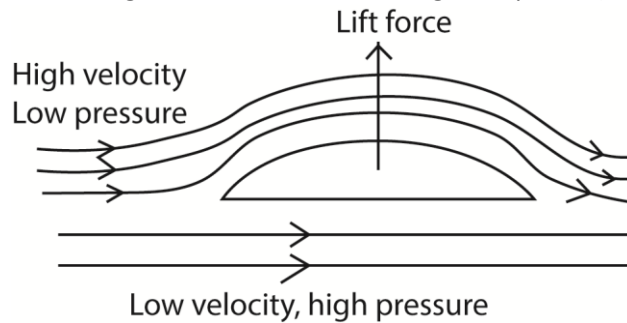
- The weight of the displaced water is determined and found to be equal to the weight of the object.

(c) (i) Write Bernoulli's equation and define each term in the equation. (02marks)

$$P + \frac{1}{2}\rho v^2 + h\rho g = \text{constant}$$

Where P = pressure, $\frac{1}{2}\rho v^2$ = kinetic energy, $h\rho g$ = potential energy per unit volume.

(ii) Explain the origin of lift force on the wings of a plane. (03marks)



- Air flows above the wing of a plane at high velocity hence low pressure.
- Below the wings, air flows at low velocity and hence high pressure.
- The difference in pressure cause a lift force, therefore net upward force.

(iv) Air flows over the upper surfaces of the wings of an aeroplane at a speed of 120ms^{-1} , and past the lower surface of the wings at 110ms^{-1} . Calculate the lift force on the aeroplane if it has a total wing area of 20m^2 . Density of air = 1.29kgm^{-3})

$$P = \frac{1}{2}\rho(v_2^2 - v_1^2)$$

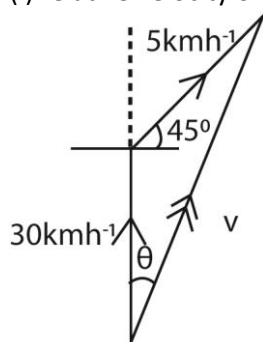
$$F = PA = \frac{1}{2} \times 1.29(120^2 - 110^2) \times 20 = 2.97 \times 10^4\text{N}$$

5. (a) What is meant by relative velocity? (01mark)

Relative velocity is the velocity of a body moves as observed from another body.

(b) A ship is heading due to north at a speed of 30ms^{-1} . Water in the lake is moving in the north-east direction at an average speed of 5kmh^{-1} . Calculate

(i) relative velocity of the ship (04 marks)



$$v_x = 5 \cos 45^\circ = 3.536$$

$$v_y = 30 + 5 \sin 45^\circ = 33.536$$

$$v = \sqrt{v_x^2 + v_y^2} = \sqrt{3.536^2 + 33.536^2} = 33.72\text{ms}^{-1}$$

$$\text{Direction of } v; \frac{5}{\sin \theta} = \frac{33.72}{\sin 135}$$

$$\theta = 6.0^\circ$$

(ii) distance off course the ship will be after 40 minutes. (02marks)

$$\text{Distance, } d = v_x t = 5 \sin 45^\circ \times \frac{40}{60} = 2.36 \text{ km}$$

(c) (i) Explain why a passenger in a car jerks forward when the brakes are suddenly applied. (03marks)

Before the brakes are applied, both the passenger and the car are moving with the same velocity. When brakes are applied, the force is exerted on the car and not the passenger. Because of inertia, the passenger tends to continue moving in a straight line.

(ii) Use Newton's second law to define the Newton. (04marks)

Consider a body of fixed mass, m acted on by constant force F and its velocity changes from u to v in time, t .

$$\text{Change in momentum} = \frac{(mv - mu)}{t}$$

$$\text{From Newton's second law; } F \propto \frac{(mv - mu)}{t} \text{ or } F = km \frac{(mv - mu)}{t}$$

$$\text{But } \frac{(mv - mu)}{t} = a$$

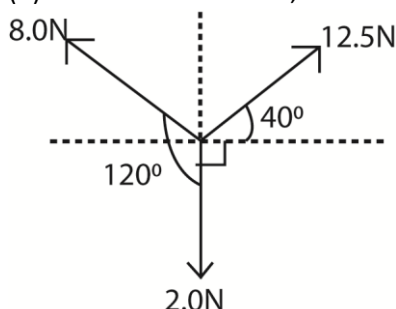
$$F = kma$$

$$\text{For } 1\text{N, } m = 1\text{kg, } a = 1\text{ms}^{-2} \Rightarrow k = 1$$

$$\therefore F = ma$$

The newton is a force which gives a mass of kg an acceleration of 1ms^{-2} .

(d) Three forces of 8.0N, 12.5N and 2.0N act on a body of mass 0.7kg as shown below



Calculate the acceleration of the body

$$F_x = 12.5 \cos 40^\circ - 8.0 \cos 30^\circ + 0 = 2.65 \text{ N}$$

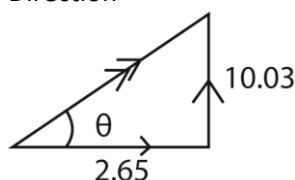
$$F_y = 12.5 \sin 40^\circ + 8.0 \sin 30^\circ - 2 = 10.03 \text{ N}$$

$$\text{Resultant force } F = \sqrt{2.65^2 + 10.03^2} = 10.37 \text{ N}$$

$$F = ma$$

$$\text{Acceleration, } a = \frac{10.37}{0.7} = 14.82 \text{ ms}^{-2}$$

Direction



$$\tan \theta = \frac{10.03}{2.65}; \theta = 75.2^\circ$$

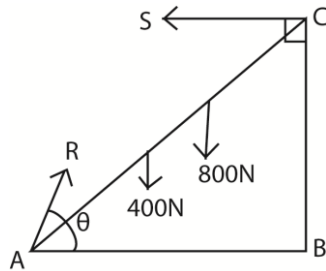
6. (a) what is meant by the centre of the mass? (01mark)

Centre of the mass is a point at which the whole mass of a body is considered to be concentrated.

(b) Explain why a long spanner is preferred to a short one in undoing a tight bolt. (03marks)

Undoing a tight nut is due to moment of a force. A long spanner provides a greater moment of force than a short one hence less force is applied.

(c) A uniform ladder of length 10m and weight 400N, leans against a smooth wall and its foot rests on rough ground. The ladder makes an angle of 60° with the horizontal. If the ladder just slips when a person of weight 800N climbs 6m up the ladder, calculate the
(i) reaction on the wall and the ground (05marks)



$$R \cos \theta = S$$

$$R \sin \theta = 1200$$

Taking moments about point A

$$400 \times 5 \cos 60^\circ + 800 \times 6 \cos 60^\circ = S \times 10 \sin 60^\circ$$

$$S = 392.6 \text{ N}$$

$$\tan \theta = \frac{1200}{392.6} \Rightarrow \theta = 71.9^\circ$$

$$R = \frac{1200}{\sin 71.9} = 1262.6 \text{ N}$$

(ii) distance another person of weight 600N can climb up the ladder so that the same reaction are exerted as in (c)(i). (02marks)

$$400 \times 5 \cos 60^\circ + L \cos 60^\circ \times 600 = 392.6 \times 10 \sin 60^\circ$$

$$L = 0.8 \text{ m}$$

(d) (i) State the principle of conservation of energy. (01mark)

Energy can neither be created nor destroyed but can be changed from form to another.

(ii) How does the principle in (d)(i) apply to a child sliding down an incline? (02marks)

Moving down an incline; potential energy is changed to kinetic energy to heat and sound

(e) A pump with power output of 147.1W can raise 2kg of water per second through a height of 5m and deliver it into a tank. Calculate the speed with which the water is delivered into the tank. (03marks)

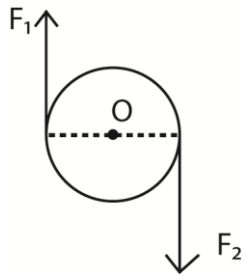
Power x time = kinetic energy of water + potential energy

$$= \frac{1}{2} m v^2 + m g h$$

$$147.1 = \frac{1}{2} \times 2 \times v^2 + 2 \times 5 \times 9.81$$

$$v = 7.0 \text{ ms}^{-2}$$

(f) Explain the effect of a **couple** on a rigid body. (03marks)



A **couple** consists of two parallel forces that are equal in magnitude, opposite in sense and do not share a line of action

7. (a) What is meant by a

(i) Brittle material (01mark)

A brittle material is a substance that breaks easily when a force is exerted on it
e.g. glass

(ii) Ductile material (01marks)

A ductile material is one that can be hammered, rolled or moulded into different shapes.

(b) Give one example of each of the materials in (a) (01mark)

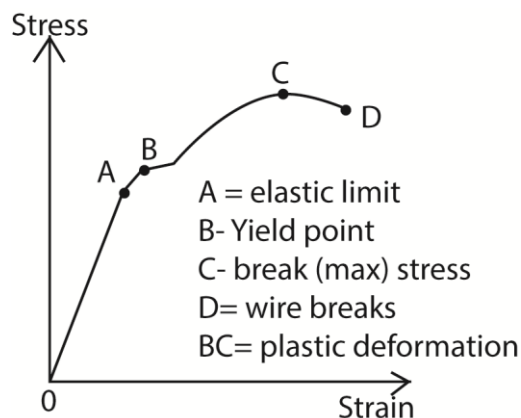
Brittle material: glass, clay, cast iron, stone

Ductile material: copper, aluminium

(c) Explain why bicycle frame are hollow (02mark)

Bicycle frame is hollow to reduce weight while maintain strength. A tube is significantly tougher to bend than a rod.

(d) (i) Sketch a labelled graph of stress against strain for a ductile material (02marks)



(ii) Explain the main features of the graph in (d)(i) (04marks)

- OA – stress is proportional to strain and the material regains its length
- AB - stress is not proportional to strain but the material regains its length
- Beyond B the material becomes permanently stretched
- CD the material undergoes plastic deformation
- Beyond D the material breaks

(e) Derive the expression for the energy stored per unit volume in a rod of length, L, Young's Modulus, Y, when stretched through distance, e. (04marks)

$$\text{Energy stored in the rod} = \frac{1}{2} Fe$$

$$\therefore \text{Energy stored per unit volume} = \frac{\frac{1}{2} Fe}{AL}$$

$$\text{But } F = \frac{Y Ae}{L}$$

$$\text{Energy stored per unit volume} = \frac{1}{2} \times \frac{Y Ae \cdot e}{AL^2} = \frac{1}{2} Y \left(\frac{e}{L} \right)^2$$

Or

For a small extension, dx

$$\text{Work done, } dw = F dx$$

From Hooke's law, $F = kx$

$$\therefore dw = kx dx \Rightarrow \text{Total work done, } w = \int dw$$

$$w = \int_0^e kx dx$$

$$\text{Energy stored} = \left| \frac{kx^2}{2} \right|_0^e, \text{ but } k = \frac{YA}{L}$$

$$\Rightarrow \text{Energy stored} = \frac{1}{2} \times \frac{Y Ae^2}{L}$$

$$\text{Energy stored per unit volume} = \frac{1}{2} \times \frac{Y Ae \cdot e}{AL^2} = \frac{1}{2} Y \left(\frac{e}{L} \right)^2$$

(f) A load of 5kg is placed on top of a vertical brass rod of radius 10mm and length 50cm. if

(i) decrease in length (03marks)

$$F = mg = 5 \times 9.81$$

$$A = \pi r^2 = \pi (10 \times 10^{-3})^2$$

$$e = \frac{FL}{AY} = \frac{5 \times 9.81 \times 0.5}{\pi (10 \times 10^{-3})^2 \times 3.5 \times 10^{10}} = 2.23 \times 10^{-6} \text{m}$$

(ii) energy stored in the rod. (02marks)

$$E = \frac{1}{2} Fe = \frac{1}{2} \times 5 \times 9.81 \times 2.23 \times 10^{-6} = 5.47 \times 10^{-5} \text{J}$$

8. (a) Define the following:

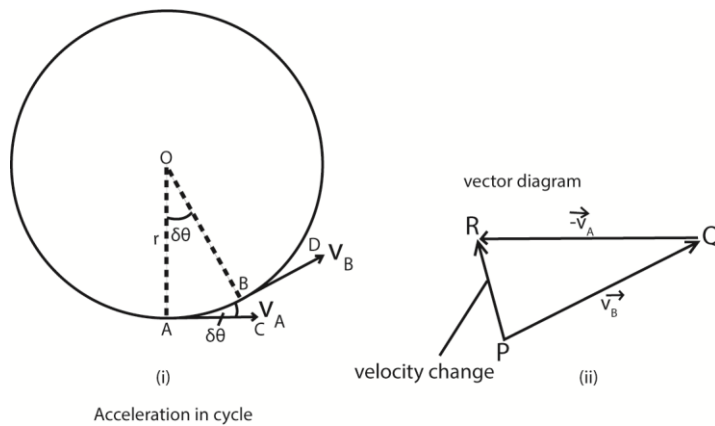
(i) Angular velocity

Angular velocity is the rate of change of angular displacement.

(ii) Period

Period is the time taken to make one complete oscillation

(b) An object moves in a circular path of radius, r, with a constant velocity, V. Derive an expression for its acceleration. (04marks)



The velocity change from A to B = $v_B - v_A$ or $v_B + (-v_A)$.

In figure 2(ii) above, PQ represents v_B in magnitude (v) and direction BD; QR represents $-v_A$ in magnitude (v) and direction (CA).

Velocity change = $v_B + (-v_A) = PR$

When δt is small, the angle AOB or $\delta\theta$ is small;
Also angle PQR equal to $\delta\theta$ is small

PR or acceleration then points toward O, the centres of the circle.

$$a = \frac{\text{velocity change}}{\text{time}} = \frac{PR}{\delta t} = \frac{v\delta\theta}{\delta t}$$

but $\frac{\delta\theta}{\delta t} = \omega$ and $v = r\omega$

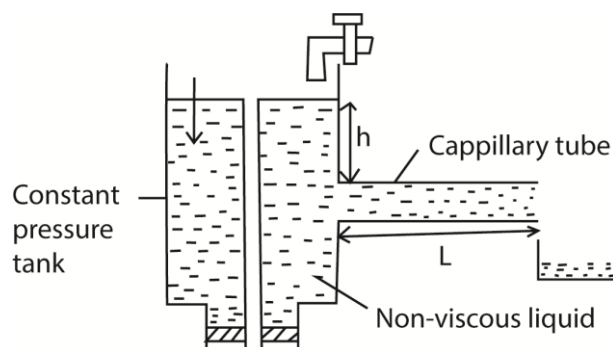
$$a = r\omega \times \omega = r\omega^2 \text{ but } \omega = \frac{v}{r}$$

$$- a = \frac{v^2}{r}$$

(c) (i) State two factors on which the rate of flow of a fluid through a tube depends.
(02marks)

- viscosity of fluid
- diameter/radius or cross sectional area of the tube
- pressure difference between its end

(ii) Describe an experiment to measure the coefficient of viscosity of a liquid using Ponselle's formula



- the liquid of density, ρ , passes slowly from a constant head tank through a capillary tube of length, l and radius r .
- for a height, h , of the tube, the volume V is collect in time t .
- the flow rate $R = \frac{V}{t}$ is calculated
- the experiment is repeated for different value of V and h .
- a graph of R against h is plotted and slope S is obtained

$$\text{For steady flow, } S = \frac{\pi r^4 P}{8\eta l}$$

$$\text{But } P = h\rho g$$

$$r = \frac{d}{2}$$

$$S = \frac{\pi \left(\frac{d}{2}\right)^4 P}{8\eta l}$$

$$\eta = \frac{\pi \left(\frac{d}{2}\right)^4 h\rho g}{8Sl}$$

(d) Find the time take for an oil drop of diameter 6.0×10^{-3} mm to fall through a distance of 4.0 cm in air of coefficient of viscosity 1.8×10^{-5} Pa.

[The density of oil and air are $8.0 \times 10^3 \text{ kg m}^{-3}$ and 1 kg m^{-3} respectively]

$$v = \frac{2r^2(P - \sigma)g}{9\eta} = \frac{2(3.0 \times 10^{-6})^2 (800 - 1) \times 9.81}{9 \times 1.8 \times 10^{-5}} = 8.7 \times 10^{-4} \text{ ms}^{-1}$$

$$\text{time} = \frac{\text{distance}}{\text{speed}} = \frac{4 \times 10^{-2}}{8.7 \times 10^{-4}} = 45.98 \text{ s}$$

9. (a) (i) State Newton's laws of motion. (03marks)

- A body continues in its state of rest or uniform motion in a straight line unless acted upon by an external force
- The rate of change of momentum of a body is directly proportional to applied force and takes place in the direction of the force
- For every action, there is an equal and opposite reaction

(ii) A molecule of a gas contained in a cube of side L strikes the wall of the cube repeatedly with a velocity u . Show that the average force F on the wall is given by

$$F = \frac{mu^2}{L}; \text{ where } m \text{ is the mass of the molecule (04marks)}$$

$$\text{Change of momentum} = mu - (-mu) = 2mu$$

$$\text{Time between collision} = \frac{2L}{u}$$

$$\text{Force} = \frac{\text{change in momentum}}{\text{time}} = 2mu \div \frac{2L}{u} = \frac{mu^2}{L}$$

(b) (i) Define linear momentum and state the law of conservation of linear momentum. (02marks)

- Linear momentum is the product of mass and its velocity
- The law of conservation of linear momentum: if the resultant force on a system of interacting bodies is zero; total linear momentum is conserved.

- (ii) A body of mass m_1 moving with velocity u , collides with another body of mass m_2 at rest. If they stick together after collision, find the common velocity with which they move (04marks)

$$\text{Initial momentum} = m_1 u + m_2 \times 0 = m_1 u$$

$$\text{Final total momentum} = (m_1 + m_2)v$$

By conservation of linear momentum

$$m_1 u = (m_1 + m_2)v$$

$$v = \frac{m_1 u}{(m_1 + m_2)}$$

- (c) A bullet of mass 10g is fired horizontally with a velocity of 300ms^{-1} into a block of wood of mass 290g which rests on a rough horizontal floor. After impact, the block and the bullet move together and come to rest when the block has travelled a distance of 15m. Calculate the coefficient of sliding friction between the block and the floor. (07marks)

By conservation of linear momentum

$$\frac{10}{1000} \times 300 + \frac{290}{1000} \times 0 = \frac{(10+290)v}{1000}$$

$$v = 10\text{ms}^{-1}$$

$$\text{From } v^2 = u^2 + 2as$$

$$0 = 10^2 + 2a \times 15$$

$$a = -3.33\text{ms}^{-2}$$

Retarding force = frictional

$$\text{Force} = ma = \frac{300}{1000} \times \frac{10}{3} = 1\text{N}$$

$$\Rightarrow \frac{F}{mg} = \frac{\frac{1}{300}}{1000} g = 0.34$$

10. (a) State Kepler's laws of planetary motion. (03marks)

- Planets describe ellipses about the sun as one focus
- The imaginary line joining the sun and planet sweeps out equal areas in equal time intervals
- The square of the periodic time of revolution of planets about the sun are proportional to the cubes of their mean distance from the sun

- (b) Use Newton's law of gravity to derive the dimension of the universal gravitational constant (03marks)

$$F = \frac{GMm}{r^2}$$

$$\Rightarrow [G] = \frac{[F][r^2]}{[M][m]} = \frac{MLT^{-2} \cdot L^2}{M^2} = M^{-1}L^3T^{-2}$$

- (c) A satellite is revolving at a height, h , above the surface of the earth with period T .

- (i) Show that the acceleration due to gravity, g , on the earth's surface is given by

$$g = \frac{4\pi^2(r_e + h)^3}{T^2 r_e^2}$$

where r_e is the radius of the earth. (06marks)

$$m(r_e + h)\omega^2 = \frac{GM_E m}{(r_e + h)^2} \text{ but, } \omega = \frac{2\pi}{T}$$

$$\frac{4\pi^2}{T^2} = \frac{GM_E}{(r_e + h)^2} \text{ also, } GM_E = gr_e^2$$

$$\frac{4\pi^2}{T^2} = \frac{gr_e^2}{(r_e + h)^2}$$

$$g = \frac{4\pi^2(r_e + h)^2}{T^2 r_e^2}$$

(ii) What is meant by parking orbit? (02marks)

Parking orbit of a satellite that it appears to be stationary to the observer on the earth's surface. The period of revolution of the satellite is equal to the period of revolution of the earth; i.e. $T = 24\text{hours}$

(d) A satellite revolves in a circular orbit at a height of 600km above the earth's surface.

Calculate the

(i) speed of the satellite. (03marks)

$$v = \sqrt{\frac{gr_e^2}{R}} = \sqrt{\frac{9.81 \times (6.4 \times 10^6)^2}{(6.4 \times 10^6 + 6 \times 10^5)}} = 7.5764 \times 10^3 \text{ms}^{-1}$$

(ii) period of the satellite. (03marks)

$$T = \frac{2\pi((r_e+h))}{v} = \frac{2\pi(6.4 \times 10^6 + 6 \times 10^5)}{7.5764 \times 10^3} = 5802.2\text{s}$$

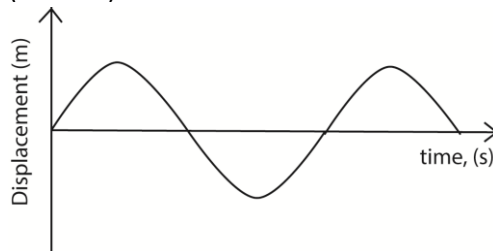
Or

$$T = \frac{2\pi}{r_e} \sqrt{\frac{(r_e+h)^3}{g}} = \frac{2\pi}{6.4 \times 10^6} \sqrt{\frac{(6.4 \times 10^6 + 6 \times 10^5)^3}{9.81}} = 5802.2\text{s}$$

11. (a)(i) Define Simple harmonic motion. (01mark)

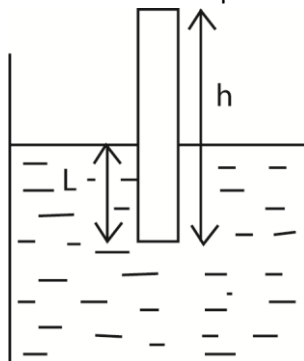
Simple harmonic motion is the periodic motion of a body whose acceleration is directly proportional to the displacement of a body from a fixed point and it is directed towards the fixed point.

(ii) Sketch a displacement-time graph for a body performing simple harmonic motion. (01mark)



(b) A uniform cylindrical rod of length 16cm and density 920kgm^{-3} floats vertically in a liquid of density 1000kgm^{-3} . The rod is depressed through a distance of 7mm and then released.

(i) Show that the rod performs simple harmonic motion (06marks)



- Let A be the cross section area of the rod and ρ be the density of the liquid
- Weight of the liquid displaced = up thrust.
- The volume of the liquid displaced = AL and therefore up thrust, $u = AL\rho g$
- When the rod is slightly displaced through a distance x , the new up thrust, $u' = A(L+x)\rho g$
- Resultant force, $F + AL\rho g - A(L+x)\rho g = -A\rho g x$

But force, $F = ma = -A\rho g x$

$$\therefore a = -\left(\frac{A\rho g}{m}\right)x = -kx$$

Since $a \propto x$; the rod performs simple harmonic motion

(ii) Find the frequency of the resultant oscillations. (04marks)

$$\omega^2 = \frac{A\rho g}{m}; m = Ah\sigma \text{ } (\sigma = \text{density of the rod})$$

$$\omega^2 = \frac{A\rho g}{Ah\sigma} = \frac{\rho g}{h\sigma}; \text{ also } \omega = 2\pi f$$

$$f = \frac{1}{2\pi} \sqrt{\frac{\rho g}{h\sigma}} = \frac{1}{2\pi} \sqrt{\frac{1000 \times 9.81}{920 \times 0.16}} = 1.3 \text{ Hz}$$

(iii) Find the velocity of the rod when is at a distance of 5mm above the equilibrium position (03marks)

$$v = \omega \sqrt{(r^2 - x^2)} = 2\pi f \sqrt{(r^2 - x^2)} = 2\pi \times 1.3 \sqrt{0.007^2 - 0.005^2} = 0.04 \text{ ms}^{-1}$$

(c) What is meant by potential energy? (01mark)

Potential energy is the energy possessed by the body by the virtue of its position or state

(d) Describe the energy changes which occur when a

(i) ball thrown upwards in air (03marks)

Chemical energy $\rightarrow$ P.E $\rightarrow$ K.E + P.E $\rightarrow$ P.E $\rightarrow$ K.E + P.E $\rightarrow$ K.E $\rightarrow$ sound + heat

(ii) loud speaker vibrating (01mark)

Electrical energy $\rightarrow$ mechanical energy $\rightarrow$ sound

12. (a)(i) Define elastic deformation and plastic deformation (02marks)

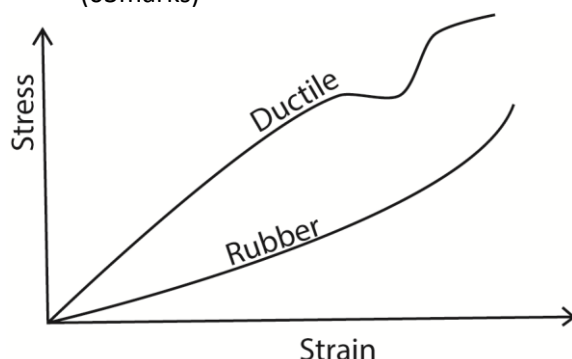
- Elastic deformation is when a material is deformed and it regains its original shape and size when the deforming force is removed.
- Plastic deformation occurs when a force is applied and the material does not regain its original shape and size when the force is removed

(ii) Explain what is meant by work hardening. (02marks)

Work hardening is the strengthening of a material by repeatedly deforming it.

Atomic planes slide over each other, this increases plane dislocations which prevent further sliding of planes.

(b) (i) Sketch using the same axes, stress-strain curves for ductile material and for rubber (03marks)



(ii) Explain the features of the curve for rubber. (03marks)

Rubber does not obey Hooke's law except for a very small range; it stretches easily without breaking and has a greatest range of elasticity. It does not undergo plastic deformation

Unstretched rubber consist of coiled molecules when a tensile force is applied, they uncoil, become straight and hard. Any further increase in tensile force makes the rubber to break.

- (c) A capillary tube is held in a vertical position with one end dipping in a liquid of surface tension γ and density ρ . If the liquid rises to a height, h , derive an expression for h in terms of γ , ρ and radius r of the tube assuming the angle of contact is zero. (04marks)

The liquid rises until the vertical component of the upward forces due to surface tension is equal to the weight of the liquid column.

$$F\gamma\cos\theta = W \text{ but } \theta = 0$$

$$\Rightarrow F\gamma = W$$

$$\gamma = \frac{F}{L}$$

$$F = \gamma L$$

$$L = 2\pi r$$

$$\text{But } W = mg \text{ and } m = V\rho \text{ (where } \rho \text{ is the density of the liquid in kg/m}^3\text{)}$$

$$W = v\rho g = 2\pi r^2 h\rho g$$

$$F\gamma = 2\pi r^2 h\rho g$$

$$\gamma \cdot 2\pi r = 2\pi r^2 h\rho g$$

$$h = \frac{2\gamma}{r\rho g}$$

γ – coefficient of surface tension

θ – angle of contact

r – radius of capillary tube

ρ – density of the liquid

- (d) A mercury drop of radius 2mm falls vertically and on hitting the ground, it splits into two drops each of radius 0.5mm. Calculate the change in surface energy given that the surface tension of mercury is 0.52Nm^{-1} . (05marks)

$$\text{Surface area of a drop} = 4\pi r^2$$

$$\text{Surface area of a big drop} = 4\pi(0.002)^2 = 5.03 \times 10^{-5}\text{m}^2$$

$$\text{Surface area of two small drops} = 2 \times 4\pi(0.0005)^2 = 6.28 \times 10^{-6}\text{m}^2$$

$$\text{Change in area} = 5.03 \times 10^{-5} - 6.28 \times 10^{-6}\text{m}^2 = 4.402 \times 10^{-5}\text{m}^2$$

$$\text{Change in surface energy} = \text{change in area} \times \text{coefficient of surface tension}$$

$$= 4.402 \times 10^{-5} \times 0.52$$

$$= 2.289 \times 10^{-5}\text{J}$$

- (e) State the effect of temperature on surface tension of a liquid. (01mark)

Increase in temperature lowers surface tension

13. (a) (i) Define dimensions of a physical quantity. (01mark)

Dimensions of a physical quantity is the way it is related to fundamental quantities; mass, length and time

- (ii) In the gas equation

$$\left(P + \frac{a}{V^2}\right)(V - b) = RT$$

Where P = pressure, V = volume, T = absolute temperature and R = gas constant, what are the dimensions of the constants a and b ? (04mark)

$$\left[\frac{a}{V^2}\right] = [P] \text{ since it is added to } P$$

$$[P] = \frac{[Force]}{[Area]} = \frac{MLT^{-2}}{L^2} = ML^{-1}T^{-2}$$

$$[V] = L^3$$

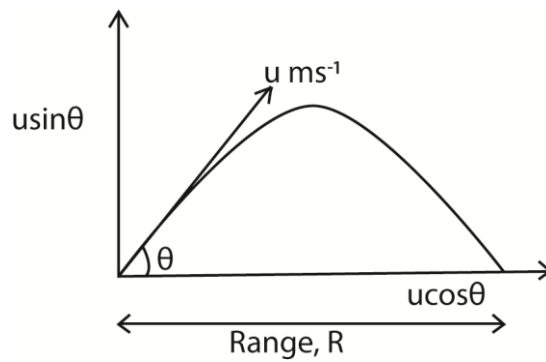
$$\Rightarrow \frac{[a]}{[L^6]} = ML^{-1}T^{-2} \Rightarrow [a] = ML^5T^{-2}$$

$$[b] = [V] \text{ since } b \text{ is subtracted from } V$$

$$[b] = L^3$$

- (b) A particle is projected from a point on horizontal plane with a velocity, u , at an angle, θ , above the horizontal. Show that the maximum horizontal range $R_{\max}$ is given by,

$$R_{\max} = \frac{u^2}{g} \text{ where, } g, \text{ is the acceleration due to gravity. (04marks)}$$



$$R = u \cos \theta \times \text{time of flight}$$

$$\text{Time of flight} = \frac{2u \sin \theta}{g}$$

$$\therefore \text{Range} = u \cos \theta \times \frac{2u \sin \theta}{g} = \frac{u^2 \sin 2\theta}{g}$$

$$\text{For maximum range } \sin 2\theta = 1$$

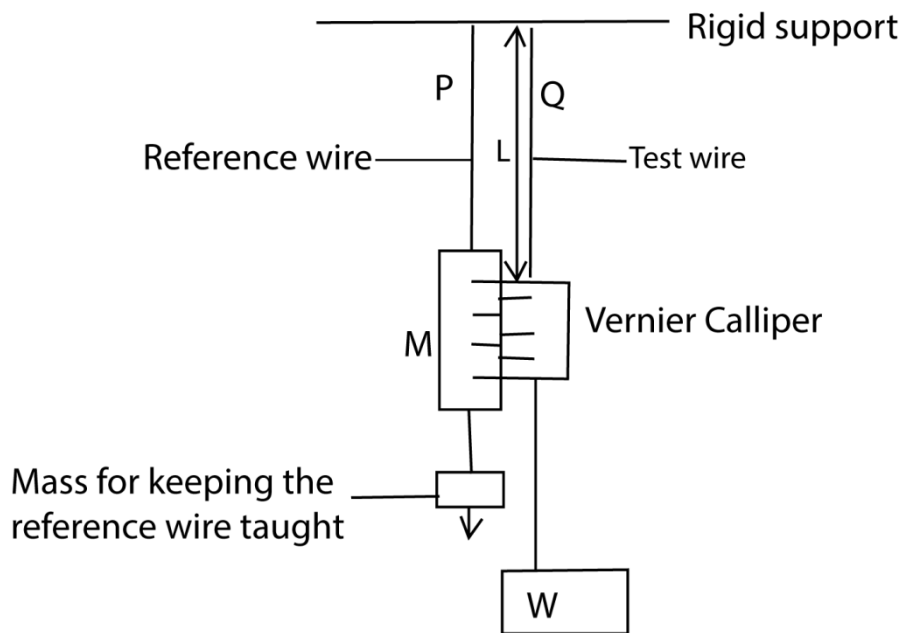
$$\Rightarrow R_{\max} = \frac{u^2}{g}$$

- (c) (i) Define elastic limit of a material. (01marks)

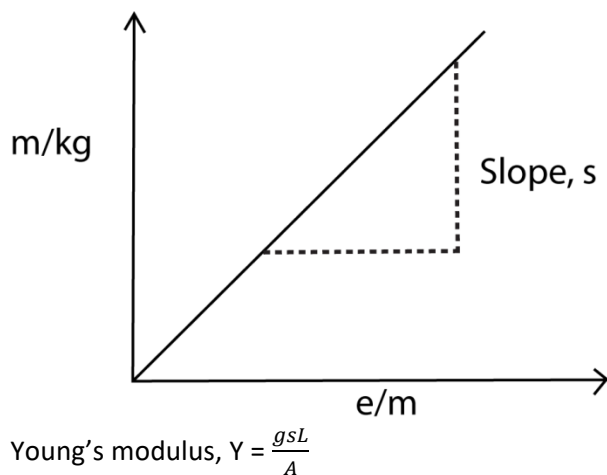
Elastic limit is the maximum load which a material can experience and still regain its original size and shape once the load has been removed.

- (ii) Describe an experiment to determine Young's Modulus of a steel wire. (06marks)

Experiment to determine Young's Modulus for a metal wire



- (i) Two thin, long wires of the same material and length P and Q are suspended from a rigid support.
- (ii) P carries a scale M in mm and it's straightened by attaching a weight at its end.
- (iii) Q carries a Vernier scale which is alongside scale M
- (iv) Various loads are added to the test wire and corresponding extensions caused are read off from a vernier scale.
- (v) The diameter ($2r$) of the wire is obtained by a micrometre screw gauge, and the cross section area of the wire $A = 4\pi r^2$
- (vi) A graph of mass (m) of the load against extension e is plotted



(d) Explain why tyres of a vehicle travelling on a hard surfaced road may burst. (04marks)

When the car moves on a hard surface, friction between the tyres and the surface causes overheating and the temperature inside the tyres increase. The increase in temperature increases the pressure inside the tyre which may lead to bursting.

14. (a) (i) What is meant by efficiency of a machine? (01mark)

Efficiency is the ratio of useful work done by a machine to the energy used by the machine; (expressed as percentage)

- (ii) A car of mass $1.2 \times 10^3 \text{ kg}$ moves up an incline at a steady velocity of 15 ms^{-1} against a frictional force of $6.0 \times 10^3 \text{ N}$. The incline is such that the car rises 1.0 m for every 10 m along the incline. Calculate the output power of the car engine. (04marks)

$$F = mg \sin \theta + F_r$$

$$= 1.2 \times 10^3 \times 9.81 \times \frac{1}{10} + 6000 = 7177.2 \text{ N}$$

$$P = Fv$$

$$= 7177.2 \times 15 = 1.077 \times 10^5 \text{ W}$$

- (b) (i) Define the impulse and momentum. (02marks)

- Impulse is a product of force and time of action of the force
- Momentum is a product of mass and its velocity

- (ii) An engine pumps water such that the velocity of the water leaving the nozzle is 15 ms^{-1} . If the water jet is directed perpendicularly on a wall and comes to a stop at the wall, calculate the pressure exerted on the wall. (03marks)

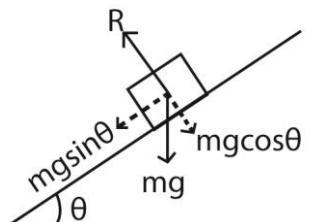
$$\text{Force exerted on the wall, } F = \rho A V^2$$

$$\text{Pressure} = \frac{F}{A} = \rho V^2 = 1000 \times 15^2 = 2.25 \times 10^5 \text{ Nm}^{-2}$$

- (c) (i) Define inertia. (01mark)

Inertia is the reluctance of a body to start moving once at rest or to stop moving once it has begun to move.

- (ii) Explain why a body placed on a rough plane will slide when the angle of inclination is increased. (04marks)



A body of mass, m placed on a plane inclined at an angle θ above the horizontal has its component $mg \sin \theta$ downwards along the plane. Since the plane is rough, $mg \sin \theta$ causes the frictional force F_r which prevents the body from sliding.

As θ increases, $mg \sin \theta$ exceeds maximum F_r and the body slides.

- (d) (i) State the conditions for a body to be in equilibrium under action of coplanar forces. (02marks)

- Resultant force on the body is zero
- Algebraic sum of moments at any point is zero.

- (ii) Briefly explain the three states of equilibrium (03marks)

- When a body in stable equilibrium is slightly displaced, its centre of gravity is raised. When released, it returns to its original position.
- When a body in stable equilibrium is slightly displaced, its centre of gravity is lowered and it continues to fall on release- topples.
- For neutral equilibrium, the centre of gravity remains the same on displacement.

15. (a) (i) What is meant by conservative forces? (01mark)

A conservative force is one for which the work done to move a body from one point to another is independent of the path taken and only depends on initial and final position of the body.

(ii) Give two examples of conservative forces (02marks)

- Mechanical energy
- Work done to move the body round a closed path.

(b) Explain the following

(i) damped oscillations (02marks)

Damped oscillation are oscillations in which the oscillatory system loses energy to the surroundings due to dissipative forces. The amplitude of the oscillations reduces with time.

(ii) Forced oscillations (02marks)

Force oscillations are those which are maintained by external force.

(c) (i) State Newton's law of gravitation (01mark)

Newton's law of gravitation states that every particle of matter attracts every other particle with a force which is directly proportional to the product of their masses and inversely proportional to the square of their distance apart.

(ii) Show that Newton's law of gravitation is consistent with Kepler's third law. (05marks)

Consider a planet of mass M_P moving around the sun of mass M_S in a circular orbit of radius r .

$$\text{Force due to gravitation, } F = \frac{GM_P M_S}{r^2}$$

$$\text{Force from circular motion, } F = \frac{M_P V^2}{r}$$

$$\text{But } \frac{GM_P M_S}{r^2} = \frac{M_P V^2}{r}$$

$$V^2 = \frac{GM_S}{r} \text{ also } V = \frac{2\pi r}{T}$$

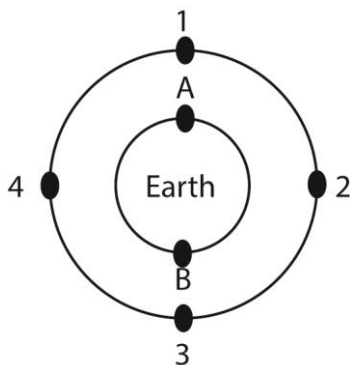
$$\Rightarrow \left(\frac{2\pi r}{T}\right)^2 = \frac{GM_S}{r}$$

$$T^2 = \frac{4\pi^2 r^3}{GM_S} \text{ or } T^2 \propto r^3$$

(d) If the earth takes 365 days to make one revolution around the sun, calculate the mass of the sun (04marks)

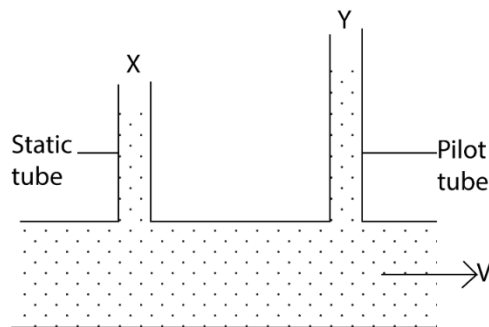
$$M_S = \frac{4\pi^2 r^3}{GT^2} = \frac{4 \times \pi^2 \times (1.5 \times 10^{11})^3}{6.67 \times 10^{-11} \times (365 \times 24 \times 60 \times 60)^2} = 2.01 \times 10^{30} \text{ kg}$$

(e) Explain briefly how satellites are used in world-wide radio or television communication. (04marks)



- A set of satellites is launched in parking orbit as shown in the diagram above.
- A radio signal from A is transmitted to a geosynchronous satellite 1

- The signals are retransmitted from satellite 1 to geosynchronous satellite 2, then to 3 and finally to B.
16. (a) (i) What is meant by fluid element and flow line as applied to fluid flow? (02mark)
- A fluid element is a molecule (the smallest volume) of the fluid which follows the flow.
 - A flow line is the path which individual molecule in a fluid element describes.
- (ii) Explain why some fluids flow more easily than others (03marks)
- Fluid flow involves different parts of a fluid moving at different velocities. Different parts of the fluid therefore slide past each other in layers. There exists frictional force between the layers which affects the flow rate. Liquids with low friction or viscosity flow faster than those with high viscosity.
- (b) (i) state Bernoulli's Principle. (01mark)
- Bernoulli's Principle states that for a streamline motion of an incompressible non viscous fluid, the sum of pressure at any point, the kinetic energy per unit volume is always constant.
- (ii) Explain how a Pilot-static tube works (04marks)



Pilot-static tube consists of a static tube which measure the static pressure and the pilot tube that measures the total pressure. Total pressure is the sum of static and dynamic pressure.

$$\text{From } P + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}$$

$$\text{Static pressure} = P + \rho gh$$

$$\text{Dynamic pressure} = \frac{1}{2}\rho v^2$$

$$\text{Total pressure, } P_y = \text{static pressure } (P_x) + \text{dynamic pressure}$$

$$= P + \frac{1}{2}\rho v^2 + \rho gh$$

For horizontal tube, h is constant

$$\text{But, Total pressure, } P_y = \text{static pressure } (P_x) + \text{dynamic pressure}$$

$$P_y = P_x + \frac{1}{2}\rho v^2$$

$$(P_y - P_x) = \frac{1}{2}\rho v^2$$

$$v = \sqrt{\left(\frac{2(P_y - P_x)}{\rho}\right)}$$

- (c) Air flowing over the upper surface of an air craft's wing causes a lift force of $6.4 \times 10^5 \text{ N}$. The air flows under the wing at a speed of 120 ms^{-1} over an area of 28 m^2 . Find the speed of air flow over an equal area of the upper surface of the air craft's wings. [Assume density of air = 1.2 kg m^{-3}] (04marks)

$$P_b + \frac{1}{2}\rho V_b^2 = P_u + \frac{1}{2}\rho V_u^2$$

$$P_b A - P_u A = \frac{1}{2}\rho(V_u^2 - V_b^2)$$

$$6.4 \times 10^4 = \frac{1}{2} \times 1.2(V_u^2 - 120^2)$$

$$V_u = 121.6 \text{ ms}^{-1}$$

(d) (i) What is meant by surface tension and angle of contact of a liquid? (02marks)

- Surface tension is the force per metre length acting in the surface at right angles to one side of the line drawn in the surface.
- Angle of contact is the angle between the solid surface and the tangent plane to the liquid surface measured through the liquid.

(ii) A water drop of radius 0.5cm is broken up into other drops of water each of radius 1mm. assuming isothermal conditions, find the total work done to break up the water drop. (04marks)

$$\text{Number of drops formed} = \frac{\frac{4}{3}\pi(0.5)^3}{\frac{4}{3}\pi(0.1)^3} = 125$$

$$\text{Total surface area} = 125 \times 4\pi r^2 = 125\pi \times 4 \times (0.1 \times 10^{-2})^2 = 1.57 \times 10^{-3} \text{ m}^2$$

$$\text{Initial surface area} = 4\pi R^2 = 4\pi(0.5 \times 10^{-2})^2 = 3.14 \times 10^{-4} \text{ m}^2$$

$$\begin{aligned} \text{Work done} &= \gamma \times \text{change in surface area} \\ &= 7.0 \times 10^{-2} (1.57 \times 10^{-3} - 3.14 \times 10^{-4}) \\ &= 8.8 \times 10^{-5} \text{ J} \end{aligned}$$

17. (a) (i) what is meant by conservative force? (01mark)

Conservative force are forces for which the work done in moving a body around a closed path is zero.

Or

Conservative force is the one for which the work done in moving a body from one point to another is independent of the path taken.

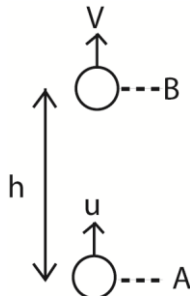
(ii) Give two examples of conservative forces. (01mark)

- Gravitational force, magnetic force, electric force, elastic force

(b) (i) State the law of conservation of mechanical energy. (01mark)

The sum of kinetic energy and potential energy is constant in the absence of dissipative forces.

(ii) A body of mass, m, is projected vertically upwards with speed, u. show that the law of conservation of mechanical energy is obeyed throughout its motion. (05marks)



$$\text{At A, K.E} = \frac{1}{2}mu^2, \text{ P.E} = 0$$

$$\text{Total energy at A} = \text{K.E} + \text{P.E} = \frac{1}{2}mu^2 + 0 = \frac{1}{2}mu^2$$

$$\text{At B, K.E} = \frac{1}{2}mv^2; \text{ P.E} = mgh$$

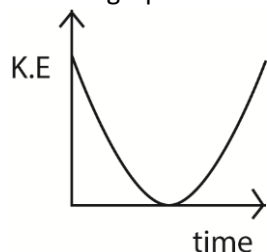
$$\text{Total energy at B,} = \frac{1}{2}mv^2 + mgh$$

But $v^2 = u^2 - 2gh$

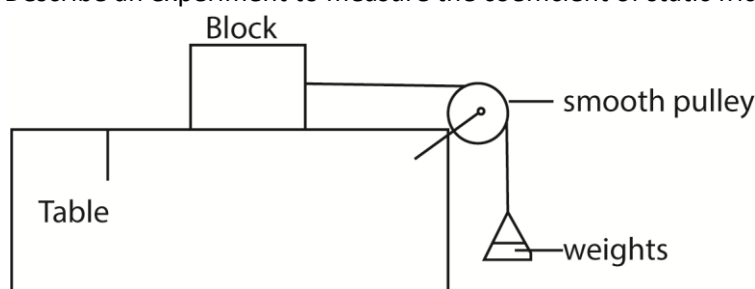
Total energy at B = $\frac{1}{2}m(u^2 - 2gh) + mgh = \frac{1}{2}mu^2$

∴ Total energy at A = total energy at B

(iii) Sketch a graph showing variation of kinetic energy by the body with time. (01 mark)

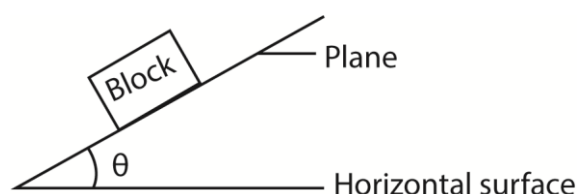


(c) (i) Describe an experiment to measure the coefficient of static friction. (04marks)



- A block of mass m is placed on a flat table and connected to a scale pan as shown in the diagram above.
- Small weights are added in bits on to the scale pan until the block just starts to move. The total weight of the scale pan and weights added is obtained, W_f .
- The coefficient of static friction, $\mu = \frac{W_f}{mg}$

Alternative method



- A block is placed on horizontal plane. The plane is tilted gently until the block just start to slide
- The angle of tilt θ is measured
- The coefficient of static friction, $\mu = \tan\theta$

(ii) State two disadvantages of friction. (01mark)

- Wastes energy
- Causes wear and tear
- Causes noise
- Generates unnecessary heat

(d) A bullet of mass 20g moving horizontally strikes and get embedded in a wooden block of mass 500g resting on a horizontal table. The block slides through a distance of 2.3m before coming to rest. If the coefficient of kinetic friction between the block and table is 0.3, calculate

(i) friction force between the block and the table. (02marks)

$$F = \mu mg = 0.3 \times 0.52 \times 9.81 = 1.53\text{N}$$

(ii) velocity of the bullet just before it strikes the block. (04marks)

$$F = ma$$

$$-1.53 = 0.52a$$

$$a = -2.94\text{ms}^{-2}$$

$$V^2 = u^2 - 2as$$

$$0 = v_1^2 - 2 \times 2.94 \times 2.3$$

$$v_1 = 3.68\text{ms}^{-1}$$

$$Mu = (m + m_1)v_1$$

$$0.02u = 0.502 \times 3.68$$

$$u = 95.7\text{ms}^{-1}$$

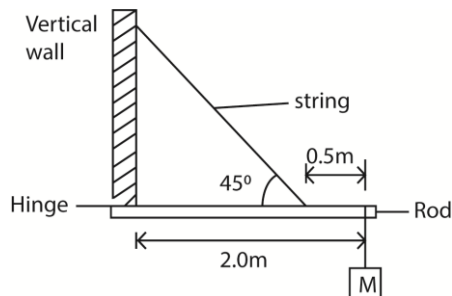
18. (a) (i) State the principle of moments. (01mark)

When a body is in mechanical equilibrium, the sum of clockwise moments about any point is equal to the sum of anticlockwise moments about the same point

(ii) Define the terms centre of gravity and uniform body. (02marks)

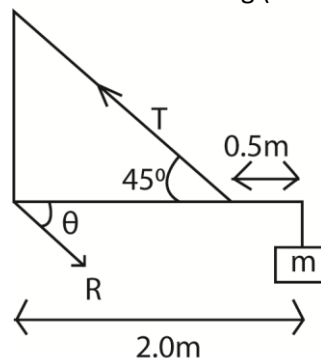
- Centre of gravity is the point where the resultant force on the body due to gravity acts.
- A uniform body is one whose centre of gravity is the same as the geometrical centre.

(b) Figure below shows a body, M of mass 20kg supported by a rod of negligible mass horizontally hinged to a vertical wall and supported by a string fixed at 0.5m from the other end of the rod.



Calculate the

(i) Tension in the string (03marks)



$$T \sin 45^\circ \times 1.5 = 20 \times 9.81 \times 2$$

$$T = 370\text{N}$$

(ii) Reaction of the hinge (03marks)

$$R \cos \theta = 370 \cos 45^\circ \dots\dots\dots(i)$$

Taking moments about O

$$R \sin \theta \times 1.5 = 20 \times 9.81 \times 0.5 \dots\dots(ii)$$

Eqn. (i) and (ii)

$$\theta = 14^\circ$$

- (iii) Maximum additional mass which can be added to the mass of 20kg before the string can break given that the string cannot support a tension of more than 500N. (02marks)

Taking moments about the hinge

$$500 \sin 45^\circ \times 1.5 = X \times 9.81 \times 2$$

$$X = 27 \text{ kg}$$

$$\text{extra mass} = 27 - 20 = 7 \text{ kg}$$

- (c) (i) Define Young's modulus. (01marks)

Young's modulus is the ratio of tensile stress to tensile strain

- (ii) Explain the precautions taken in determinations of Young's modulus of a wire. (06marks)

- After each reading, the load is removed to check that the wire returns to its original length, to ensure that elastic limit is not exceeded.
- Long wires are used to achieve measurable expansion
- Thin wires are used to produce high tensile stress
- Identical wires are used to eliminate error of expansion or contraction due to changes in temperature.

- (iii) Explain why a piece of rubber stretches much more than a metal wire of the same length and cross section (02marks)

Rubber consist of coiled molecules while metal does not. When load is applied to rubber, the molecules uncoil leading to a larger extension

19. (a) State Kepler's laws of planetary motion (03marks)

- Planets revolve in elliptical orbits with the sun at the focus.
- The imaginary line joining the sun to any planet sweeps out equal areas in equal time intervals
- The square of the period of revolution of a planet is proportional to the cube of the mean distance from the sun to planet

- (b) (i) what is a parking orbit? (01mark)

A parking orbit is the path in space followed by a satellite whose period of revolution is equal to the period of rotation of the earth.

- (ii) Derive an expression for the period, T, of a satellite in a circular orbit of radius, r, above the earth in terms of mass of earth, m, gravitational constant, G and r. (04marks)

$$\frac{GmM_s}{r^2} = M_s r \omega^2 \text{ but } \omega = \frac{2\pi}{T}$$

$$\frac{Gm}{r^2} = r \left(\frac{4\pi^2}{T^2} \right)$$

$$T = 2\pi \sqrt{\frac{r^3}{Gm}}$$

- (c) (i) A satellite of mass 200kg is launched in a circular orbit at a height of $3.59 \times 10^7 \text{ m}$ above the earth's surface. Find the mechanical energy of the satellite. (03marks)

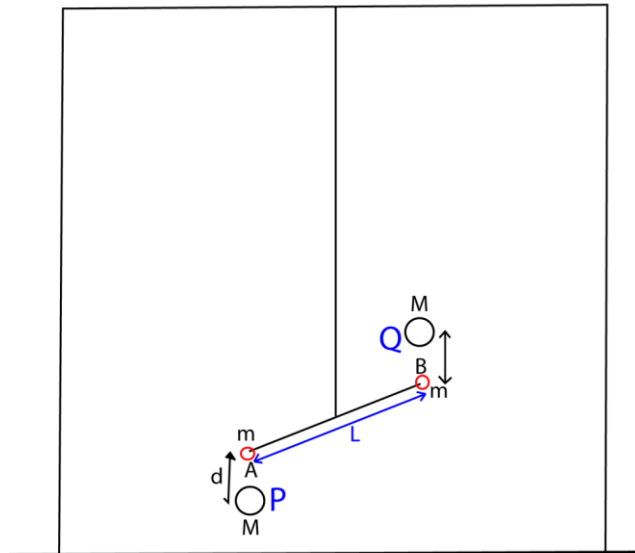
$$M.E = \frac{-GMm}{2r} = \frac{-6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 200}{2(3.59 \times 10^7 + 6.4 \times 10^6)} = -9.41 \times 10^8$$

- (ii) Explain what will happen to the satellite if its mechanical energy was reduced.
(03marks)

When mechanical energy, $M.E = \frac{-GMm}{2r}$; is reduced, the satellite falls to orbit of smaller radius

- (d) Describe laboratory method of determining the universal gravitational constant, G.
(06marks)

Determining gravitational constant



- Two equal lead spheres A and B each of mass, m, are attached to end of a bar AB of length, L.
 - The bar AB is suspended from a ceiling.
 - Large spheres P and Q are brought towards A and B respectively from the opposite side
 - Large spheres P and Q altered small spheres A and B respectively by equal and opposite gravitational forces give rise to gravitational torque, F, which in turn twist the suspended through angle θ .
 - A resting torque of the wire opposes the twisting of the wire from equilibrium position
- Then

$$F = C\theta = \frac{GMm}{d^2}$$

$$G = \frac{C\theta d^2}{MmL}$$

Where

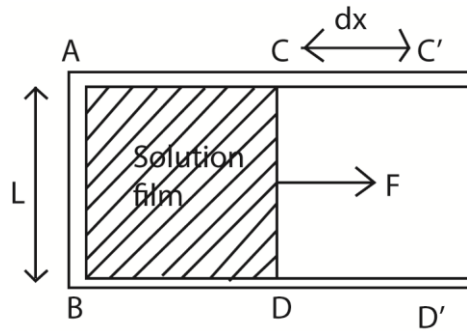
d = distance between the centre of A and P or B and Q.

C = the twisting couple per unit twist ($\theta = 1$)

20. (a) (i) Distinguish between surface tension and surface energy (01mark)

- Surface tension is a force per unit length acting at right angle to one side of an imaginary line drawn in the liquid surface
- Surface energy is the work done in increasing area of the surface by 1m^2 under isothermal conditions.

- (ii) Show the surface energy and surface tension are numerically equal. (03marks)



- F a wire frame ABCD is put in a solution of surface tension γ and a film of the solution forms on ABCD; and if a force F is used to extend the film to ABC'D' ;
- Then surface tension, $\gamma = \frac{F}{2L}$
- Surface energy, $\sigma = \frac{Fdx}{2Ldx} = \frac{2\gamma Ldx}{2Ldx} = \gamma$
 $\therefore$ Surface energy, $\sigma =$ surface tension, γ

(iii) Explain why water dripping out of a tap does so in spherical shapes. (03marks)

For any given volume, a sphere is a shape that offer minimum surface area and therefore the most stable

(b) Two soap bubbles of radius 2.0cm and 4.0cm respectively coalesce under isothermal conditions. If the surface tension of the soap solution is $2.5 \times 10^{-2} \text{ Nm}^{-1}$, calculate the excess pressure inside the resulting soap bubble. (04marks)

$$2(\pi r_1^2) + 2(\pi r_2^2) = 2(\pi R^2)$$

$$R = \sqrt{r_1^2 + r_2^2} = \sqrt{2^2 + 4^2} = 4.47 \text{ cm}$$

$$P_1 - P_0 = \frac{4\gamma}{R} = \frac{4 \times 2.5 \times 10^{-2}}{4.47 \times 10^{-2}} = 2.24 \text{ Pa}$$

(c) (i) State Bernoulli's principle (0marks)

Bernoulli's Principle states that for a streamline motion of an incompressible non viscous fluid, the sum of pressure at any point and kinetic energy per unit volume is always constant.

(ii) Explain how wind at a high speed over the roof of a building can cause the roof to be ripped off the building. (03marks)

Wind blowing at a high speed over the roof of a building causes pressure above the roof to decrease below the pressure in the building where the wind is slow. This difference in pressure causes a resultant force that pushes the roof off the building.

(iii) An aeroplane has a mass of 8,000kg and wing area of 8.0 m^2 . When moving through still air, the ratio of its velocity to that of the air above its wings is 0.25. At what velocity will the aeroplane be able to just lift off the ground? (Density of air = 1.3 kgm^{-3})

- Minimum force to lift an aeroplane = $8000 \times 9.81 = 78480 \text{ N}$
- If v is the velocity of the aeroplane, then velocity of air below the wings $v_b = v$.
- Velocity of the air above the aeroplane = $v_a = \frac{v}{0.25} = \frac{v_b}{0.25}$ or $v_a = 4v$
- From Bernoulli's Principle, $P_b + \frac{1}{2}\rho v_b^2 = P_a + \frac{1}{2}\rho v_a^2$
 $P_b - P_a = \frac{1}{2}\rho(v_a^2 - v_b^2) = \frac{1}{2} \times 1.3 ((4v)^2 - v^2) = 9.75v^2$
 But force = pressure x area
 $\Rightarrow 78480 = 9.75v^2 \times 8$

$$v = 31.72\text{ms}^{-1}$$

21. (a)(i) What is projectile motion? (01 marks)

Projectile motion is motion of the body which after being given an initial velocity moves under the influence of gravity.

(ii) A bomb is dropped from an aeroplane when it is directly above a target at a height of 1402.5m. The aeroplane is moving horizontally with a speed of 500kmh⁻¹. Determine whether the bomb will hit the target. (05marks)

$$Y = ut + \frac{1}{2}at^2$$

$$-1402.2 = 0 + \frac{1}{2} \times 9.81 \times t^2$$

$$t = 16.9\text{s}$$

$$\text{Horizontal velocity of the plane} = 500\text{kmh}^{-1} = \frac{500 \times 1000}{60 \times 60} = 138.89\text{ms}^{-1}$$

$$\text{Distance of the bomb from the target} = 138.89 \times 16.9 = 2347.2\text{m}$$

Hence the bomb misses the target by 2347.2m

(b) (i) Define angular velocity. (01mark)

Angular velocity is the rate of change of angle for a body moving in a circular path.

(ii) A satellite is revolving around the earth in a circular orbit at an altitude of 6 x 10⁵m where the acceleration due to gravity is 9.4 ms⁻². Assuming that the earth is spherical, calculate the period of the satellite. (03marks)

$$Mg = mr\omega^2$$

$$g = \frac{4\pi^2 r}{T^2}$$

$$T = \sqrt{\left(\frac{4\pi^2(6.4 \times 10^6 + 6.0 \times 10^5)}{9.4}\right)} = 5.42 \times 10^3\text{s}$$

(c) (i) State Newton's laws of motion (03marks)

- A body continues in its state of rest or uniform motion in a straight line unless acted upon by an external force
- The rate of change of momentum of a body is directly proportional to applied force and takes place in the direction of the force
- For every action, there is an equal and opposite reaction

(ii) Explain how a rocket is kept in motion. (04marks)

Fuel is burst in a combustion chamber and exhaust gases are expelled at high velocity. This causes a large backward momentum. From the principle of conservation of linear momentum, an equal forward momentum is gained by the rocket.

Due to continuous combustion of the fuel, there is a large change in forward momentum which lead to the thrust, hence maintaining the motion of the rocket.

(iii) Explain why passengers in a bus are thrown backwards when the bus suddenly start moving (03marks)

Passengers are thrown backwards because of inertia. When the bus sets off the passenger tend to stay at rest because the force acts on the bus does not act on the passengers.

22. (a) (i) What is meant by Young's modulus? (03marks)

Young's Modulus is the ratio of tensile stress to tensile strain of a material

(ii) State Hooke's law (01mark)

Hooke's law states that the extension of a material is proportional to the stretching force provided the elastic limit is not exceeded.

- (iii) Derive an expression for energy released in a unit volume a stretched wire in terms of stress and strain. (04marks)

Suppose a force, F , stretches the wire by extension x

Work done, W = average force $\times$ extension = $\frac{1}{2}Fx$ = stored energy

Energy stored per unit volume = $\frac{W}{AL}$; where AL is the volume of the wire

Hence energy store = $\frac{1}{2} \times \left(\frac{F}{A}\right) \left(\frac{x}{L}\right) = \frac{1}{2} \times \text{stress} \times \text{strain}$

- (b) A steel wire of length 0.6m and cross-section area $1.5 \times 10^{-6}\text{m}^2$ is attached at B to a copper wire BC of length 0.39m and cross section area $3.0 \times 10^{-6}\text{m}^2$. The combination is suspended vertically from a fixed point at A and supports a weight of 250N at C. find the extension in each of the wires, given that Young's Modulus for steel is $2.0 \times 10^{11}\text{Nm}^{-2}$ and that of copper is $1.3 \times 10^{11}\text{Nm}^{-2}$. (05marks)

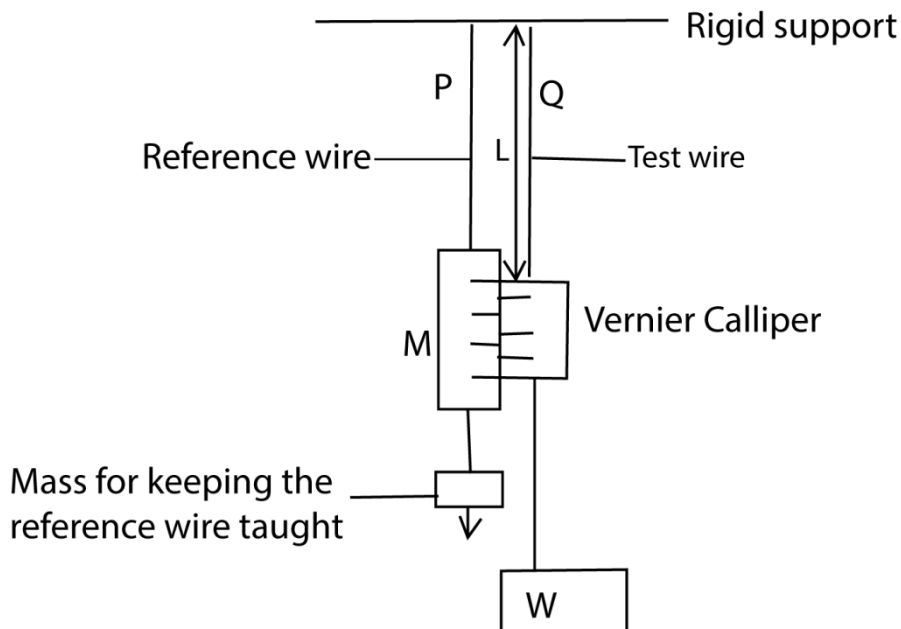
From $e = \frac{FL}{AE}$

For steel, $e_1 = \frac{250 \times 0.6}{1.5 \times 10^{-6} \times 2.0 \times 10^{11}} = 5.0 \times 10^{-4}\text{m}$

For copper, $e_2 = \frac{250 \times 0.39}{3.0 \times 10^{-6} \times 1.3 \times 10^{11}} = 2.5.0 \times 10^{-4}\text{m}$

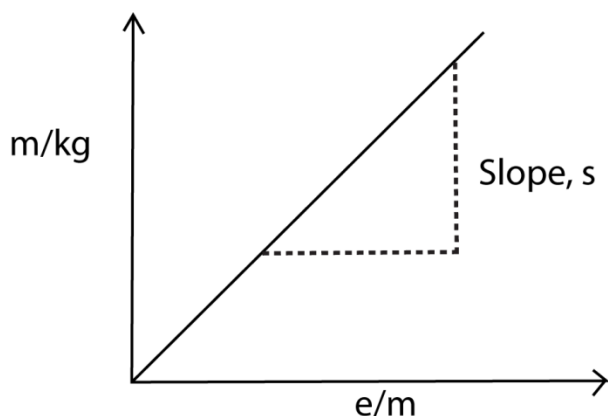
- (c) With the aid of a labelled diagram, describe an experiment to determine the Young's Modulus of a steel wire (07marks)

Experiment to determine Young's Modulus for a metal wire



- Two thin, long wires of the same material and length P and Q are suspended from a rigid support.
- P carries a scale M in mm and it's straightened by attaching a weight at its end.

- (iii) Q carries a Vernier scale which is alongside scale M
- (iv) Various loads are added to the test wire and corresponding extensions caused are read off from a vernier scale.
- (v) The diameter ($2r$) of the wire is obtained by a micrometre screw gauge, and the cross section area of the wire $A = 4\pi r^2$
- (vi) A graph of mass (m) of the load against extension e is plotted



Young's modulus, $Y = \frac{gL}{A}$

- (d) Explain the term plastic deformation in metals (02marks)
During plastic deformation, some crystal planes slide over each other. The movement of dislocation takes place and on removing the stress, the original shape and size are not recovered due to energy loss in form of heat.
- 23. (a) Define work and energy (02marks)
Work is a product of force and distance moved in the direction of force.
Energy is the ability to do work
- (b) Explain whether a person carrying a bucket of water does any work on the bucket while walking on a levelled road. (03marks)
There is no net force on the bucket in horizontal direction. The only force he exerts on the bucket is against the weight mg of the bucket perpendicular to the direction of motion.
From work = $F\cos 90 = 0$, there is no work done on the bucket
- (c) A pump discharges water through a nozzle of diameter 4.5cm with speed of 62ms^{-1} into a tank 16m above the intake.
- (i) Calculate the work done per second by the pump in raising the water if the pump is ideal. (04marks)

$$\begin{aligned}
 \text{Total work done per second} &= P.E + K.E \\
 &= mgh + \frac{1}{2} mv^2 \\
 &= 10^3 \pi (2.25 \times 10^{-2})^2 \times 62 (9.81 \times 16 + \frac{1}{2} \times 62^2) \\
 &= 2.05 \times 10^5 \text{Js}^{-1}
 \end{aligned}$$

- (ii) Find the power wasted if the efficiency of the pump is 73% (02marks)

$$\begin{aligned}
 \text{Efficiency} &= \frac{P_{out}}{P_{in}} \times 100 = 73 \\
 P_{in} &= \frac{2.05 \times 10^5}{73} = 2.81 \times 10^6 \text{W}
 \end{aligned}$$

$$\text{Power lost} = P_{in} - P_{out} = 2.81 \times 10^6 - 2.05 \times 10^5 = 7.6 \times 10^4 \text{W}$$

- (iii) Account for the power loss in (c)(ii) (02marks)

Power is lost in overcoming friction and some is converted into sound and heat

(d) (i) State work-energy theorem. (01mark)

It states that work done by the net force acting on a body is equal to the change in its kinetic energy.

(ii) Prove the work-energy theorem for a body moving with constant acceleration. (03marks)

From $v^2 = u^2 + 2as$

$$s = \frac{v^2 - u^2}{2a}$$

Work done = $F \times s$ but $F = ma$

$$\begin{aligned} &= ma \left(\frac{v^2 - u^2}{2a} \right) \\ &= \frac{1}{2}mv^2 - \frac{1}{2}mu^2 \end{aligned}$$

Therefore work done = change in kinetic energy

(e) Explain briefly what is meant by internal energy of a substance. (03marks)

The internal energy of a body or a substance is the total sum of kinetic energy and potential energy of the particles of a substance is the internal energy of a substance

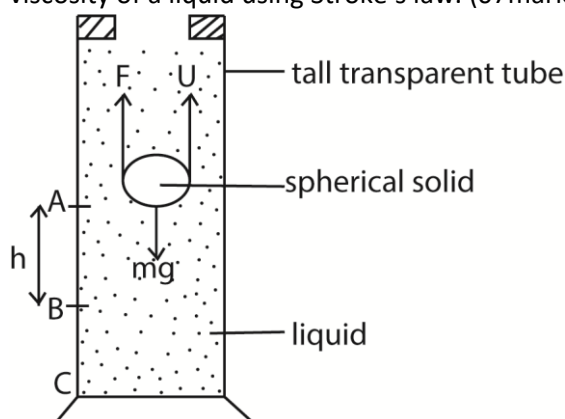
24. (a) Define coefficient of viscosity and state its units. (02marks)

Coefficient of viscosity is the frictional force on unit area of a liquid in a region of unit velocity gradient. Units Pas or Nsm^{-2}

(b) Explain the origin of viscosity in air and account for the effect of temperature on it. (05marks)

In air, molecules are further apart and have negligible intermolecular forces. Therefore the molecules move randomly colliding with one another and continuously transferring momentum to the neighbouring layers. The transfer of momentum constitute viscosity of air. When the temperature increases the molecules move faster, their kinetic energy increases and make more frequent collision. This increases the transfer of momentum and lead to increase in viscosity.

(c) Describe, stating the necessary precautions an experiment to measure the coefficient of viscosity of a liquid using Stoke's law. (07marks)



- A liquid of known density, ρ , is put in a tall transparent glass with reference marks A and B, h metres apart
- A spherical solid of radius a and density, σ , is dropped into the liquid and time t taken to drop from A to B is determined.
- Terminal velocity, $v_0 = \frac{h}{t}$

The coefficient viscosity, $\eta = \frac{2r^2(\sigma - \rho)g}{9v_0}$

Assumptions

The spherical solid moves with terminal velocity by the time it reaches A

Precautions

- The glass tube should be very wide compared to the diameter of the ball.
- The point C should be far away from the top of the tube
- Temperature is constant

(d) A steel ball bearing of diameter 8.0mm falls steadily through oil and covers a vertical height of 20.0cm in 0.56s. If the density of steel is 7800kgm^{-3} and that of oil is 900kgm^{-3} , calculate the

(i) up thrust on the ball (03marks)

$$U = \frac{4}{3}\pi r^3 \rho g = \frac{4}{3}\pi \times (4 \times 10^{-3})^3 \times 900 \times 9.81 = 2.37 \times 10^{-3}\text{N}$$

(ii) viscosity of the oil (03marks)

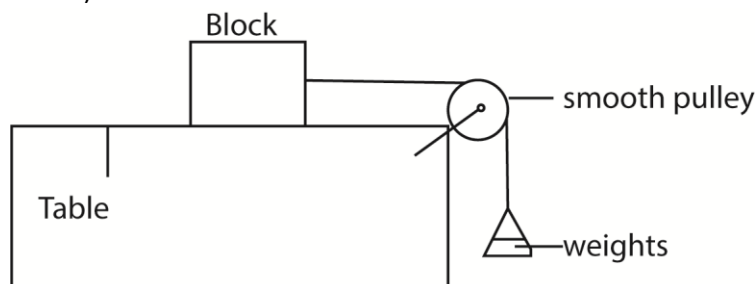
From $\eta = \frac{2r^2(\sigma - \rho)g}{9v_0}$

$$\eta = \frac{2(4 \times 10^{-3})^2 \times 9.81(7800 - 900)}{9 \times 0.357} = 0.674\text{Nsm}^{-2}$$

25. (a) Using the molecular theory, explain the laws of friction between solid surfaces. (06marks)

- For any two solid surfaces in contact, there are small humps and hollows that form contact points.
- Therefore, the actual area of contact is indeed small which creates very high pressure at the points of contact.
- This pushes the molecules very close that the forces of attraction between them welds the surfaces at these points.
- Thus, a force that opposes motion in any direction is created.

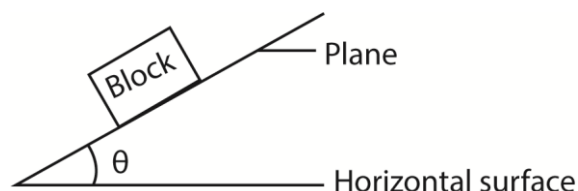
(b) With the aid of a labelled diagram, describe how the coefficient of static friction for an interface between a rectangular block of wood and a plane surface can be determined. (06marks)



- A block of mass m is placed on a flat table and connected to a scale pan as shown in the diagram above.

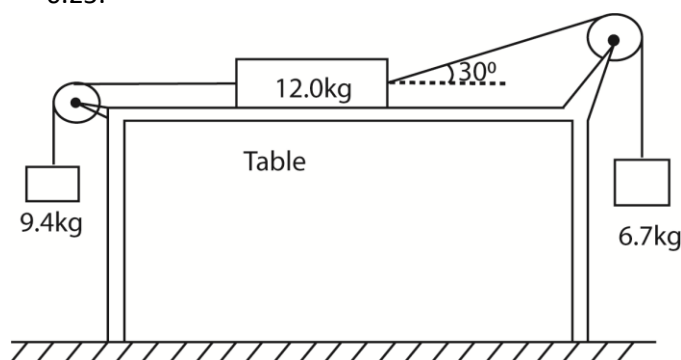
- Small weights are added in bits on to the scale pan until the block just starts to move. The total weight of the scale pan and weights added is obtained, W_f .
- The coefficient of static friction, $\mu = \frac{W_f}{mg}$

Alternative method



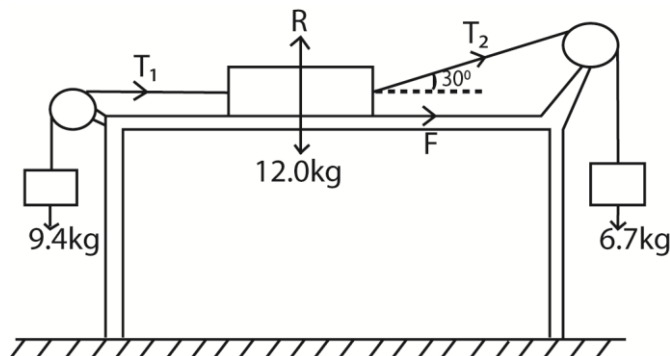
- A block is placed on horizontal plane. The plane is tilted gently until the block just start to slide
- The angle of tilt θ is measured
- The coefficient of static friction, $\mu = \tan\theta$

(c) The diagram below shows three masses connected by inextensible strings which pass over smooth pulleys. The coefficient of friction between the table and the 12.0kg mass is 0.25.



If the system is released from rest, determine the

(i) Acceleration of the 12.0kg mass (05marks)



$$9.4g - T_1 = 9.4a \dots\dots\dots (i)$$

$$T_1 - T_2 \cos 30^\circ - F = 12a \dots\dots\dots (ii)$$

$$T_2 - 6.7g = 6.7a \dots\dots\dots (iii)$$

$$F = \mu R = 0.25(12g - T_2 \times 0.5) = 3g - \frac{T_2}{8}$$

$$a = 0.53 \text{ms}^{-2}$$

(ii) Tension in each string (03marks)

$$T_2 = 6.7a + 6.7g = 6.7(0.53 + 9.81) = 69.3\text{N}$$

$$T_1 = 9.4g - 9.4a = 9.4(9.81 - 0.53) = 87.2\text{N}$$

26. (a) Define terminal velocity (01mark)

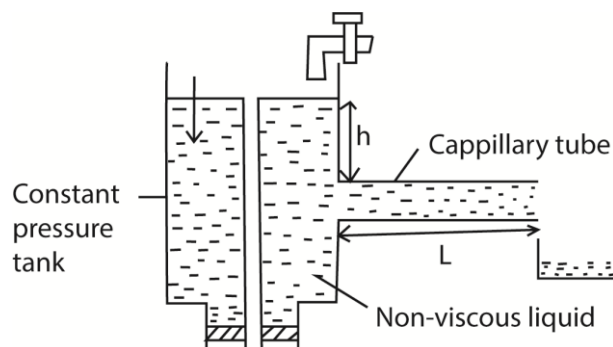
Terminal velocity is the maximum velocity attained by a body falling through a viscous fluid.

(b) Explain laminar flow and turbulent flow (03marks)

Laminar flow is the type of flow where equidistant layers of fluid from the axis of flow have the same velocity flow line are parallel to the axis of flow and the flow is orderly.

Turbulent flow is the type of flow where equidistant layers of a fluid from the axis of flow have varied velocities. The flow lines are not parallel and the flow is disorderly.

(c) Describe an experiment to measure the coefficient of viscosity of water using Ponselle's formula. (07marks)



- the liquid of density, ρ , passes slowly from a constant head tank through a capillary tube of length, l and radius r .
- for a height, h , of the tube, the volume V is collect in time t .
- the flow rate $R = \frac{V}{t}$ is calculated
- the experiment is repeated for different value of V and h .
- a graph of R against h is plotted and slope S is obtained

$$\text{For steady flow, } S = \frac{\pi r^4 P}{8\eta l}$$

$$\text{But } P = h\rho g$$

$$r = \frac{d}{2}$$

$$S = \frac{\pi \left(\frac{d}{2}\right)^4 P}{8\eta l}$$

$$\eta = \frac{\pi \left(\frac{d}{2}\right)^4 h\rho g}{8Sl}$$

(d) (i) State Bernoulli's principle (01 mark)

For non-viscous incompressible fluid flowing steadily, the sun of pressure plus kinetic energy per unit volume Plus potential energy per unit volume is constant.

(ii) Explain why a person standing near a railway line is sucked towards the railway line when a fast moving train passes. (03marks)

Between the man and the train, the velocity of air is increased due to the motion of the train resulting in a decrease in pressure according to Bernoulli's Principle. Behind the man, the flow velocity is lower and pressure is higher. This results in a resultant force towards the train, hence the man is sucked in

- (e) A horizontal pipe of cross sectional area 0.4m^2 , tapers to a cross section area of 0.2m^2 . The pressure at the large section of the pipe is $8.0 \times 10^4\text{Nm}^{-2}$ and the velocity of water through the pipe is 11.2ms^{-1} . If the atmospheric pressure is $1.01 \times 10^5\text{Nm}^{-2}$, find the pressure at the small section of the pipe. (05marks)

$$A_1V_1 = A_2V_2$$

$$0.4 \times 11.2 = 0.2 \times V_2$$

$$V_2 = 24\text{ms}^{-1}$$

$$P_1 + \frac{1}{2}\rho V_1^2 + \rho gh_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho gh_2$$

$$\text{Since } h_1 = h_2$$

$$P_1 + \frac{1}{2}\rho V_1^2 = P_2 + \frac{1}{2}\rho V_2^2$$

$$8.0 \times 10^4 + \frac{1}{2} \times 10^3 \times 11.2^2 = P_2 + \frac{1}{2} \times 10^3 \times 24^2$$

$$P_2 = 7.784 \times 10^4\text{Pa}$$

27. (a) (i) State the law of conservation of linear momentum (01mark)

If no external force acts on a system of colliding objects, the total momentum of the objects in a given direction before collision is equal to the total momentum in the same direction after collision

- (ii) A body explodes and produces two fragments of mass m and M . If the velocities of the fragments are u and v respectively. Show that the ratio of the kinetic energies of the fragments is

$$\frac{E_1}{E_2} = \frac{M}{m} \text{ where } E_1 \text{ is the kinetic energy of } m \text{ and } E_2 \text{ is the kinetic energy of } M.$$

$$E_1 = \frac{1}{2}mu^2 \text{ and } E_2 = \frac{1}{2}Mv^2$$

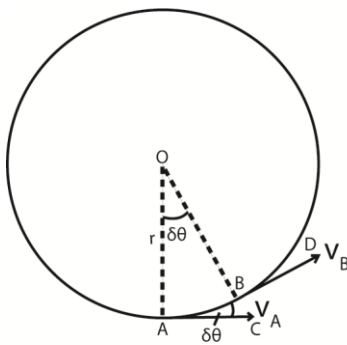
From the principle of conservation of linear momentum $mu = -Mv$

$$v = \frac{-mu}{M}$$

$$E_2 = \frac{1}{2}M\left(\frac{-mu}{M}\right)^2 = \frac{1}{2}M \times \frac{m^2u^2}{M^2} = \frac{1}{2}mu^2 \times \frac{m}{M} = E_1 \frac{m}{M}$$

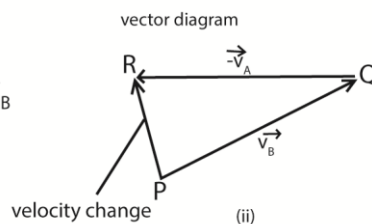
$$\frac{E_1}{E_2} = \frac{M}{m}$$

- (b) Show that the centripetal acceleration of an object moving with constant velocity, v , in a circle of radius, r is $\frac{v^2}{r}$. (04marks)



(i)

Acceleration in circle



(ii)

The velocity change from A to B = $v_B - v_A$ or $v_B + (-v_A)$.

In figure 2(ii) above, PQ represents v_B in magnitude (v) and direction BD; QR represents $-v_A$ in magnitude (v) and direction (CA).

Velocity change = $v_B + (-v_A) = PR$

When δt is small, the angle AOB or $\delta\theta$ is small;

Also angle PQR equal to $\delta\theta$ is small

PR or acceleration then points toward O, the centres of the circle.

$$a = \frac{\text{velocity change}}{\text{time}} = \frac{PR}{\delta t} = \frac{v\delta\theta}{\delta t}$$

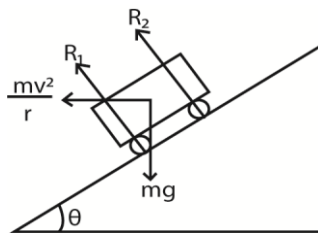
but $\frac{\delta\theta}{\delta t} = \omega$ and $v = r\omega$

$$a = r\omega \times \omega = r\omega^2 \text{ but } \omega = \frac{v}{r}$$

$$- a = \frac{v^2}{r}$$

- (c) A car of mass 1000kg moves round a banked track at constant speed of 108kmh^{-1} . Assuming the total reaction at the wheels is normal to the track, and the radius of curvature of the track is 100m, calculate the:

- (i) angle of inclination of the track to the horizontal (04marks)



$$Fr\theta m \tan\theta = \frac{v^2}{rg}$$

$$v = 108\text{kmh}^{-1} = \frac{108 \times 1000}{60 \times 60} = 30\text{ms}^{-1}$$

$$\tan\theta = \frac{30^2}{100 \times 9.81}$$

$$\theta = 42.5^\circ$$

- (ii) reaction at the wheels (02marks)

$$\text{From } (R_1 + R_2) \sin\theta = \frac{mv^2}{r}$$

$$\Rightarrow R_1 + R_2 = \frac{mv^2}{r \sin\theta} = \frac{1000 \times 30^2}{100 \sin 42.5^\circ} = 1.33 \times 10^4 \text{N}$$

- (d) (i) Define uniformly accelerated motion (01mark)

Uniformly accelerated motion is where velocity changes by the same amount in the same time interval

- (ii) A train starts from rest at station A and accelerates at 1.25ms^{-2} until it reaches a speed of 20ms^{-1} . It then travels at this steady speed for a distance of 1.56km and then decelerates at 2ms^{-2} to come to rest at station B. Find the distance from A to B. (04marks)

For accelerated motion using $v^2 = u^2 + 2as$

$$20^2 = 0^2 + 2(1.25)s$$

$$s = 160\text{m}$$

For deceleration:

$$0 = 20^2 - 2 \times 2 \times s$$

$$s = 100\text{m}$$

$$\text{Total distance} = 160 + 1560 + 100 = 1820\text{m}$$

28. (a)(i) State Kepler's laws of planetary motion. (03marks)

- Planets describe ellipses about the sun as one focus
- The imaginary line joining the sun and planet sweeps out equal areas in equal time intervals
- The square of the periodic time of revolution of planets about the sun are proportional to the cubes of their mean distance from the sun

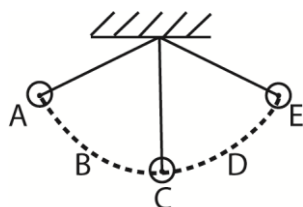
- (ii) Estimate the mass of the sun, if the orbit of the earth around the sun is circular. (04marks)

$$M = \frac{4\pi^2 r^3}{GT^2} = \frac{4\pi^2 \times (1.5 \times 10^{11})^3}{6.67 \times 10^{-11} \times (365 \times 24 \times 60 \times 60)} = 2.0 \times 10^{30}\text{kg}$$

- (b) Explain Brownian motion (03marks)

Continuous random and haphazard (zig-zag) motion of fluid particles caused by repeated collision of particles exerting a resultant force on each other which changes in magnitude and direction.

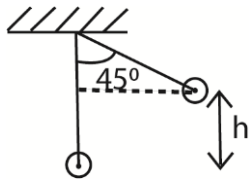
- (c) Explain the energy changes which occur when a pendulum is set into motion. (03marks)



Potential energy at A → Kinetic + potential energy at B → kinetic at C → Kinetic + potential energy at D → potential energy at E

- (d) A simple pendulum of length 1m has a bob of mass 100g . It is displaced from mean position A to position B so that the string makes an angle of 45° with the vertical. Calculate the

(i) maximum potential energy of the bob. (03marks)



$$h = 1 - \cos 45 = 0.293$$

$$P.E = mgh = 0.1 \times 9.81 \times 0.293 = 0.287J$$

(ii) velocity of the bob when the string makes an angle of 30° with the vertical. [Neglect air resistance]

$$\text{Height of the ball when the string makes } 30^\circ = 1 - \cos 30 = 0.134$$

$$\text{Potential energy at this point} = mgh = 0.1 \times 9.81 \times 0.134 = 0.122J$$

$$\text{Kinetic energy} = \text{change in potential energy} = 0.287 - 0.122 = 0.165J$$

Let the velocity be v

$$\Rightarrow \frac{1}{2} \times 0.1 \times v^2 = 0.165$$

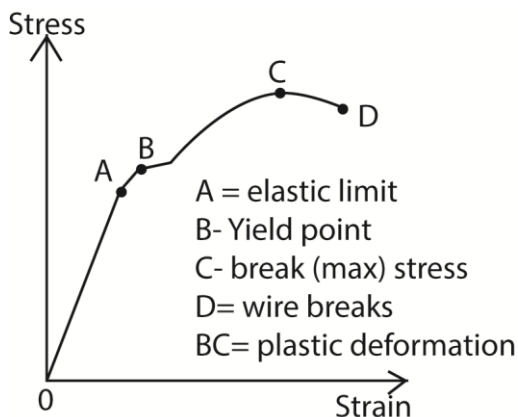
$$v = 1.8ms^{-1}$$

29. (a) State Hooke's law. (01mark)

Hooke's law states that extension is proportional to the load provided the proportionality limit is not exceeded.

(b) A copper wire is stretched until it breaks.

(i) Sketch a stress-strain graph for the wire and explain the main features of the graph. (04marks)



- OA – stress is proportional to strain and the material regains its length
- AB - stress is not proportional to strain but the material regains its length
- Beyond B the material becomes permanently stretched
- CD the material undergoes plastic deformation
- Beyond D the material breaks

(ii) Explain what happens to the energy used to stretch the wire at each stage. (04marks)

- During elastic deformation, atoms are slightly displaced from equilibrium position. When the load is applied to the wire, energy used to stretch wire becomes elastic potential energy
- When the wire is stretched beyond elastic limit, permanent displacement of atoms occurs. The energy is used to break some interatomic bond and some is released as heat.
- At the breaking point, energy is used to break the interatomic bonds.

(iii) Derive the expression for the work done to stretch a spring of force constant, k , by a distance, x . (03marks)

$$dw = Fdx$$

$$\text{Work done} = \int_0^x Fdx$$

$$\text{But } F = kx$$

$$\therefore W = \int_0^x kx dx = \frac{1}{2} kx^2$$

(c)(i) Define Young's Modulus. (01mark)

Young's Modulus is the ratio of tensile stress to tensile strain

(ii) Two identical steel bars A and B of radius 2.0mm are suspended from the ceiling. A mass of 2.0kg is attached to the free end of bar A. Calculate the temperature to which B should be raised so that the bars are again equal in length.

[Young's Modulus of steel = $1.0 \times 10^{11} \text{ Nm}^{-2}$]

[Linear expansivity of steel = $1.2 \times 10^{-5} \text{ K}^{-1}$] (05mark)

$$e = \frac{Fl}{AE}, \text{ also } e = \alpha \Delta\theta \text{ where } \Delta\theta \text{ is temperature change}$$

$$\Rightarrow \Delta\theta = \frac{F}{AE\alpha} = \frac{2 \times 9.81}{\pi (2.0 \times 10^{-3})^2 \times 1.0 \times 10^{11} \times 1.2 \times 10^{-5}} = 1.4 \text{ K}$$

(d) Why does an iron roof make cracking sound at night? (02marks)

During the day, the roof is heated, it expands and buckles since it is fixed. At night, the roof contracts due to fall in temperature. As it straightens again sound is produced.

30. (a) Define the following terms as applied to oscillatory motion

(i) Amplitude (01mark)

Amplitude is the maximum displacement of a particle from equilibrium or mean position

(ii) Period (01mark)

Period is the time taken to make 1 cycle.

(b) State four characteristics of simple harmonic motion. (02marks)

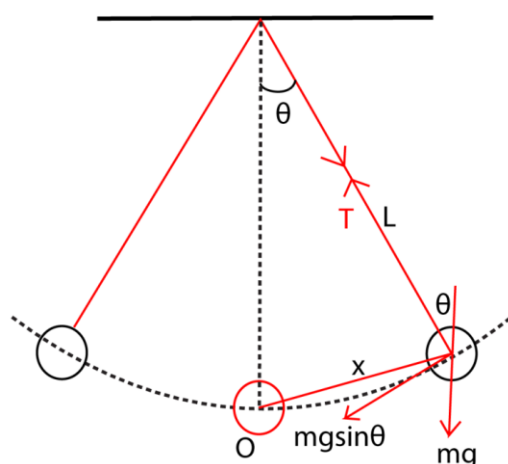
- A periodic motion
- Acceleration is proportional to displacement
- Acceleration is directed towards a fixed point
- Mechanical energy is conserved.

(c) A mass, m is suspended from a rigid support by a straight string of length L . The mass is pulled aside so that the string makes an angle, θ , with the vertical and then released.

(i) Show that the mass executes simple harmonic motion with a period $T = 2\pi \sqrt{\frac{L}{g}}$.

Suppose a body of mass, m , attached to a string is displaced through a small angle θ

and then released. The resultant force on the body towards O is $mg\sin\theta$.



By Newton's 2nd law

$$ma = -mg\sin\theta$$

$$a = -g\sin\theta$$

If θ is small and measured in radians $\theta \approx \sin\theta = \frac{x}{L}$

$$a = g\frac{x}{L}$$

But $a = -\omega^2 x$

$$\omega = \sqrt{\frac{L}{g}}$$

$$T = \frac{2\pi}{\omega}$$

$$T = 2\pi\sqrt{\frac{L}{g}}$$

(ii) Explain why this mass comes to a stop after a short time. (02marks)

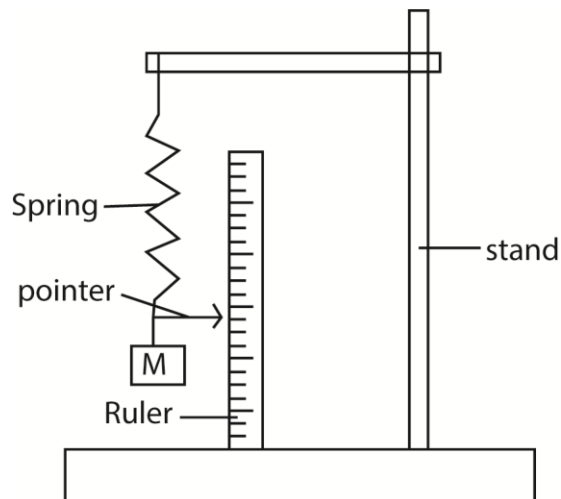
The mass comes to a stop due to the presence of dissipative forces leading to loss of energy and amplitude reduces with time.

(d) A piston in a car engine performs a simple harmonic motion of frequency 12.5Hz. If the mass of the piston is 0.50kg and its amplitude of vibration is 45mm, find the maximum force on the piston. (03marks)

$$\text{Maximum force} = m\omega^2 A \text{ but } \omega = 2\pi f$$

$$\text{Maximum force, } F = 0.5 \times (2\pi \times 12.5)^2 \times 0.045 = 138.8\text{N}$$

(e) Describe an experiment to determine the acceleration due to gravity, g , using a spiral spring, of known constant. (06marks)

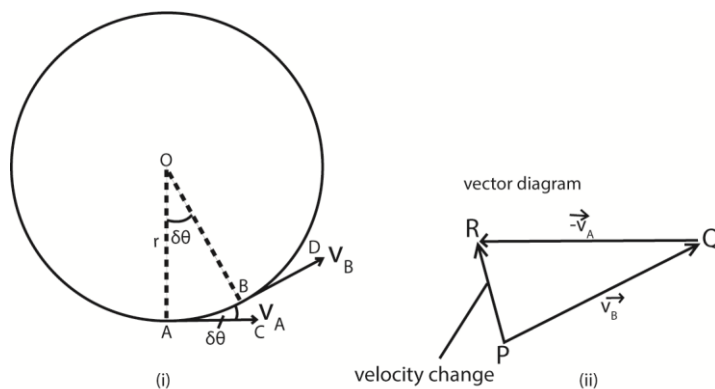


- Clamp the spring on a retort stand
- Fix a horizontal pin at free end of the spring to act as a pointer.
- Place a vertical meter rule next the pointer and note the initial pointer position, P_1 .
- Suspend a known mass, M , to the free end of the spring, note and record the new position of the pointer, P_2 .
- Calculate extension, $e = P_2 - P_1$.
- Find the extensions for different masses
- Plot a graph of e against M
- Calculate the slope, S of the graph
- Calculate the acceleration due to gravity, $g = kS$ (k = force constant)

31. (a) Explain what is meant by centripetal force. (02marks)

Centripetal force is the force that keeps a body moving in a circular path. It's directed towards the centre of the path.

(b)(i) Derive an expression for centripetal force acting on a body of mass, M , moving in a circular path of radius, r . (06marks)



Acceleration in cycle

The velocity change from A to B = $v_B - v_A$ or $v_B + (-v_A)$.

In figure 2(ii) above, PQ represents v_B in magnitude (v) and direction BD; QR represents $-v_A$ in magnitude (v) and direction (CA).

Velocity change = $v_B + (-v_A) = PR$

When δt is small, the angle AOB or $\delta\theta$ is small;

Also angle PQR equal to $\delta\theta$ is small

PR or acceleration then points toward O, the centres of the circle.

$$a = \frac{\text{velocity change}}{\text{time}} = \frac{PR}{\delta t} = \frac{v\delta\theta}{\delta t}$$

but $\frac{\delta\theta}{\delta t} = \omega$ and $v = r\omega$

$$a = r\omega \times \omega = r\omega^2 \text{ but } \omega = \frac{v}{r}$$

$$- a = \frac{v^2}{r}$$

$$\text{Centripetal force} = ma = \frac{mv^2}{r} = mr\omega^2$$

- (ii) A body moving in a circular path of radius 0.5m makes 40 revolutions per second. Find the centripetal force if the mass is 1kg (03marks)

$$F = mr\omega^2 \text{ but } \omega = 2\pi f$$

$$= 1 \times 0.5 \times (2\pi \times 40)^2 = 1.36 \times 10^4 \text{N}$$

- (c) Explain the following

- (i) A mass attached to a string rotating at constant speed in a horizontal circle will fly off at a tangent of the string breaks. (02marks)

If the string breaks, the mass will not have any centripetal force and will continue in a straight line along the tangent.

- (ii) A cosmonaut in a satellite which is in a free circular orbit around the earth experiences the sensation of weightlessness even though there is influence of gravitational field on earth. (03marks)

The sensation of weight is caused by the reaction of the floor on a person. In orbit, the cosmonaut and the floor have the same acceleration towards the centre of the earth.

The floor exerts no supporting force on the cosmonaut. (i.e. the reaction, $R = 0$)

- (d) (i) Derive an expression for maximum horizontal distance travelled by a projectile in terms of the initial speed, u , and the angle of projection, θ , to the horizontal. (02marks)

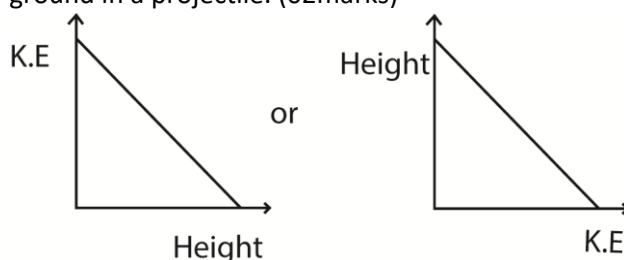
Horizontally, $x = ut\cos\theta$

Vertically, $y = utsin\theta - \frac{1}{2}gt^2$

$$\text{But } y = 0; t = \frac{2usin\theta}{g}$$

$$\therefore \text{Range} = \frac{2u^2sin\theta cos\theta}{g} = \frac{u^2sin2\theta}{g}$$

- (ii) Sketch a graph to show the relationship between kinetic energy and height above the ground in a projectile. (02marks)



32. (a)(i) What is meant by the following terms, steady flow and viscosity? (02marks)

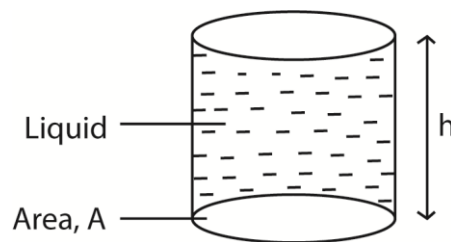
- Steady flow is the flow where the velocity of the liquid past any given point is constant.

- Viscosity is the friction between layers of a fluid.

(ii) Explain the effect of increase in temperature on viscosity of a liquid. (03marks)

- When temperature rises, the molecular separation of liquid molecules increases and the intermolecular forces decrease. The resistance to flow then decreases hence a decrease in viscosity.

(b) (i) Show that the pressure, P , exerted at a depth, h , below the free surface of a liquid of density, ρ , is given by $P = h\rho g$. (03marks)



Weight of a liquid above $A = mg$

But $= Ah\rho$

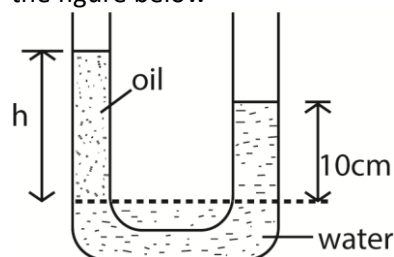
$$\Rightarrow \text{Weight} = \text{Force} = Ah\rho g$$

$$\text{Pressure} = \frac{F}{A} = \frac{Ah\rho g}{A} = h\rho g$$

(ii) Define relative density. (01mark)

Relative density is the ratio of the mass of any volume of a substance to the mass of an equal volume of water

(iii) A U-tube whose ends are open to atmosphere, contains water and oil as shown in the figure below



Given the density of oil is 800kgm^{-3} , find the value of h .

Pressure of oil and that of water at the dotted line are equal, if the density of oil $= \sigma$ and that of water $= \rho$, then

$$h\sigma g = 0.1\rho g$$

$$h = \frac{0.1\rho}{\sigma} = \frac{0.1 \times 100}{800} = 0.125\text{m} = 12.5\text{cm}$$

(c) A metal ball of diameter 10mm is timed as it falls through oil at a steady speed. It takes 0.5s to fall through a vertical distance of 0.3m. Assuming that the density of metal is 7500kgm^{-3} and that of oil is 900kgm^{-3} , find

(i) the weight of the ball (02marks)

Weight = volume x density of the ball x acceleration due to gravity

$$= \frac{4}{3}\pi r^3 \sigma g = \frac{4}{3}\pi (5 \times 10^{-3})^3 \times 7500 \times 9.81 = 3.85 \times 10^{-2} \text{N}$$

(ii) the up thrust on the ball (02marks)

Up thrust = volume of water displaced x density of water x acceleration due to gravity

$$= \frac{4}{3}\pi r^3 \rho g = \frac{4}{3}\pi (5 \times 10^{-3})^3 \times 1000 \times 9.81 = 4.62 \times 10^{-3} \text{N}$$

(iii) the coefficient of viscosity of the oil (03marks)

$$W = U + F$$

$$mg = U + 6\pi\eta r v_0$$

$$\text{But } v_0 = \frac{0.30}{0.6} = 0.6 \text{ms}^{-1}$$

$$\eta = \frac{mg - U}{6\pi r v_0} = \frac{3.85 \times 10^{-2} - 4.62 \times 10^{-3}}{6\pi \times (5 \times 10^{-3}) \times 0.6} = 0.6 \text{Pa (or } 0.6 \text{Nm}^{-2}\text{s)}$$

[Assume the viscous force = $6\pi\eta r v_0$ where η is the coefficient of viscosity, r is the radius of the ball, v_0 is the terminal velocity]

33. (a) Define the following terms

(i) Uniform acceleration (01mark)

Uniform acceleration is a constant rate of change of velocity

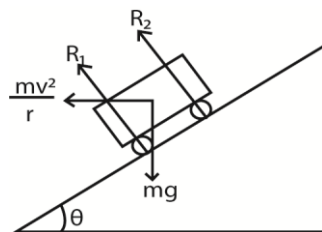
(ii) Angular velocity (01mark)

Angular velocity is the rate of change of angular displacement

(b) (i) What is meant by banking a track? (01mark)

Banking of roads is defined as the phenomenon in which the edges are raised for the curved roads above the inner edge to provide the necessary centripetal force to the vehicles so that they take a safe turn.

(ii) Derive an expression for the angle of banking θ for a car of mass, m , moving at speed, v , round a banked track of radius, r . (04marks)



$$\text{Resolving horizontally: } (R_1 + R_2)\sin\theta = \frac{mv^2}{r} \dots\dots\dots (i)$$

$$\text{Resolving vertically: } (R_1 + R_2)\cos\theta = mg \dots\dots\dots (ii)$$

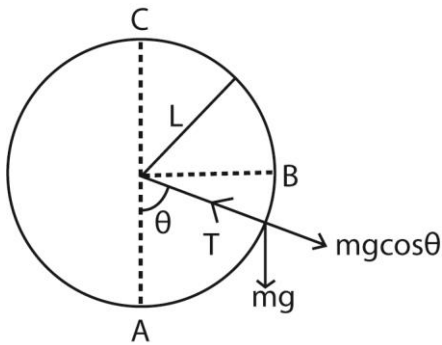
Eqn. (i) and Eqn. (ii);

$$\tan \theta = \frac{v^2}{rg}$$

$$\theta = \tan^{-1}\left(\frac{v^2}{rg}\right)$$

(c) A bob of mass, m is tied to an inelastic thread of length, L , and whirled with constant speed in a vertical circle

(i) With the aid of a sketch diagram, explain the variation of tension in the string along the circle. (05 marks)



At A, $\theta = 0$

$$\Rightarrow T = \frac{mv^2}{L} + mg$$

At B, $\theta = 90^\circ$

$$\Rightarrow T = \frac{mv^2}{L}$$

At C, $\theta = 180^\circ$

$$\Rightarrow T = \frac{mv^2}{L} - mg$$

(ii) If the string breaks at one point along the circle, state the most likely position and explain the subsequent motion of the bob.

The string breaks at the lowest point, A of the circle because tension the string is highest. Motion is tangential to the circle and when the string breaks, the bob follows a parabolic path.

(d) A body of mass 15kg is moved from earth's surface to a point 1.8×10^6 m above the earth. If the radius of the earth is 6.4×10^6 m and the mass of the earth is 6.0×10^{24} kg; calculate the work done in taking the body to that point (06marks)

$$\text{On earth, } P.E_1 = \frac{-GmM}{R_s}$$

$$\text{Above the earth } P.E_2 = \frac{-GmM}{r}, \quad r = ((6.4 + 1.8) \times 10^6) = 8.2 \times 10^6 \text{m}$$

$$\text{Work done} = GmM \left(\frac{1}{R_s} - \frac{1}{r} \right)$$

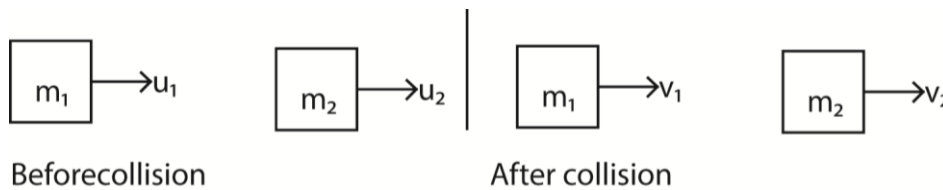
$$= 6.67 \times 10^{-11} \times 6.0 \times 10^{24} \times 15 \left(\frac{1}{6.4 \times 10^6} - \frac{1}{8.2 \times 10^6} \right)$$

$$= 2.06 \times 10^8 \text{ J}$$

34. (a) State Newton's laws of motion. (03marks)

- A body continues in its state of rest or uniform motion in a straight line unless acted upon by an external force
- The rate of change of momentum of a body is directly proportional to applied force and takes place in the direction of the force
- For every action, there is an equal and opposite reaction

(b) Use Newton's laws of motion to show that when two bodies collide their momentum is conserved. (04marks)



During collision, each body exerts a force of impact on each other according to Newton's second law of motion.

Let I be the impulse on A, then the impulse on B = -I.

$$I = M_1 v_1 - m_1 u_1 \dots\dots\dots (i)$$

$$-I = m_2 v_2 - m_2 u_2 \dots\dots\dots (ii)$$

Equation (i) + equation (ii)

$$0 = M_1 v_1 - m_1 u_1 + m_2 v_2 - m_2 u_2$$

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

(c) Two balls P and Q travelling in the same line in opposite directions with speeds of 6ms^{-1} and 15ms^{-1} respectively make a perfect collision. If the masses of P and Q are 8kg and 5kg respectively, find the

(i) final velocity of P, (04marks)

$$m_1 u_1 + m_2 u_2 = (m_1 + m_2) v$$

$$-8 \times 6 + 5 \times 15 = (8 + 5) v$$

$$v = -2.08\text{ms}^{-1} \text{ in the same direction as that of Q}$$

(ii) change in kinetic energy. (04marks)

Change in kinetic energy = initial K.E – Final K.E

$$= \left(\frac{1}{2} \times 8 \times 6^2 - \frac{1}{2} \times 5 \times 15^2 \right) - \frac{1}{2} \times 13 \times 2.08^2$$

$$= 678.38 \text{ J}$$

(d) (i) What is an impulse of a force? (01marks)

An impulse is a product of force and time of action of force

(ii) Explain why a long jumper should normally land on sand. (04marks)

By landing on sand, the time take to come to rest is increased and hence the rate of change of momentum is reduced. Therefore the force on the jumpers legs is reduced thus less pain in the legs.

35. (a) (i) What is meant by viscosity. (01mark)

Viscosity is the frictional force per unit area of a liquid where the velocity gradient is unity.

(ii) Explain the effect of temperature on viscosity of a liquid. (03marks)

Increase in temperature of a liquid increases the separation between the molecules and reduce the intermolecular attraction leading to a decrease in viscosity.

(b) Derive an expression for terminal velocity of a sphere of radius, a , falling in a liquid of viscosity, η . (04marks)

At terminal velocity, $mg = U + F_v$

$$\Rightarrow \frac{4}{3}\pi a^3 \sigma g = \frac{4}{3}\pi a^3 \rho g - 6\pi a \eta v_0$$

$$v_0 = \frac{2ga^2(\sigma - \rho)}{9\eta} \text{ where;}$$

σ = density of the sphere

ρ = density of the liquid

η = viscosity of the fluid

g = acceleration due to gravity

(c) Explain why velocity of a liquid at a wide part of a tube is less than that at a narrow part. (02marks)

Volume flow per second is constant, so by the equation of continuity $AV = \text{constant}$, the velocity is inversely proportional to cross section area.

(d) A solid weighs 237.5g in air and 12.5g when totally immersed in a fluid of density $9.0 \times 10^2 \text{ kg m}^{-3}$. Calculate the density of the liquid in which the sold would float with one fifth of its volume exposed above the liquid surface.

$$\text{Up thrust} = \frac{(237.5 - 12.5)}{1000} = 0.225 \text{ kg}$$

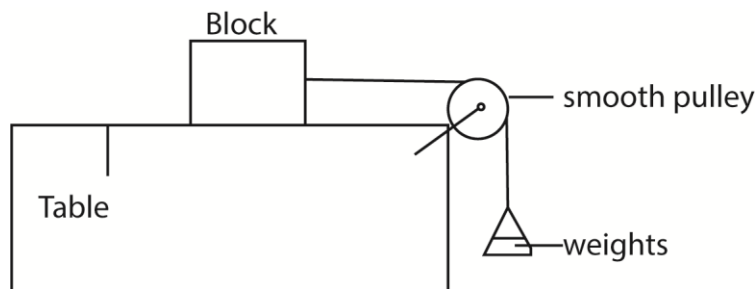
$$\text{Volume} = \frac{0.225}{900}$$

$$\text{Volume the liquid displaced} = \frac{4}{5} \times \frac{0.225}{900}$$

$$\text{The } \frac{4}{5} \times \frac{0.225}{900} \rho = 237.5$$

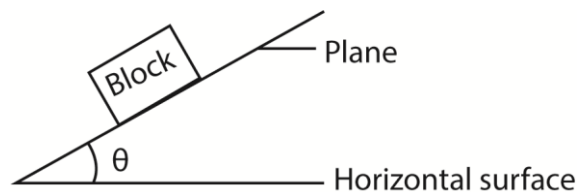
$$\rho = 1187.5 \text{ kg m}^{-3}$$

(e) Describe an experiment to measure the coefficient of static friction between a rectangular block of wood and a plane surface. (04marks)



- A block of mass m is placed on a flat table and connected to a scale pan as shown in the diagram above.
- Small weights are added in bits on to the scale pan until the block just starts to move. The total weight of the scale pan and weights added is obtained, W_f .
- The coefficient of static friction, $\mu = \frac{W_f}{mg}$

Alternative method



- A block is placed on horizontal plane. The plane is tilted gently until the block just start to slide
- The angle of tilt θ is measured
- The coefficient of static friction, $\mu = \tan\theta$

36. (a) (i) What is meant by simple harmonic motion? (01mark)

Simple harmonic motion is the periodic motion of a body whose acceleration is proportional to the displacement from a fixed point and directed towards the fixed point.

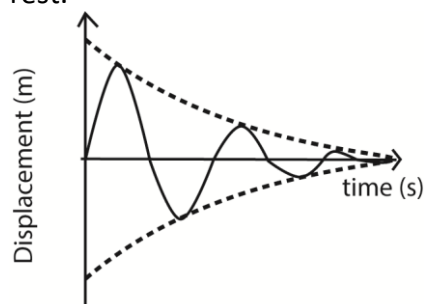
(ii) State two practical examples of simple harmonic motion. (01mark)

- Motion of pistons in an engine
- Motion of balance wheel of a pendulum clock

(iii) Using graphical illustrations, distinguish between under damped and critically damped oscillations (04marks)

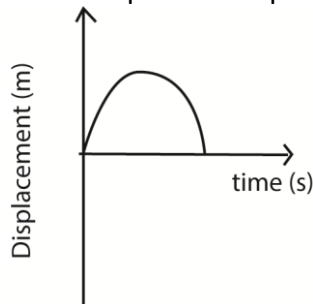
(i) **Under damped oscillation**

These are oscillations in which the system experiences low resistance/dissipative forces such that it loses energy gradually and amplitude of oscillations decrease gradually until the system finally comes to rest.

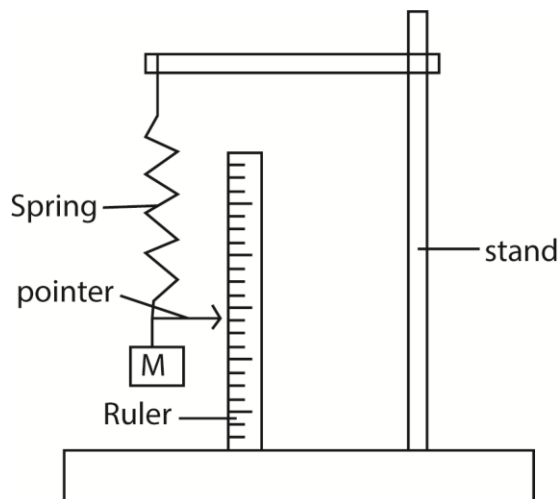


(ii) Critically damped

These are oscillation which occur when a system is displaced but does not oscillate and return to equilibrium position in the minimum possible time. The magnitude of resistive forces is such that they do not allow the system to vibrate past this equilibrium position.



(b) (i) Describe an experiment to measure acceleration due to gravity using a spiral spring (06marks)



- Clamp the spring on a retort stand
- Fix a horizontal pin at free end of the spring to act as a pointer.
- Place a vertical meter rule next the pointer and note the initial pointer position, P_1 .
- Suspend a known mass, M , to the free end of the spring, note and record the new position of the pointer, P_2 .
- Calculate extension, $e = P_2 - P_1$.
- Find the extensions for different masses
- Plot a graph of e against M
- Calculate the slope, S of the graph
- Calculate the acceleration due to gravity, $g = kS$ (k = force constant)

(ii) State two limitations to the accuracy of the value obtained in (b)(i).

- Upthrust
- Accurate reading of initial and final pointer position

(c) A horizontal spring of force constant 200Nm^{-1} fixed at one end has a mass of 2kg attached to the free end and resting on a smooth horizontal surface. The mass is pulled through a distance of 40.0cm and released.

Calculate the

(i) Angular speed

$$\text{From } T = 2\pi \sqrt{\frac{m}{K}}$$

$$T = 2\pi \sqrt{\frac{2}{200}} = 0.628\text{s}$$

$$\text{But } \omega = \frac{2\pi}{T} = \frac{2\pi}{0.628} = 10\text{rad s}^{-1}$$

- (ii) Maximum velocity attained by a vibrating body. (02marks)

$$v_{\max} = \omega A$$

$$= 10 \times 4 \times 10^{-2} = 0.4\text{ms}^{-1}$$

- (iii) Acceleration when the body is half way towards the centre from its initial position (02marks)

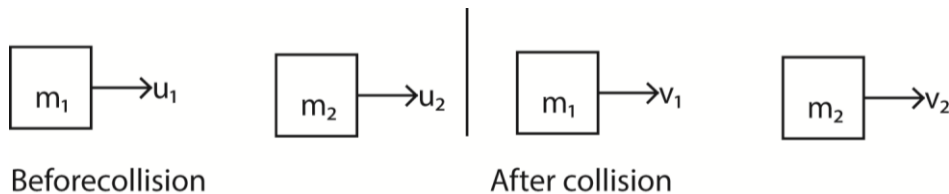
$$a = -\omega^2 x \quad \text{but } x = \frac{0.04}{2} = 0.02\text{m}$$

$$a = -10^2 \times 0.02 = 2\text{ms}^{-2}$$

37. (a) (i) State the law of conservation of linear momentum. (01mark)

The law of conservation of linear momentum states that for a system of interacting bodies, their total momentum remains constant provided there is no external force acting.

- (ii) Use Newton's law to derive the law in (a) (i) (04marks)



During collision, each body exerts a force of impact on each other according to Newton's second law of motion.

Let I be the impulse on A, then the impulse on B = $-I$.

$$I = M_1 v_1 - m_1 u_1 \dots\dots\dots (i)$$

$$-I = m_2 v_2 - m_2 u_2 \dots\dots\dots (ii)$$

Equation (i) + equation (ii)

$$0 = M_1 v_1 - m_1 u_1 + m_2 v_2 - m_2 u_2$$

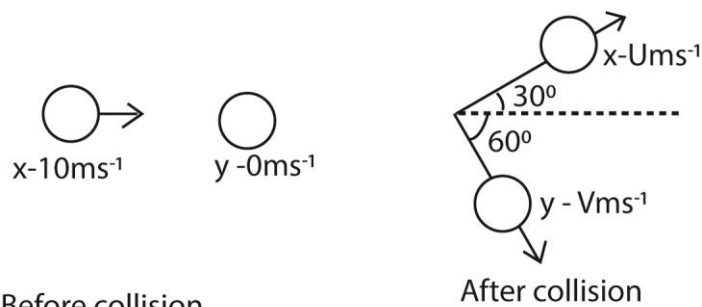
$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

- (b) Distinguish between elastic and inelastic collision (01mark)

- During an elastic collision, the interacting bodies separate after interaction and there is conservation of total kinetic energy.
- During inelastic collision, there is bouncing after interaction and there is loss of kinetic energy.

- (c) An object X of mass M , moving with a velocity of 10ms^{-1} collides with a stationary object Y of equal mass. After collision, X moves with a speed u at an angle 30° to the initial direction, while Y, moves with a speed V at angle 90° to the new direction of X.

- (i) Calculate the speeds U and V (05marks)



Applying the law of conservation of linear momentum in horizontal direction

$$m \times 10 = mU \cos 30^\circ + mV \cos 60^\circ$$

$$10 = U \frac{\sqrt{3}}{2} + \frac{V}{2} \dots\dots\dots (i)$$

Applying the law of conservation of linear momentum in vertical direction

$$m \times 0 = mU \sin 30^\circ - mV \sin 60^\circ$$

$$0 = \frac{U}{2} - V \frac{\sqrt{3}}{2}$$

$$U = V\sqrt{3} \dots\dots\dots (ii)$$

Eqn. (i) and Eqn. (ii)

$$U = 8.66 \text{ ms}^{-1}$$

$$V = 5 \text{ ms}^{-1}$$

(ii) Determine whether the collision is elastic or not. (03marks)

$$\text{Kinetic energy before} = \frac{1}{2} m \times 10^2 = 50 \text{ mJ}$$

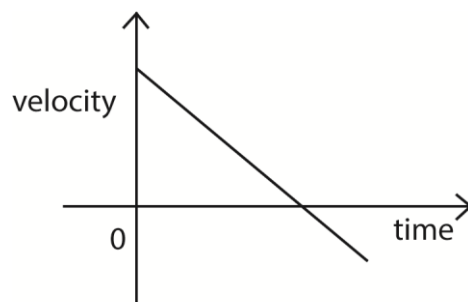
$$\text{Kinetic energy after collision} = \frac{1}{2} m \times 5^2 + \frac{1}{2} m \times 8.66^2 = 50 \text{ mJ}$$

Since kinetic energy is conserved, the collision is elastic.

(d) (i) Define uniform acceleration. (01mark)

Uniform acceleration is the a constant rat of change of velocity

(ii) With the aid of a velocity-time graph, describe the motion of a body projected vertically upwards. (03marks)



When a body is projected vertically upwards with velocity, V , it undergoes uniform retardation, g . At maximum height, the velocity becomes zero. It then accelerated uniformly downwards.

- (iii) Calculate the range of a projectile which is fired at an angle of 45° to the horizontal with a speed of 20ms^{-1} . (02marks)

$$R = \frac{u^2 \sin 2\theta}{g} = \frac{20^2 \times \sin 90}{9.81} = 40.77\text{m}$$

38. (a)(i) State Archimedes' principle. (01mark)

Archimedes' Principle state that when a body is wholly or partially immersed in a fluid, it experiences an up thrust equal to the weight of the fluid displaced.

- (ii) A solid weighs 20.0g in air, 15.0g in water and 16.0g in a liquid, R. Find the density of R (03marks)

Mass of displaced water = $20.0 - 15.0 = 5.0\text{g}$

Mass of liquid displaced = $20.0 - 16.0 = 4.0\text{g}$

Relative density of the liquid = $\frac{4}{5} = 0.8$

- (b) (i) What is meant by simple harmonic motion? (01 mark)

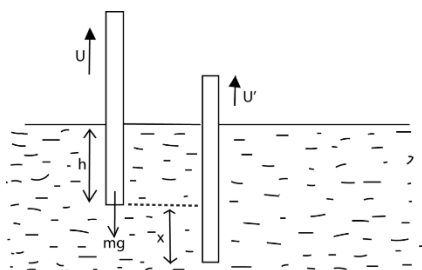
Simple harmonic motion is a periodic motion where the acceleration is always directed towards a fixed point and is proportional to the displacement from that point.

- (ii) Distinguish between damped and forced oscillations (02marks)

- Damped oscillation are oscillation in which the amplitude of oscillating system gradually decrease to zero due to the presence of dissipative forces like air resistance
- Forced oscillation are those whose continuity is maintained by periodic input of energy.

- (c) A cylinder of length, L , and cross section area A and density σ floats in a liquid of density, ρ . The cylinder is pushed down slightly and released.

- (i) show that it performs simple harmonic motion. (05marks)



At equilibrium position, the body sinks to a height, h , below the liquid surface

Up thrust = weight of the body

But $U = Ahpg$

$mg = AL\sigma g$ (i)

A is the cross section area of a cylinder

When a body is displaced through a distance, x , and released,

Up thrust = $(h + x) Apg$

Resultant force = $mg - (h + x) Apg$

But, $m = Ah\rho = AL\sigma$

$$h = \frac{L\sigma}{\rho}$$

$$Ahp_a = Ahp_g - Ahp_g - A\rho gx$$

$$a = \frac{-A\rho gx}{Ah\rho} = \frac{-gx}{h}$$

substituting for h

$$a = -\frac{\rho g}{\sigma L}x = -kx \text{ hence simple harmonic motion}$$

(ii) Derive the expression for period of the oscillation. (02marks)

$$\omega = \sqrt{\frac{\rho g}{\sigma L}} \text{ but } T = \frac{2\pi}{\omega}$$

$$T = 2\pi \sqrt{\frac{\sigma L}{\rho g}}$$

(d) A spring of force constant 40Nm^{-1} is suspended vertically. A mass of 0.1kg suspended from the spring is pulled down a distance of 5mm and released. Find the

(i) period of the oscillation (02marks)

$$\omega = \sqrt{\frac{k}{m}} \text{ but } T = \frac{2\pi}{\omega}$$

$$T = 2\pi \sqrt{\frac{m}{k}} = 2\pi \sqrt{\frac{0.1}{40}} = 0.314\text{s}$$

(ii) maximum acceleration of the mass (02marks)

$$\omega^2 = \frac{k}{m} = \frac{400}{0.1} = 400$$

$$a_{\max} = \omega^2 x = 400 \times 5 \times 10^{-3} = 2\text{ms}^{-2}$$

(iii) net force acting on the mass when it is 2mm below the centre of oscillation.

(02marks)

$$F = kx = 40 \times 2 \times 10^{-3} = 0.08\text{N}$$

39. (a) Define viscosity of a fluid (01mark)

Viscosity is the frictional force between layers of a liquid.

(b) (i) Derive an expression for terminal velocity attained by a sphere of density, σ , and radius, a , falling through a fluid of density, ρ and viscosity, η . (05marks)

At terminal velocity, $mg = U + F$

$$\Rightarrow \frac{4}{3}\pi a^3 \sigma g = \frac{4}{3}\pi a^3 \rho g - 6\pi a \eta v_0$$

$$v_0 = \frac{2ga^2(\sigma - \rho)}{9\eta} \text{ where;}$$

σ = density of the sphere

ρ = density of the liquid

η = viscosity of the fluid

g = acceleration due to gravity

v_0 = terminal velocity

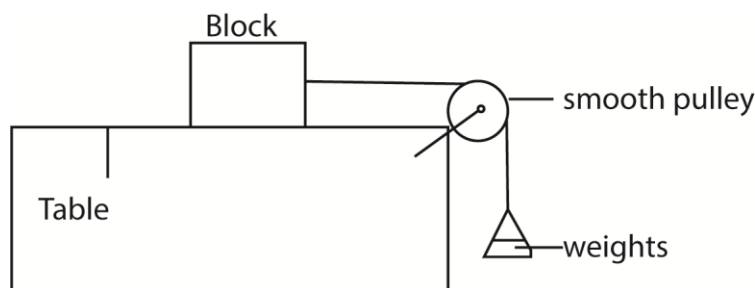
(ii) Explain the variation of viscosity of a liquid with temperature. (02marks)

As temperature increases, the separation of molecules increase and the intermolecular forces decrease leading to the decrease in viscosity.

(c) (i) State the laws of friction. (02marks)

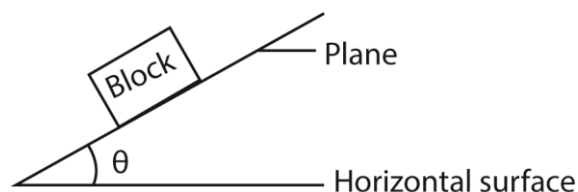
- The frictional force between two surfaces opposes their relative motion.
- The frictional force is independent of the area of contact of the given surfaces when the normal reaction is constant,
- The limiting frictional force is proportional to the normal reaction for the case of static friction. The frictional force is proportional to the normal reaction for the case of kinetic (dynamic) friction, and is independent of the relative velocity of the surfaces.

(ii) With the aid of a well labelled diagram, describe an experiment to determine the coefficient of kinetic friction between two surfaces. (05marks)



- A block of mass m is placed on a flat table and connected to a scale pan as shown in the diagram above.
- Small weights are added in bits on to the scale pan until the block just starts to move. The total weight of the scale pan and weights added is obtained, W_f .
- The coefficient of static friction, $\mu = \frac{W_f}{mg}$

Alternative method



- A block is placed on horizontal plane. The plane is tilted gently until the block just start to slide
- The angle of tilt θ is measured
- The coefficient of static friction, $\mu = \tan\theta$

(d) A body slides down a rough plane inclined at 30° to horizontal. If the coefficient of kinetic friction between the body and the plane is 0.4, find the velocity after it has travelled 6m along the plane. (05marks)

$$\text{From } ma = mg\sin\theta - \mu mg\cos\theta$$

$$a = 9.81\sin 30 - 0.4 \times 9.81 \times \cos 30 = 1.5\text{ms}^{-2}.$$

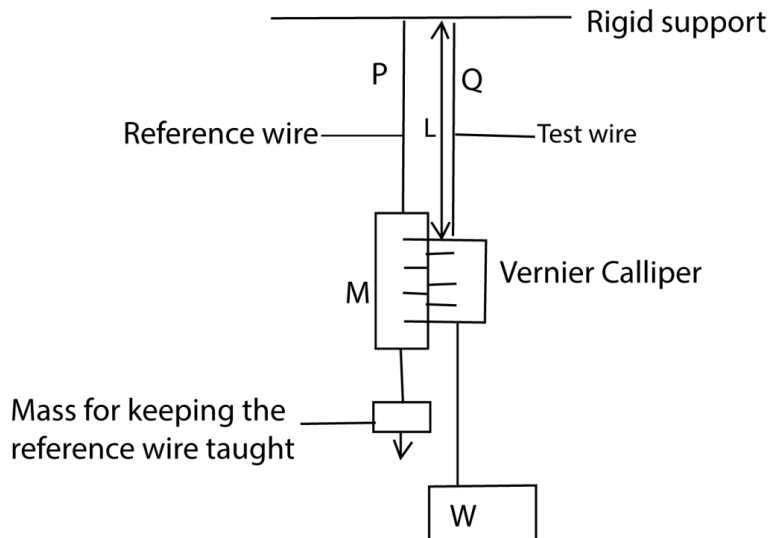
$$\text{From } v^2 = u^2 - 2as$$

$$v^2 = 0 + 2 \times 1.5 \times 6$$

$$v = 4.243\text{ms}^{-1}$$

40. (a) (i) Describe the terms tensile stress and tensile strain as applied to a stretched wire. (02marks)

- Tensile stress is the ratio of the stressing force applied on the wire to the cross sectional area of the wire.
 - Tensile strain is the ratio of extension in a wire to original length of the wire.
- (ii) Distinguish between elastic limit and proportional limit. (02marks)
- Elastic limit is the point beyond which a material does not regain its original length and shape when the load is removed.
 - Proportional limit is a point beyond which the extension of a material is not proportional to the applied force or load.
- (b) With the aid of a labelled diagram, describe an experiment to investigate the relationship between tensile stress and tensile strains of a steel wire. (07marks)



- Two thin, long wires of the same material and length P and Q are suspended from a rigid support.
 - P carries a scale M in mm and it's straightened by attaching a weight at its end.
 - Q carries a Vernier scale which is alongside scale M
 - Various loads are added to the test wire and corresponding extensions caused are read off from a vernier scale.
 - The diameter (2r) of the wire is obtained by a micrometre screw gauge, and the cross section area of the wire $A = 4\pi r^2$
 - The strain, $\frac{e}{l_0}$ and stress, $\frac{F}{A}$ are obtained
 - The procedure is repeated for different values of F and e
 - A graph of stress against strain is plotted. From the graph it is found that in the first part stress is proportional to strains up to a certain point beyond which it not proportional.
- (c)(i) A load of 60N is applied to a steel wire of length 2.5m and cross sectional area of 0.22mm^2 . If Young's Modulus for steel is 210GPa, find the expansion produced. (03marks)
- $$\Delta t = \frac{FL}{AE} = \frac{60 \times 2.5}{(0.22 \times 10^{-6} \times 210 \times 10^9)} = 3.25 \times 10^{-3}\text{m}$$
- (ii) If the temperature rise of 1K causes a fractional increase of 0.001%, find the change in length of a steel wire of length 2.5 when the temperature increases by 4K. (03marks)
- 1K causes an extension of $\frac{2.5 \times 0.001}{100}$

4K causes an extension of $\frac{2.5 \times 0.001}{100} \times \frac{4}{1} = 1 \times 10^{-4} \text{m}$

(d) The velocity, V , of a wave in a material of Young's Modulus, E and density, ρ , is given by

$$V = \sqrt{\frac{E}{\rho}}. \text{ Show that the relationship is dimensionally correct. (03marks)}$$

$$\text{LHS, } [V] = \text{LT}^{-1} \dots\dots\dots (i)$$

$$\text{Since } [E] = \text{ML}^{-1}\text{T}^{-2} \text{ and } [\rho] = \text{ML}^{-3}$$

$$\Rightarrow \text{RHS} = \left[\frac{\text{ML}^{-1}\text{T}^{-2}}{\text{ML}^{-3}} \right]^{\frac{1}{2}} = \text{LT}^{-1} \dots\dots\dots (ii)$$

From eqn. (i) and eqn. (ii) the relation is dimensionally consistent.

41. (a) (i) Define the term impulse (01mark)

Impulse is the product of force and time for which the force acts.

(ii) State Newton's laws of motion (03marks)

- A body continues in its state of rest or uniform motion in a straight line unless acted upon by an external force
- The rate of change of momentum of a body is directly proportional to applied force and takes place in the direction of the force
- For every action, there is an equal and opposite reaction

(b) A bullet of mass 10g travelling horizontally at a speed of 100ms^{-1} strikes a block of wood of mass 900g suspended by a light vertical string and is embedded in the block which subsequently swings freely. Find the

(i) vertical height through which the block rises. (04marks)

$$\text{From } mu = (m + M)v$$

$$10 \times 10^{-3} \times 100 = (10 \times 10^{-3} + 900 \times 10^{-3})v$$

$$v = 1.1\text{ms}^{-1}$$

$$\text{Using } v^2 = u^2 + 2as$$

$$0 = 1.1^2 - 2gh$$

$$h = 6.2 \times 10^{-2}\text{m}$$

(ii) Kinetic energy lost by the bullet (03marks)

$$\text{K.E lost} = \text{K.E before collision} - \text{K.E after collision}$$

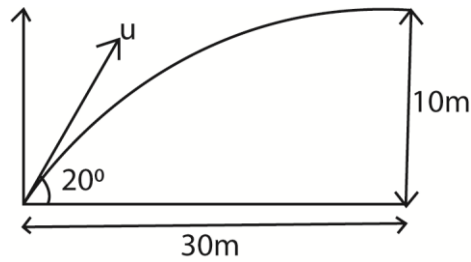
$$= \frac{1}{2} \times 10 \times 10^{-3} \times 100^2 - \frac{1}{2} \times 910 \times 10^{-3} \times 1.1^2 = 49.45\text{J}$$

(c) Explain the terms time of flight and range as applied to projectile motion. (02marks)

- Time of flight is the time taken by the projectile to move from the point of projection to the point where it lands on a plane through the point of projection.
- Range is the horizontal distance from the point of projection to the point where the projectile lands along the plane through the point of projection.

(d) A stone is projected at an angle of 20° in horizontal and just clears a wall which is 10m high and 30m from the point of projection. Find the

(i) speed of projection. (04marks)



$$\text{Using } y = x \tan \alpha + \frac{gx^2 \sec \alpha}{2u^2}$$

$$10 = 30 \tan 20^\circ - \frac{9.81 \times 30^2 \sec 20^\circ}{2u^2}$$

$$u = 71.5 \text{ ms}^{-1}$$

(ii) Angle which the stone makes with the horizontal as it clears the wall. (03marks)

$$u_x = 71.5 \cos 20 = 67.188 \text{ ms}^{-1}$$

$$u_y = 71.5 \sin 20 - 9.81 \times \frac{30}{71.5 \cos 20} = 20.07 \text{ ms}^{-1}$$

$$\tan \theta = \frac{20.07}{67.188}$$

$$\theta = 16.6^\circ$$

42. (a) Define the following terms

(i) Velocity

Velocity is the rate of change of displacement with time

(ii) Moment of a force

Moment of force is the product of the force and perpendicular distance from the point to the point of action of the force.

(b) (i) A ball is projected vertically up wards with a speed of 50 ms^{-2} . on return it passes a point of projection, and falls 78m below. Calculate the total time taken. (05marks)

$$\text{From } s = ut + \frac{1}{2}at^2$$

$$-78 = 50t - \frac{1}{2} \times 9.81 \times t^2; t = 11.57 \text{ s}$$

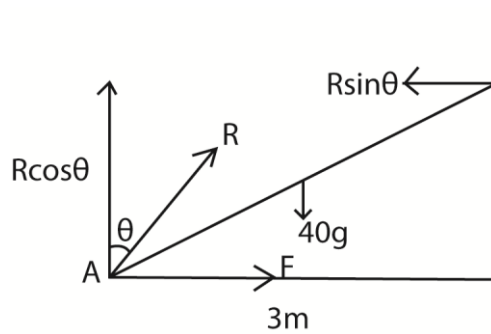
(ii) State energy changes that occurred during the motion of the ball in (b)(i) above. (03marks)

$$\text{K.E} \rightarrow \text{P.E} + \text{K.E} \rightarrow \text{P.E} \rightarrow \text{P.E} + \text{K.E} \rightarrow \text{K.E} \rightarrow \text{sound} + \text{heat}$$

(c) (i) State the conditions required for mechanical equilibrium to be attained. (02marks)

The algebraic sum of moments of all forces about a point is zero

(ii) A uniform ladder of mass 40kg length 5m, rests with its upper end against a smooth vertical wall and with its lower end at 3m from the wall on a rough ground. Find the magnitude and direction of the force exerted at the bottom of the ladder. (06marks)



$$R\cos\theta = 40g \dots\dots\dots (i)$$

Taking moments about A

$$4R\sin\theta = 40g \times \frac{3}{2}$$

$$R\sin\theta = 15g \dots\dots\dots (ii)$$

By squaring Eqn. (i) and Eqn. (ii) and adding them;

$$R^2\cos^2\theta + R^2\sin^2\theta = 1600g^2 + 225g^2$$

$$R = 42.72g = 42.72 \times 9.81 = 420\text{N}$$

$$\text{Eqn. (ii)} \div \text{Eqn. (i)}$$

$$\tan\theta = \frac{15g}{40g} = 0.375$$

$$\theta = 20.60$$

$\therefore$ the force at the bottom = 420N at an angle 20.6° to the vertical

(d) State four instances where increasing friction is useful. (02marks)

- Walking
- Sharpening of blades
- Lighting a match
- Braking of vehicles.

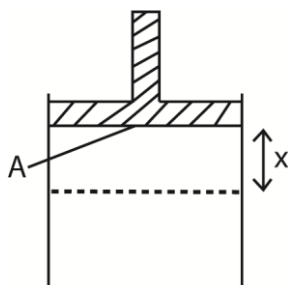
43. (a) What is meant by simple harmonic motion? (01mark)

Simple harmonic motion is a motion whose acceleration is directly proportional to the displacement from a fixed point and is directed towards the fixed point.

(b) A cylindrical vessel of cross-section area A , contains air of volume V , at pressure, P , trapped by frictionless air tight piston of mass, M . the piston is pushed down and released.

(i) If the piston oscillates with simple harmonic motion, show that its frequency, f , is given by

$$f = \frac{A}{2\pi} \sqrt{\frac{P}{MV}} \quad (06\text{marks})$$



$P = \frac{F}{A}$; $F = PA = mg$ where m = mass of the piston pushed through a small distance, dx .

Restoring force, $F_r = (P_2A - mg)$

$$\Rightarrow -(P_2A - mg) = ma$$

$$-(P_2A - PA) = ma \dots\dots\dots (i)$$

From Boyle's law

$$P_1V_1 = P_2V_2 = PV$$

$$\Rightarrow P_2(V - Ax) = PV$$

$$P_2 = \frac{PV}{V - Ax}$$

$$\therefore -PA \left(\frac{V}{V - Ax} - 1 \right) = -PA \left(\frac{Ax}{V - Ax} \right) = ma$$

$$\text{For small } x; ma = - \left(\frac{PA^2x}{V} \right) \Rightarrow a = - \left(\frac{PA^2}{mV} \right) x;$$

Compare with $a = -\omega^2x$ for S.H.M

$$\Rightarrow \omega^2 = \left(\frac{PA^2}{mV} \right) \Rightarrow \omega = \sqrt{\frac{PA^2}{mV}} = 2\pi f$$

$$\Rightarrow f = \frac{A}{2\pi} \sqrt{\frac{P}{mV}}$$

(ii) Show that the expression for f , in (b)(i) is dimensionally correct. (03marks)

$$[f] = \left[\frac{A}{2\pi} \sqrt{\frac{P}{mV}} \right]$$

$$[\text{L.H.S}] = T^{-1}$$

$$[\text{R.H.S}] = \sqrt{\frac{L^4 M L^{-1} T^{-2}}{M L^3}} = T^{-1}$$

$$[\text{L.H.S}] = [\text{R.H.S}]$$

Hence the equation is dimensionally correct

- (c) A particle executing simple harmonic motion vibrates in a straight line. Given that the speeds of the particle are 4ms^{-1} and 2ms^{-1} when the particle is 3cm and 6cm respectively from the equilibrium, calculate the

(i) amplitude of oscillation. (03marks)

$$\text{From } V^2 = \omega^2(a^2 - x^2)$$

$$16 = \omega^2(a^2 - (3 \times 10^{-2})^2) \dots\dots\dots (i)$$

$$4 = \omega^2(a^2 - (6 \times 10^{-2})^2) \dots\dots\dots (ii)$$

From equations (i) and (i)

$$a = 6.7\text{cm}$$

$$\omega = 66.67\text{rads}^{-1}$$

(ii) frequency of the particle. (03marks)

$$\text{From } \omega = 2\pi f$$

$$f = \frac{66.67}{2\pi} = 10.6\text{s}^{-1}$$

- (d) Give two examples of oscillatory motion which approximate to simple harmonic motion and state the assumption made in each case. (04marks)

- Swing of a suspended pendulum bod
- Vibration of a loaded spring

44. (a) (i) State Archimedes' Principle. (01mark)

Archimedes' Principle states that when an object is wholly or partially immersed in a fluid, it experiences an up thrust equal to the weight of the fluid displaced.

- (ii) Use Archimedes' Principle to derive an expression for resultant force on a body of weight, W, and density, σ , totally immersed in a fluid of density, ρ . (04marks)

Up thrust (U) = weight of fluid displaced

$$= mg$$

$$= V\rho g$$

$$\text{Resultant force } Fr = W - V\rho g \text{ but } V = \frac{W}{\sigma g}$$

$$\therefore Fr = W - \frac{W\rho g}{\sigma g} = W \left(1 - \frac{\rho}{\sigma}\right)$$

- (b) A tube of uniform cross sectional area of $4 \times 10^{-3}\text{m}^2$ and mass 0.2kg is separately floated vertically in water of density $1.0 \times 10^3\text{kgm}^{-3}$ and in oil of density $8.0 \times 10^2\text{kgm}^{-3}$. Calculate the difference in the lengths immersed (04marks)

$$m = PV = \rho AL$$

$$\text{For water, } L_w = \frac{m}{A\rho} = \frac{0.2}{1000 \times 4 \times 10^{-3}} = 0.05\text{m}$$

$$\text{For oil, } L_o = \frac{m}{A\rho} = \frac{0.2}{800 \times 4 \times 10^{-3}} = 0.0625\text{m}$$

Difference in length = $0.0625 - 0.05 = 0.0125\text{m}$

(c) (i) Define surface tension in terms of work (01mark)

Surface tension is the work done to increase the surface area of a liquid under isothermal conditions.

(ii) Use the molecular theory to account for surface tension of a liquid. (04marks)

- Liquid molecules attract each other.
- The molecules within the body of the liquid (bulk) molecules is attracted equally by neighbors in all direction, hence, the force on the bulk molecules is zero,
- For a surface molecules, there is a net inward force because there are no molecules above the surface to attract them equally.
- To the surface, work must be done against the inward attractive force, hence, a molecule in the surface of a liquid has a greater potential energy than a molecule in the bulk. The potential energy stored in molecules at the surface is called free surface energy or surface tension.
- Due to the attractive forces experienced by surface molecules due to their neighbours put in a state of tension; the liquid surface behave as a stretched skin.

(iii) Explain the effect of increasing temperature of a liquid on its surface tension. (04marks)

When a liquid is heated, the average kinetic energy of its molecules increase. So the intermolecular of attraction decrease because molecules spend less time in the neighbourhood of a given molecule. At the same time, more molecule enter the liquid surface which lowers the potential energy of the surface thereby lowering the surface tension.

(iv) Calculate the excess pressure inside a soap bubble of diameter 3.0cm if the surface tension of the soap solution is $2.5 \times 10^{-2}\text{Nm}^{-1}$. (02marks)

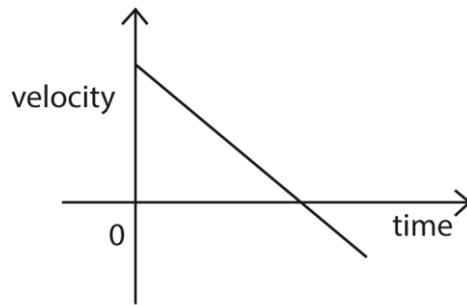
$$\text{Excess pressure} = \frac{4\gamma}{r} = \frac{4 \times 2.5 \times 10^{-2}}{1.5 \times 10^{-2}} = 6.67\text{Pa}$$

45. (a) (i) Define the term velocity and displacement. (02marks)

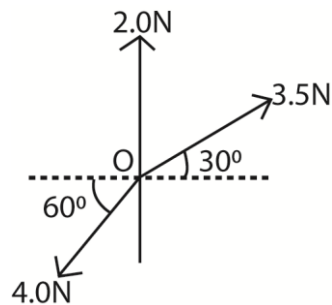
Velocity is the rate of change of displacement

Displacement is the distance moved in specified direction

(ii) Sketch velocity against time for an object thrown vertically upwards. (02marks)



(b)



Three forces of 3.5N, 4.0N and 2.0N, act at O as shown in the figure above. Find the resultant force. (04marks)

Suppose the components of the resultant force of the x and y direction are X and Y respectively;

$$F_x = 3.5 \cos 30^\circ - 4 \cos 60^\circ = 1.031 \text{ N}$$

$$F_y = 2.0 + 3.5 \sin 30^\circ - 4.0 \sin 60^\circ = 0.286 \text{ N}$$

$$F = \sqrt{F_x^2 + F_y^2} = \sqrt{1.031^2 + 0.286^2} = 1.07 \text{ N}$$

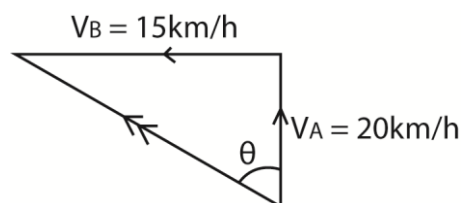
$$\theta = \tan^{-1} \left(\frac{0.286}{1.031} \right) = 15.5^\circ$$

the resultant force is 1.07N making 15.5° with the horizontal.

(c) (i) What is meant by saying that a body is moving with velocity relative to another? (01marks)

If a body is moving with a velocity, v , relative to another means that it has velocity, v , as seen by an observer from another body.

(ii) A ship, A is travelling due north at 20 km h^{-1} and ship B is travelling due east at 15 km h^{-1} . Find the velocity of A relative to B. (03marks)

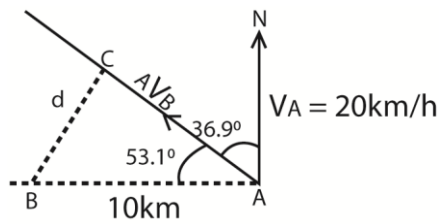


$${}_A V_B = \sqrt{20^2 + 15^2} = 25 \text{ km/h}$$

$$\theta = \tan^{-1} \left(\frac{15}{20} \right) = 36.9^\circ$$

the relative velocity of A relative to B = 25km/h in the direction $\text{N}36.9^\circ\text{W}$

- (iii) If the ship B in (c)(ii) is 10km due west of A at noon. Find the shortest distance apart and when it occurs. (05marks)



d is the shortest distance of approach

$$d = 10 \sin 53.1^\circ = 8 \text{ km}$$

$$\text{Time taken} = \frac{\text{distance along the relative path}}{\text{relative velocity}} = \frac{10 \cos 53.1^\circ}{25} = 0.24 \text{ hours.}$$

- (d) (i) What is meant by a couple in mechanics? (01mark)

A couple is a pair of equal parallel and opposite forces whose line of action do not coincide.

- (ii) State the conditions for equilibrium of a system of coplanar forces

The vector sum of all forces must be zero i.e. in translational equilibrium

Or

The algebraic sum of all the moments of the forces about any point is zero, i.e. there is no rotation equilibrium.

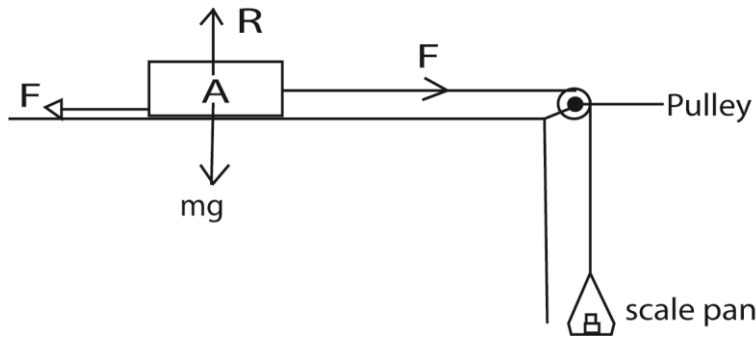
46. (a) (i) State the laws of friction between solid surfaces (03marks)

- The frictional force between two surfaces opposes their relative motion.
- The frictional force is independent of the area of contact of the given surfaces when the normal reaction is constant,
- The limiting frictional force is proportional to the normal reaction for the case of static friction. The frictional force is proportional to the normal reaction for the case of kinetic (dynamic) friction, and is independent of the relative velocity of the surfaces.

- (ii) Explain the origin of friction force between two solid surfaces in contact. (03marks)

- For any two solid surfaces in contact, there are small humps and hollows that form contact points.
- Therefore, the actual area of contact is indeed small which creates very high pressure at the points of contact.
- This pushes the molecules very close that the forces of attraction between them welds the surfaces at these points.
- Thus, a force that opposes motion in any direction is created.

- (iii) Describe an experiment to measure the coefficient of kinetic friction between two solid surfaces. (03marks)



- A block of mass m is placed on a flat table and connected to a scale pan as shown in the diagram above.
- Weights are added to the scale-pan, and each time A is given a slight push.
- At one stage A continues to move with a constant velocity.
- The coefficient of kinetic friction, $\mu = \frac{W_f}{mg}$; where W_f = weight of the scale pan plus added weights.

- (b) (i) A car of mass 1000kg moves along a straight surface with speed of 20ms^{-1} . When brakes are applied steadily, the car comes to rest after travelling 50m. Calculate the coefficient of friction between the surface and the tyre. (04marks)

Initial kinetic energy of the car = work done against friction

$$\frac{1}{2}mu^2 = F \times s$$

$$\frac{1}{2} \times 1000 \times 20^2 = F \times 50$$

$$F = 4000\text{N}$$

$$\text{But } F = \mu R = \mu mg$$

$$\Rightarrow 4000 = \mu \times 1000 \times 9.81$$

$$\mu = 0.408$$

- (ii) State the energy changes which occur from the time brakes are applied to the time the car comes to rest. (02marks)

Kinetic energy $\rightarrow$ heat and sound

- (c) (i) State two disadvantages of friction (01mark)

- Wears machines
- Wears shoes
- Causes unnecessary noise in moving parts of a machines.
- Produces unnecessary heat

- (ii) Give one method of reducing friction between solid surfaces. (01mark)

- By lubrication
- Using ball bearings or rollers
- Making surfaces smooth

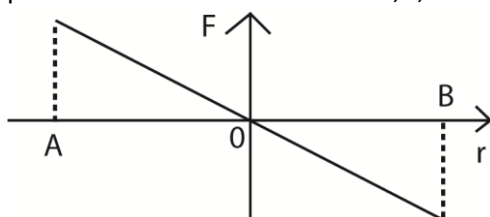
- (d) Explain what happens when a small steel ball is dropped centrally in a tall jar containing oil. (03marks)

- It experiences a drag force, F and an up thrust, U , upwards and weight, W , downwards.
- Initially, $W > F + U$, so the ball accelerates downwards.
- As velocity increases, F increases until a time when $W = F + U$, and consequently ball moves with a constant terminal velocity.

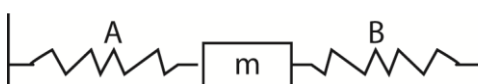
47. (a) (i) Define simple harmonic motion. (01mark)

It is periodic motion in which the acceleration of the body along the path of the body is directed towards a fixed point in the line of motion and is proportional to the displacement of the body from a fixed point

(ii) A particle of mass m executes simple harmonic motion between two points A and B about equilibrium position O. sketch a graph of the restoring force acting on the particle as a function of distance, r , moved by the particle. (02marks)



(b)



Two springs A and B of spring constant K_A and K_B respectively are connected to mass m as shown in the figure above. The surface on which the mass slides is frictionless.

(i) Show that when the mass is displaced slightly, it oscillates with simple harmonic

motion of frequency, f given by $f = \frac{1}{2\pi} \sqrt{\frac{K_A + K_B}{m}}$ (04marks)

If the body is displaced through a small displacement, x towards B;

$$\Rightarrow \text{Resultant force } F = (K_A + K_B)x$$

$$\text{From } F = ma$$

$$ma = -(K_A + K_B)x$$

$$a = -\left(\frac{K_A + K_B}{m}\right)x$$

This is of the form $a = -\omega^2 x$ where $\omega = \sqrt{\left(\frac{K_A + K_B}{m}\right)}$, hence simple harmonic motion.

(ii) If the two springs in the figure above are identical such that $K_A = K_B = 5.0 \text{ Nm}^{-1}$ and mass $m = 50 \text{ g}$, calculate the period of oscillation (03marks)

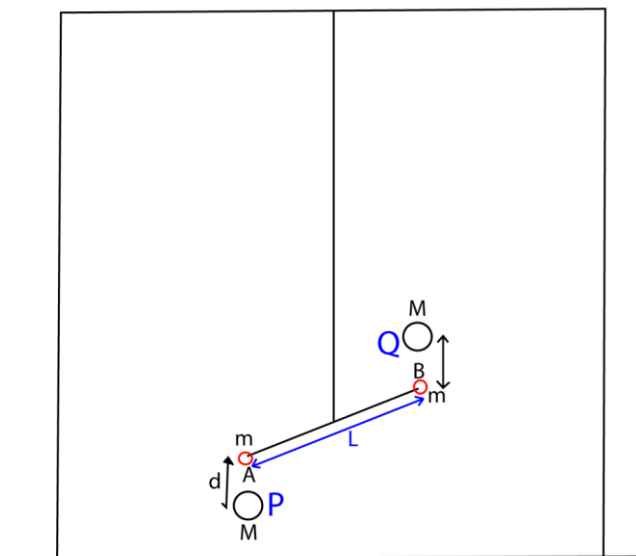
$$\omega = 2\pi f = \sqrt{\left(\frac{K_A + K_B}{m}\right)}$$

$$f = \frac{1}{2\pi} \sqrt{\left(\frac{K_A + K_B}{m}\right)}$$

$$T = \frac{1}{f} = 2\pi \sqrt{\frac{m}{K_A + K_B}} = 2\pi \sqrt{\frac{50 \times 10^{-3}}{5.0 + 5.0}} = 0.44s$$

- (c) (i) With the aid of a diagram, describe an experiment to determine the universal gravitational constant, G. (06marks)

Determining gravitational constant



- Two equal lead spheres A and B each of mass, m, are attached to end of a bar AB of length, L.
- The bar AB is suspended from a ceiling.
- Large spheres P and Q are brought towards A and B respectively from the opposite side
- Large spheres P and Q altered small spheres A and B respectively by equal and opposite gravitational forces give rise to gravitational torque, F, which in turn twist the suspended through angle θ .
- A resting torque of the wire opposes the twisting of the wire from equilibrium position

Then

$$F = C\theta = \frac{GMm}{d^2}$$

$$G = \frac{C\theta d^2}{MmL}$$

Where

d = distance between the centre of A and P or B and Q.

C = the twisting couple per unit twist ($\theta = 1$)

- (ii) If the moon moves round the earth in a circular orbit of radius = 4.0×10^8m and takes exactly 27.3 days to go round once, calculate the value of acceleration due to gravity, g, at the earth's surface. (04marks)

$$\frac{GmM}{R^2} = m\omega^2 R; \text{ But } GM = gr_s^2$$

$$\Rightarrow \frac{gr_s^2}{R^2} = \omega^2 R$$

$$g = \frac{\omega^2 R^3}{r_s^2}$$

$$\omega = \frac{2\pi}{T}$$

$$g = \frac{4\pi^2 R^3}{T^2 r_s^2} = \frac{4\pi^2 (4.0 \times 10^8)^3}{(27.3 \times 24 \times 60 \times 60)^2 (6.4 \times 10^6)^2} = 11.09 \text{ ms}^{-2}$$

48. (a) State

(i) Newton's laws of motion (03marks)

- A body continues in its state of rest or uniform motion in a straight line unless acted upon by an external force
- The rate of change of momentum of a body is directly proportional to applied force and takes place in the direction of the force
- For every action, there is an equal and opposite reaction

(ii) The principle of conservation of momentum (01mark)

When a body is in mechanical equilibrium, the sum of clockwise moments about any point is equal to the sum of anticlockwise moments about the same point

(b) A bod A of mass m_1 moves with velocity u_1 and collides head on elastically with another body B of mass m_2 which is at rest. If the velocities of A and B are v_1 and v_2 respectively and given that $X = \frac{m_1}{m_2}$, show that

(i) $\frac{u_1}{v_1} = \frac{X+1}{X-1}$ (04marks)

From principle of conservation of momentum

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2 \text{ but } u_2 = 0$$

$$\Rightarrow m_1 u_1 = m_1 v_1 + m_2 v_2$$

$$v_2 = \frac{m_1 u_1 - m_1 v_1}{m_2} = X u_1 - X v_1 = X(u_1 - v_1) \dots\dots\dots (i)$$

For an elastic collision, total kinetic energy is conserved.

$$\text{Hence: } \frac{1}{2} m_1 u_1^2 = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2$$

$$m_1 u_1^2 = m_1 v_1^2 + m_2 v_2^2 \dots\dots\dots (ii)$$

Substituting Eqn. (i) in eqn (ii)

$$m_1 u_1^2 = m_1 v_1^2 + m_2 (X(u_1 - v_1))^2$$

Divide both sides by m_2

$$X u_1^2 = X v_1^2 + (X(u_1 - v_1))^2$$

$$\Rightarrow X(u_1^2 - v_1^2) = X^2 (u_1 - v_1)^2$$

$$(u_1 + v_1)(u_1 - v_1) = X(u_1 - v_1)^2$$

$$(u_1 + v_1) = X(u_1 - v_1)$$

Collecting like terms

$$v_1(X+1) = u_1(X-1)$$

$$\frac{u_1}{v_1} = \frac{X+1}{X-1}$$

(ii) $\frac{v_2}{v_1} = \frac{2X}{X-1}$ (03marks)

From $\frac{u_1}{v_1} = \frac{X+1}{X-1}$

$$u_1 = v_1 \left(\frac{X+1}{X-1} \right)$$

Substituting for u_1 in Eqn. (b)(i)

$$v_2 = X \left(v_1 \left(\frac{X+1}{X-1} \right) - v_1 \right)$$

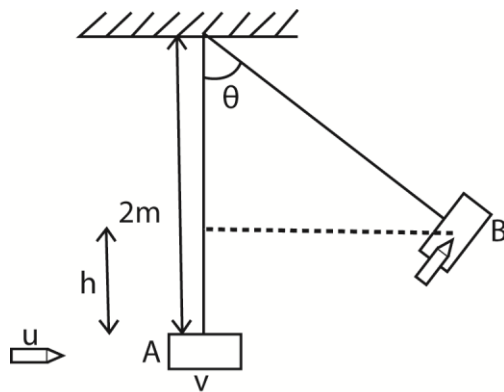
$$\begin{aligned} \frac{v_2}{v_1} &= X \left(\left(\frac{X+1}{X-1} \right) - 1 \right) = X \left(\frac{X+1-X-1}{X-1} \right) \\ &= \frac{2X}{X-1} \end{aligned}$$

(c) Distinguish between conservative and non-conservative forces. (02marks)

For conservative forces, the work done by the force through a closed path is zero whereas for non-conservative forces, the work done through a closed path is not zero

(d) A bullet of mass 40g is fired from a gun at 200ms^{-1} and hit a block of wood of mass 2kg which is suspended by a light vertical string 2m long. If the bullet gets embedded in the wooden block.

(i) Calculate the maximum angle the string makes with the vertical. (06marks)



From principle of conservation of linear momentum

$$m_1 u = (m_1 + m_2) v$$

$$(40 \times 10^{-3}) \times 200 = [2 + (40 \times 10^{-3})] v$$

$$v = 3.92\text{ms}^{-1}$$

If the block after collision moves to height h to B, from the principle of conservation of mechanical energy

K.E at A = Potential energy at B

$$\frac{1}{2} m v^2 = m g h$$

$$\therefore h = \frac{v^2}{2g} = \frac{3.92^2}{2 \times 9.81} = 0.78\text{m}$$

$$\cos \theta = \frac{2-h}{2} = 0.61$$

$$\theta = 52.4^\circ$$

(ii) State a factor on which the angle of swing depends. (01mark)

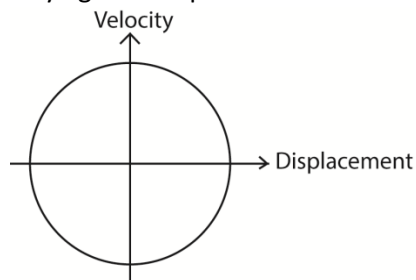
- Speed of the bullet
- Length of the string
- Mass of the block

49. (a) Define simple harmonic motion (SHM). (01mark)

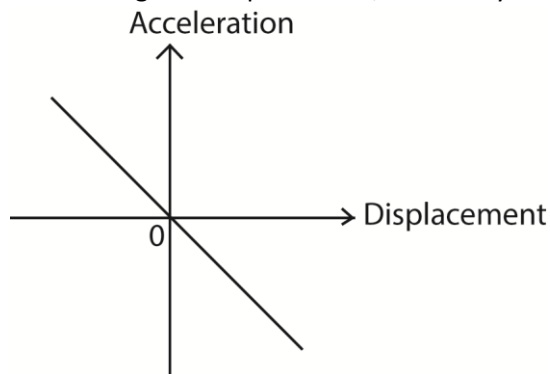
It is periodic motion in which the acceleration of the body along the path of the body is directed towards a fixed point in the line of motion and is proportional to the displacement of the body from a fixed point

(b) Sketch a graph of:

(i) velocity against displacement for a body executing SHM. (03marks)

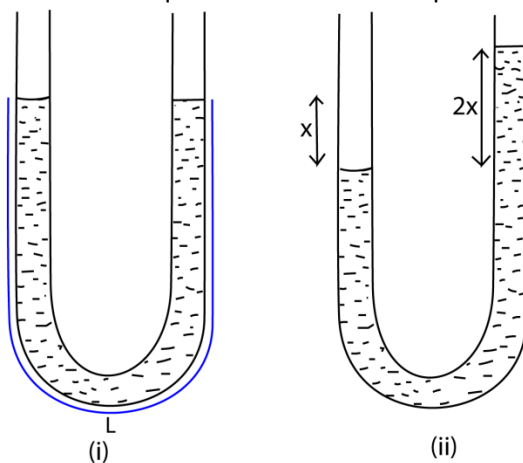


(ii) Acceleration against displacement, for a body executing SHM



(c) A glass U-tube containing a liquid is tilted slightly and then released.

(i) Show that the liquid oscillates with simple harmonic motion. (04mark)



A liquid of density ρ contained in a U-tube of cross section area A and column L , if the liquid is displaced slightly through a distance x from equilibrium position

The restoring force of the liquid = $2xA\rho g$

Using Newton's 2nd law,

$$ma = -2xA\rho g$$

$$a = -\frac{2xA\rho g}{m} \text{ but, } m = AL\rho$$

$$a = -\frac{2xg}{L}$$

$$\text{But } a = -\omega^2 x$$

$$\omega = \sqrt{\frac{2g}{L}}$$

$$T = \frac{2\pi}{\omega}$$

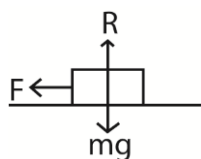
$$T = 2\pi \sqrt{\frac{L}{2g}}$$

$$\text{Frequency, } f = \frac{1}{T} = \frac{1}{2\pi} \sqrt{\frac{2g}{L}}$$

(ii) Explain why the oscillations ultimately come to rest. (03marks)

Resistive forces lead to loss of energy, causing a gradual decrease in amplitude and eventually oscillation die out

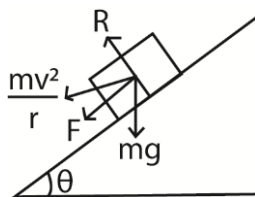
(d) Explain why maximum speed of a car on a banked road is higher than on an unbanked road. (04marks)



Along a circular path on a horizontal road, the frictional force provides the centripetal force

$$\text{i.e. centripetal force} = \frac{mv_1^2}{r} = \mu R$$

On a banked road, the centripetal force is provided by the component of normal reaction, R , and the component of friction



$$\text{Centripetal force} = \frac{mv_2^2}{r} = F\cos\theta + R\sin\theta$$

$$\text{But } F = \mu R$$

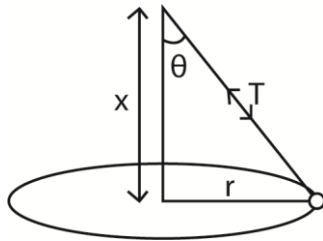
$$\text{Centripetal force} = \frac{mv_2^2}{r} = \mu R\cos\theta + R\sin\theta$$

$$\text{For } 0^\circ < \theta < 90^\circ, \mu\cos\theta + \sin\theta > \mu$$

$$\text{Therefore, } v_2 > v_1$$

(e) A small bob of mass 0.2kg is suspended by an inextensible string of length 0.8m. The bob is then rotated in a horizontal circle of radius 0.4m. Find

(i) linear speed of the bob (03marks)



$$x^2 = 0.8^2 - 0.4^2$$

$$x = 0.692\text{m}$$

$$T \sin \theta = \frac{mv^2}{r} \dots\dots\dots (i)$$

$$T \cos \theta = mg$$

Eqn. (i) and Eqn (ii)

$$\tan \theta = \frac{v^2}{rg}$$

$$v^2 = rg \tan \theta$$

$$v = \sqrt{0.4 \times 9.81 \times \frac{0.4}{0.692}} = 1.51\text{ms}^{-1}$$

(ii) tension in the string. (02marks)

$$T = \frac{mg}{\cos \theta} = 0.2 \times 9.81 \times \frac{0.8}{0.692} = 2.29\text{N}$$

50. (a) State Kepler's laws of planetary motion. (03marks)

- Planets describe ellipses about the sun as one focus
- The imaginary line joining the sun and planet sweeps out equal areas in equal time intervals
- The square of the periodic time of revolution of planets about the sun are proportional to the cubes of their mean distance from the sun

(b) (i) A satellite moves in a circular orbit of radius, R, about a planet of mass, M, with period

T. Show that $R^3 = \frac{GMT^2}{4\pi^2}$, where G is the universal gravitational constant. (04marks)

Force of attraction, $F = \frac{GMm}{R^2}$ where m is the mass of the satellite.

Centripetal force = $m\omega^2 R$ where $\omega = \frac{2\pi}{T}$

$$\Rightarrow \frac{GMm}{R^2} = m \left(\frac{2\pi}{T} \right)^2 R$$

$$R^3 = \frac{GMT^2}{4\pi^2}$$

(ii) The period of the moon around the earth is 27.3 days. If the distance of the moon from the Earth is $3.83 \times 10^5\text{km}$, calculate the acceleration due to gravity at the surface of the Earth. (04marks)

$$\frac{GM}{R^3} = \frac{4\pi^2}{T^2}$$

Near the earth's surface, $\frac{GMm}{r_e^2} = mg$

$$\Rightarrow GM = gr_e^2 = \frac{4\pi^2 R^3}{T^2}$$

$$g = \frac{4\pi^2 R^3}{T^2 r_e^2} = \frac{4\pi^2 (3.83 \times 10^8)^3}{(27.3 \times 24 \times 60 \times 60)^2 (6.4 \times 10^6)^2} = 9.73\text{ms}^{-2}$$

- (iii) Explain why any resistance to forward motion of an artificial satellite results into an increase in its speed. (04marks)

If the satellite encountered a resistance in orbit;

Total energy = M.E = $\frac{-GM_em_s}{2R}$ decreases. Its orbit radius R decreases to R'

$$\text{K.E} = \frac{1}{2} m_s v^2 = \frac{-GM_em_s}{2R'}$$

This means that the final kinetic energy and velocity increases.

- (c) (i) What is meant by weightlessness? (02marks)

Weightlessness is a condition of zero reaction, the body has the same acceleration as the acceleration due to gravity.

- (ii) Why does acceleration due to gravity vary with location on the surface of the earth? (03marks)

The earth is elliptical with equatorial radius bigger than the polar radius. At the equator, the body is less attracted towards the earth than at the pole. Therefore gravity at the equator is less than the gravity at the poles. The earth rotates about the polar axis. A body at the pole is practically stationary while the body towards the equator experiences a centripetal force.

$$M\omega^2 R = mg - mg'$$

$$\therefore g' = g - \omega^2 R$$

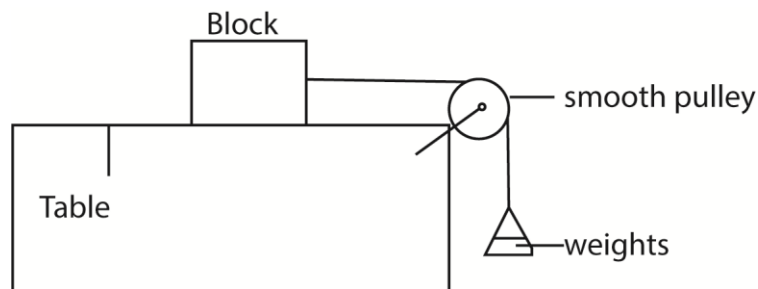
51. (a) (i) State the laws of solid friction. (03marks)

- The frictional force between two surfaces opposes their relative motion.
- The frictional force is independent of the area of contact of the given surfaces when the normal reaction is constant,
- The limiting frictional force is proportional to the normal reaction for the case of static friction. The frictional force is proportional to the normal reaction for the case of kinetic (dynamic) friction, and is independent of the relative velocity of the surfaces.

- (ii) Using molecular theory, explain the laws stated in (a)(i) (03marks)

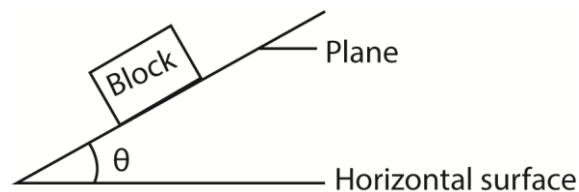
- Actual area of contact between solid surfaces is very small. Therefore pressure at points of contact is very high; projections emerge to produce adhesion or welding. The force which oppose motion is obtained (Law I)
- The actual area of contact is the sum of the areas of tiny projections that adhere to each other and are nearly independent of the surface areas of contact. (law II)
-
- Increase in weight increases the actual area of contact and hence greater limiting frictional force.

- (b) Describe an experiment to determine the coefficient of static friction for an interface between a rectangular block of wood and plane surface. (04marks)



- A block of mass m is placed on a flat table and connected to a scale pan as shown in the diagram above.
- Small weights are added in bits on to the scale pan until the block just starts to move. The total weight of the scale pan and weights added is obtained, W_f .
- The coefficient of static friction, $\mu = \frac{W_f}{mg}$

Alternative method



- A block is placed on horizontal plane. The plane is tilted gently until the block just start to slide
- The angle of tilt θ is measured
- The coefficient of static friction, $\mu = \tan\theta$

(c) (i) State the difference between conservative and non-conservative forces, give one example each. (03marks)

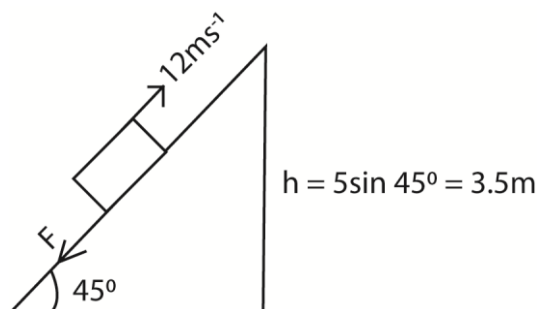
For conservative forces, the work done by force in a closed loop is zero e.g. gravitational force, magnetic force and electrostatic force

For non-conservative forces, work done by force in a closed loop is not zero. E.g. frictional force.

(ii) State the work-energy theorem. (01mark)

Work done by the resultant force on the body is equal in kinetic energy of the body

(iii) A block of mass 6.0kg is projected with a velocity of 12ms^{-1} up a rough plane inclined at 45° to horizontal. If it travels 5.0m up the plane, find the friction force. (04marks)



Initial kinetic energy = work done against resistance force.

$$\therefore \frac{1}{2}mv^2 = mgsin 45^\circ + F \times s$$

$$\frac{1}{2} \times 6 \times 12^2 = 6 \times 9.81 \times \sin 45^\circ + F \times 5$$

$$F = 44.8\text{N}$$

(d) Explain the effect of temperature on the viscosity of a liquid.

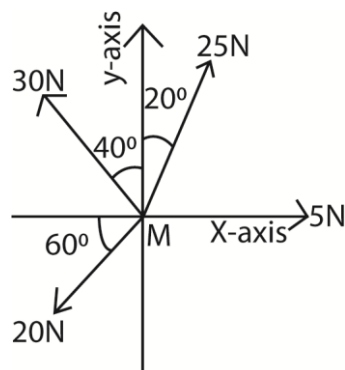
An increase in temperature of a liquid leads to an increase in molecular separation which weakens the intermolecular forces of attraction thereby reducing viscosity.

52. (a) (i) Define vector and scalar quantities and give one example of each. (03marks)

A vector quantity has both magnitude and direction e.g. velocity, displacement, force, acceleration due to gravity

A scalar quantity has only magnitude e.g. mass, volume, speed

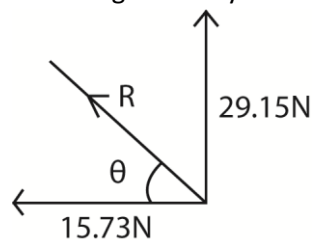
(ii)



A body, M, of mass 6kg is acted on by forces of 5N, 20N, 25N and 30N as shown in the figure above. Find the acceleration of M (05marks)

Resolving horizontally: $5 + 25\cos 70^\circ - 30\cos 50^\circ - 20\cos 60^\circ = -15.73\text{N}$

Resolving vertically: $30\sin 50^\circ + 25\sin 70^\circ - 20\sin 60^\circ = 29.15\text{N}$



$$R = \sqrt{29.15^2 + 15.73^2} = 33.12\text{N}$$

$$\theta = \tan^{-1} \left(\frac{29.15}{15.73} \right) = 61.7^\circ$$

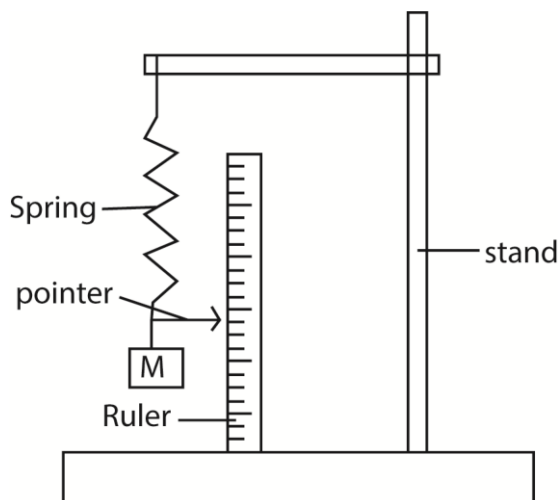
From $F = ma$

$$a = \frac{33.12}{6} = 5.52\text{ms}^{-1}$$

(b) (i) What is meant by acceleration due to gravity? (01mark)

Acceleration due to gravity is the force of attraction due to gravity exerted on 1kg mass. Or is the rate of change of velocity of a body moving freely under gravity.

- (ii) Describe how you would use a spiral spring, a retort stand with a clamp, a pointer, seven 50g masses, a meter rule and a stop clock to determine the acceleration due to gravity. (06marks)



- Suspend a spiral spring from the clamp of a retort stand.
- Attach the pointer to the free end of the spring such that it is horizontal.
- Read and record the initial pointer position on a meter rule supported vertically.
- Suspend a 50g mass from the spring and record the new position of the pointer and calculate the extension, x , of the spring
- Displace the 50g mass through a small vertical distance and release it.
- Measure the time for a reasonable number of oscillations
- Calculate the period T of oscillations. Repeat the procedure for different value of masses.
- Plot a graph of T^2 against x , and find the slope, S , of the graph
- Calculate g from $g = \frac{4\pi^2}{S}$

- (iii) State any two sources of error in the experiment in (b)(ii) above. (01marks)

- Reading positions of the pointer
- Determining period T

- (iv) A body of mass 1kg moving with simple harmonic motion has speeds of 5ms^{-1} and 3ms^{-1} when it is at distances of 0.10m and 0.2m respectively from equilibrium point. Find the amplitude of the motion. (04marks)

$$v^2 = \omega^2(A^2 - x^2)$$

$$5^2 = \omega^2(A^2 - 0.1^2) \dots\dots\dots (i)$$

$$3^2 = \omega^2(A^2 - 0.2^2) \dots\dots\dots (ii)$$

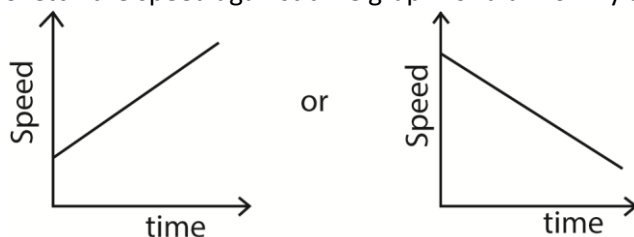
From (i) and (ii)

$$A = 0.24\text{m}$$

53. (a)(i) What is meant by uniformly accelerated motion? (01marks)

Uniformly accelerated motion is one for which velocity increases by equal amounts in equal successive time interval

(ii) Sketch the speed against time graph for a uniformly accelerated body. (01mark)



(iii) Derive the expression: $S = ut + \frac{1}{2}at^2$, for the distance, S , moved by a body which is initially travelling with speed u and is uniformly accelerated for time t .

$$s = \left(\frac{u+v}{2}\right)t \text{ but } v = u + at$$

$$s = \frac{(u+u+at)t}{2}$$

$$= ut + \frac{1}{2}at^2$$

(b) A projectile is fired horizontally from the top of a cliff 250m high. The projectile lands 1.414×10^3 m from the bottom of the cliff. Find the

(i) initial speed of the projectile. (05marks)

$$\text{From } y = u_y t + \frac{1}{2}at^2$$

$$-250 = 0 - \frac{1}{2} \times 9.81 \times t^2;$$

$$t = 7.14s$$

$$\text{Horizontally, } x = u_x t$$

$$1.414 \times 10^3 = 7.14u_x$$

$$u_x = 198\text{ms}^{-1}$$

(ii) velocity of the projectile just before it hits the ground. (05marks)

$$v_y = u_y + at$$

$$= 0 - 9.81 \times 7.14 = 70\text{ms}^{-1}$$

$$v = \sqrt{u_x^2 + u_y^2} = \sqrt{198^2 + 70^2} = 210\text{ms}^{-1}$$

$$\theta = \tan^{-1}\left(\frac{70}{198}\right) = 19.5^\circ \text{ to the horizontal}$$

(c) Describe an experiment to determine the centre of gravity of a plane sheet of material having irregular shape (04marks)

- three holes are drilled around the edge of the sheet of irregular object.
- The cardboard is suspended from a pin through one of the holes. When the cardboard is freely suspended, a plumb line is suspended from the same pin.
- A line is drawn to mark the line where the plumb line passes.
- The procedure is repeated for the other two holes.

- The point of intersection of the three line is the centre of gravity

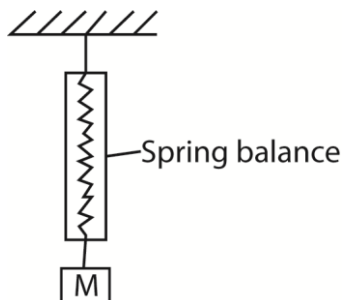
54. (a) (i) Define force and power. (02marks)

A force is something that changes or tends to change a body's state of rest or uniform motion in straight line.

Power is the rate of doing work

(ii) Explain why more energy is required to push a wheel barrow uphill than on a level ground. (03mark)

(b)



A mass, M, is suspended from a spring balance as shown in the figure above. Explain what happens to the reading of the spring balance when the setup is raised slowly to a very high height above the ground. (02marks)

On a level ground, work is only done against frictional force, while when moving uphill work is done against friction force and gravity. As the setup is raised to a greater height, acceleration due to gravity decrease; so the weight of M decreases, therefore the reading of the spring balance also decreases.

(c) (i) State the work-energy theorem (01mark)

Work done by the resultant force on the body is equal in kinetic energy of the body

(ii) A bullet of mass 0.1kg moving horizontally with a speed of 420ms^{-1} strikes a block of mass 2.0kg at rest on a smooth table and becomes embedded in it. Find the kinetic energy lost if they move together. (04marks)

$$m_1 u_1 = (m_1 + m_2) v$$

$$0.1 \times 420 = 2.1 v$$

$$v = 20\text{ms}^{-1}$$

$$\text{loss in K.E} = \frac{1}{2} m_1 u^2 - \frac{1}{2} (m_1 + m_2) v^2$$

$$= \frac{1}{2} \times 0.1 \times 420^2 - \frac{1}{2} \times 2.1 \times 20^2$$

$$= 8400\text{J}$$

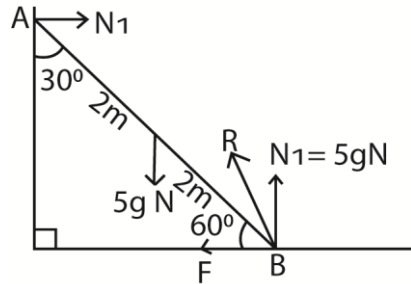
(d) State the condition for equilibrium of a rigid body under the action of coplanar forces. (02marks)

- the sum of forces acting in any one direction is equal to the sum of forces acting in the opposite direction (the resultant force on the body = 0)

- the sum of clockwise moments about any point is equal to the sum of anticlockwise moments about the same point.

(e) A 3m long ladder rests at an angle 60° to the horizontal against a smooth vertical wall on a rough ground. The ladder weighs 5kg and its centre of gravity is one- third from the bottom of the ladder.

(i) Draw a sketch diagram to show the forces acting on the ladder. (02marks)



(ii) Find the reaction of the ground on the ladder (04marks)

Taking moments about A;

$$F \times 3 \cos 30^\circ + 5g \times 2 \sin 30^\circ = 5g \times 3 \sin 30^\circ$$

$$F = 9.44 \text{ N}$$

$$R = \sqrt{9.44^2 + (3 \times 9.91)^2} = 49.95 \text{ N}$$

$$\theta = \tan^{-1} \left(\frac{9.44}{49.05} \right) = 10.9^\circ \text{ to the vertical}$$

55. (a) (i) Define stress and strain (02marks)

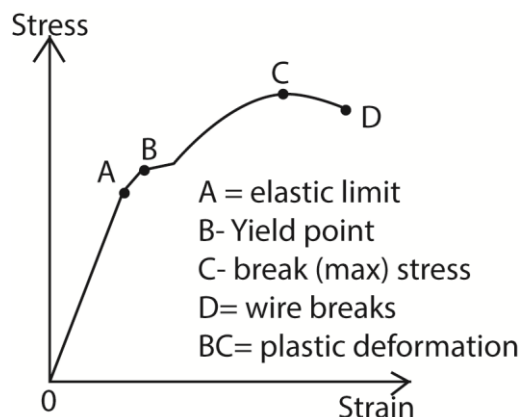
Stress is force per unit area.

Strain is force per unit length

(ii) Determine the dimensions of Young's modulus. (03marks)

$$Y = \frac{\text{stress}}{\text{strain}} = \frac{F}{A} \div \frac{e}{L} = \frac{MLT^{-2}}{L^2} \times \frac{L}{L} = ML^{-1}T^{-2}$$

(b) Sketch a graph of stress versus strain for a ductile material and explain its features. (06marks)



- OA – stress is proportional to strain and the material regains its length
- AB - stress is not proportional to strain but the material regains its length
- Beyond B the material becomes permanently stretched

- CD the material undergoes plastic deformation
- Beyond D the material breaks

(c) A steel wire of cross section area 1mm^2 is cooled from a temperature of 60°C to 15°C .

Find the:

(i) strain (02marks)

$$\text{Strain} = \alpha\Delta\theta = 1.1 \times 10^{-5} \times (60 - 15) = 4.95 \times 10^{-4}$$

(ii) force needed to prevent it from contracting. (03marks)

[Young's Modulus = $2.0 \times 10^{11}\text{Pa}$, Coefficient of linear expansion of steel = $1.1 \times 10^{-5}\text{K}^{-1}$]

Force = $AY\text{strain}$

$$= 10^{-6} \times 2 \times 10^{11} \times 4.95 \times 10^{-4}$$

$$= 99\text{N}$$

(d) Explain the energy changes which occur during plastic deformation (04marks)

During plastic deformation, molecular separation increase leading to a gain in elastic potential energy and heat is evolved. This heat is not recoverable when stress is reduced to zero.

56. (a) (i) State Archimedes' Principle. (01mark)

Archimedes' Principle states that when a body is fully or partially immersed in a fluid, it experiences an up thrust equal to the weight of the fluid displaced.

(ii) Describe an experiment to determine the relative density of an irregular solid which floats in water

- Weigh the solid in air = W
- Attach a sinker to irregular solid and weigh them when the solid is outside but the sinker immersed in water = W_1
- Weigh the solid and the sinker when the both completely immersed in water = W_2 .
- Upthrust on irregular solid in water = $W_1 - W_2$

$$\text{Relative density} = \frac{W}{W_1 - W_2}$$

(iii) A block of wood floats at an interface between water and oil with 0.25 of its volume submerged in oil. If the density of the wood is $7.3 \times 10^2\text{kgm}^{-3}$, find the density of oil. (04marks)

From mass = volume x density

Mass of water displaced = $0.75V \times 1000$ where V = volume of wood

Mass of oil displaced = $0.25V\rho$ where ρ = density of oil

Mass of water displaced + mass of oil displaced = mass of wood

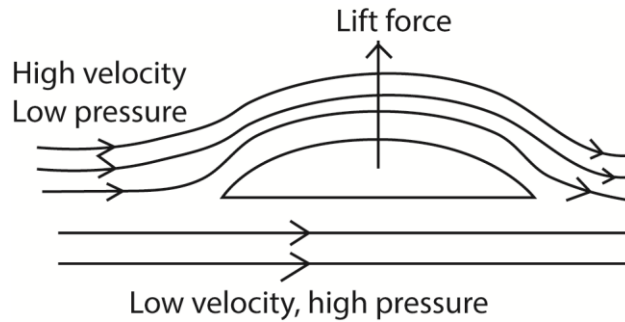
$$0.75V \times 1000 + 0.25V\rho = 7.3 \times 10^2V$$

$$\rho = 80\text{kgm}^{-3}$$

(b) (i) State Bernoulli's Principle. (04marks)

For non- viscous incompressible fluid, flowing steadily, the sum of the pressure, kinetic energy and potential energy per unit volume is constant.

(ii) Explain the origin of the lift force on the wings of an aeroplane at take-off. (04marks)



- Air flows above the wing of a plane at high velocity hence low pressure.
- Below the wings, air flows at low velocity and hence high pressure.
- The difference in pressure cause a lift force, therefore net upward force.

(c) Water flowing in a pipe on the ground with a velocity of 8ms^{-1} and at gauge pressure of $2.0 \times 10^5\text{Pa}$ is pumped into a water tank 10m above the ground. The water enters the tank at a pressure of $1.0 \times 10^5\text{Pa}$. Calculate the velocity with which the water enters the tank. (03marks)

From $P + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}$ where P = atmospheric pressure+ gauge pressure

$$3 \times 10^5 + \frac{1}{2} \times 10^3 \times 8^2 + 0 = 1 \times 10^5 + \frac{1}{2} \times 10^3 \times v^2 + 10^3 \times 9.81 \times 10$$

$$V = 16.4\text{ms}^{-1}$$

(d) Describe how terminal velocity can be measured. (04marks)

- A viscous fluid is filled in a tall jar
- A spherical ball is dropped centrally into the fluid and time t taken by the ball to fall through known distance, d , between known points is determined.
- Terminal velocity, $v_0 = \frac{d}{t}$
- The experiment is repeated to obtain average value.

57. (a) Distinguish between scalar and vector quantities giving two example each. (03marks)

- A scalar quantity has magnitude but not direction e.g. volume, mass
- A vector quantity has both magnitude and direction, e.g. velocity, acceleration, displacement, force.

(b) The equation for volume, V , of a liquid flowing through a pipe in time t , under steady

flow is given by $\frac{V}{t} = \frac{\pi r^4 P}{8\eta L}$ where

r = radius of the pipe

P = pressure difference between two point of the pipe

L = length of the pipe

η = coefficient of viscosity of the liquid

If the dimensions of η are $\text{ML}^{-1}\text{T}^{-1}$, show that the above equation is dimensionally consistent.

$$[\text{L.H.S}] = \left[\frac{V}{t} \right] = \text{L}^3\text{T}^{-1}$$

$$[\text{R.H.S}] = \frac{[r^4][P]}{[\eta][L]} = \frac{\text{L}^4 \times \text{MLT}^{-2}\text{L}^{-2}}{\text{ML}^{-1}\text{T}^{-1} \times \text{L}} = \text{L}^3\text{T}^{-1}$$

Since $[\text{L.H.S}] = [\text{R.H.S}]$, the equation is dimensionally consistent.

(c) (i) define linear momentum. (01mark)

Momentum of a body is the product of its mass and velocity

- (ii) State the law of conservation of linear momentum. (01mark)

When bodies in a system interact, the total momentum remains constant provided no external force on the system.

- (iii) Show the law in (c)(ii) above follows from Newton's law of motion. (03marks)

Let bodies A and B collide

From Newton's second law of motion,

$$\text{Force on A due to B, } F_A = \frac{m_a v_a - m_a u_a}{t}$$

$$\text{Force on B due to A, } F_B = \frac{m_b v_b - m_b u_b}{t}$$

From Newton's third law; $F_A = -F_B$

$$\frac{m_a v_a - m_a u_a}{t} = - \frac{m_b v_b - m_b u_b}{t}$$

$$\Rightarrow (m_a v_a - m_a u_a) - (m_b v_b - m_b u_b) = 0$$

- (iv) Explain why, when catching a fast moving ball, the hands are drawn back while the ball is being brought to rest. (02marks)

Drawing hands back allows for a longer time of action reducing force of impact and damage to hands.

- (d) A car of mass 100kg travelling at uniform velocity of 20ms^{-1} collides perfectly inelastically with a stationary car of mass 1500kg. Calculate the loss in kinetic energy of the car as a result of the collision. (04marks)

$$m_1 u_1 = (m_1 + m_2) v$$

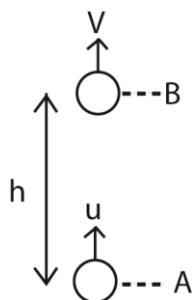
$$v = \frac{m_1 u_1}{(m_1 + m_2)} = \frac{1000 \times 20}{2500} = 8\text{ms}^{-1}$$

$$\begin{aligned} \text{loss in K.E} &= \frac{1}{2} m_1 u^2 - \frac{1}{2} (m_1 + m_2) v^2 \\ &= \frac{1}{2} \times 1000 \times 20^2 - \frac{1}{2} \times 2500 \times 8^2 \\ &= 1.2 \times 10^5 \text{J} \end{aligned}$$

- (e) (i) What is meant by conservation of energy? (01mark)

Energy changes from one form to another, the total amount of energy after the change must be equal to the initial amount of energy.

- (ii) Explain how conservation of energy applies to an object **falling** from rest in a vacuum. (02marks)



At A, K.E = $\frac{1}{2}mu^2$, P.E = 0

Total energy at A = K.E + P.E = $\frac{1}{2}mu^2 + 0 = \frac{1}{2}mu^2$

At B, K.E = $\frac{1}{2}mv^2$; P.E = mgh

Total energy at B, = $\frac{1}{2}mv^2 + mgh$

But $v^2 = u^2 - 2gh$

Total energy at B = $\frac{1}{2}m(u^2 - 2gh) + mgh = \frac{1}{2}mu^2$

∴ Total energy at A = total energy at B

58. (a) Explain the term

(i) Ductility (01mark)

Ductility is the ability of a material to be transformed into different shapes without crumbling

(ii) Stiffness (01mark)

Stiffness is the ability of a material to oppose change in shape

(b) A copper wire and steel wire each of length 1.0m and diameter 1.0mm are joined end to end to form a composite wire 2.0m long. Find the strain in each when the composite stretches by 2.0×10^{-3} m.

[Young's Modulus for copper and steel are 1.2×10^{11} Pa and 2.0×10^{11} Pa respectively]
(07marks)

$$F_1 = k_1 e_1; \quad F_2 = k_2 e_2$$

$$\text{But } F_1 = F_2$$

$$\therefore k_1 e_1 = k_2 e_2 \Rightarrow e_1 = \frac{k_2 e_2}{k_1} = \frac{Y_2 e_2}{Y_1} = \frac{2 \times 10^{11}}{1.2 \times 10^{11}} e_2 = 2 \times 10^{-3}$$

$$e_2 = 0.75 \times 10^{-3} \text{ m}$$

$$\text{strain in steel wire} = \frac{e_2}{l_2} = \frac{0.75 \times 10^{-3}}{1} = 0.75 \times 10^{-3}$$

$$e_1 = 1.25 \times 10^{-3} \text{ m}$$

$$\text{Strain in copper wire} = \frac{e_1}{l_1} = \frac{1.25 \times 10^{-3}}{1} = 1.25 \times 10^{-3}$$

(c) (i) Define centre of gravity (01mark)

Centre of gravity is the point through which the gravitational forces act.

(ii) Describe an experiment to find the centre of gravity of a flat irregular piece of cardboard. (03marks)

- three holes are drilled around the edge of the sheet of irregular object.
- The cardboard is suspended from a pin through one of the holes. When the cardboard is freely suspended, a plumb line is suspended from the same pin.
- A line is drawn to mark the line where the plumb line passes.
- The procedure is repeated for the other two holes.

(d) Explain the laws of solid friction using molecular theory (07marks)

- The frictional force between two surfaces opposes their relative motion, this because the actual area of contact between solid surfaces is very small. Therefore pressure at points of contact is very high; projections emerge to produce adhesion or welding. The force which oppose motion is obtained
- The frictional force is independent of the area of contact of the given surfaces when the normal reaction is constant, because the actual area of contact is the sum of the areas of tiny projections that adhere to each other and are nearly independent of the surface areas of contact.
- The limiting frictional force is proportional to the normal reaction for the case of static friction. The frictional force is proportional to the normal reaction for the case of kinetic (dynamic) friction, and is independent of the relative velocity of the surfaces. This is because increase in weight increases the actual area of contact and hence greater limiting frictional force.

59. (a) What is meant by the following terms?

(i) Velocity gradient. (01mark)

Velocity gradient is the change of velocity between two points per unit length of separation of the points.

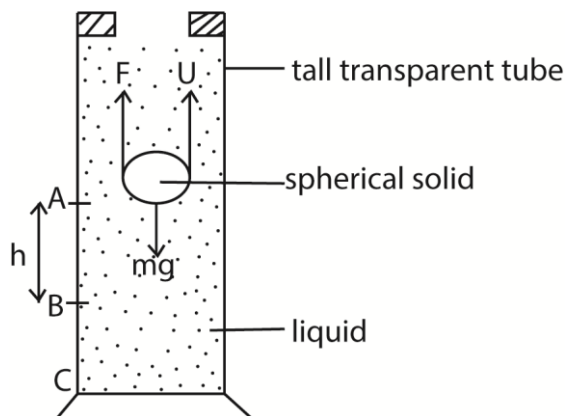
Or

It is the rate of change of velocity with change in distance of separation.

(ii) Coefficient of viscosity (01mark)

Coefficient of viscosity is the tangential force per unit area of fluid which resists the motion of one layer over another in a region of unit velocity gradient.

(b) Derive an expression for terminal velocity of a steel ball-bearing of radius, r , and density, ρ , falling through a liquid of density, σ , and coefficient of viscosity, η . (05marks)



- A liquid of known density, ρ , is put in a tall transparent glass with reference marks A and B, h metres apart
- A spherical solid of radius a and density, σ , is dropped into the liquid and time t taken to drop from A to B is determined.
- Terminal velocity, $v_0 = \frac{h}{t}$

$$\text{The coefficient viscosity, } \eta = \frac{2r^2(\sigma - \rho)g}{9v_0}$$

Assumptions

The spherical solid moves with terminal velocity by the time it reaches A

Precautions

- The glass tube should be very wide compared to the diameter of the ball.
- The point C should be far away from the top of the tube
- Temperature is constant

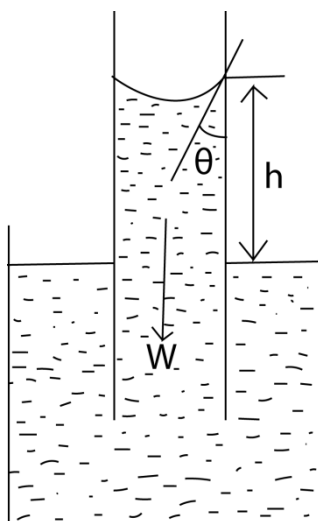
(c) (i) Define surface tension (01mark)

Is the force acting at right angle at one side of imaginary line of length 1m drawn in the surface of a liquid.

(ii) Explain the origin of surface tension. (03marks)

- Liquid molecules attract each other.
- The molecules within the body of the liquid (bulk) molecules is attracted equally by neighbors in all direction, hence, the force on the bulk molecules is zero,
- For a surface molecule, there is a net inward force because there are no molecules above the surface to attract them equally.
- To the surface, work must be done against the inward attractive force, hence, a molecule in the surface of a liquid has a greater potential energy than a molecule in the bulk. The potential energy stored in molecules at the surface is called free surface energy or surface tension.
- Due to the attractive forces experienced by surface molecules due to their neighbours put in a state of tension; the liquid surface behave as a stretched skin.

(iii) Describe an experiment to measure surface tension of a liquid by capillary method. (06marks)



The liquid rises until the vertical component of the upward forces due to surface tension is equal to the weight of the liquid column.

$$F\gamma\cos\theta = W$$

$$\gamma = \frac{F}{L}$$

$$F = \gamma L$$

$$L = 2\pi r$$

But $W = mg$ and $m = V\rho$ (where ρ is the density of the liquid in kg/m^3)

$$W = v\rho g = 2\pi r^2 h\rho g$$

$$F\gamma\cos\theta = 2\pi r^2 h\rho g$$

$$\gamma \cdot 2\pi r \cos\theta = 2\pi r^2 h\rho g$$

$$h = \frac{2\gamma \cos\theta}{r\rho g}$$

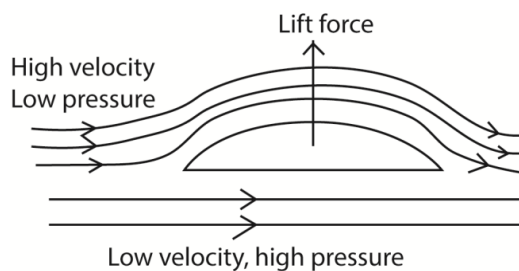
γ – coefficient of surface tension

θ – angle of contact

r – radius of capillary tube

ρ – density of the liquid

- (d) Explain, with the aid of a diagram why air-flow over the wings of an aircraft at take-off cause a lift. (03marks)



- Air flows above the wing of a plane at high velocity hence low pressure.
- Below the wings, air flows at low velocity and hence high pressure.
- The difference in pressure cause a lift force, therefore net upward force.

60. (a) (i) Define angular velocity. (01marks)

Angular velocity is the rate of change of angle of rotation of an object moving in a circular path about the centre.

- (ii) Derive an expression for the force, F , on a particle of mass, m , moving with angular velocity, ω , in a circle of radius, r . (03marks)

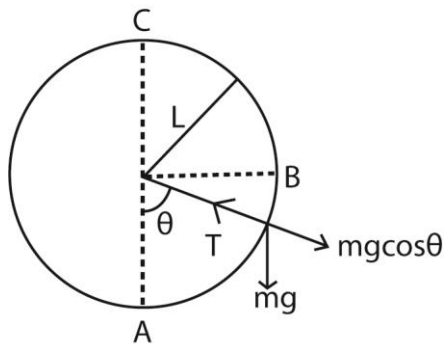
$$F = ma = \frac{mv^2}{r} \text{ since } a = \frac{v^2}{r}$$

$$\text{But } v = \omega r$$

$$\therefore F = \frac{m(\omega r)^2}{r} = m\omega^2 r$$

- (b) A stone of mass 0.5kg is attached to a string of length 0.5m which will break if the tension in it exceeds 20N. The stone is whirled in a vertical circle, the axis of rotation being at a vertical height of 1.0m above ground. The angular speed is gradually increased until the string breaks.

- (i) In what position is the string most likely to break? (02marks)



At A, $\theta = 0$

$$\Rightarrow T = \frac{mv^2}{L} + mg$$

At B, $\theta = 90^\circ$

$$\Rightarrow T = \frac{mv^2}{L}$$

At C, $\theta = 180^\circ$

$$\Rightarrow T = \frac{mv^2}{L} - mg$$

The string breaks at the lowest point, A of the circle because tension the string is highest.

(ii) At what angular speed will the string break? (03marks)

String breaks $T = m\omega^2 r + mg$

$$20 = 0.5 \times 0.5 \times \omega^2 + 0.5 \times 9.81$$

$$\Omega = 7.77 \text{ rad s}^{-1}$$

$$v = \omega r = 7.77 \times 0.5 = 3.9 \text{ m s}^{-1}$$

(iii) Find the position where the stone hits the ground when the string breaks. (03marks)

Vertical distance to be covered = 0.5m

$$s = ut + \frac{1}{2}at^2$$

but initial component of vertical velocity = 0

$$\Rightarrow 0.5 = \frac{1}{2} \times 9.81 \times t^2$$

$$t = 0.3 \text{ s}$$

$$\text{Horizontal distance} = 3.9 \times 0.3 = 1.17 \text{ m}$$

(c) Explain briefly the action of a centrifuge. (03marks)

Consider a body falling through a viscous fluid. For small speed, the liquid opposes motion with a resisting force, f , proportional to the velocity, v .

$f = kv$ where k is a constant of proportionality.

At terminal velocity, $v_t = \frac{mg}{k}$

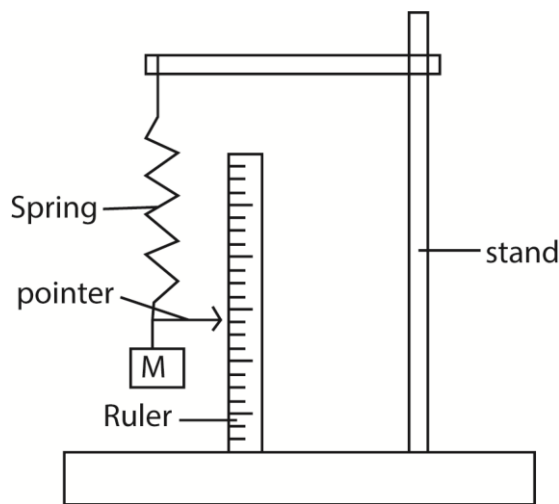
If a container is whirled at high speed, the particles will move approximately in circles with speed, v , and acceleration = $\frac{v^2}{r}$.

When they reach their terminal velocity, v_t , relative to the fluid, the resisting force of the fluid on the particle, $f = kv_t$ must be equal to the mass of the particle multiplied by its acceleration such that the terminal velocity, v_t of the particles relative to the fluid is given by $v_t = \frac{mv^2 \div r}{k}$

The terminal speed or sedimentation rate is increased by a factor of $\frac{v^2}{rg}$ which may be in thousands.

Centrifuges are used to separate cream from milk, silt from river water, blood cells from plasma, e.t.c

(d) Describe how the acceleration due to gravity can be measured using helical spring of unknown force constant, and the other relevant apparatus. (05marks)

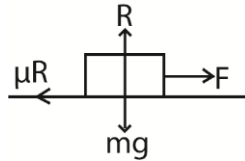


- Suspend a spiral spring from the clamp of a retort stand.
- Attach the pointer to the free end of the spring such that it is horizontal.
- Read and record the initial pointer position on a meter rule supported vertically.
- Suspend a mass, m , from the spring and record the new position of the pointer and calculate the extension, x , of the spring
- Displace the mass, m , through a small vertical distance and release it.
- Measure the time for a reasonable number of oscillations
- Calculate the period T of oscillations. Repeat the procedure for different value of masses.
- Plot a graph of T^2 against x , and find the slope, S , of the graph
- Calculate g from $g = \frac{4\pi^2}{S}$

61. (a) State the laws of friction (04marks)

- Friction force oppose relative motion between surfaces in contact.
- Friction force is independent of area of contact provided normal reaction is constant.
- The friction force is directly proportional to the normal reaction.

- (b) A block of mass 5.0kg resting on the floor is given a horizontal velocity of 5.0ms^{-1} and comes to rest in a distance of 7.0m. Find the kinetic friction between the block and the floor. (04marks)



$$\text{From } v^2 = u^2 + 2as$$

$$0 = 5^2 - 2a \times 7$$

$$a = 1.79\text{ms}^{-2}$$

$$F = ma = 5 \times 1.79 = 8.95\text{N}$$

$$R = mg = 5 \times 9.81 = 49.05\text{N}$$

Also friction force, $F = \mu R$

$$\mu = \frac{F}{R} = \frac{8.95}{49.05} = 0.18$$

- (c) (i) State the law of conservation of linear momentum (01mark)

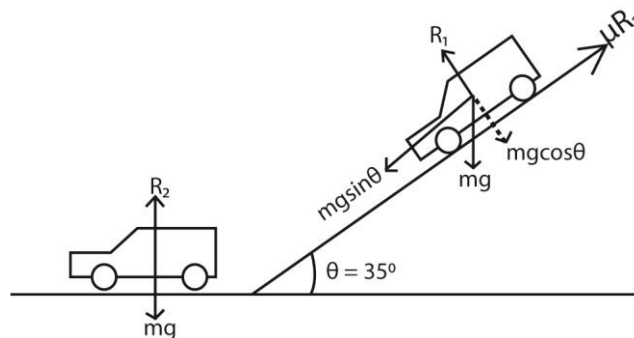
The law of conservation of momentum states that if no external force acts on a system of colliding objects, the total momentum of the objects in a given direction is constant.

- (ii) What are perfectly inelastic collision? (01mark)

Two bodies are said to be perfectly inelastic after collision if

- Momentum is conserved while kinetic energy is not conserved
- The bodies stick together and move with common velocity.
- Coefficient of restitution is equal to zero.

- (d) A car of 1500kg rolls from rest down a road inclined to the horizontal at an angle 35° , through 50m. The car collides with another car of identical mass at the bottom of the incline. If the two cars interlock on collision, and the coefficient of kinetic friction is 0.20, find the common velocity of the vehicles. (08marks)



$$\text{For the vehicle } ma = mg \sin \theta - \mu R_1$$

$$ma = mg \sin \theta - \mu mg \cos \theta$$

$$a = 9.81 \sin 35^\circ - 0.2 \times 9.81 \cos 35^\circ$$

$$= 4\text{ms}^{-2}$$

The velocity of the first car before collision

$$v^2 = u^2 + 2as$$

$$v^2 = 0 + 2 \times 4 \times 50$$

$$v = 20\text{ms}^{-1}$$

Horizontal component of velocity, $u_1 = 20 \cos 35^\circ = 16.4\text{ms}^{-1}$

After collision, momentum conserved.

$$m_1 u_1 = (m_1 + m_2) v$$

$$v = \frac{1500 \times 16.4}{(1500 + 1500)} = 8.2 \text{ ms}^{-1}$$

(e) Discuss briefly the energy transformation which occur in (d) above

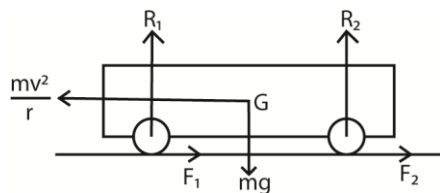
The potential energy of the car on the slope is converted to kinetic energy and heat due to friction. Then the kinetic energy is converted to sound and heat due to friction.

62. (a) Define angular velocity (01mark)

Angular velocity is the rate of change of the angle of rotation for an object moving in a circular path about the centre.

(b) A car of mass, m , travels round a circular track of radius, r , with velocity, V .

(i) Sketch a diagram to show the forces acting on the car. (02marks)



(ii) Show that the car does not overturn if $V^2 < \frac{arg}{2h}$, where a is the distance between the wheels, h , is the height of the centre of gravity above the ground and g is acceleration due to gravity. (05marks)

Suppose the car is moving with velocity, v , around a horizontal circular track of radius, r . if m is the mass of the car and R_1 and R_2 are normal reactions at the inner and outer wheels respectively and F_1 and F_2 are the corresponding frictional forces, then for circular motion:

$$F_1 + F_2 = \frac{mv^2}{r} \dots\dots\dots (i)$$

For vertical equilibrium

$$R_1 + R_2 = mg \dots\dots\dots(ii)$$

Taking moments about G

Clockwise moments = anticlockwise moments

$$(F_1 + F_2)h + R_1 \frac{a}{2} = R_2 \frac{a}{2}$$

$$(F_1 + F_2)h = \frac{a}{2} (R_2 - R_1) = \dots\dots\dots (iii)$$

Substituting Eqn. (i) into Eqn. (iii)

$$\frac{mv^2 h}{r} = \frac{a}{2} (R_2 - R_1) \dots\dots\dots(iv)$$

From (ii)

$$R_1 = mg - R_2$$

From equation (iv)

$$\frac{mv^2h}{r} = \frac{a}{2} (R_2 - (mg - R_2)) = \frac{a}{2} (2R_2 - mg)$$

$$2R_2 = \frac{2mv^2h}{ar} + mg = m\left(\frac{2v^2h}{ar} + g\right)$$

$$R_2 = \frac{m}{2} \left(\frac{2v^2h}{ar} + g \right)$$

$$\text{Also } R_2 = mg - R_1$$

From equation (iv)

$$\frac{mv^2h}{r} = \frac{a}{2} ((mg - R_1) - R_1) = \frac{a}{2} (mg - 2R_1)$$

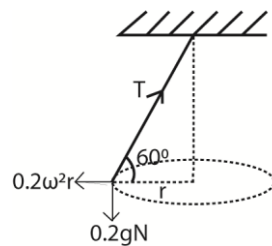
$$2R_1 = mg - \frac{2mv^2h}{ar}$$

$$R_1 = \frac{m}{2} \left(g - \frac{2v^2h}{ar} \right)$$

When the car is about to overturn, $g = \frac{2v^2h}{ar}$, $R_1 = 0$, $v^2 = \frac{gar}{2h}$

- (c) A pendulum bob of mass 0.2kg is attached to one end of an inelastic string of length 1.2m. The bob moves in a horizontal circle with the string inclined at 30° to the vertical. Calculate

- (i) the tension in the string (02marks)



Resolving vertically

$$T \sin 60^\circ = 0.2g = 0.2 \times 9.81$$

$$T = 2.27 \text{ N}$$

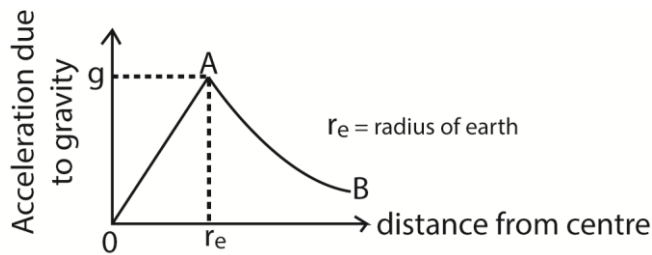
- (ii) the period of motion (04marks)

$$T \cos 60^\circ = 0.2\omega^2 r; \omega = \frac{2\pi}{T}; r = 1.2 \cos 60^\circ = 0.6 \text{ m}$$

$$2.27 \cos 60^\circ = 0.2 \times \frac{4\pi^2}{T^2} \times 0.6$$

$$\text{Period, } T = 2.04 \text{ s}$$

- (d) Explain and sketch the variation of acceleration due to gravity with distance from the centre of the earth (06marks)



- Inside the earth, assuming uniform density, the acceleration due to gravity varies linearly with distance from the centre.
- For points outside the earth, the acceleration due to gravity varies inversely as the square distance from the centre. i.e. $g \propto \frac{1}{r^2}$ where r is the distance from the surface of the earth. Therefore outside the earth gravity decreases with height.

63. (a) (i) What is meant by simple harmonic motion? (01mark)

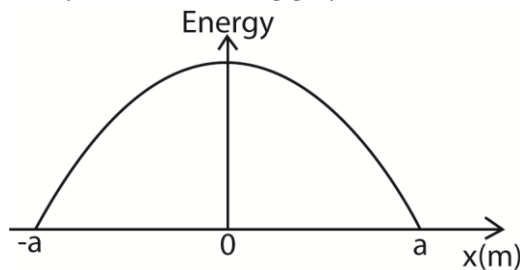
Simple harmonic motion is a periodic motion whose acceleration is directed towards a fixed point and is proportional to the displacement from the fixed point.

(ii) Show with the aid of a suitable sketch graph how kinetic energy of a mass attached at the end of an oscillating light spring changes with distance from equilibrium position. (04marks)

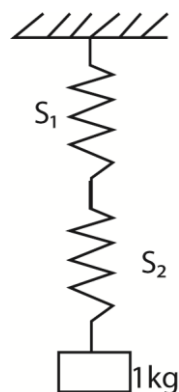
$$\text{Kinetic energy} = \frac{1}{2}mv^2; \text{ but } v = \pm\omega\sqrt{a^2 - x^2}$$

$$\Rightarrow \text{K.E} = \frac{1}{2}m\omega^2(a^2 - x^2)$$

This yield the following graph



(b)



A mass of 1.0kg is hang from two springs S_1 and S_2 connected in series as shown above.

The force constant of the springs are 100Nm^{-1} and 200Nm^{-1} respectively. Find

(i) The extension produced in combination. (04marks)

At equilibrium the tension in each spring = $T = mg$

$$\Rightarrow k_1 e_1 = mg$$

$$100 \times e_1 = 1 \times 9.81$$

$$e_1 = 9.81 \times 10^{-2} \text{m}$$

Also;

$$k_2 e_2 = mg$$

$$200 \times e_2 = 1 \times 9.81$$

$$e_2 = 4.905 \times 10^{-2} \text{m}$$

$$\text{Total extension} = e_1 + e_2 = (9.81 + 4.905) \times 10^{-2} \text{m} = 0.14715 \text{ m}$$

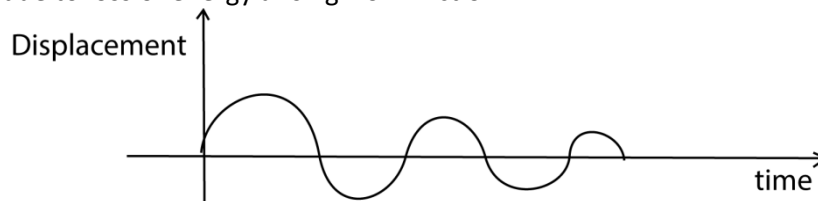
- (ii) The frequency of oscillation of the mass if it is pulled downwards through a small distance and released. (06marks)

$$T = 2\pi \sqrt{\frac{e}{g}} = 2\pi \sqrt{\frac{0.14715}{9.81}} = 0.77 \text{s}$$

$$f = \frac{1}{T} = \frac{1}{0.77} = 1.3 \text{Hz}$$

- (c) Explain with the aid of a sketch graph, what would happen to the oscillations in (b)(ii) above if the mass was immersed in a liquid such as water. (04marks)

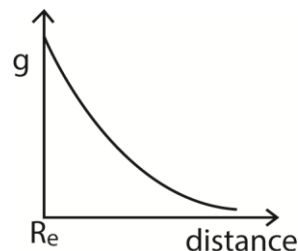
If the mass is immersed in water, the amplitude decreases until the oscillations die away due to loss of energy arising from friction.



64. (a) (i) Define gravitational field strength. (01mark)

The gravitational field strength at any point in gravitational field is the gravitational force experienced by a unit mass placed at that point provided that the unit mass itself does not cause any change in the field

- (ii) Draw a sketch graph to show how the gravitational field strength varies with height, h , above the earth's surface. (02marks)



- (b) The period of simple pendulum is measured at different locations along a given longitude. Explain what is observed. (06marks)

From the equator towards the pole along a longitude the radius of the earth, R_e , decreases.

$$\text{Since } mg = \frac{GMm}{R_e^2} \Rightarrow g \propto \frac{1}{R_e^2}$$

Therefore, g increases towards the pole.

$$\text{From period, } T = 2\pi \sqrt{\frac{l}{g}} \Rightarrow T \propto \frac{1}{\sqrt{g}}$$

Therefore, Period T decrease from the equator towards the pole

- (c) Derive the expression for the escape velocity of a rocket fired from earth. (03marks)

The work done in moving a body of mass, m, from the surface of the earth to infinity is given by

$$W = -\frac{GMm}{\infty} - \left(-\frac{GMm}{R}\right) \text{ but } \frac{GMm}{\infty} = 0$$

$$= \frac{GMm}{R}$$

$$\Rightarrow \frac{1}{2}mv^2 \geq \frac{GMm}{R}$$

$$v = \sqrt{\frac{2GM}{R}} \text{ where } r \text{ is the radius of the earth}$$

- (d) The rings of the planet Saturn consist of a vast number of small particles, each in a circular orbit about the planet. Calculate the speed of the particles nearest to Saturn if its mass is 6.0×10^{26} kg (04marks)

Centripetal force = Gravitational force of attraction between the planet and the particle.

$$\Rightarrow \frac{GMm}{r^2} = \frac{mv^2}{r}$$

$$v = \sqrt{\frac{GM}{r}} = \sqrt{\frac{6.67 \times 10^{-11} \times 6.0 \times 10^{26}}{r}} = \frac{2.0 \times 10^8}{\sqrt{r}}$$

- (e) The moon moves in a circular orbit of radius 3.84×10^8 m around the earth with a period of 2.36×10^5 s. Calculate the gravitational field of the earth at the moon. (04marks)

If r_e and r_0 are the radii of the earth and the moon's orbit around the earth respectively, and g' is the gravitational field strength of the earth at the moon;

$$\text{From } g \propto \frac{1}{r^2}$$

$$g \propto \frac{1}{r_e^2} \text{ also } g' \propto \frac{1}{r_0^2}$$

$$\Rightarrow \frac{g'}{g} \propto \frac{r_e^2}{r_0^2}$$

$$g' = \frac{(6.4 \times 10^6)^2}{(3.84 \times 10^8)^2} \times 9.81 = 2.73 \times 10^{-3} \text{ ms}^{-2}$$

65. (a) Distinguish between fundamental and derived physical quantities. Give two examples of each. (04marks)

Fundamental quantities are those physical quantities which cannot be expressed in terms of other quantities using mathematical equations. They include mass (M), length (L) and time (T).

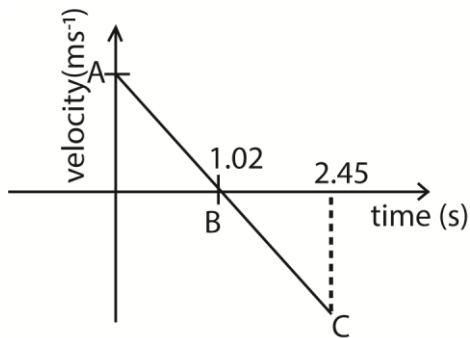
Derived quantities are those physical quantities which can be expressed in terms of fundamental quantities, e.g., density, velocity, pressure.

- (b) (i) What is meant by scalar and vector quantities? (02marks)

A **scalar** is a physical quantity with magnitude but no direction.

A **vector** is a physical quantity with both magnitude and direction.

- (ii) A ball is thrown vertically upwards with a velocity 10 m s^{-1} from a point 3.0 m above ground. Describe with the aid of a velocity-time sketch graph, the subsequent motion of the ball. (10marks)



The body is projected at A, rises with uniform acceleration up to B which is at a vertical height, h , from the point of projection. At B, $v = 0$

From $v^2 = u^2 + 2as$

$$0 = 10^2 - 2 \times 9.81h$$

$$h = 5.1\text{m}$$

the time taken to cover the height, h , is obtained from; $v = u + at$

$$0 = 10 - 9.81t$$

$$t = 1.02\text{s}$$

From B, the ball falls with uniform acceleration and if it takes time, t s to strike C.

From $y = ut + \frac{1}{2}at^2$

$$-5 = 10t - 4.9t^2$$

$$t = 2.45\text{s}$$

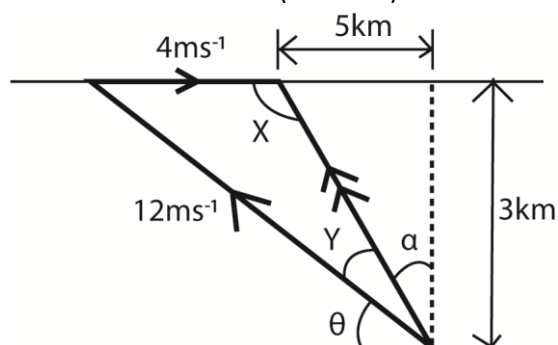
Velocity at C

From $v^2 = u^2 + 2as$

$$v^2 = 0 + 2 \times 9.81 \times 10.1$$

$$v = 14.1\text{ms}^{-2}$$

- (c) A boat crosses a river 3km wide flowing at 4ms^{-1} to reach a point on the opposite bank 5km upstream. The boat's speed in still water is 12ms^{-1} . Find the direction in which the boat must be headed. (04marks)



$$\alpha = \tan^{-1} \frac{5}{3} = 59.04^\circ$$

$$X = 90 + 59.04 = 159.04$$

Applying the sine rule to the vector triangle OQR

$$\frac{\sin Y}{4} = \frac{\sin 149.04}{12}; Y = 9.87^\circ$$

$$\text{But } \theta + Y + \alpha = 90^\circ$$

$$\theta = (90 - 9.87 - 59.04) = 21.09^\circ$$

therefore the boat should be steered in a direction making of 21.080 to the river up stream

66. (a) Define the following terms:

(i) Angular velocity (01mark)

Angular velocity is the rate of change of the angle swept out by the radius joining a body to the centre of circular path.

(ii) Centripetal acceleration (01mark)

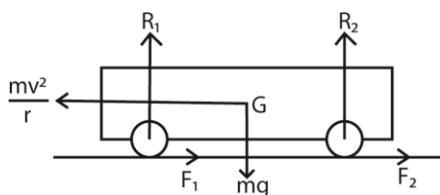
Centripetal acceleration is the rate of change of velocity for a body describing a circular path and is always directed towards the centre of the path.

(b) (i) Explain why a racing car can travel faster on a banked road than on flat track of the same curvature. (04marks)

(ii) Derive an expression for the speed with which a car can negotiate a bend on a banked track without skidding. (03marks)

- **On a flat track**

For Suppose the car is moving with velocity, v , around a horizontal circular track of radius, r . if m is the mass of the car and R_1 and R_2 are normal reactions at the inner and outer wheels respectively and F_1 and F_2 are the corresponding frictional forces, then for circular motion:



$$F_1 + F_2 = \frac{mv^2}{r} \dots\dots\dots (i)$$

For vertical equilibrium

$$R_1 + R_2 = mg \dots\dots\dots(ii)$$

Taking moments about G

Clockwise moments = anticlockwise moments

$$(F_1 + F_2)h + R_1 \frac{a}{2} = R_2 \frac{a}{2} \text{ (a = distance between the wheels, h = the height of the centre of gravity from the ground)}$$

$$(F_1 + F_2)h = \frac{a}{2} (R_2 - R_1) = \dots\dots\dots (iii)$$

Substituting Eqn. (i) into Eqn. (iii)

$$\frac{mv^2 h}{r} = \frac{a}{2} (R_2 - R_1) \dots\dots\dots(iv)$$

From (ii)

$$R_1 = mg - R_2$$

From equation (iv)

$$\frac{mv^2 h}{r} = \frac{a}{2} (R_2 - (mg - R_2)) = \frac{a}{2} (2R_2 - mg)$$

$$2R_2 = \frac{2mv^2h}{ar} + mg = m\left(\frac{2v^2h}{ar} + g\right)$$

$$R_2 = \frac{m}{2}\left(\frac{2v^2h}{ar} + g\right)$$

$$\text{Also } R_2 = mg - R_1$$

From equation (iv)

$$\frac{mv^2h}{r} = \frac{a}{2}((mg - R_1) - R_1) = \frac{a}{2}(mg - 2R_1)$$

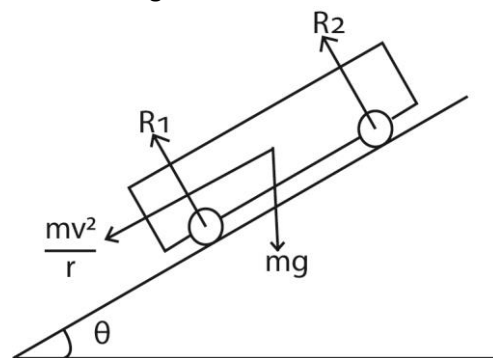
$$2R_1 = mg - \frac{2mv^2h}{ar}$$

$$R_1 = \frac{m}{2}\left(g - \frac{2v^2h}{ar}\right)$$

When the car is about to overturn, $g = \frac{2v^2h}{ar}$, $R_1 = 0$, $v^2 = \frac{gar}{2h}$

The maximum velocity of a car to negotiate a bend of radius r on a flat track, $v = \sqrt{\frac{gar}{2h}}$

- On banked ground



Resolving horizontally

$$(R_1 + R_2) \sin \theta = \frac{mv^2}{r} \dots\dots\dots (i)$$

Resolving vertically;

$$(R_1 + R_2) \cos \theta = mg \dots\dots\dots (ii)$$

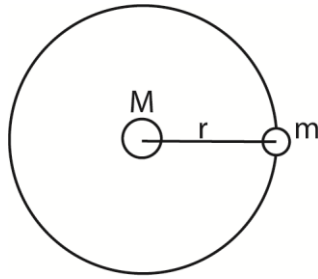
Divide equation (i) by Eqn. (ii)

$$\tan \theta = \frac{v^2}{rg}$$

$$v = \sqrt{rg \tan \theta}$$

(c) a Show how to estimate the mass of the sun if the period and radius of one of its planets are known. (03marks)

Suppose the sun of mass M and a planet has the mass, m , in a circular orbit of radius, r



The centripetal force is provided by the gravitational force between the sun and the planet.

$$\Rightarrow \frac{GMm}{r^2} = \frac{mv^2}{r}$$

$$M = \frac{v^2 r}{G}; \text{ but } v = \omega r = \left(\frac{2\pi}{T}\right) r$$

$$M = \frac{4\pi^2 r^3}{GT^2}$$

So if r and T are known, the mass of the sun M can be calculated.

- (d) The gravitational potential, U , at the surface of a planet of mass M and radius R is given by $U = -\frac{GM}{R}$, where G is gravitational constant.

Derive an expression for the lowest velocity, V , which an object of mass, m , must have at the surface of the planet if it is to escape from the planet. (04marks)

$$W = -\frac{GMm}{\infty} - \frac{-GMm}{R} \text{ but } \frac{GMm}{\infty} = 0$$

$$= \frac{GMm}{R}$$

$$\Rightarrow \frac{1}{2}mv^2 \geq \frac{GMm}{R}$$

$$v = \sqrt{\frac{2GM}{R}} \text{ where } r \text{ is the radius of the earth and } v \text{ is the velocity of projection}$$

- (e) Communication satellites orbit the earth in synchronous orbits. Calculate the height of communication satellite above the earth. (04marks)

If the satellite has a mass, m , and moves in an orbit of radius, r , about the earth of mass M , then

$$\frac{GMm}{R} = \frac{mv^2}{r} \text{ but } v = \omega r = \left(\frac{2\pi}{T}\right) r$$

$$r = \sqrt[3]{\frac{GMT^2}{4\pi^2}} \text{ but } GM = gr_e^2$$

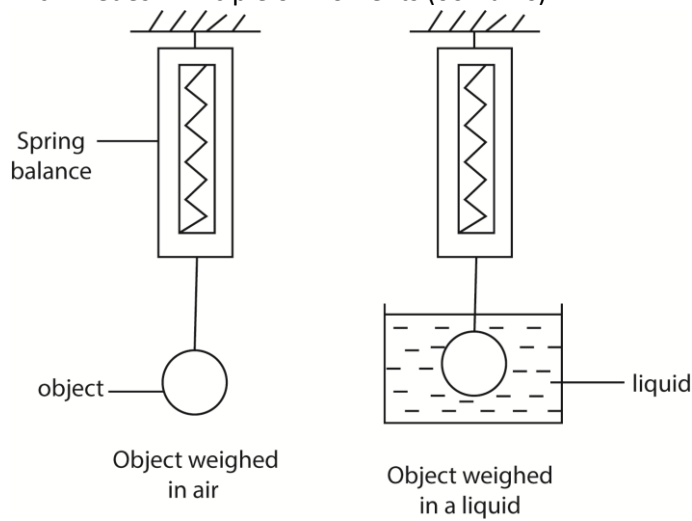
$$r = \sqrt[3]{\frac{gr_e^2 T^2}{4\pi^2}} = \sqrt[3]{\frac{9.81 \times (6.4 \times 10^6)^2 \times (24 \times 60 \times 60)^2}{4\pi^2}} = 4.24 \times 10^7 \text{ m}$$

$$\text{Hence height above the earth} = (4.24 \times 10^7 - 6.4 \times 10^6) = 3.6 \times 10^7 \text{ m}$$

67. (a) State the law of floatation. (01mark)

The law of floatation state that a floating body displaces its own weight of the fluid in which it floats

(b) With the aid of a diagram, describe how to measure the relative density of a liquid using Archimedes' Principle of moments (06marks)



- A solid is weighed in air = M g
- Then a solid s weighed when totally immersed in a liquid whose relative density is required = m_1 g
- Then a solid s weighed when totally immersed in water = m_2 g

Calculations

Upthrust in the liquid = $M - m_1$

Upthrust in water = $M - m_2$

Relative density of the liquid = $\frac{M - m_1}{M - m_2}$

Or density of the liquid = $\left(\frac{M - m_1}{M - m_2}\right) \times \text{density of water}$

(c) A cross sectional area of a ferry at its water-line is 720m^2 . if sixteen cars of average mass 1100kg are placed on board, to what extra depth will the boat sink in the water?

(04marks)

Let the extra depth be x ;

From $\rho = \frac{m}{V}$; $\Rightarrow m = \rho V$; but $V = 720x$

$\therefore 1000 \times 720x = 16 \times 110$

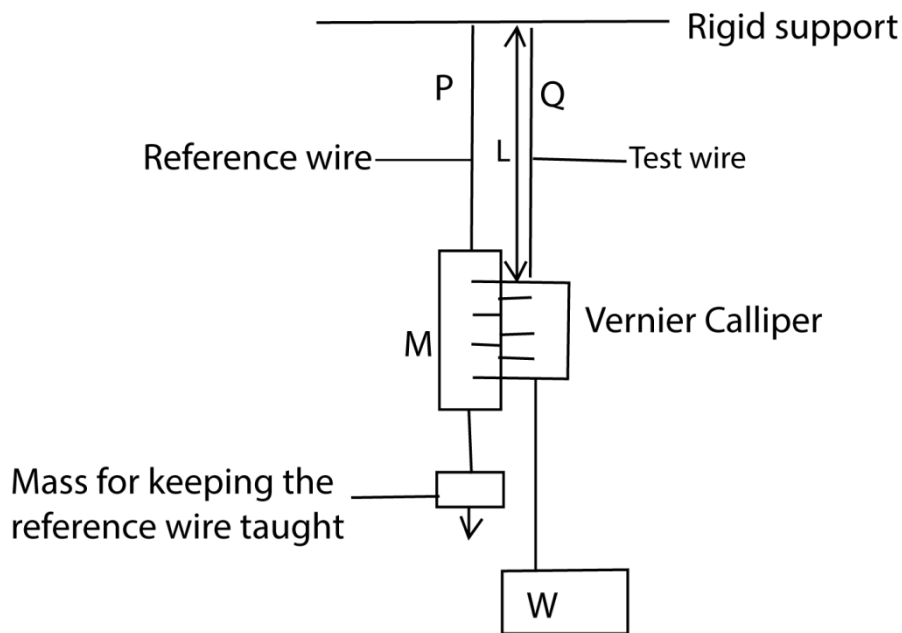
$x = 0.034\text{m}$

(d) (i) Define longitudinal stress and Young's Modulus of elasticity. (02marks)

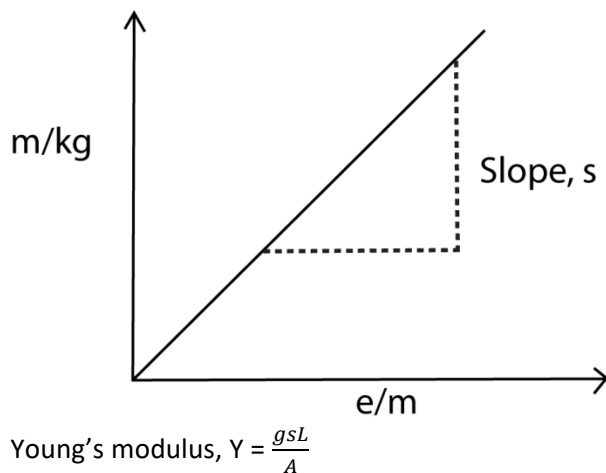
Longitudinal stress is the force acting on a cross-section area of 1m^2 .

(ii) Describe how to determine Young's Modulus for steel wire. (07marks)

Experiment to determine Young's Modulus for a metal wire



- (vii) Two thin, long wires of the same material and length P and Q are suspended from a rigid support.
- (viii) P carries a scale M in mm and it's straightened by attaching a weight at its end.
- (ix) Q carries a Vernier scale which is alongside scale M
- (x) Various loads are added to the test wire and corresponding extensions caused are read off from a vernier scale.
- (xi) The diameter ($2r$) of the wire is obtained by a micrometre screw gauge, and the cross section area of the wire $A = 4\pi r^2$
- (xii) A graph of mass (m) of the load against extension e is plotted



68. (a) A mass of 0.1kg is suspended from a light spring of force constant 24.5Nm^{-1} . Calculate the potential energy of the mass. (04marks)
- Elastic potential energy, $P.E = \frac{1}{2} kx^2$ (i)
- From Hooke's law, $mg = kx$
- $\Rightarrow x = \frac{mg}{k}$ (ii)
- Substituting eqn. (ii) in eqn. (i)

$$P.E = \frac{(mg)^2}{2k} = \frac{(0.1 \times 9.81)^2}{2 \times 24.5} = 1.96 \times 10^{-2} \text{J}$$

(b) (i) State four characteristics of simple harmonic motion. (04marks)

- The acceleration is always directed towards a fixed point in the motion line
- The acceleration is directly proportional to the displacement from a fixed point
- It is periodic
- Total mechanical energy is conserved.

(ii) Show that the speed of a body moving with simple harmonic motion of angular velocity, ω , is given by $V = \omega(A^2 - x^2)^{1/2}$, where A is the amplitude and x is the displacement from equilibrium position. (04marks)

If x is the displacement, from $a = -\omega^2 x$

$$a = \frac{dv}{dt} = \frac{dv}{dx} x \frac{dx}{dt} = V \frac{dv}{dx}$$

$$\Rightarrow V \frac{dv}{dx} = -\omega^2 x$$

$$\int v dv = -\omega^2 \int x dx$$

$$\frac{v^2}{2} = -\frac{\omega^2 x^2}{2} + c \dots\dots\dots (i)$$

But $x = A, v = 0$

$$\Rightarrow c = \frac{\omega^2 A^2}{2}$$

Substituting c in eqn.(i)

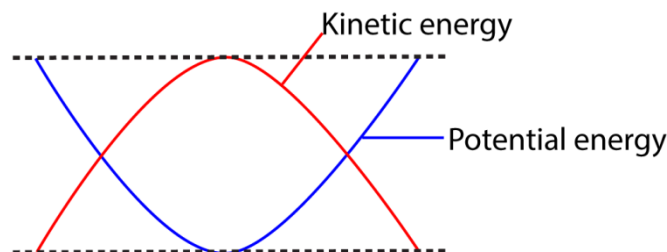
$$v^2 = \omega^2(A^2 - x^2)$$

Or

$$v = \omega(A^2 - x^2)^{1/2},$$

(iii) Sketch graphs to show the variation with displacement, of kinetic and potential energies of a body moving with simple harmonic motion (02marks)

Variation of kinetic and potential energy in S.H.M



(c) A mass of 0.1kg suspended from a spring of force constant 24.5Nm^{-1} is pulled vertically downwards through a distance 5.0cm and released. Find the

(i) period of acceleration (02marks)

$$\text{From } T = 2\pi \sqrt{\frac{m}{k}}$$

$$T = 2\pi \sqrt{\frac{0.1}{24.5}} = 0.4 \text{s}$$

(ii) position of the mass 0.3s after release. (04marks)

From $x = A \sin(\omega t + \epsilon)$; where ϵ is the phase angle which is dependent on the position of the particle when the timing starts.

Given that $A = -5\text{cm} = -5 \times 10^{-2}\text{m}$ (displacement is negative because it is below the equilibrium position).

$$\therefore -5 \times 10^{-2} = 5 \times 10^{-2} \times \sin \epsilon$$

$$\epsilon = \frac{\pi}{2} \text{ radians}$$

At $t = 0.3\text{s}$

$$x = 5 \times 10^{-2} \sin(0.3\omega - \frac{\pi}{2})$$

$$\text{But } \omega = \frac{2\pi}{T} = \frac{2\pi}{0.4} = 15.7 \text{ rads}^{-1}$$

$$x = 5 \times 10^{-2} \sin(0.3 \times 15.7 - \frac{\pi}{2}) = 1.19 \times 10^{-4} \text{m}$$

69. (a) (i) what is meant by the dimensions of a physical quantity? (01mark)

Dimensions of a physical quantity is the way a physical quantity is related to the fundamental quantities of mass (M), length (L) and time (T)

(ii) For stream line flow of non-viscous, incompressible fluid, the pressure, P , at a point is related to height, h , and the velocity, V by the equation $(P-a) = \rho g(h-b) + \frac{1}{2}(\rho v^2 - d)$ where a , b , and d , are constants and ρ is the density of the fluid and g is the acceleration due to gravity. Given that the equation is dimensionally consistent, find the dimensions of a , b and d . (03marks)

$$[a] = [P] = \text{ML}^{-1}\text{T}^{-2}$$

$$[b] = [h] = \text{L}$$

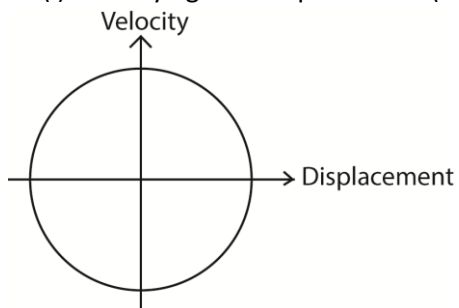
$$[d] = [V^2] = (\text{LT}^{-1})^2 = \text{L}^2\text{T}^{-2}$$

(b) Define simple harmonic motion. (01marks)

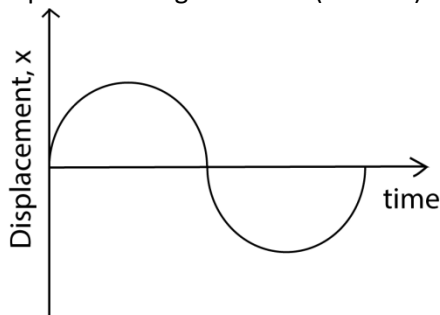
Simple harmonic motion is a periodic motion whose acceleration is directed towards a fixed point and is proportional to the displacement from the fixed point.

(c) Sketch the following graphs for a body performing simple harmonic motion:

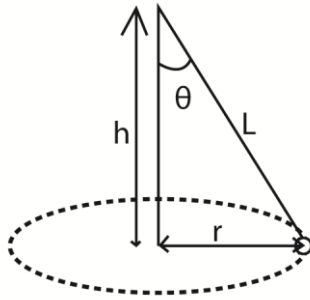
(i) velocity against displacement (01mark)



(ii) displacement against time (01mark)



- (d) The period of oscillation of a conical pendulum is 2.0s. If the string makes 60° to the vertical at the point of suspension, calculate the
 (i) vertical height of the point of suspension above the circle. (03marks)



For conical pendulum, $T = 2\pi \sqrt{\frac{h}{g}}$

$$h = \frac{T^2 g}{4\pi^2} = \frac{2^2 \times 9.81}{4\pi^2} = 0.994\text{m}$$

- (ii) length of the string (01 mark)

$$h = L \cos \theta$$

$$L = \frac{0.994}{\cos 60} = 1.1.99\text{m}$$

- (iii) Velocity of the mass attached to the string (03marks)

$$V = \omega r; r = L \sin \theta = 1.99 \sin 60 = 1.723\text{m}$$

$$\omega = \frac{2\pi}{T} = \pi \Rightarrow V = 1.723\pi \times = 5.41\text{ms}^{-1}$$

- (e) (i) give one example of an oscillatory motion which approximates simple harmonic motion

- Simple pendulum
- Mass of helical spring
- Liquid oscillating in U-tube

- (ii) What approximation is made in (e)(i) above? (01mark)

- For simple pendulum, the angle of displacement is small and air friction is negligible
- Helical spring, displacement is small
- Oscillating liquid in U tube experience negligible friction and small displacement

- (f) Explain why the acceleration of a ball bearing falling through a liquid decreases continuously until it becomes zero. (04marks).

Viscous force increases with velocity until the Upthrust + viscous force = weight of the ball reducing acceleration to zero

70. (a) (i) State Newton's law of universal gravitation. (01mark)

The gravitational force of attraction between two bodies in the universe is proportional to the product of their masses and inversely proportional to the square of their distance apart.

- (iii) Show that this law is consistent with Kepler's third law. (03marks)

By Newton's law of gravitation, $F = \frac{GMm}{r^2}$

From uniform circular motion, $mr\omega^2 = \frac{GMm}{r^2}$; but $\omega = \frac{2\pi}{T}$

$$\text{Thus } \frac{GMm}{r^2} = \left(\frac{mr \times 4\pi^2}{T^2} \right)$$

$$\Rightarrow T^2 = \left(\frac{4\pi^2}{GM} \right) r^3$$

Thus $T^2 \propto r^3$ - Kepler's law.

- (iii) Two alternative units for gravitational field strength are Nkg^{-1} and ms^{-2} . Use the method of dimensions to show that the two units are equivalent. (03marks)

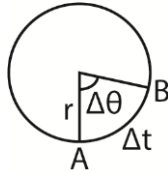
Nkg^{-1} is the unit of $\frac{\text{Force}}{\text{mass}}$

$$\frac{[\text{Force}]}{[\text{mass}]} = \frac{MLT^{-2}}{M} = LT^{-2}$$

Also $[\text{ms}^{-2}] \equiv LT^{-2}$

Hence the two units are equivalent

- (b) (i) Derive an expression for speed of a body moving uniformly in a circular path. (03marks)



Let the body move from A to B in time Δt such that the radius sweeps through a small angle $\Delta\theta$

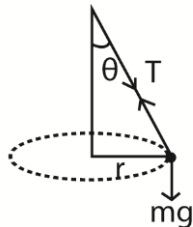
$$\text{Average speed} = \frac{\text{distance}}{\text{time}} = \frac{r\Delta\theta}{\Delta t}$$

For small values of $\Delta\theta$ and Δt , $\frac{d\theta}{dt} = \omega$

Hence average speed, $v = r\omega$

- (ii) Explain why a force is necessary to maintain a body moving with constant speed in a circular path. (02marks)
To provide centripetal force
- (c) A small mass attached to a string suspended from a fixed point moves in a circular path at constant speed in horizontal plane.

- (i) Draw a diagram showing the force acting on the mass. (01mark)



- (ii) Derive an equation showing the angle of inclination of the string depends on the speed of the mass and radius of the circular path. (03marks)

$$\text{Resolving horizontally, } T\sin\theta = \frac{mv^2}{r} \dots\dots\dots (i)$$

$$\text{Resolving vertically, } T\cos\theta = mg \dots\dots\dots (ii)$$

Combining eqn. (i) and eqn (ii)

$$\tan\theta = \frac{v^2}{rg}$$

(d) (i) Define moment of force. (01mark)

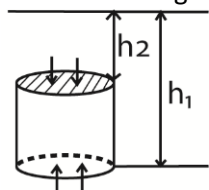
Moment of force is the product of force and the perpendicular distance from axis of rotation to the line of action of force.

(ii) A wheel of radius 0.2m is pivoted at its centre. A tangential force of 4.0N acts on the wheel so that the wheel rotates with uniform velocity. Find the work done by the force to turn the wheel through 10 revolutions. (03marks)

$$\text{Work done} = F \times 2\pi r \times \text{number of revolutions} = 4 \times 0.5 \times 2\pi \times 10 = 151\text{J}$$

71. (a) (i) Show that the weight of a fluid displaced by an object is equal to up thrust on the object. (05marks)

Consider a vertical cylinder of cross section area, A, immersed in a liquid of density ρ as shown in the diagram below



If H is the atmospheric pressure.

$$\text{Pressure on top} = h_2\rho g + H$$

$$\text{Pressure at the base} = h_1\rho g + H$$

$$\text{Force on the base} = (h_1\rho g + H)A$$

$$\text{Force on the top} = (h_2\rho g + H)A$$

$$\text{Resultant force} = (h_1 - h_2)\rho g A$$

$$\text{But } (h_1 - h_2)A = \text{volume of the cylinder} = \text{volume of liquid displaced.}$$

$$\therefore (h_1 - h_2)\rho g A = \text{weight of the liquid displaced} = \text{Upthrust.}$$

(ii) A piece of metal of mass $2.60 \times 10^{-3}\text{kg}$ and density $8.4 \times 10^3\text{kgm}^{-3}$ is attached to a block of wax of mass $1.0 \times 10^{-2}\text{kg}$ and density $9.2 \times 10^2\text{kgm}^{-3}$. When the system is placed in a liquid, it floats with wax just submerged. Find the density of the fluid. (04marks)

Let the density of the liquid = ρ

Upthrust = weight of the system

$$V\rho g = (2.6 \times 10^{-3} + 1 \times 10^{-2})g$$

$$\left(\frac{2.6 \times 10^{-3}}{8.4 \times 10^3} + \frac{1.0 \times 10^{-2}}{9.2 \times 10^2} \right) \rho = 1.26 \times 10^{-2}$$

$$\rho = 1.13 \times 10^3\text{kgm}^{-3}$$

(b) Explain the

(i) term laminar flow and turbulent flow. (04marks)

Laminar flow: Equidistant fluid layers from the axis of flow have the same velocity. Lines of flow are always parallel to the axis of flow

Turbulent flow: equidistant fluid layers from the axis of flow have different velocities. Lines of flow cross each other.

(ii) effects of temperature on viscosity of liquids and gases. (03marks)

- In liquids increasing temperature increases molecular speed and separation. This reduces the molecular attractive forces and viscosity reduces.

- In gases increase in temperature increases molecular speed and therefore momentum transfer when they collide increases. This increases viscosity.

(c) (i) distinguish between static pressure and dynamic pressure. (02marks)

- **Static pressure** at a point is the pressure which the fluid would have if were at rest.
- **Dynamic pressure** is the pressure due to fluid motion.

(ii) A pitot-static tube fitted with a pressure gauge is used to measure the speed of a boat at sea. Given that the speed of the boat does not exceed 10 mms^{-1} and the density of water is 1000 kgm^{-3} , calculate the minimum pressure on the gauge. (02marks)

$$\text{Maximum pressure} = \frac{1}{2} \rho v^2 = \frac{1}{2} \times 1050 \times 10^2 = 5.25 \times 10^4 \text{ Pa}$$

72. (a) Define the terms surface tension and surface energy. (01mark)

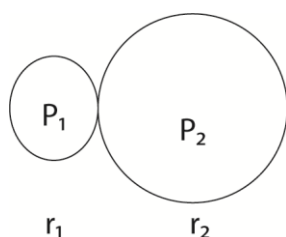
It is the work done per unit area in increasing surface area of a liquid under isothermal conditions.

(b) (i) Calculate the work done against surface tension in blowing a soap bubble of diameter 15mm, if the surface tension of soap solution is $3.0 \times 10^{-2} \text{ Nm}$. (03marks)

$$\text{New surface area created} = 2 \times 4\pi r^2$$

$$\begin{aligned} \text{Energy required} &= \gamma A = 3.0 \times 10^{-2} \times 2 \times 4\pi \times (7.5 \times 10^{-3})^2 \\ &= 4.24 \times 10^{-5} \text{ J} \end{aligned}$$

(ii) A soap bubble of radius r_1 is attached to another bubble of radius r_2 . If r_1 is less than r_2 . Show that the radius of curvature of the common interface is $\frac{r_1 r_2}{r_2 - r_1}$. (05marks)



For A

$$P_1 - H = \frac{4\gamma}{r_1} \dots\dots\dots (i)$$

For B

$$P_2 - H = \frac{4\gamma}{r_2} \dots\dots\dots (ii)$$

From equations (i) and (ii)

$$P_1 - P_2 = \frac{4\gamma}{r_1} - \frac{4\gamma}{r_2} \dots\dots\dots (iii)$$

$$P_1 - P_2 = \frac{4\gamma}{r} \dots\dots\dots (iv)$$

From equation (iii) and (iv)

$$\frac{4\gamma}{r} = \frac{4\gamma}{r_1} - \frac{4\gamma}{r_2}$$

$$\frac{1}{r} = \frac{1}{r_1} - \frac{1}{r_2}$$

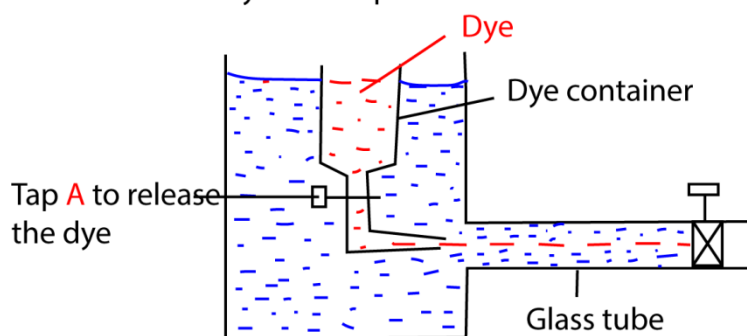
$$\frac{1}{r} = \frac{r_2 - r_1}{r_2 r_1}$$

$$r = \frac{r_2 r_1}{r_2 - r_1}$$

- (c) (i) Define coefficient of viscosity of a liquid. (01mark)
It is the tangential stress per unit velocity gradient.
- (ii) Describe an experiment to demonstrate streamline and turbulent flow in liquids. (06marks)

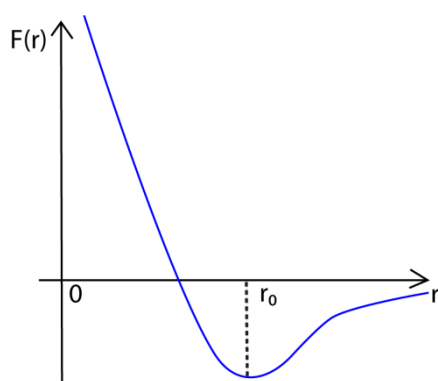
Experiment to demonstrate laminar and turbulent flow

Reynold's experiment



- Water is kept flowing at a constant velocity from a constant water tank.
- The rate of flow of a dye is controlled by a tap A.
- At low water velocity a streamline of a dye is observed flowing through water. This is laminar flow
- A turbulent flow is observed when the velocity of water is increased here the dye mixes with water.

- (d) (i) Sketch a graph of potential energy against separation of two molecules of a substance. (01mark)



- (ii) Explain the main features of the graph in (d)(i). (03marks)

At $r = r_0$, the resultant force is zero and the corresponding potential energy is minimum. So r_0 is the equilibrium separation

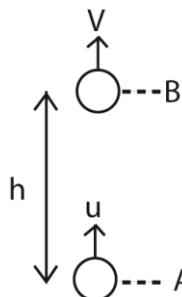
For $r < r_0$, the net force is repulsive, whereas $r > r_0$, the net force is attractive in order to

restore the e separation to the equilibrium separation of r_0 .

73. (a) (i) State the principle of conservation of mechanical energy. (01mark)

The total mechanical energy (K.E + P.E) of a body in an isolated system is constant.

(ii) Show that a stone thrown vertically upwards obeys the principle in (a)(i) above throughout its upward motion. (04marks)



At A, K.E = $\frac{1}{2}mu^2$, P.E = 0

Total energy at A = K.E + P.E = $\frac{1}{2}mu^2 + 0 = \frac{1}{2}mu^2$

At B, K.E = $\frac{1}{2}mv^2$; P.E = mgh

Total energy at B = $\frac{1}{2}mv^2 + mgh$

But $v^2 = u^2 - 2gh$

Total energy at B = $\frac{1}{2}m(u^2 - 2gh) + mgh = \frac{1}{2}mu^2$

$\therefore$ Total energy at A = total energy at B

(b)(i) A wind turbine made of a blade of radius, r , is driven by wind of speed, V . If σ is the density of air, derive an expression for minimum power, P , which can be developed by the turbine in terms of σ , r and V . (03marks)

$$\text{K.E} = \frac{1}{2}mv^2$$

Volume of air striking blade per second = $\pi r^2 v$

Mass of air striking the blade per second = $\pi r^2 v^3 \sigma$

$\therefore$ Power available = K.E of air per second

$$= \frac{1}{2}\pi r^2 v^3 \sigma$$

(ii) Explain why the power attained is less than the maximum value in (b)(i) above. (02marks)

- Velocity of air is not reduced to zero as assumed in the calculation which means that not all the K.E of the air per second is passed on to the blade
- Some power is wasted as heat due to friction forces in the parts

(c) State the conditions under which the following will be conserved in collision between two bodies

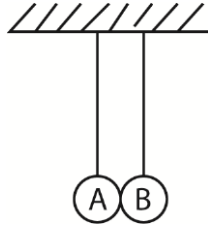
(i) linear momentum (10mark)

- no external force on interacting bodies

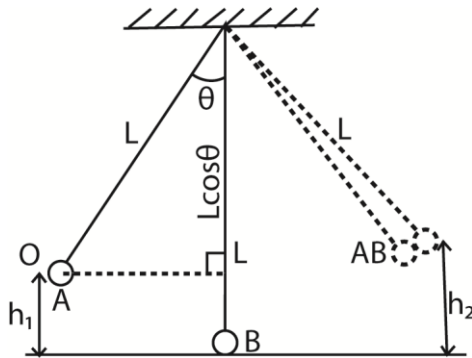
(ii) kinetic energy (01mark)

- The interaction must be perfectly elastic or must move separately after collision

(d) Two pendulum bobs A and B of equal length L , and masses $3M$ and M respectively. The pendula are hung with bobs in contact as shown below



The bob A is displaced such that the string makes an angle θ with the vertical and released. If A makes a perfectly inelastic collision with B, find the height to which B rises. (08marks)



Let h_1 be the height of A above the ground when the string is inclined at an angle θ to the vertical

$$h_1 = L - L \cos \theta$$

K.E of A before collision = Initial P.E of A at O

$$\text{Initial P.E at O} = 3Mgh_1 = 3MgL(1 - \cos \theta) \dots\dots\dots (i)$$

If u_1 is the velocity of A before collision

$$\frac{1}{2}(3M)u_1^2 = 3MgL(1 - \cos \theta)$$

$$u_1 = \sqrt{2gL(1 - \cos \theta)}$$

Momentum is conserved after collision, if v is the velocity after collision

$$3M\sqrt{2gL(1 - \cos \theta)} = (3M + M)v$$

$$v = \frac{3}{4}\sqrt{2gL(1 - \cos \theta)}$$

From conservation of energy, kinetic energy before collision = maximum potential energy gained.

$$\frac{1}{2} \times (3M + M) \left(\frac{3}{4}\sqrt{2gL(1 - \cos \theta)} \right)^2 = (3M + M)gh_2$$

$$\frac{1}{2} \times \frac{9}{16} (2gL(1 - \cos\theta)) = gh_2$$

$$h_2 = \frac{9}{16} gL(1 - \cos\theta)$$

74. (a) Define the following terms

(i) Stress (01mark)

Stress is the force acting per unit cross sectional area

Strain is the extension per unit original length.

(ii) Strain (01mark)

(b) The velocity, V , of sound travelling along a rod made of a material of Young's Modulus,

Y , and density, ρ is given by $V = \sqrt{\frac{Y}{\rho}}$.

Show that the formula is dimensionally consistent. (03marks)

$$[V] = LT^{-1}$$

$$[Y] = \frac{[F][L]}{[A][e]} = \frac{MLT^{-2}L}{L^2.L} = MLT^{-2}$$

$$[\rho] = ML^{-3}$$

$$[V] = \sqrt{\frac{[Y]}{[\rho]}} = \sqrt{\frac{MLT^{-2}}{ML^{-3}}} = LT^{-1}$$

Hence the formula is dimensionally consistent.

(c) State the measurement necessary in the determination of Young's Modulus of a metal wire. (02marks)

- Original length of the sample wire
- Diameter, d , of the wire to find $A = \frac{\pi d^2}{4}$
- Extension, e , of the wire
- load

(d) Explain why the following precautions are taken during an experiment to determine Young's Modulus of a metal wire.

(i) two long, thin wires of the same material are suspended from a common support. (02marks)

Long and thin to enable measurable extension

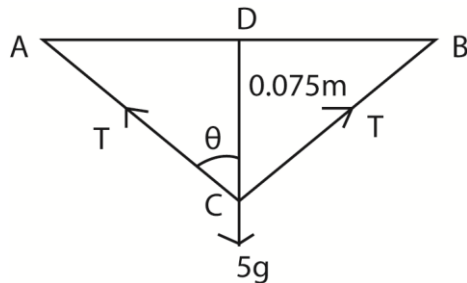
Same material and suspended from common support to cater for thermal expansion and other factors

(ii) the readings of the vernier are also taken when the loads are gradually removed in steps. (01marks)

To ensure that elastic limit is not exceeded, and to obtain average values for extensions.

- (e) The ends of a uniform wire of length 2.00m are fixed to points A and B which are 2.00m apart in the same horizontal line. When a 5kg mass is attached to the mid-point C of the wire, the equilibrium position of C is 7.5cm below the line AB. Given that Young's Modulus for the material of the wire is $2.0 \times 10^{11} \text{Pa}$, find

(i) the strain in the wire (03marks)



$$AC = CB = \sqrt{(0.075)^2 + 1^2} = 1.003\text{m}$$

$$ACB = 2 \times 1.003 = 2.006\text{m}$$

$$\text{Extension} = 2.006 - 2.000 = 0.006\text{m}$$

$$\text{Strain} = \frac{e}{L} = \frac{0.006}{2} = 3 \times 10^{-3}$$

(ii) the stress in the wire, (02marks)

$$\text{From } E = \frac{\text{Stress}}{\text{Strain}}$$

$$\text{Stress} = 2 \times 10^{11} \times 3 \times 10^{-3} = 6 \times 10^8 \text{Nm}^{-2}$$

(iii) The energy stored in the wire (04marks)

Resolving vertically;

$$T \cos \theta + T \cos \theta = mg$$

$$2T \cos \theta = mg \text{ but } \theta = \tan^{-1} \left(\frac{1}{0.075} \right) = 85.7^\circ$$

$$\therefore T = \frac{Mg}{2 \cos \theta} = \frac{5 \times 9.81}{2 \cos 85.7^\circ} = 327.1\text{N}$$

$$\text{Energy stored} = \frac{1}{2} T e = \frac{1}{2} \times 327.1 \times 6 \times 10^{-3} = 0.9813\text{J}$$

(iv) State any assumptions made. (01mark)

Elastic limit is not exceeded.

75. (a) Define surface tension and derive its dimensions (03marks)

Surface tension is the force per unit length acting perpendicularly to one side of an imaginary line.

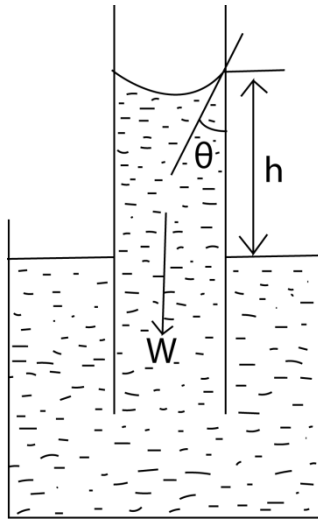
$$\gamma = \frac{\text{Force}}{\text{length}} = \frac{[Ma]}{[L]} = \frac{MLT^{-2}}{L} = MT^{-2}$$

(b) Explain using the molecular theory the occurrence of surface tension. (04 marks)

Molecules at the liquid surface have greater molecular separation than the equilibrium separation. These molecules experience greater attraction from their neighbours. This puts

them in a state of tension. Thus the liquid surface behaves like a stretched elastic skin, a phenomenon called surface tension

(c) Derive an experiment to measure surface tension of a liquid by the capillary tube method. (06marks)



A capillary tube of radius, r , is vertically placed in a liquid. The liquid rises until the vertical component of the upward forces due to surface tension is equal to the weight of the liquid column.

$$F\gamma\cos\theta = W$$

$$\gamma = \frac{F}{L}$$

$$F = \gamma L$$

$$L = 2\pi r$$

But $W = mg$ and $m = V\rho$ (where ρ is the density of the liquid in kg/m^3)

$$W = v\rho g = 2\pi r^2 h\rho g$$

$$F\gamma\cos\theta = 2\pi r^2 h\rho g$$

$$\gamma \cdot 2\pi r \cos\theta = 2\pi r^2 h\rho g$$

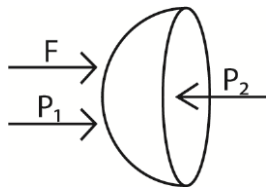
$$\gamma = \frac{hr\rho g}{2\cos\theta}$$

γ – coefficient of surface tension

θ – angle of contact

ρ – density of the liquid

(d) (i) Show that the excess pressure in a soap bubble is given by $P = \frac{4\gamma}{r}$, (03marks)



A soap bubble has two liquid surfaces in contact with air, one inside the bubble and the other outside the bubble.

The force, F , on one half of the bubble due to surfaces is thus $= \gamma \times 2\pi r \times 2 = 4\pi r\gamma$

For equilibrium of A, it follows that.

$$4\pi r\gamma + \pi r^2 \times P_1 = \pi r^2 \times P_2$$

Where P_2 , and P_1 are pressure inside and outside the bubble respectively

Simplifying

$$P_2 - P_1 = \frac{4\gamma}{r}$$

Therefore, excess pressure, $P = \frac{4\gamma}{r}$

- (ii) Calculate the total pressure within a bubble of air of radius 0.1mm in water if the bubble is formed 10cm below the water surface and surface tension of water is $7.27 \times 10^{-2} \text{Nm}^{-1}$. [Atmospheric pressure = $1.01 \times 10^5 \text{Pa}$] (05marks)

$$\text{Excess pressure} = \frac{2\gamma}{r} = \frac{2 \times 7.27 \times 10^{-2}}{0.1 \times 10^{-2}} = 1454 \text{Pa}$$

$$\begin{aligned} \text{Total pressure within the bubble} &= \text{atmospheric pressure} + h\rho g + \text{excess pressure} \\ &= 1.01 \times 10^5 + (0.1 \times 10^3 \times 9.81) + 1454 \\ &= 1.034 \times 10^5 \text{Pa} \end{aligned}$$

76. (a) (i) Define coefficient of viscosity and determine its dimensions. (04marks)

Coefficient of viscosity is the fractional force acting on an area of 1m^2 of a fluid when it is in a region of unit velocity gradient.

$$\eta = \frac{\text{Force}}{\text{velocity gradient}} = \frac{F}{A(V_2 - V_1)/L}$$

$$[\eta] = \frac{[F]}{[A][(V_2 - V_1)/L]} = \frac{MLT^{-2}}{L^2 \times (\frac{LT^{-1}}{L})} = ML^{-1}T^{-1}$$

- (ii) The resistive force on a steel ball bearing of radius, r , falling with speed, V , in a liquid of viscosity, η is given by $F = K\eta rV$, where K is a constant. Show that K is dimensionless. (04marks)

$$K = \frac{F}{\eta rV}$$

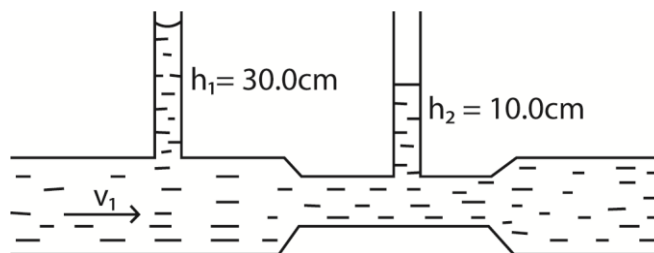
$$[K] = \frac{[F]}{[\eta][r][V]} = \frac{MLT^{-2}}{(ML^{-1}T^{-1})(L)(LT^{-1})} = 1$$

$\therefore K$ is dimensionless

- (b) Write down Bernoulli's equation for fluid flow, defining all symbols used (03marks)

$P + \frac{1}{2}\rho v^2 + h\rho g = \text{constant}$, where P = pressure, ρ = density of fluid, v = velocity of fluid, h = height above a reference level and g = acceleration due to gravity.

- (c) A venturi meter consists of a horizontal tube with a constriction which replaces part of the piping system as shown below



If the cross-sectional area of the main pipe is $5.81 \times 10^{-3} \text{m}^2$ and that of the constriction is $2.58 \times 10^{-3} \text{m}^2$, find the velocity v_1 of the liquid in the main pipe. (5marks)

From $P + \frac{1}{2}\rho v^2 + h\rho g = \text{constant}$

$$P_1 + \frac{1}{2}\rho v_1^2 + h_1\rho g = P_2 + \frac{1}{2}\rho v_2^2 + h_2\rho g \text{ but } P_1 = P_2$$

$$g(h_1 - h_2) = \frac{1}{2}(v_2^2 - v_1^2)$$

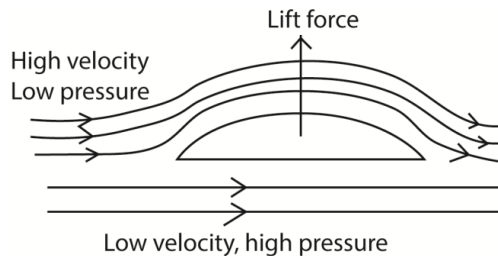
Also $A_1v_1 = A_2v_2$ from continuity equation

$$\frac{v_1}{v_2} = \frac{A_1}{A_2} \Rightarrow v_2 = \frac{A_1v_1}{A_2}$$

$$\therefore g(h_1 - h_2) = \frac{1}{2}\left(\left(\frac{A_1}{A_2}\right)^2 - 1\right)v_1^2$$

$$0.2 \times 9.81 = \frac{1}{2}\left[\left(\frac{5.81}{2.58}\right)^2 - 1\right]v_1^2; v_1 = 0.98\text{ms}^{-1}$$

(d) Explain the origin of the lift on an aeroplane at take-off. (04marks)



- Air flows above the wing of a plane at high velocity hence low pressure.
- Below the wings, air flows at low velocity and hence high pressure.
- The difference in pressure cause a lift force, therefore net upward force.

77. (a) (i) State Newton's laws of motion (03marks)

- A body continues in its state of rest or uniform motion in a straight line unless acted upon by an external force
- The rate of change of momentum of a body is directly proportional to applied force and takes place in the direction of the force
- For every action, there is an equal and opposite reaction

(ii) Define impulse and derive its relation to linear momentum of the body on which it acts. (03marks)

Impulse is the product of force and the time for which it acts.

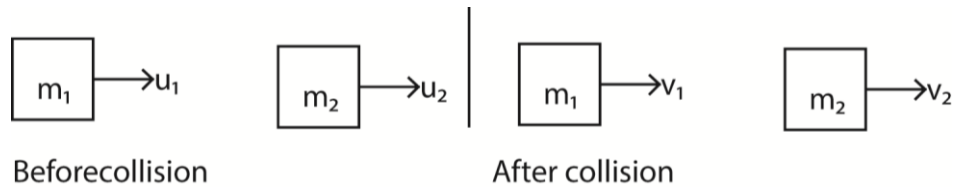
$$F = ma$$

$$F = m\left(\frac{v-u}{t}\right)$$

$$Ft = mv - mu$$

Hence impulse = change in momentum

(b) A body of mass m_1 and velocity, u_1 collides head on with a body of mass, m_2 having velocity, u_2 in the same direction as u_1 . Use Newton's laws to show that the quantity $m_1u_1 + m_2u_2$ is conserved. (5marks)



During collision, each body exerts a force of impact on each other according to Newton's second law of motion.

Let I be the impulse on A, then the impulse on B = $-I$.

$$I = M_1 v_1 - m_1 u_1 \dots\dots\dots (i)$$

$$-I = m_2 v_2 - m_2 u_2 \dots\dots\dots (ii)$$

Equation (i) + equation (ii)

$$0 = M_1 v_1 - m_1 u_1 + m_2 v_2 - m_2 u_2$$

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

- (c) A ball of mass 0.5kg is allowed to drop from rest, from a point a distance of 5.0m above a horizontal concrete floor. When the ball first hits the floor, it rebounds to a height of 3.0m.

- (i) What is the speed of the ball just after the first collision with the floor? (3marks)

$$\text{From } v^2 = u^2 + 2as$$

$$v^2 = 0 + 2 \times 9.81 \times 5$$

$$v = 9.9 \text{ms}^{-1}$$

$$\text{After collision, using } v^2 = u^2 + 2as$$

$$0 = u^2 - 2 \times 9.81 \times 3$$

$$u = 7.672 \text{ms}^{-1}$$

- (ii) If the collision lasted 0.01s, find the average force which the floor exerts on the ball. (02marks)

Impulse = change in momentum.

$$F = m \left(\frac{v-u}{t} \right) = \frac{0.5(7.672-9.9)}{0.01} = 878.9 \text{N}$$

78. (a) (i) state Archimedes' Principle. (01mark)

Archimedes' Principle states that when a body is wholly or partially immersed in a fluid, it experiences an upthrust equal to the weight of fluid displaced.

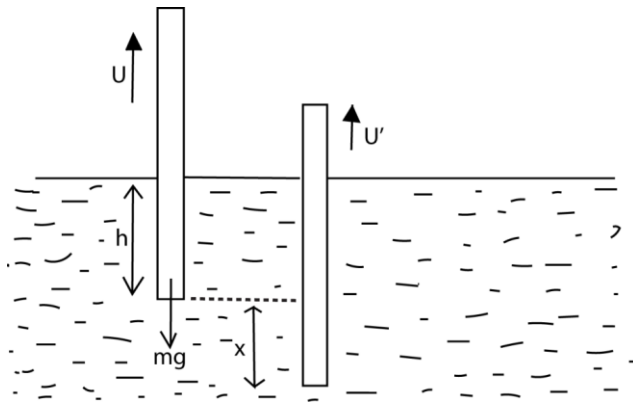
- (ii) What is simple harmonic motion? (02marks)

Simple harmonic motion is a periodic motion of a body in which the acceleration due to of the body is directly proportional to the displacement from a fixed point and directed to that fixed point.

- (b) A uniform cylindrical rod of length 0.08m, cross sectional area 0.02m^2 and density 900kgm^{-3} floats vertically in a liquid of density 1000kgm^{-3} . The rod is displaced through a distance of 0.005m and released.

- (i) Show that the rod performs simple harmonic motion. (05marks)

Consider a cylinder of mass, m , floating vertically in a liquid of density, ρ , to a depth, h



At equilibrium position, the body sinks to a height, h , below the liquid surface

Up thrust = weight of the body

But $U = Ahpg$

$$mg = Ahpg \dots\dots\dots(i)$$

A is the cross section area of a cylinder

When a body is displaced through a distance, x , and released,

$$\text{Up thrust} = (h + x) Apg$$

$$\text{Resultant force} = mg - (h + x) Apg$$

$$\text{But, } m = Ah\rho$$

$$Ahp = Ahpg - Ahpg - Apgx$$

$$a = \frac{-Apgx}{Ahp} = \frac{-gx}{h}$$

$$\text{But } a = -\omega^2 x$$

Hence it performs simple harmonic motion with $\omega^2 = \frac{g}{h}$

(ii) Find the frequency of the resultant oscillation. (04marks)

$$\text{From } \omega = 2\pi f$$

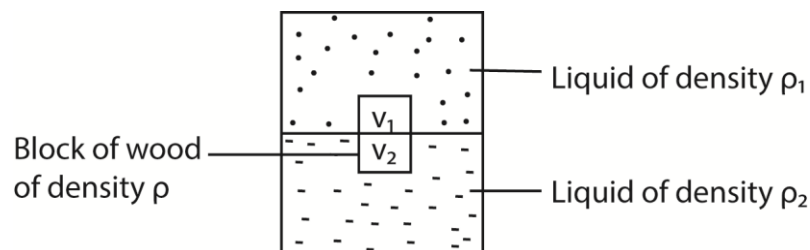
$$4\pi^2 f^2 = \frac{g}{h}$$

$$f = \frac{1}{2\pi} \sqrt{\frac{g}{h}} = \frac{1}{2\pi} \sqrt{\frac{9.81}{0.08}} = 1.76$$

(iii) Find the velocity of the rod when it is a distance of 0.004m above the equilibrium position. (03marks)

$$v = \omega \sqrt{a^2 - x^2} = 2\pi f \sqrt{a^2 - x^2} = 2\pi \times 1.76 \sqrt{0.005^2 - 0.003^2} = 0.04 \text{ms}^{-1}$$

(c)



A block of wood of density ρ floats at the interface between immiscible liquids of densities ρ_1 and ρ_2 as shown in the figure above.

(i) Show that the ratio of volumes v_1 to v_2 of the block in the two liquids is given by

$$\frac{v_1}{v_2} = \frac{\rho_2 - \rho}{\rho - \rho_1} \text{ (04marks)}$$

Total upthrust = weight of a liquid displaced
= weight of floating solid

$$\Rightarrow V_1 \rho_1 g + V_2 \rho_2 g = (V_1 + V_2) \rho g$$

$$V_1(\rho_1 - \rho) = V_2(\rho - \rho_2)$$

$$\frac{V_1}{V_2} = \frac{\rho - \rho_2}{\rho_1 - \rho}$$

- (ii) What happens when this block of wood is replaced with a denser one? (01mark)

The block sinks deeper

79. (a) Distinguish between scalar and vector quantities. Give two examples each. (03marks)

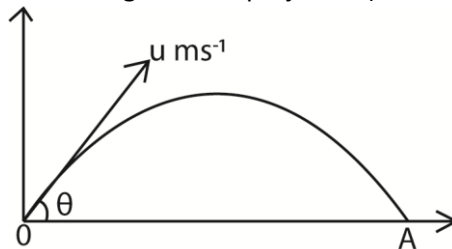
A scalar quantity has magnitude but no direction, e.g. volume, Mass, speed, density, temperature

A vector quantity has magnitude and direction, e.g. acceleration, velocity, and displacement, momentum, impulse

- (b) (i) Define the time of flight and range as applied to projectile motion. (02 marks)

Time of flight is the time taken by a projectile to move from the point of projection to where it lands

- (ii) A projectile is fired in air with a speed $u \text{ ms}^{-1}$ at an angle θ to the horizontal. Find the time of flight of the projectile (02marks)



At point A, the vertical distance covered above the point of projection is zero

$$\text{From } s = ut + \frac{1}{2}at^2$$

$$0 = u \sin \theta \times t - \frac{1}{2}gt^2$$

$$t = \frac{2u \sin \theta}{g}$$

therefore the time of flight of projectile is $\frac{2u \sin \theta}{g}$.

- (c) State the conditions for equilibrium of a rigid body under action of coplanar forces. (02marks)

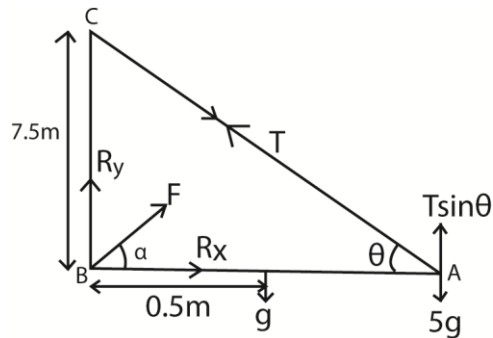
- The algebraic sum of all the forces acting in one direction is equal to the algebraic sum of all the forces acting in the opposite direction.

Or

- The algebraic sum of all moments of forces at any given point is equal to zero.

- (d) A mass of 5.0kg is suspended from the end A of a uniform beam of mass 1kg and length 1.0m. The end B of the beam is hinged in a wall. The beam is kept horizontal by a rope attached to A and a point C, in the wall at a height 0.75m above B.

- (i) Draw a sketch diagram to show the forces acting on the beam. (02marks)



- (ii) Calculate the tension in the rope. (04marks)

Moments At B: $T \times 1 \sin \theta = 1.0 \times 0.5 + 5g \times 1$

But $\tan \theta = 36.9^\circ$

$$T = \frac{5.5 \times 9.8}{\sin 36.9} = 89.9 \text{ N}$$

- (iii) What is the force exerted by the hinge on the beam? (05marks)

$$R_x = 0.8T = 0.8 \times 89.9 = 71.9 \text{ N}$$

$$R_y = 6 \times 9.81 - 0.6 \times 89.9 = 4.9 \text{ N}$$

$$\text{Resultant, } R = \sqrt{R_x^2 + R_y^2} = \sqrt{71.9^2 + 4.9^2} = 72.1 \text{ N}$$

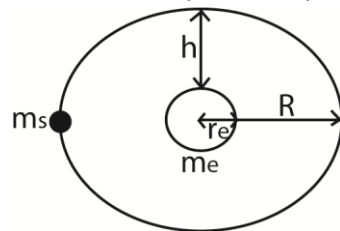
$$\text{Direction: } \tan \alpha = \frac{R_y}{R_x} = \frac{4.9}{71.9}; \alpha = 3.89^\circ$$

80. (a) State Kepler's laws of gravitation (03marks)

- Planets describe ellipses about the sun as one focus
- The imaginary line joining the sun and planet sweeps out equal areas in equal time intervals
- The square of the periodic time of revolution of planets about the sun are proportional to the cubes of their mean distance from the sun

- (b) (i) Show that the period of a satellite in a circular orbit of radius r about the earth is

given by $T = \left(\frac{4\pi^2}{GM_s} \right)^{\frac{1}{2}} r^{\frac{3}{2}}$ where G is the universal constant and M_s is the mass of the earth. (05marks)



Centripetal force required to maintain circular motion is provided by the gravitational force of attraction between the earth and satellite.

From Newton's of gravitation

$$F = \frac{Gm_s m_e}{R^2}$$

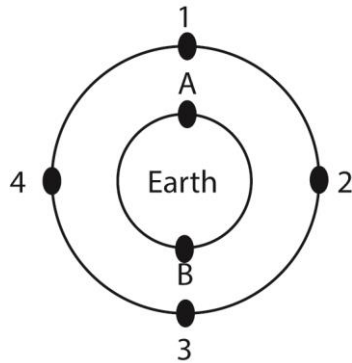
$$\therefore m_s \omega^2 R = \frac{Gm_s m_e}{R^2}$$

$$\omega^2 = \frac{Gm_e}{R^3} \text{ but } \omega = \frac{2\pi}{T}$$

$$\Rightarrow \left(\frac{2\pi}{T}\right)^2 = \frac{Gm_e}{R^3}$$

$$T = \left(\frac{4\pi^2}{GM_s}\right)^{\frac{1}{2}} r^{\frac{3}{2}}$$

- (ii) Explain briefly how world-wide radio or television communication can be achieved with the help of satellites. (04marks)



- A set of satellites is launched in parking orbit as shown in the diagram above.
- A radio signal from A is transmitted to a geosynchronous satellite 1
- The signals are retransmitted from satellite 1 to geosynchronous satellite 2, then to 3 and finally to B.

- (c) A satellite of mass 100kg is in a circular orbit at height of 3.39×10^7 m above the earth's surface.

- (i) Find the mechanical energy of the satellite (04marks)

Mechanical energy, M.E. = $\frac{-Gm_em}{2r}$; $r = (3.59 \times 10^7 + 6.4 \times 10^6) = 4.23 \times 10^7$ m

$$M.E = \frac{-6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 100}{2 \times 4.23 \times 10^7} = -4.71 \times 10^8 \text{J}$$

- (ii) Explain what would happen if the mechanical energy was decreased. (04marks)

From M.E. = $\frac{-Gm_em}{2r}$, when mechanical energy decreases, r , also decreases.

Therefore the satellite drops into an orbit of smaller radius. If mechanical energy continued to decrease, the satellite would enter the earth's atmosphere and would eventually burn out due to frictional resistance. Velocity and kinetic energy increase.



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1. (a) (i) State any three properties of ultraviolet radiation. (03marks)
 (ii) What is a black body? (01mark)
- (b) A cylindrical metal rod with a well- insulated curved surface has one end blackened and then exposed to thermal radiation from a body at a temperature 500K. If the equilibrium temperature of the blackened end is 400K and the length of the rod is 10cm, calculate the temperature of the other end. [Thermal conductivity of the metal = $500\text{Wm}^{-1}\text{K}^{-1}$] (04marks)
- (c) (i) Describe Electrical method of determining the specific heat capacity of a good conducting solid. (06marks)
 (ii) Give two reasons why the value obtained using the method in (c)(i) may not be accurate. (02marks)
- (d) Explain why cloudy nights are warmer than cloudless ones.
2. (a)(i) What is meant by a reversible process? (02marks)
 (ii) Distinguish between a saturated vapour and unsaturated vapour. (02marks)
 (iii) Explain why evaporation causes cooling (03marks)
- (b) Describe an experiment to determine the temperature dependence of saturated vapour pressure of water. (07marks)
- (c) (i) State Dalton's law of partial pressures. (07marks)
 (ii) A sealed container has liquid water, water vapour and air all at 27°C . The total pressure inside the container is 69cmHg. When the temperature is raised to 85°C , the total pressure changes to 96cmHg. If the saturated vapour pressure of water at 27°C is 5cmHg and water vapour remains saturated, calculate the saturated vapour pressure of water at 85°C . (05marks)
3. (a) Define the following:
 (i) Thermal conductivity. (01marks)
 (ii) Specific latent heat of vaporization. (01mark)
- (b) A boiler with a base made of rod steel 15cm thick, rests on a hot stove. The area of the bottom of the boiler is $1.5 \times 10^3 \text{ cm}^2$. The water inside the boiler is at 100°C . If 750g of water is evaporated every 5 minutes, find the temperature of the surface of the boiler in contact with the stove. [Thermal conductivity of steel = $50.2\text{Wm}^{-1}\text{K}^{-1}$, specific latent heat of vaporization of water = $2.26 \times 10^6 \text{ Jkg}^{-1}$]
- (c) Hot water in a metal tank is kept constant at 65°C by an immersion heater in the water. The tank has lagging all around it of thickness 20mm and thermal conductivity $0.04\text{Wm}^{-1}\text{K}^{-1}$ and its surface area is 0.5m^2 . The heat lost per second by the lagging is 0.8W per degree excess

above the surroundings. Calculate the power of immersion heater if the temperature of the surroundings is 15°C . (05marks)

(d)(i) Define thermometric property (01mark)

(ii) Define how a liquid-in-glass thermometer can be used to measure temperature in degrees Celsius. (04marks)

(iii) A thermometer is constructed with a liquid which expands according to relation.

$V_t = V_0(1 + \alpha t + \beta t^2)$. Where V_t is the volume at $t^{\circ}\text{C}$ and V_0 is the volume at 0°C on the scale of the gas thermometer and α and β are constants.

Given that $\alpha = 1000\beta$, what will the liquid thermometer read when the gas thermometer reads 50°C .

4. (a) Define the following quantities:

(i) Thermometric property (01mark)

(ii) Specific heat capacity (01mark)

(b) (i) state two examples of commonly used thermometric properties. (01mark)

(ii) Describe briefly how to determine the lower and upper fixed points for an uncalibrated liquid-in-glass thermometer (04marks)

(c) (i) Describe with the aid of a diagram, an experiment to determine the specific heat capacity of a liquid using the continuous flow method. (07marks)

(ii) State two advantages of the continuous flow method over the method of mixtures. (01mark)

(iii) State two disadvantages of the method in (c)(i) (01mark)

(d) The brake lining of the wheel of a car of mass 800kg have total mass of 4.8kg and are made of a material of specific heat capacity $1200\text{Jkg}^{-1}\text{K}^{-1}$. If the car is at 15ms^{-1} and is brought to rest by applying the brakes, calculate the maximum possible temperature rise of the brake lining. (04marks)

5. (a) (i) What is meant by conduction of heat? (01mark)

(ii) Explain why mercury conducts heat better than water. (03marks)

(iii) Explain the occurrence of land and sea breezes. (06marks)

(b) A copper sphere of radius 7cm and density 900kgm^{-3} , is heated to a temperature of 127°C and then transferred to an evacuated enclosure whose walls are at a temperature of 27°C . Calculate

(i) net rate of loss of heat by the copper sphere

(ii) temperature of copper sphere after 5minutes

(c) Explain why heating system based on the circulation of steam are more efficient than those based on circulation of boiling water. (02marks)

6. (a) (i) what is meant by a black body? (02marks)

(ii) Give two examples of a black body. (01mark)

(b) With aid of graphs describe how radiation emitted by a black body varies with wavelength for two temperatures.

- (c) (i) Define thermal conductivity. (01mark)
(ii) Describe an experiment to determine thermal conductivity of glass. (07marks)
- (d) Radiation from the sun falls normally on a blackened roof measuring 20m x 50m. If half of the solar energy is lost in passing through the earth's atmosphere, calculate the energy incident on the roof per minute. [Temperature of the sun's surface = 6000K; radius of the sun = 7.5×10^8 m, distance of the sun from the earth = 1.5×10^{11} m]
7. (a) (i) State the thermometric property used in a constant-volume gas thermometer (01mark)
(ii) Give two characteristics of a good thermometric property, (02marks)
- (b) (i) Describe the steps taken to set up a Celsius scale of temperature for a mercury-in glass thermometer. (04marks)
(ii) State four disadvantages of a mercury in glass thermometer. (04marks)
- (c) Describe with the aid of a diagram the operation of an optical pyrometer (06marks)
- (d) When oxygen is withdrawn from a tank of volume 50L, the reading of a pressure gauge attached to the tank drops from 4.4×10^5 Pa to 7.8×10^5 Pa. If the temperature of the gas remaining in the tank falls from 30°C to 10°C, calculate the mass of oxygen withdrawn.
8. (a)(i) What is meant by boiling point? (01marks)
(ii) Explain why the boiling point of a liquid increases with an increase in the external pressure. (05marks)
- (b) (i) Explain how the pressure of a fixed mass of a gas can be increased at
- Constant temperature (03marks)
 - Constant volume (03marks)
- (c) Sketch a pressure versus volume curve for a real gas undergoing compression (0marks)
- (d) The cylinder of an exhaust pump has a volume of 5cm³. If it is connected through a valve to a flask of volume 225 cm³ containing air at a pressure of 75cmHg, calculate the pressure of air in the flask after two strokes of the pump, assuming that the temperature of the air remains constant.
9. (a) (i) Define thermal conductivity. (01mark)
(ii) Explain the mechanism of heat transfer by convection. (03marks)
- (b) (i) State Newton's law of cooling (01mark)
(ii) Describe briefly an experiment to verify Newton's law of cooling. (05marks)
- (c) A wall is constructed using two types of bricks. The temperatures of the inner and outer surface of the wall are 29°C and 21°C respectively. The value of thermal conductivity for the inner brick is $0.4 \text{ W m}^{-1} \text{ K}^{-1}$ and that of the outer brick is $0.8 \text{ W m}^{-1} \text{ K}^{-1}$.
- (i) Explain why in a steady state the rate of thermal energy transfer is the same in both layers. (0marks)
- (ii) If each layer is 12 cm thick, find the temperature at the interface between the layers. (04marks)
- (d) Explain the greenhouse effect and how it leads to a rise in the earth's temperature. (04marks)
10. (a) (i) Define specific latent heat of fusion (01mark)
(ii) State the effect of impurities on melting point (01mark)
- (b) Explain why there is no change in temperature when a substance is melting (04marks)

- (c) With the aid of a labelled diagram, describe the continuous flow method of measuring the specific heat capacity of a liquid. (06marks)
- (d) In an experiment to determine the specific latent heat of fusion of ice, heating coil is placed in a filter funnel and surrounded by lumps of ice. The following sets of reading were obtained.

V(V)	4.0	6.0
I(A)	2.0	3.0
Mass of water m (g) collected in 500s	14.9	29.8

Calculate

- (i) Specific latent heat of fusion of ice (04marks)
 - (ii) Energy gained in the course of obtaining the first set of readings (03marks)
- (e) Why are two sets of reading necessary in (d) above. (01mark)
11. (a) (i) State Dalton's law of partial pressures. (01marks)
- (ii) Using the expression $p = \frac{1}{3} \rho c^2$, where p is the pressure of a gas of density ρ and mean square speed c^2 , derive Dalton's law of partial pressures for two gases. (05marks)
- (b) (i) What is meant by isothermal process and adiabatic process. (02marks)
- (ii) Explain why adiabatic expansion of a gas causes cooling (03marks)
- (c) A gas at a temperature of 17°C and pressure $1.0 \times 10^5 \text{ Pa}$ is compressed isothermally to half its original volume. It is then allowed to expand adiabatically to its original volume
- (i) Sketch a P-V curve for the above process (02marks)
 - (ii) If the specific heat capacity at constant pressure is $2100 \text{ J mol}^{-1} \text{ K}^{-1}$ and at constant volume is $1500 \text{ J mol}^{-1} \text{ K}^{-1}$, find the final temperature of the gas (04marks)
- (d) (i) What is meant by saturated vapour? (01mark)
- (ii) Explain briefly the effect of altitude on the boiling point of a liquid (02marks)
12. (a)(i) Define a black body. (01mark)
- (ii) Sketch and explain graphs of intensity versus wavelength for three different temperatures of a black body. (03marks)
- (b) Describe with the aid of a diagram how an optical radiation pyrometer is used to measure temperature. (06marks)
- (c) (i) State Prevost's theory of heat exchanges (01marks)
- (ii) Metal sphere of radius 1.5cm is suspended within an evacuated enclosure whose walls are at 320K. The emissivity of the metal is 0.40. Find the power input required to maintain the sphere at a temperature of 320K, if heat conduction along the support is negligible. (04marks)
- (d) A metal boiler is 1.5cm thick. Find the difference in temperature between the inner and outer surfaces if 40kg of water evaporate from the boiler per meter squared per hour. [Latent heat of vaporization of water = 2268 kJ kg^{-1} , Thermal conductivity of the metal of the boiler = $63 \text{ W m}^{-1} \text{ K}^{-1}$] (05marks)

- 13.(a) (i) State four desirable properties a material must have to be used as a thermometric substance. (02marks)
- (ii) State why scales of temperature based on different thermometric properties may not agree. (01mark)
- (b) With the aid of a diagram explain how a bolometer is used to detect thermal radiation. (06marks)
- (c) Describe, with the aid of a diagram an experiment to determine specific heat of vaporization of steam using the method of mixtures. (07marks)
- (d) A 600W electricity heater is used to raise the temperature of a certain mass of water in a thermos flask from room temperature to 80°C . The same temperature rise is obtained when steam from a boiler is passed into an equal mass of water at room temperature in the same time. If 16g of water were being evaporated every minute in the boiler, find the specific latent heat of vaporization of steam, assuming no heat losses. (04marks)
- 14.(a) Define the following
- (i) Absolute zero (01marks)
- (ii) Cooling correction (01marks)
- (b) (i) State Dalton's law of partial pressures (01mark)
- (ii) The kinetic theory expression for the pressure, P , of ideal gas of density, ρ , and mean square speed, c^2 is $P = \frac{1}{3}\rho c^2$. Use the expression to deduce Dalton's law (03marks)
- (c) Explain clearly the steps taken to determine the cooling correction when measuring the specific heat capacity of a poor conductor by the method of mixtures. (07marks)
- (d) The density of air at 0°C and pressure of 101kPa is 1.29kgm^{-3} . Calculate pressure of 300kPa. (03marks)
- 15.(a) Define thermal conductivity of material and state its units. (02marks)
- (b) Describe an experiment to determine the thermal conductivity of copper. (06marks)
- (c) A double glazed window has two glasses each of thickness 4.0mm separated by a layer of air of thickness 1.5mm. If the two inner air-glass surfaces have steady temperature of 20°C and 4°C respectively. Find the
- (i) temperatures of the outer air-glass surfaces (03marks)
- (ii) the amount of heat that flows across an area of the window of 2m^2 in 2 hours. [Conductivity of glass = $0.72\text{Wm}^{-1}\text{K}^{-1}$ and that of air = $0.025\text{Wm}^{-1}\text{K}^{-1}$]
- (d)(i) What is a black body? (01mark)
- (ii) Explain how a welder can protect the eyes from damage. (03marks)
- (iii) Calculate the wavelength of the radiation emitted by a black body at 6000K [Wien's displacement constant = $2.9 \times 10^{-3}\text{mK}$] (02marks)
- 16.(a) (i) State two differences between saturated and unsaturated vapours. (02marks)
- (ii) Sketch graphs of vapour against temperature for an ideal gas and for saturated water vapour originally at 0°C (03marks)

- (b) The specific heat capacity of oxygen at constant volume is $719 \text{ J kg}^{-1} \text{ K}^{-1}$ and its density at standard temperature and pressure is 1.429 kg m^{-3} . Calculate the specific heat capacity of oxygen at constant pressure (04marks)
- (c) (i) With the aid of a labelled diagram, describe an experiment to determine standard saturated vapour pressure of water. (05marks)
- (ii) State how the experiment set up in (c) (i) may be modified to determine a saturated vapour pressure of above atmospheric pressure (01marks)
- (d)(i) Define ideal gas (01mark)
- (ii) State and explain the conditions under which real gases behave as ideal gases. (04marks)
17. (a) (i) What is a black body?(01marks)
- (ii) Explain with the aid of a diagram how black body can be approximated. (03marks)
- (iii) With the aid of sketch graphs explain the salient features of the spectral distribution of black body radiation (04 marks)
- (b) Give four properties of ultraviolet radiation. (02marks)
- (c) Describe an experiment to compare the energy radiated by two surfaces at different temperatures (04marks)
- (d) (i) State Stefan's law. (01mark)
- (ii) The earth receives energy from the sun at the rate of $1.4 \times 10^3 \text{ W m}^{-2}$. If the ratio of the earth's orbit to the sun's radius is 216, calculate the surface temperature of the sun. (05marks)
18. (a) Define specific latent heat of vaporization. (01mark)
- (b) With the aid of labelled diagram, describe an experiment to measure the specific latent heat of vaporization of a liquid using an electrical method. (07marks)
- (c) Explain the effect of pressure on the boiling point of a liquid. (02marks)
- (d) A liquid of specific heat capacity $2.8 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$ and specific latent heat of vaporization $9.00 \times 10^5 \text{ J kg}^{-1}$ is contained in a flask of heat capacity 800 J K^{-1} at a temperature of 32°C . An electric heater rated 1 kW is immersed in 2.5 kg of the liquid and switched on for 12 minutes, calculate the amount of liquid that boiled off, given that the boiling point of the liquid is 80°C . (06marks)
- (e) (i) Two thermometers are used to measure the temperature of a body. Explain why the temperatures may be different. (02marks)
- (ii) A platinum resistance thermometer has a resistance of 5.42Ω at the triple point of water. Calculate the resistance at a temperature of 50.0°C . (02marks)
19. (a) Define
- (i) Specific heat capacity (01mark)
- (ii) Specific latent heat of vaporization of a liquid. (01 mark)

- (b) With the aid of a labelled diagram, describe the electrical method of determining the specific heat capacity of a solid (07marks)
- (c) An electrical heater rated 48W, 12V is placed in a well-insulated metal of mass 1.0kg at a temperatures of 18°C. When power is switched on for 5minutes, the temperature of the metal rises to 34°C. Find the specific heat capacity of the metal (04marks)
- (d) (i) State Newton's law of cooling (01marks)
- (ii) Use Newton's law of cooling to show that $\frac{d\theta}{dt} = -k(\theta - \theta_R)$
- Where $\frac{d\theta}{dt}$ is the rate of fall of temperature, and θ_R is the temperature of the surrounding.
- (e) Explain why evaporation causes cooling. (03marks)
20. (a) The pressure, P, of an ideal gas is given by $P = \frac{1}{3}\rho c^2$, where ρ is the density of the gas and c^2 its mean square speed.
- (i) Show clearly the steps taken to derive this expression (06marks)
- (ii) State the assumptions made in deriving this expression (02marks)
- (b) Sketch the pressure versus volume curve for a real gas for temperatures above and below the critical temperature. (03marks)
- (c) For 1 mole of a real gas, the equation of state is $\left(P + \frac{a}{V^2}\right)(V - b) = RT$
- Explain the significance of the terms $\frac{a}{V^2}$ and b. (02marks)
- (d) A balloon of volume $5.5 \times 10^{-2} \text{m}^3$ is filled with helium to a pressure of $1.10 \times 10^5 \text{Nm}^{-2}$ at a temperature of 20°C. Calculate the
- (i) the number of helium atoms in the balloon (03marks)
- (ii) net force acting on the square meter of material of the balloon if the atmospheric temperature is $1.01 \times 10^5 \text{Nm}^{-2}$ (04marks)
21. (a) (i) Define thermal conductivity of a material (01mark)
- (ii) Describe an experiment to determine the thermal conductivity of copper. (06marks)
- (b) (i) What is a black body? (01 marks)
- (ii) Describe how infrared radiation can be detected using a bolometer. (03marks)
- (iii) Give one characteristic property of infrared radiation. (01mark)
- (c) (i) A spherical black body of radius 2.0cm at -73°C is suspended in an evacuated enclosure whose walls are maintained at 27°C. If the rate of exchange of thermal energy is equal to 1.85Js^{-1} , find the value of Stefan's constant, (05marks)
- (ii) Calculate the wavelength at which the radiation emitted by the enclosure has maximum intensity (03mark)

22. (a)(i) Define the terms specific heat capacity and specific latent heat of fusion (02marks)
 (ii) Explain the changes that take place in the molecular structure of substances during fusion and evaporation (04marks)
- (b) With the aid of a labelled diagram describe an experiment to determine the specific heat capacity of a liquid using the continuous flow method. (08marks)
- (c) Steam at 100°C is passed into a copper calorimeter of mass 150g containing 340g of water at 15°C . This is done until the temperature of the calorimeter and its content is 71°C . If the mass of the calorimeter and its content is found to be 525g, calculate the specific latent heat of vaporization of water. (06marks)
23. (a) (i) Define saturated vapour pressure. (01mark)
 (ii) Describe with the aid of a diagram, how saturated vapour pressure of a liquid can be determined at a given temperature. (06marks)
- (b) Use the kinetic theory to explain the following observations
 (i) Saturated vapour pressure of a liquid increases with temperature. (03marks)
 (ii) Saturated vapour pressure is not affected by decrease in volume at constant pressure. (03marks)
- (c) When hydrogen gas is collected over water, the pressure in the tube at 15°C and 75°C are 65.5cm and 105.6cm of mercury respectively. If the saturated vapour pressure at 15°C is 1.42cm of mercury, find its value at 75°C (04marks)
- (d) Explain why the molar heat capacity of an ideal gas at constant pressure differs from the molar heat capacity at constant volume (03marks)
24. (a) (i) Define thermal conductivity. (01mark)
 (ii) Compare the mechanism of heat transfer in poor conductor and good conductor. (05marks)
- (b) Describe, with the aid of a diagram how you would measure the thermal conductivity of a poor conductor, stating the necessary precautions (08marks)
- (c) A cylindrical iron vessel with a base of diameter 15cm and thickness 0.30cm has its base coated with a thin film of soot of thickness 0.10cm. It is then filled with water at 100°C and placed on a large block of ice at 0°C . Calculate the initial rate at which the ice will melt (06marks) (thermal conductivity of soot = $0.12\text{Wm}^{-1}\text{K}^{-1}$)
25. (a)(i) State Boyles law (01mark)
 (ii) Describe an experiment to verify Boyles' law (06mark)
 (iii) Explain why the pressure of a fixed mass of a gas rises if its temperature is increased. (02marks)
- (b) (i) Define the term thermometric property and give four examples (03marks)
 (ii) State two qualities of a good thermometric property. (01mark)
- (c) (i) With reference to a liquid in glass thermometer, describe the step involved in setting up a Kelvin scale of temperature (03marks)
 (ii) State one advantage and one disadvantage of the resistance thermometer. (01mark)
- (d) A resistance thermometer has resistance of 21.42Ω at the ice point, 29.10Ω at steam point and 28.11Ω at some unknown temperature θ . Calculate θ on the scale of this thermometer. (03marks)

26. (a) Define specific heat capacity of a substance and state its units (02marks)
- (b) (i) Describe how specific heat capacity of a liquid can be obtained by continuous flow method. (07marks)
- (ii) State one disadvantage of this method. (01mark)
- (c) An electric kettle rated 1000W, 240V is used on 220V mains to boil 0.52kg of water. If the heat capacity of the kettle is 400J K^{-1} and the initial temperature of water is 20°C , how long will the water take to boil? (04marks)
- (d) (i) Distinguish between isothermal and adiabatic changes (02marks)
- (ii) An ideal gas at 18°C is compressed adiabatically until the volume is halved. Calculate the final temperature of the gas. [Assume specific heat capacities of the gas at constant pressure and volume are $2100\text{J kg}^{-1}\text{K}^{-1}$ and $1500\text{J kg}^{-1}\text{K}^{-1}$] respectively. (04marks)
27. (a) State Stefan's law of black body radiation. (01marks)
- (b) Briefly describe how a thermopile can be used to detect thermal radiation. (05marks)
- (c) Explain the temperature distribution along
- (i) a perfectly lagged metal bar (02marks)
- (ii) an unlagged metal bar. (02marks)
- (d) The wall of a furnace is constructed with two layers. The inner layer is made of bricks of thickness 10.0cm and thermal conductivity $0.8\text{ W m}^{-1}\text{K}^{-1}$ and the outer layer is made of material of thickness 10.0 cm and thermal conductivity $1.6\text{ W m}^{-1}\text{K}^{-1}$. The temperatures of the inner and outer surfaces are 600°C and 460°C respectively.
- (i) Explain why in steady state, the rate of thermal energy transfer must be the same in both layers. (01mark)
- (ii) Calculate the rate of heat flow per square meter through the wall. (05marks)
- (e) Explain the greenhouse effect and how it is related to global warming. (04marks)
28. (a) (i) Define the term specific heat capacity and internal energy and state their units. (03marks)
- (ii) Why is the distinction between specific heat capacity at constant pressure and that at constant volume important for gases, but less important for solids and liquids? (04marks)
- (b) Explain why the temperature of a liquid does not change when the liquid is boiling? (02marks)
- (c) One kilogram of water is converted to steam at a temperature of 100°C and a pressure of $1.0 \times 10^5\text{Pa}$. If the density of steam is 0.58kg m^{-3} and specific heat of vaporization of water is $2.3 \times 10^6\text{J kg}^{-1}$, calculate the
- (i) external work done (04marks)
- (ii) internal energy (03marks)
- (d) Explain why the specific latent heat of fusion and specific latent heat of vaporization of a substance at the same pressure are different. (04marks)
29. (a) (i) Explain the difference between isothermal and adiabatic expansion of a gas. (02marks)
- (ii) Using same axes and point, sketch graphs of pressure versus volume for fixed mass of a gas undergoing isothermal and adiabatic changes. (03marks)
- (b) Show that work, W , done by a gas which expands reversibly from V_0 to V_1 is given by

$$W = \int_{V_0}^{V_1} p dv \text{ (04marks)}$$

- (c) (i) State two differences between real and ideal gases (02marks)
(ii) Draw a labelled diagram showing P-V isothermals for a real gas above and below the critical temperature. (03marks)
- (d) Ten moles of a gas, initially at 27°C are heated at constant pressure of $1.01 \times 10^5 \text{ Pa}$ and volume increased from 0.25 m^3 to 0.375 m^3 . Calculate the increase in internal energy.
[Assume $C_p = 28.5 \text{ J mol}^{-1} \text{ K}^{-1}$] (06marks)
- 30.(a) What is meant by the following?
(i) Conduction
(ii) Convection
(iii) Greenhouse effect (06marks)
- (b) One end of a long copper bar is heated in a steam chest and the other end is kept cool by current of circulating water. Explain with the aid of sketch graphs, the variation of temperature along the bar, when steady state has been attained if the bar is
(i) lagged (02marks)
(ii) exposed to the surrounding (02marks)
- (c) (i) What is meant by a black body? (01mark)
(ii) Describe how a black body can be approximated in practice. (04marks)
- (d) (i) State Prevost's theory of heat exchange. (01mark)
(ii) Sketch the variation with wavelength of the intensity of radiation emitted by a black body at two different temperatures. (01mark)
- (e) A cube of side 1.0cm has a grey surface that emits 50% of the radiation emitted by a black body at the same temperature. If the cube's temperature is 700°C, calculate the power radiated by the cube. (03marks)
31. (a) (i) Define the term thermometric property. (01mark)
(ii) State two thermometric properties. (01mark)
(iii) With the aid of a labelled diagram, describe how the room temperature can be measured using uncalibrated resistance thermometer. (06marks)
- (b) (i) Define specific heat capacity of a substance. (01mark)
(ii) Hot water at 85°C and cold water 10°C are ran into a bath at a rate of $3.0 \times 10^{-2} \text{ m}^3 \text{ min}^{-1}$ and V , respectively. At the point of filling the bath, the temperature of the mixture of water 40°C. Calculate the time taken to fill the bath is its capacity is 1.5 m^3 .
- (c) The specific latent heat of fusion of a substance is significantly different from its specific latent heat of vaporization at the same pressure. Explain how the difference arises. (04marks)
- (d) Explain in terms of specific heat capacity why water is used in a car radiator other than any other liquid. (02mark)

32. (a) (i) state Boyles law. (01mark)
 (ii) Describe an experiment that can be used to verify Boyles' law. (06marks)
 (b) Explain the following observations using the kinetic theory.
 (i) A gas fills any container in which it is placed and exerts pressure on its walls. (03marks)
 (ii) The pressure of a fixed mass of a gas rises when temperature is increased at constant volume. (02 marks)
 (c) (i) What is meant by a reversible process. (01marks)
 (ii) State the conditions necessary for isothermal and adiabatic processes to occur, (04marks)
 (d) A mass of an ideal gas of volume 200cm^3 at 144K expands adiabatically to a temperature of 137K . Calculate its new volume. (Take $\gamma = 1.40$)
33. (a) Define thermal conductivity. (01mark)
 (b)(i) Explain the mechanism of thermal conduction in nonmetallic solids. (03marks)
 (ii) Why are metals better thermal conductors than nonmetallic solids? (02marks)
 (c) With the aid of a diagram, describe an experiment to determine the thermal conductivity of a poor conductor. (06marks)
 (d) (i) What is meant by a black body? (01mark)
 (ii) Sketch curves showing the spectral distribution of energy radiated by a black body at three different temperatures. (02marks)
 (iii) Describe the main features of the curves you have drawn in (d)(ii) (02marks)
 (e) A small blackened solid copper sphere of radius 2cm is placed in an evacuated enclosure whose walls are kept at 100°C . Find the rate at which energy must be supplied to the sphere to keep its temperature at 127°C . (03marks)
34. (a) Define the following terms
 (i) Specific latent heat of vaporization (01mark)
 (ii) Coefficient of thermal conductivity
 (b) With the aid of a labelled diagram, describe an experiment to measure the specific latent heat of vaporization of water by electrical method (07marks)
 (c) An appliance rated 240V , 200W evaporates 20g of water in 5 minutes. Find the heat loss if specific latent heat of vaporization is $2.26 \times 10^6 \text{Jkg}^{-1}$. (03marks)
 (d) Explain why at a given external pressure a liquid boils at constant temperature. (04marks)
 (e) With the aid of a suitable sketch graphs, explain the temperature distribution along lagged and unlagged metal rods, heated at one end. (04marks)
35. (a) Describe an experiment to verify Newton's law of cooling. (05marks)
 (b) (i) Distinguish between a real and an ideal gas. (03marks)
 (ii) Derive the expression

$$P = \frac{1}{3} \rho \bar{c}^2$$
 for the pressure of an ideal gas of density, ρ , and mean square speed $\bar{c}^2$
 (c) (i) Explain why the pressure of a fixed mass of a gas in a closed container increases when the temperature of the container is raised. (02marks)
 (ii) Nitrogen gas is trapped in a container by a movable piston. If the temperature of the gas is raised from 0°C to 50°C at constant pressure of $4.0 \times 10^5 \text{Pa}$ and the total heat added is 3.0

$\times 10^4$ J, calculate the work done by the gas. [The molar heat capacity of nitrogen at constant pressure is $29.1 \text{ J mol}^{-1} \text{ K}^{-1}$, $C_p/C_v = 1.4$]

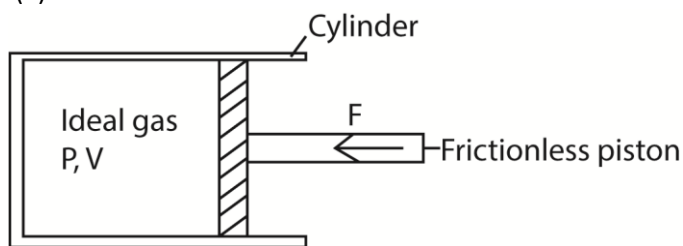
36. (a) (i) State the laws of black body radiation (02marks)
 (ii) Sketch the variation of intensity with wavelength in a black for different temperatures. (03marks)
- (b) (i) What is a perfectly black body? (01marks)
 (ii) How can a perfectly black body be approximated in reality? (04marks)
- (c)(i) The energy intensity received by a spherical planet from a star is $1.4 \times 10^3 \text{ W m}^{-2}$. The star is of radius $7.0 \times 10^5 \text{ km}$ and is $14.0 \times 10^7 \text{ km}$ from the planet.
 (i) Calculate the surface temperature of the star. (04marks)
 (ii) State any assumptions you have made in (c)(i) above (01marks)
- (d) (i) What is convection? (01mark)
 (ii) Explain the occurrence of land and sea breeze. (04marks)
37. (a) (i) Define a thermometric property and give two examples (02marks)
 (ii) When is the temperature of 0K attained? (02marks)
- (b)(i) With reference to constant-volume gas thermometer, define temperature on the Celsius scale (02marks)
 (ii) State two advantages and two disadvantages of the constant-volume gas thermometer. (02marks)
- (c) (i) Define triple point of water (01mark)
 (ii) Describe how you would measure the temperature of a body on the thermodynamic scale using a thermocouple. (03marks)
- (d) The resistance, R_θ of platinum varies with the temperature $^\circ\text{C}$ as measured by the constant-volume gas thermometer according to the equation

$$R_\theta = 50.0 + 0.17\theta + 3.0 \times 10^{-4}\theta^2$$
 (i) Calculate the temperature on the platinum scale corresponding to 60°C on the gas scale. (06marks)
 (ii) Account for the difference between the two values and state the temperatures at which they agree. (02marks)
38. (a) (i) Define latent heat (01mark)
 (ii) Explain the significance of latent heat in regulation of body temperature (03marks)
- (b) (i) using kinetic theory, explain boiling of a liquid (03mark)
 (ii) Describe how you would determine the specific latent heat of vaporization of water by the method of the mixtures (05marks)
- (iii) Explain why latent heat of vaporization is always greater than that of fusion. (02marks)
- (c) In an experiment to determine the specific latent heat of vaporization of a liquid using the continuous flow calorimeter, the following results were obtained.

Voltage, V/V	Current, I/A	Mass collected in 300s/g
7.4	2.6	5.8
10.0	3.6	11.3

Calculate the power of the heater required to evaporate 3.0g of water in 2 minutes (06marks)

39. (a)



A fixed mass of an ideal gas is confined in a cylinder by frictionless piston of cross section area A . the piston is in equilibrium under the action of force, F as shown in the figure above. Show that the work done, W , by the gas when it expands from V_1 to V_2 is given by

$$W = \int_{V_1}^{V_2} P dV \quad (03\text{marks})$$

(b) State the first law of thermodynamics and use it to distinguish between Isothermal and adiabatic changes in a gas. (05marks)

(c) The temperature of 1mole of helium gas at a pressure of $1.0 \times 10^5 \text{Pa}$ increases from 20°C to 100°C when the gas is compressed adiabatically.

Find the final pressure of the gas. (Take $\gamma = 1.67$) (04 marks)

(d) With the aid of a P-V diagram, explain what happens when a real gas is compressed at different temperatures. (04marks)

(e) The root-mean square speed of the molecules of a gas is 44.72ms^{-1} . Find the temperature of the gas if its density is $9.0 \times 10^{-2} \text{kgm}^{-3}$ and the volume is 42.0m^3 . (04marks)

40. (a) Define saturated vapour pressure (S.V.P) (01mark)

(b) Use the kinetic theory of matter to explain the following observations

(i) saturated vapour pressure of a liquid increases with temperature. (03marks)

(ii) saturated vapour pressure is not affected by decrease in volume at constant temperature. (03marks)

(c) Describe how saturated vapour pressure of a liquid at various temperatures can be determined. (07marks)

(d) (i) State Dalton's law of partial pressures (01mark)

(ii) A horizontal tube of uniform bore, closed at one end, has some air trapped by a small quantity of water. The length of the enclosed air column is 20cm at 12°C .

Find stating any assumptions made, the length of air column when the temperature is raised to 38°C .

[S.V.P of water at 12°C and 38°C are 10.5mmHg and 49.5mmHg respectively. Atmospheric pressure = 75cmHG] (05marks)

41.(a) (i) Define specific heat capacity of a substance. (01mark)

(ii) State three advantages of the continuous flow method over the method of mixtures in determination of the specific heat capacity of a liquid. (03marks)

(b) In a continuous flow experiment, a steady difference of temperature of 1.5°C is maintained when the rate of liquid flow is 4.5gs^{-1} and the rate of electrical heating is 60.5W. On reducing the liquid flow rate to 1.5gs^{-1} , 36.5W is required to maintain the same temperature difference.

Calculate the

- (i) Specific heat capacity of the liquid. (04marks)
- (ii) Rate of heat loss to the surroundings (03marks)

(c) (i) Describe an electrical method for determination of the specific heat capacity of a metal. (06marks)

(ii) State the assumptions made in the above experiment. (02marks)

(iii) Comment about the accuracy of the results of the experiment in (c)(i) above. (01marks)

42. (a)(i) Define thermal conductivity. (01mark)

(ii) Explain the mechanism of heat transfer in metals (03marks)

(b) Two brick walls each of thickness 10cm are separated by an air-gap of thickness 10cm. the outer faces of the brick walls are maintained at 20°C and 5°C respectively.

(i) Calculate the temperatures of the inner surfaces of the walls. (06marks)

(ii) Compare the rate of heat loss through the layer of air with that through a single brick wall. (03marks)

[Thermal conductivity of air is $0.02 \text{ Wm}^{-1}\text{K}^{-1}$, and that of bricks is $0.6 \text{ Wm}^{-1}\text{K}^{-1}$]

(c)(i) State Stefan's law of black body radiation. (01mark)

(ii) The average distance of Pluto from the sun is about 40 times that of the Earth from the sun. If the sun radiated as a black body at 600K, and is $1.5 \times 10^{11} \text{ m}$ from the Earth, Calculate the temperature of Pluto. (06marks)

43. (a)(i) What is meant by term fixed point in thermometry? Give two examples (02marks)

(ii) How is temperature on Celsius scale defined on a platinum resistance thermometer? (02marks)

(b) Explain the extent to which two thermometers based on different properties but calibrated using the same fixed points are likely to agree when used to measure temperature.

(i) near one of the fixed point (02marks)

(ii) mid-way between two fixed points (02marks)

(c) The continuous flow method is used in determination of the specific heat capacity of liquids.

(i) What are the principal advantages of this method compared to the method of mixtures? (03marks)

(ii) In such a method, 50g of water is collected in 1 minute. The voltmeter and ammeter readings are 12.0V and 2.50A respectively, while the inflow and outflow temperatures are 20°C and 28°C respectively. When the flow rate is reduced to 25 gmin^{-1} , the voltmeter and ammeter read 8.8V and 1.85A respectively while the temperatures remain constant. Calculate the specific heat capacity of water. (05marks)

(d) What are the advantages of a thermocouple over a constant volume thermometer for measuring temperature? (04marks)

44.(a)(i) What is meant by isothermal and adiabatic changes? (02marks)

(ii) Using the same axes, and starting from the same point, sketch a P-V diagram to illustrate the changes in (a)(i) (02marks)

(b) An ideal gas is trapped in a cylinder by a movable piston. Initially it occupies a volume of $8 \times 10^{-3} \text{m}^3$ and exerts a pressure of 108kPa. The gas undergoes an isothermal expansion until its volume is $27 \times 10^{-3} \text{m}^3$. It is then compressed adiabatically to the original volume of the gas.

(i) Calculate the final pressure of the gas (06marks)

(ii) Sketch and label the two stages on a p-v diagram. (02marks)

[The ratio of the principal molar heat capacities of the gas = 5:3]

(c) (i) Define molar heat capacities at constant pressure. (01mark)

(ii) Derive the expression $C_p - C_v = R$, for 1mole of a gas (05marks)

(iii) In which ways does a real gas differ from an ideal gas? (02marks)

45. (a) (i) Define thermal conductivity. (01mark)

(ii) State two factors which determine the rate of heat transfer through a material (02marks)

(b)(i) Describe with the aid of a diagram an experiment to measure the thermal conductivity of glass. (08marks)

(ii) Briefly discuss the advantages of the apparatus in (b)(i). (02marks)

(c) Metal rods of copper, brass are welded together to form Y shaped figure.

The cross-section area of each rod is 2cm^2 . The free end of copper rod are maintained at 100°C , while the free ends of brass and steel rods are maintained at 0°C . If there is no heat loss from the surfaces of the rods and the length of the rods are 0.46m, 0.13m and 0.12m respectively.

(i) Calculate the temperature of the junction (05marks)

(ii) Find the heat current in the copper rod. (02marks)

[Thermal conductivities of copper, brass and steel are $385 \text{Wm}^{-1}\text{K}^{-1}$, $109 \text{Wm}^{-1}\text{K}^{-1}$ and $50.2 \text{Wm}^{-1}\text{K}^{-1}$ respectively.]

46. (a) What is meant by:

(i) Thermometric property (01mark)

(ii) Triple point (01mark)

(b) (i) Describe the steps taken to establish a temperature scale. (05marks)

(ii) Explain why two thermometers may give different values for the same unknown temperature. (02marks)

(c) (i) Describe, with the aid of a diagram, how a constant-volume gas thermometer may be used to measure temperature. (06marks)

(ii) State three corrections that need to be made when using the thermometer in (c)(i) above. (03marks)

(iii) State and explain the sources of inaccuracies in using mercury in glass thermometer, (02marks)

47. (a) Define thermal conductivity of a material and state its units (02marks)
- (b) Describe with the aid of a diagram how the thermal conductivity of a poor conductor can be determined. (07marks)
- (c) A cooking saucepan made of iron has a base area of 0.05m^2 and thickness of 2.5mm . It has a thin layer of soot of average thickness 0.5mm on its bottom surface. Water in the saucepan is heated until it boils at 100°C . The water boils away at a rate of 0.60kg per minute and the side of the soot nearest to the heat source is at 150°C . Find the thermal conductivity of soot.
- [Thermal conductivity of iron = $66\text{Wm}^{-1}\text{K}^{-1}$ and specific latent heat of vaporization = 2200kJ/kg]
- (d) (i) What is a black body? (01mark)
- (ii) Sketch the spherical distribution of black body radiation for three different temperatures and describe their main features. (04marks)
48. (a) Derive the expression $P = \frac{1}{3}\rho c^2$ for the pressure, P , of an ideal gas of density ρ and mean square speed, c^2 . State any assumptions made (07marks)
- (b) A gas is confined in a container of volume 0.1m^3 at a pressure of $1.0 \times 10^5\text{Nm}^{-2}$ and temperature of 300K . If the gas is assumed to be ideal, calculate the density of the gas. (The relative molecular mass of the gas is 32) (05marks)
- (c) What is meant by
- (i) isothermal change
- (ii) adiabatic change (02marks)
- (d) A gas at a pressure of $1.0 \times 10^6\text{Pa}$ is compressed adiabatically to half its volume and then allowed to expand isothermally to its original volume. Calculate the final pressure of the gas.
- [Assume the ratio of the principal specific heat capacities $c_p/c_v, \gamma = 1.4$] (06marks)
49. (a) (i) Define molar heat capacity of a gas at constant volume. (01mark)
- (ii) The specific heat capacity of oxygen at constant volume is $719\text{Jkg}^{-1}\text{K}^{-1}$. If the density of oxygen at s.t.p is 1.429kgm^{-3} , calculate the specific heat capacity of oxygen at constant pressure. (04marks)
- (b) Indicate the different states of a real gas at different temperatures and pressure versus volume sketch graph.
- (c) (i) In deriving the expression $P = \frac{1}{3}\rho c^2$ for the pressure of an ideal gas, two of the assumptions made are not valid for a real gas. State these assumptions. (02marks)
- (ii) The equation of state of one mole of a real gas is $\left(P + \frac{a}{v^2}\right)(v - b) = RT$
- Account for the terms $\frac{a}{v^2}$ and b (02marks)
- (d) Use the expression $P = \frac{1}{3}\rho c^2$; for the pressure of an ideal gas to derive Dalton's law of partial pressures (04marks)
- (e) Explain, with the aid of a volume versus temperature sketch graph, what happens to a gas cooled at constant pressure from room temperature to zero Kelvin. (04marks)
50. (a) What is meant by black body? (01mark)
- (b) Describe how an approximate black body can be realized in practice. (02marks)

- (c)(i) Draw sketch graphs to show how variation of relative intensity of black body radiation with wavelength for three different temperatures. (02marks)
- (ii) Describe the features of the sketch in (c)(i) above. (03marks)
- (d)(i) State Stefan's law (01mark)
- (ii) A solid copper sphere of diameter 10 mm and temperature of 150K is placed in an enclosure maintained at a temperature of 290K. Calculate, stating assumptions made, the initial rate of rise of temperature of the sphere.
[Density of copper = $8.93 \times 10^3 \text{ kg m}^{-3}$, specific heat capacity of copper = $3.7 \times 10^2 \text{ J kg}^{-1} \text{ K}^{-1}$]
(07marks)
- (e) With the aid of a labelled diagram, describe how a thermopile can be used to determine infrared radiation. (04marks)
51. (a) (i) What is meant by kinetic theory of gases? (03marks)
- (ii) Define an ideal gas (01mark)
- (iii) State and explain conditions under which real gases behave like ideal gases. (04mark)
- (b) (i) Describe an experiment to show that a liquid boils only when its saturated vapor pressure is equal to external pressure (05marks)
- (ii) Explain how cooking at a pressure of 76cm of mercury and temperature of 100°C may be achieved on top of high mountains. (03marks)
- (c) (i) Define root-mean-square speed of molecules of a gas. (01mark)
- (ii) The mass of hydrogen and oxygen atoms are $1.66 \times 10^{-27} \text{ kg}$ and $2.66 \times 10^{-26} \text{ kg}$ respectively. What is the ratio of the root mean square speed of hydrogen to that of oxygen molecules at the same temperature? (03marks)
52. (a) State the assumption made in the derivation of the expression $P = \frac{1}{3} \rho \overline{c^2}$ for pressure of an ideal gas (02marks)
- (b) Use the expression in (a) above to deduce Dalton's law of partial pressures. (03marks)
- (c) Describe an experiment to determine the saturation vapor pressure of a liquid. (06marks)
- (d) (i) What is meant by a reversible isothermal change? (02marks)
- (ii) State the conditions for achieving a reversible isothermal change. (02marks)
- (e) An ideal gas at 27°C and at a pressure of $1.01 \times 10^5 \text{ Pa}$ is compressed reversibly and isothermally until its volume is halved. It is then expanded reversibly and adiabatically to twice its original volume. Calculate the final pressure and temperature of the gas if $\gamma = 1.4$ (05marks)
53. (a) Explain the mechanism of heat conduction in solids. (03marks)
- (b) Describe a method of determining the thermal conductivity of cork in form of a thin sheet. (06marks)
- (c) A window of height 1.0m and width 1.5m contains a double glazed unit consisting of two single glass panes, each of thickness 4.0mm separated by an air gap of 2.0mm. Calculate the rate at which heat is conducted through the window if the temperatures of external surfaces of glass are 20°C and 30°C respectively.
[Thermal conductivities of glass and air are $0.72 \text{ W m}^{-1} \text{ K}^{-1}$ and $0.025 \text{ W m}^{-1} \text{ K}^{-1}$ respectively]
(07marks)
- (d) (i) State Stefan's law. (01mark)

- (ii) The element of a 1.0kW electric fire is 30.0cm long and 1.0cm in diameter. If the temperature of the surroundings is 20°C, estimate the working temperature of the element. [Stefan's constant, $\sigma = 5.7 \times 10^{-18} \text{Wm}^{-2}\text{K}^{-4}$] (03marks)
54. (a) (i) Define specific heat capacity of a substance (01mark)
 (ii) State how heat losses are minimized in calorimetry (02mark)
 (b) (i) What is meant by cooling correction? (01marks)
 (ii) Explain how the cooling correction may be estimated in the determination of the heat capacity of poor by the method of mixtures (05marks)
 (iii) Explain why a small body cools faster than a larger one of the same material. (04marks)
 (c) Describe how you would determine the specific heat capacity of a liquid by the continuous flow method. (07marks)
55. (a) Define thermal conductivity of a substance and state its units. (02marks)
 (b) Flux of solar energy incident on the earth's surface is $1.36 \times 10^3 \text{Wm}^{-2}$.
 Calculate
 (i) The temperature of the surface of the sun (04marks)
 (ii) The total power emitted by the sun (03marks)
 (iii) The rate of loss of mass by the sun (03marks)
- (c)(i) Explain how heat is conducted through a glass rod. (03marks)
 (ii) Why is a metal a better conductor of heat than glass? (02marks)
 (iii) Explain briefly why it is necessary to use a thin specimen of large cross-section area in determining thermal conductivity of a poor conductor of heat. (03marks)
56. (a) (i) Explain what happens when a quantity of heat is applied to a fixed mass of a gas (02marks)
 (ii) Derive the relationship between the principal molar heat capacities C_p and C_v for an ideal gas. (05marks)
 (b) (i) What is adiabatic process? (01mark)
 (ii) A bicycle pump contains air at 290K. The piston of the pump is slowly pushed in until the volume of the air enclosed is one fifth of the total volume of the pump. The outlet is sealed off and the piston suddenly pulled out to full extension. If no air escapes, find its temperature immediately after pulling the piston. (Take $C_p/C_v = 1.4$) (03marks)
 (c) (i) Distinguish between unsaturated and saturated vapors. (02marks)
 (ii) Draw graphs to show the relationship between pressure and temperature for ideal gas and for saturated water vapour originally at 0°C. (03marks)
 (d) In an experiment, the pressure of a fixed mass of air at constant temperature is 10.4kPa. When the volume is halved, keeping the temperature constant, the pressure becomes 19.0kPa. Discuss the applicability of the above results in verifying Boyle's law. (04marks)
57. (a) Explain why temperature remains constant during change of phase. (04marks)
 (b) Describe with the aid of labelled diagram, an electrical method for determination of specific latent heat of vaporization of a liquid. (07marks)
 (c) Water vapour and liquid water are confined in an air tight vessel. The temperature of the water is raised until all the water has evaporated.

Draw a sketch graph to show how the pressure of water vapour changes with temperature and account for its main features. (06marks)

- (d) Calculate the work done against the atmosphere when 1kg of water turns into vapour at atmospheric pressure of $1.01 \times 10^5 \text{ Pa}$.

[Density of water vapour = 0.598 kg m^{-3}] (03marks)

58. (a)(i) Describe Searle's method of determining the thermal conductivity of a good conductor of heat. (07marks)

(ii) Why is the method in (a)(i) best suited for a good conductor of heat? (02marks)

- (b) The two ends of a metal bar of length 1.0m are perfectly lagged up to 20cm from either end. The ends of the bar maintained at 100°C and 0°C respectively.

(i) Sketch a graph of temperature versus distance of a bar. (02marks)

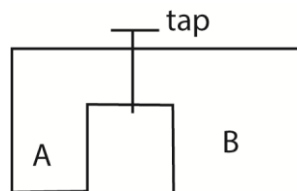
(ii) Explain the features of the graph in (b)(i) (03marks)

- (c) The external wall of a house consists of two layers of brick separated by an air cavity. The outer face of the wall is at a temperature of 45°C while the inside of the house is at 20°C . If the thickness of each brick layer is 15cm and of air cavity is 5cm, calculate the temperatures of the walls in contact with air in the cavity. (06marks)

59. (a) (i) State Boyle's law. (01mark)

(ii) What is meant by partial pressure of a gas (01 mark)

(iii)



Two cylinders A and B of volumes V and $3V$ respectively are separately filled with a gas. The cylinders are connected as shown above with the tap closed. The pressures of A and B are P and $4P$ respectively. When the tap is opened the common pressure becomes 60 Pa . Assuming isothermal conditions find the value of P . (04marks)

- (b) (i) State three differences between ideal and real gases. (03marks)

(ii) Sketch a pressure versus volume curve for a real gas undergoing compression below its critical temperature. (01mark)

(iii) Explain the main features of the curve in (b)(ii) above (03marks)

- (c) Two similar cylinders P and Q contain different gases at the same pressure. When gas is released from P the pressure remains constant for some time before it starts dropping. When gas is released from Q the pressure continuously drops. Explain the observation above. (05marks)

- (d) Using the expression for the kinetic pressure of an ideal gas, deduce the ideal gas equation of

$$\frac{1}{2} m \bar{c^2} = \frac{3}{2} K_B T \quad (02\text{marks})$$

60. (a)(i) State the desirable properties of a material must have to be used as thermometric substance, (02marks)

- (ii) Explain why scales of temperature based on different thermometric properties may not agree. (01marks)
- (b) (i) Draw a labelled diagram to show a simple constant volume gas thermometer. (03marks)
- (ii) Describe how a simple constant volume gas thermometer can be used to establish a Celsius scale of temperature. (05marks)
- (iii) State the advantages and disadvantages of mercury in glass thermometer and constant-volume gas thermometer. (03marks)
- (c) The resistance of the element of platinum resistance thermometer is 4.00Ω at ice point and 5.46Ω at steam point. What is the temperature on the platinum resistance scale would correspond to a resistance of 9.84Ω . (03marks)
- (d) The mean kinetic energy of one mole of helium gas at room temperature is $3.74 \times 10^3\text{J}$. Calculate room temperature.



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1. (a) (i) State any three properties of ultraviolet radiation.(03marks)

- Produces ionization
- Produces fluorescence
- Affects photographic films
- Produces photoelectric effect
- Absorbed by glass
- Can be polarized
- Promotes chemical reactions

(ii) What is a black body? (01mark)

A black body is one that absorbs all radiations incident on it without reflecting nor transmitting any.

(b) A cylindrical metal rod with a well- insulated curved surface has one end blackened and then exposed to thermal radiation from a body at a temperature 500K. If the equilibrium temperature of the blackened end is 400K and the length of the rod is 10cm, calculate the temperature of the other end. [Thermal conductivity of the metal = $500\text{Wm}^{-1}\text{K}^{-1}$] (04marks)

$$\begin{aligned}\text{Power absorbed} &= \sigma A(T_2^4 - T_1^4) \\ &= 5.67 \times 10^{-8} A(500^4 - 400^4) \\ &= 2092.13A\end{aligned}$$

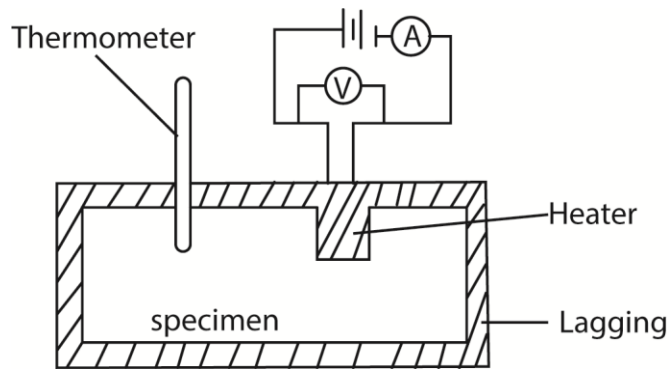
$$\begin{aligned}\text{Power conducted} &= \frac{Q}{t} = KA \frac{\Delta\theta}{L} \\ &= \frac{A(400-T)}{10} \times 500 = 50(400 - T)A\end{aligned}$$

Power absorbed = power conducted

$$50(400 - T)A = 2092.13A$$

$$T = 358.16\text{K}$$

(c) (i) Describe Electrical method of determining the specific heat capacity of a good conducting solid. (06marks)



- Two holes are drilled into the specimen solid of mass m .
- A thermometer is inserted in one of the holes and an electric heater into the other hole. The holes are then filled with a good conducting fluid, e.g. oil to ensure thermal contact.
- The apparatus is insulated and initial temperature θ_0 is recorded.
- The heater is switched on at the same time a stop clock is started.
- The steady values of ammeter reading, I and voltmeter reading, V are recorded.
- After considerable temperature rise, the heater is switched off and stop clock stopped.
- The highest temperature θ_1 recorded and time t taken noted.
- The specific heat capacity, c , of the conducting solid is calculated from

$$c = \frac{IVt}{m(\theta_1 - \theta_0)}$$

(ii) Give two reasons why the value obtained using the method in (c)(i) may not be accurate.

(02marks)

- some heat is lost to the surrounding through the insulator
- some heat is absorbed by the thermometer and heater
- the solid expands during heating and so external work is done against atmospheric pressure.

(d) Explain why cloudy nights are warmer than cloudless ones.

During day, radiation is absorbed from the sun by earth. At night, the earth radiated heat into the atmosphere.

On a cloudless night, the radiated heat is lost. On cloudy night, the clouds form blanketing layer which reflects back the heat to the earth and warmth feeling.

2. (a)(i) What is meant by a reversible process? (02marks)

A reversible process is a process that can proceed in a reverse direction by very small change in conditions making it take place through exactly same steps.

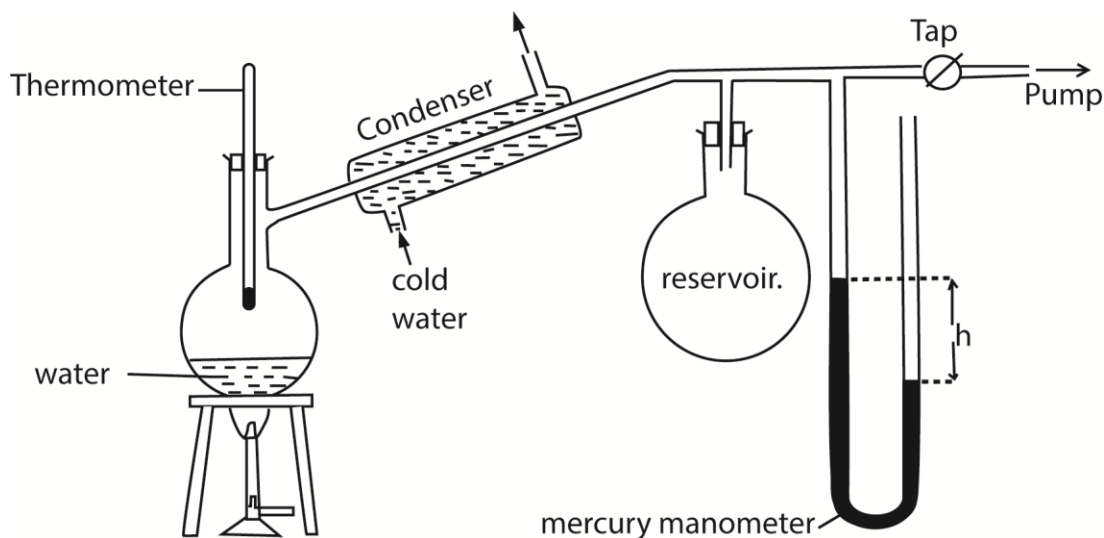
(ii) Distinguish between a saturated vapour and unsaturated vapour. (02marks)

A saturated vapour is one that is in a dynamic equilibrium with its own liquid while unsaturated vapour is not in dynamic equilibrium with its own liquid.

(iii) Explain why evaporation causes cooling (03marks)

When a liquid vaporizes, it absorbs latent heat of vaporization from the body from which evaporation occurs. Hence the body cools.

(b) Describe an experiment to determine the temperature dependence of saturated vapour pressure of water. (07marks)



- The pressure of the air in R is shown by the mercury manometer; if its height is h , the pressure in mm mercury is $P = H - h$, where H is the barometer height.
- The tap is opened and the pressure above water varied using the pump to a suitable value.
- The tap is closed and water in the flask is heated until it boils.
- The temperature θ and difference in mercury levels, h , are noted and recorded.
- The saturated vapour pressure, $P = (H \pm h)$ is calculated.
- The procedure is repeated for other values of θ and h .
- A graph of P versus θ is plotted and it shows that saturated vapour pressure, P , increases with temperature, θ .

(c) (i) State Dalton's law of partial pressures. (07marks)

Dalton's law states that the total pressure of a mixture of gases that do not react chemically is equal to the sum of the partial pressures of the components of a gas.

(ii) A sealed container has liquid water, water vapour and air all at 27°C . The total pressure inside the container is 69 cmHg. When the temperature is raised to 85°C , the total pressure changes to 96 cmHg. If the saturated vapour pressure of water at 27°C is 5 cmHg and water vapour remains saturated, calculate the saturated vapour pressure of water at 85°C .

(05marks)

$$T_1 = 27 + 273 = 300\text{K}$$

$$T_2 = 85 + 273 = 358\text{K}$$

$$\text{Partial pressure at } T_1; P_1 = 69 - 5 = 64\text{ cmHg}$$

$$\text{Partial pressure at } T_2, P_2 = (96 - P)\text{ cmHg}$$

$$\text{Using } \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \text{ but } V_1 = V_2 = V$$

$$\frac{64V}{300} = \frac{(96 - P)V}{358}$$

$$P = 19.63\text{ cmHg}$$

3. (a) Define the following:

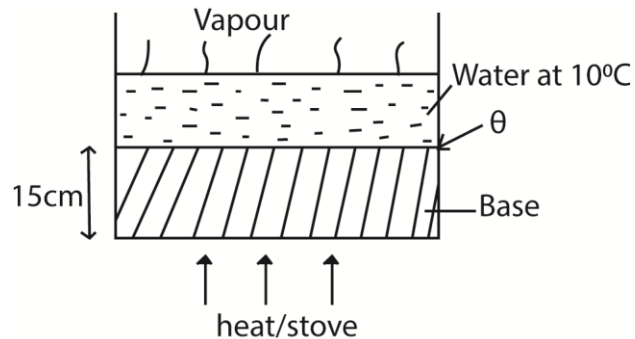
(i) Thermal conductivity. (01marks)

Thermal conductivity is the rate of heat flow per unit cross section area per unit temperature gradient

(ii) Specific latent heat of vaporization. (01mark)

Specific latent heat of vaporization is the amount of heat energy required to change 1kg of a liquid to vapour at constant temperature.

(b) A boiler with a base made of rod steel 15cm thick, rests on a hot stove. The area of the bottom of the boiler is $1.5 \times 10^3 \text{ cm}^2$. The water inside the boiler is at 100°C . If 750g of water is evaporated every 5 minutes, find the temperature of the surface of the boiler in contact with the stove. [Thermal conductivity of steel = $50.2 \text{ Wm}^{-1}\text{K}^{-1}$, specific latent heat of vaporization of water = $2.26 \times 10^6 \text{ Jkg}^{-1}$]



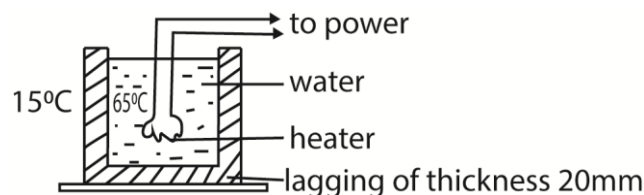
Rate of heat flow through the boiler = Rate of heat supplied to vaporize water

$$kA \frac{\Delta\theta}{L} = \frac{ml_v}{t}$$

$$\frac{50.2 \times 0.15(\theta - 100)}{15 \times 10^{-2}} = \frac{0.75 \times 2.26 \times 10^6}{5 \times 60}$$

$$\theta = 2128^\circ\text{C}$$

(c) Hot water in a metal tank is kept constant at 65°C by an immersion heater in the water. The tank has lagging all around it of thickness 20mm and thermal conductivity $0.04 \text{ Wm}^{-1}\text{K}^{-1}$ and its surface area is 0.5 m^2 . The heat lost per second by the lagging is 0.8 W per degree excess above the surroundings. Calculate the power of immersion heater if the temperature of the surroundings is 15°C . (05marks)



$$K = 0.04 \text{ Wm}^{-1}\text{K}^{-1}, A = 0.5 \text{ m}^2, L = 20 \times 10^{-3} \text{ m}$$

Let θ be the temperature of the lagging

$$\text{Excess temperature} = (\theta - 15)$$

$$\text{Heat lost per second} = 0.8(\theta - 15)$$

$$\text{The rate of heat flow} = KA \frac{\Delta\theta}{L} = 0.04 \times 0.5 \times \frac{(65 - \theta)}{20 \times 10^{-3}}$$

At steady state

Heat lost per second = Rate of heat flow

$$0.8(\theta - 15) = 0.04 \times 0.5 \times \frac{(65 - \theta)}{20 \times 10^{-3}}$$

$$\theta = 42.8^\circ\text{C}$$

$$\text{Power of heater} = 0.8(42.8 - 15) = 22\text{W}$$

(d)(i) Define thermometric property (01mark)

Thermometric property is a physical measurable property that varies linearly and continuously with temperature and is constant at constant temperature.

(ii) Define how a liquid-in-glass thermometer can be used to measure temperature in degrees Celsius. (04marks)

- A bulb is inserted in pure ice-water mixture.
- After some time, the length l_0 of mercury thread is recorded.
- The bulb is inserted in steam and constant length l_{100} of mercury thread is recorded.
- When l_θ is the length of mercury thread inserted in an unknown enclosure of temperature, θ° , then;

$$\theta = \left(\frac{l_\theta - l_0}{l_{100} - l_0} \right) \times 100^\circ\text{C}$$

(iii) A thermometer is constructed with a liquid which expands according to relation.

$V_t = V_0(1 + \alpha t + \beta t^2)$. Where V_t is the volume at $t^\circ\text{C}$ and V_0 is the volume at 0°C on the scale of the gas thermometer and α and β are constants.

Given that $\alpha = 1000\beta$, what will the liquid thermometer read when the gas thermometer reads 50°C .

$$\text{Using } \theta = \left(\frac{V_\theta - V_0}{V_{100} - V_0} \right) \times 100^\circ\text{C}$$

$$V_{50} = V_0(1 + \alpha(50) + \beta(50)^2).$$

$$V_{100} = V_0(1 + \alpha(100) + \beta(100)^2).$$

$$\theta = \left(\frac{V_0(1 + 50000\beta + 2500\beta) - V_0}{V_0(1 + 100000\beta + 10000\beta) - V_0} \right) \times 100^\circ\text{C}$$

$$= 47.73^\circ\text{C}$$

4. (a) Define the following quantities:

(i) Thermometric property (01mark)

Thermometric property is a physical measurable property that varies linearly and continuously with temperature and is constant at constant temperature.

(ii) Specific heat capacity (01mark)

Specific heat capacity is the amount of heat requires to raise the temperature of 1kg mass of a substance by 1K or 1°C

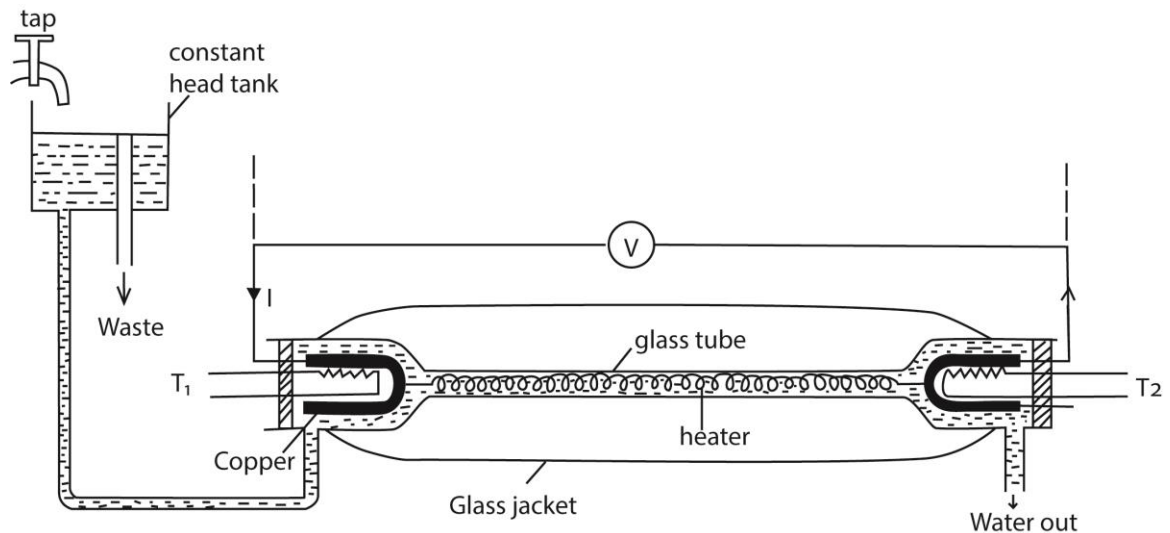
(b) (i) state two examples of commonly used thermometric properties. (01mark)

- Volume of constant mass of a gas at constant pressure
- Pressure of a gas at constant volume
- Electrical resistance of a platinum wire
- e.m.f of a thermocouple

(ii) Describe briefly how to determine the lower and upper fixed points for an uncalibrated liquid-in-glass thermometer (04marks)

- the bulb of the thermometer is immersed in pure ice-water mixture; the level of liquid column falls to a constant length. The level of the liquid column is marked and is the lower fixed point.
- the bulb of the thermometer is then immersed in steam from pure water; the level of liquid column rises to a constant length. The level of the liquid column is marked and is the upper fixed point.

(c) (i) Describe with the aid of a diagram, an experiment to determine the specific heat capacity of a liquid using the continuous flow method. (07marks)



- A liquid is allowed to flow at constant rate
- Power is switched on and the liquid is heated until temperatures registered by T_1 and T_2 are steady and the values θ_1 and θ_2 respectively are recorded.
- The p.d V and current I are recorded from the voltmeter and ammeter respectively
- The mass, m of a liquid collected in time t is recorded
- At steady state; $VIt = mc(\theta_2 - \theta_1) + h$ (i)
where h is heat lost to the surrounding
- The rate of flow is changed and the voltage and current are adjusted until the steady readings of T_1 and T_2 are θ_1 and θ_2 respectively
- If m_1 , V_1 and I_1 are the values mass of liquid collected in time t, voltmeter and ammeter readings respectively, then
 $V_1 I_1 t = m_1 c(\theta_2 - \theta_1) + h$ (ii)
Subtracting (ii) from (i)

$$c = \frac{(V_1 - V_2)I_1 t}{(m - m_1)(\theta - \theta_1)}$$

(ii) State two advantages of the continuous flow method over the method of mixtures. (01mark)

- No cooling correction is required
- Heat capacity of the apparatus is not required
- Temperature measured at leisure when steady
- Resistance of the heater not required

(iii) State two disadvantages of the method in (c)(i) (01mark)

- larger volumes of liquid required
- not suitable for volatile liquids.

(d) The brake lining of the wheel of a car of mass 800kg have total mass of 4.8kg and are made of a material of specific heat capacity $1200 \text{ J kg}^{-1} \text{ K}^{-1}$. If the car is at 15 ms^{-1} and is brought to rest by applying the brakes, calculate the maximum possible temperature rise of the brake lining. (04marks)

Mechanical energy = heat absorbed by the lining

$$\frac{1}{2}mv^2 = mc\theta \text{ where } \theta \text{ is temperature change}$$

$$\frac{1}{2} \times 800 \times 15^2 = 4.8 \times 1200 \times \theta$$

$$\theta = 15.6^\circ \text{C}$$

5. (a) (i) What is meant by conduction of heat? (01mark)

Conduction of heat is a process of heat transfer by which heat flows from a hotter region of a substance to the cold regions without the bulk movement of a substance as a whole.

(ii) Explain why mercury conducts heat better than water. (03marks)

Mercury has free electrons capable of transferring energy without any part of mercury moving. Mercury atoms are closer allowing conduction of atomic vibrations while in water there is no free electrons and atoms are farther apart.

(iii) Explain the occurrence of land and sea breezes. (06marks)

During day, the land is heated to a high temperature than the sea. Hot air expands and rises from land. A stream of cool air from the sea blows towards the land to replace the uprising air, hence sea breeze occurs.

At night the land cools faster because it is no longer heated by the sun. The sea retains the warmth because it is heated deeply. Warm less dense air rises from the sea surface and air from land blows to replace it leading to land breeze.

(b) A copper sphere of radius 7cm and density 900kgm^{-3} , is heated to a temperature of 127°C and then transferred to an evacuated enclosure whose walls are at a temperature of 27°C . Calculate

(i) net rate of loss of heat by the copper sphere

$$P = A\sigma(T_1^2 - T_0^2) = 4\pi R^2\sigma(T_1^2 - T_0^2) = 4\pi(0.07)^2 \times 5.67 \times 10^{-8} (400^4 - 300^4) = 61.122\text{Js}^{-1}$$

(ii) temperature of copper sphere after 5minutes

$$\text{Average rate of heat loss} = \frac{61.122+0}{2} = 30.6\text{Js}^{-1}$$

$$P = mc\frac{d\theta}{dt} = \frac{4}{3}\pi r^3 \rho c \frac{d\theta}{dt}$$

$$30.6 = \frac{4}{3}\pi(0.007)^3 \times 900 \times 400 \times \frac{d\theta}{dt}$$

$$\frac{d\theta}{dt} = 0.059\text{Ks}^{-1}$$

(c) Explain why heating system based on the circulation of steam are more efficient than those based on circulation of boiling water. (02marks)

A given mass of steam gives out more energy than an equal amount of water because of the specific latent heat.

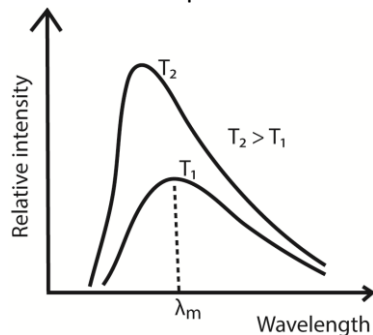
6. (a) (i) what is meant by a black body? (02marks)

A black body is a body that absorbs all radiations incident on it and transmits and reflects none

(ii) Give two examples of a black body. (01mark)

- The sun
- Star
- Black hole (remnants of a star after it has used up all its energy)
- An almost enclosed blackened surface with hole/furnace with small hole

(b) With aid of graphs describe how radiation emitted by a black body varies with wavelength for two temperatures.

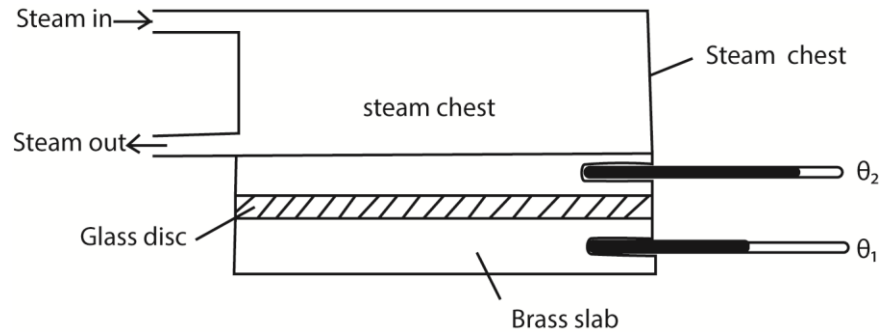


- For every wave length, relative intensity increases as temperature is increased.
- The wavelength at which maximum intensity occur shifts to the shorter wavelength as temperature is increased.
- λ_{max} is the wavelength of radiation emitted at maximum intensity/emission of a black body at a particular temperature.

(c) (i) Define thermal conductivity. (01mark)

Thermal conductivity is the rate of heat transfer per unit cross section area per unit temperature gradient.

(ii) Describe an experiment to determine thermal conductivity of glass. (07marks)



- Glass is cut in form of a thin disc of cross section area, A and thickness, x .
- The disc is sandwiched between a steam chest and brass slab of mass, m and specific heat capacity, c .
- Steam is passed through the chest until the thermometers register steady temperatures, θ_1 and θ_2 .
- Then, $\frac{\theta}{t} = kA \left(\frac{\theta_2 - \theta_1}{x} \right)$
- The glass disc is removed and brass slab is heated directly by steam chest, until its temperature is about 10°C above θ_1 .
- Steam chest is removed and the top of the glass slab is covered by the glass disc.
- The temperature of the slab is recorded at suitable time interval until its temperature is about 10°C below θ_1 .
- A graph of temperature against time is plotted and its slope is determined at θ_1

$$\frac{\theta}{t} = mcs$$

$$\therefore kA \left(\frac{\theta_2 - \theta_1}{x} \right) = mcs$$

$$k = \frac{mcsx}{A(\theta_2 - \theta_1)} \text{ but } A = \frac{\pi D^2}{4}$$

$$\therefore k = \frac{4mcsx}{\pi D^2(\theta_2 - \theta_1)}$$

- (d) Radiation from the sun falls normally on a blackened roof measuring $20\text{m} \times 50\text{m}$. If half of the solar energy is lost in passing through the earth's atmosphere, calculate the energy incident on the roof per minute. [Temperature of the sun's surface = 6000K ; radius of the sun = $7.5 \times 10^8\text{m}$, distance of the sun from the earth = $1.5 \times 10^{11}\text{m}$]

$$\text{Power radiated by the sun, } P = A\sigma T^4 = 4\pi r^2\sigma T^4$$

$$\text{Power incident on sphere, } P_i = \frac{P}{2} = 2\pi r^2\sigma T^4$$

$$\text{Power received by roof, } P_r = \frac{A_1}{A} \times P_i$$

$$= \frac{L \times W}{4\pi R^2} \times 2\pi r^2\sigma T^4$$

$$= \frac{20 \times 50 \times 2\pi \times (7.5 \times 10^8)^2 \times 5.7 \times 10^{-8} \times 6000^4}{4\pi \times (1.5 \times 10^{11})^2}$$

$$= 923,400\text{W}$$

Energy incident on roof per minute

$$P_i = P_r \times 60 \text{ (1minute)}$$

$$= 923,400 \times 60$$

$$= 5.54 \times 10^7\text{J}$$

7. (a) (i) State the thermometric property used in a constant-volume gas thermometer (01mark)
pressure

(ii) Give two characteristics of a good thermometric property, (02marks)

- should vary linearly with change in temperature
- Should vary continuously with temperature
- Should be sensitive to temperature changes
- Should be measurable
- Should vary over a wide range of temperature.

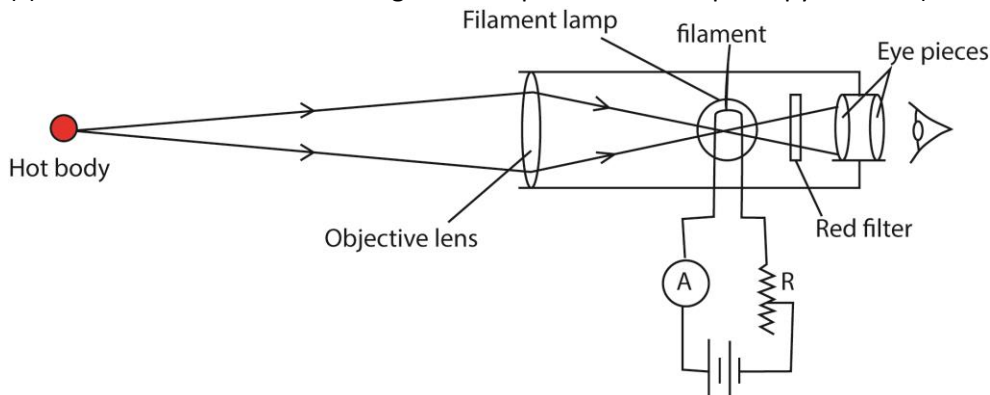
(b) (i) Describe the steps taken to set up a Celsius scale of temperature for a mercury-in glass thermometer. (04marks)

- A bulb is inserted in pure ice-water mixture.
- After some time, the length l_0 of mercury thread is recorded.
- The bulb is inserted in steam and constant length l_{100} of mercury thread is recorded.
- When l_θ is the length of mercury thread inserted in an unknown enclosure of temperature, θ° , then $\theta = \left(\frac{l_\theta - l_0}{l_{100} - l_0} \right) \times 100^\circ \text{C}$

(ii) State four disadvantages of a mercury in glass thermometer. (04marks)

- it is not very sensitive
- it cannot measure rapidly changing temperature
- it is delicate, i.e. it breaks easily

(c) Describe with the aid of a diagram the operation of an optical pyrometer (06marks)



- the filament is focused on the eye piece and the objective focuses the object so that the image of the object lies in the same plane as the filament
- Light from the hot object and the filament is passed through the red filter and viewed by the eyepiece.
- Current is adjusted by the rheostat R until the filament and the object are equally bright.
- The temperature of the hot body is then read from the calibrated ammeter, A.

(d) When oxygen is withdrawn from a tank of volume 50L, the reading of pressured gauge attached to the tank drops from $4.4 \times 10^5 \text{ Pa}$ to $7.8 \times 10^5 \text{ Pa}$. If the temperature of gas remaining in the tank falls from 30°C to 10°C , calculate the mass of oxygen withdrawn.

$$PV = nRT$$

$$n_1 = \frac{P_1 V}{RT_1} = \frac{21.4 \times 10^5 \times 50 \times 10^{-3}}{8.31 \times 303} = 42.5 \text{ moles}$$

$$n_2 = \frac{7.8 \times 10^5 \times 50 \times 10^{-3}}{8.31 \times 283} = 16.6 \text{ moles}$$

$$\text{Change in mass, } \Delta m = (n_1 - n_2)MR$$

$$= (42.5 - 16.6) \times 32$$

$$= 828.8 \text{ g}$$

8. (a)(i) What is meant by boiling point? (01marks)

The boiling point of a liquid is the temperature at which its saturated vapour pressure equals the external pressure.

(ii) Explain why boiling point of a liquid increases with increase in the external pressure. (05marks)

When the liquid boils its saturated vapour pressure = external pressure and saturated vapour pressure increases with increasing temperature. When external pressure is raised, a liquid will boil at higher saturated pressure which occurs at high temperature.

(b) (Explain how the pressure of a fixed mass of a gas can be increased at

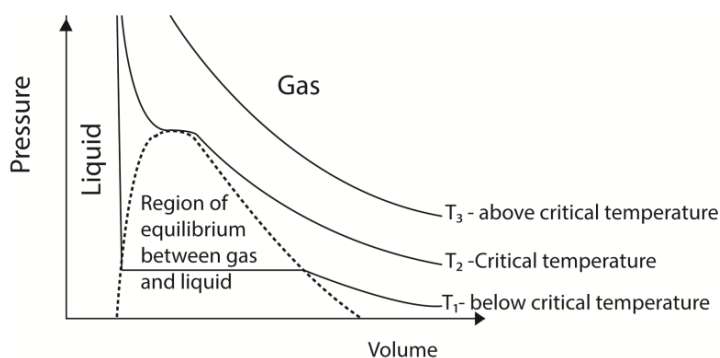
(i) Constant temperature (03marks)

By reducing the volume occupied by a gas, the molecules take less time to move between the walls of the container as the distance is reduced. The number of collisions per unit area increases hence pressure increases at constant temperature.

(ii) Constant volume (03marks)

By heating the gas, the molecules gain more kinetic energy. The molecules will bombard the walls many times per unit time per unit area. The total rate of change of momentum will increase hence pressure will increase

(c) Sketch a pressure versus volume curve for a real gas undergoing compression (03 marks)



- Above the critical temperature a gas obeys Boyle's law.
- Below the critical temperature a gas exist as unsaturated vapour at low pressure when the pressure is increase it condenses until all the gas is turned into a liquid.

(d) The cylinder of an exhaust pump has a volume of 5 cm^3 . If it is connected through a valve to a flask of volume 225 cm^3 containing air at a pressure of 75 cmHg , calculate the pressure of air

in the flask after two strokes of the pump, assuming that the temperature of the air remain constant.

First stroke

$$P_1 V_1 = P_2 V_2 \text{ but } V_2 = 225 + 25 = 250 \text{ cm}^3$$

$$75 \times 225 = P_2 \times 250$$

$$P_2 = 67.5 \text{ cmHg}$$

Second stroke

$$P_2 V_2 = P_3 V_3$$

$$P_3 = \frac{67.5 \times 225}{250} = 60.8 \text{ cmHg}$$

Alternatively

$$P_n = \left(\frac{V_2}{V_1 + V_2} \right)^n P, \text{ n = number of strokes}$$

$$= \left(\frac{225}{225 + 25} \right)^2 \times 75 = 60.75 \text{ cmHg}$$

9. (a) (i) Define thermal conductivity. (01mark)

Thermal conductivity is the rate of heat flow per unit cross sectional area per unit temperature gradient.

- (ii) Explain the mechanism of heat transfer by convection. (03marks)

When a fluid is heated from underneath, it expands and becomes less dense than fluid above. The warm less dense fluid rises to the top and the cool more dense fluid from above moves downwards to take place. This process continues and circulating current of the fluid is established until the whole fluid is heated up.

- (b) (i) State Newton's law of cooling (01mark)

It states that the rate of loss of heat is proportional to the excess temperature between the body and the surroundings under forced convections or steady draught.

- (ii) Describe briefly an experiment to verify Newton's law of cooling. (05marks)

Hot water in a calorimeter is placed near an open window. The temperature of the water is recorded at suitable time intervals. A graph of temperature against time is plotted.

Slope of the graph is obtained at temperature θ_1 . More values of the slope are obtained at different temperatures, $\theta_2, \theta_3, \theta_4, \dots$

For each temperature, excess temperature, $(\theta - \theta_R)$ is calculated, where θ_R is the room temperature.

A graph of slopes against excess temperature is plotted.

A straight line graph through the origin verifies Newton's law.

- (c) A wall is constructed using two types of bricks. The temperatures of the inner and outer surface of the wall are 29°C and 21°C respectively. The value of thermal conductivity for the inner brick is $0.4 \text{ Wm}^{-1}\text{K}^{-1}$ and that of the outer brick is $0.8 \text{ Wm}^{-1}\text{K}^{-1}$.

- (i) Explain why in a steady state the rate of thermal energy transfer is the same in both layers. (02marks)

No heat is lost to the surrounding as it flows through the inner and outer surfaces. The temperature gradient across the composite wall is constant.

- (ii) If each layer is 12 cm thick, find the temperature at the interface between the layers.

(04mrks)

$$\text{From } \frac{Q}{t} = \frac{KA(\theta_2 - \theta_1)}{l_0}$$

$$\frac{0.4A(29 - \theta)}{12 \times 10^{-2}} = \frac{0.3A(\theta - 21)}{12 \times 10^{-2}}$$

$$\therefore \theta = 23.7^\circ\text{C}$$

- (d) Explain the greenhouse effect and how it leads to rise of the earth temperature. (04marks)

The short wavelength radiation from the sun penetrates the atmosphere and is absorbed by the earth's surface. This absorbed energy warms the earth which then re-radiates long wavelength radiations e.g. infrared radiation. Some of this radiated energy absorbed (trapped) by the atmosphere. This leads to increased temperature on the earth with time referred to as global warming.

10. (a) (i) Define specific latent heat of fusion (01mark)

Specific latent heat of fusion is the amount of heat required to change 1kg mass of a substance from solid to liquid without change of temperature.

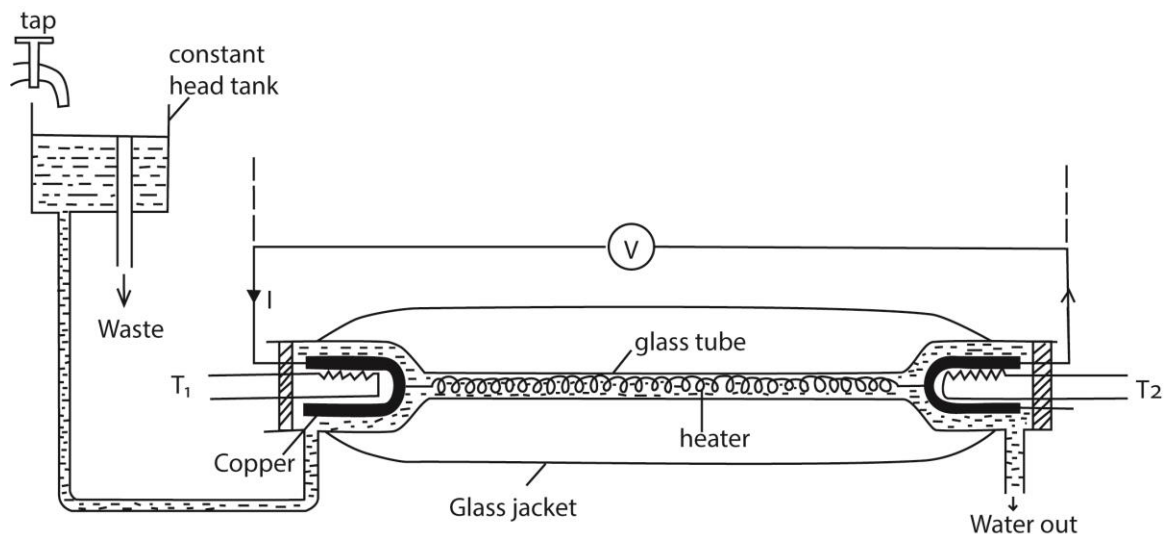
- (ii) State effect of impurities on melting point (01mark)

Impurities lower the melting point.

- (b) Explain why there is no change in temperature when a substance is melting (04marks)

Supply of heat to a melting solid reduces the forces of attraction between the molecules and increases the separation between them. This increases the potential energy (P.E) between the molecules while keeping kinetic energy (K.E) of the molecules the same. Further increase in separation between the molecules causes the regular pattern to collapse as the solid changes to liquid. Until this process is complete, the temperature does not change.

- (c) With the aid of a labelled diagram, describe the continuous flow method of measuring the specific heat capacity of a liquid. (06marks)



- A liquid is allowed to flow at constant rate

- Power is switched on and the liquid is heated until temperatures registered by T_1 and T_2 are steady and the values θ_1 and θ_2 respectively are recorded.
- The p.d V and current I are recorded from the voltmeter and ammeter respectively
- The mass, m of a liquid collected in time t is recorded
- At steady state; $VIt = mc(\theta_2 - \theta_1) + h$ (i)
where h is heat lost to the surrounding
- The rate of flow is changed and the voltage and current are adjusted until the steady readings of T_1 and T_2 are θ_1 and θ_2 respectively
- If m_1 , V_1 and I_1 are the values mass of liquid collected in time t , voltmeter and ammeter readings respectively, then
 $V_1 I_1 t = m_1 c (\theta_2 - \theta_1) + h$ (ii)
Subtracting (ii) from (i)
$$c = \frac{(VI - V_1 I_1)t}{(m - m_1)(\theta - \theta_1)}$$

(d) In an experiment to determine the specific latent heat of fusion of ice, heating coil is placed in a filter funnel and surrounded by lumps of ice. The following sets of reading were obtained.

V(V)	4.0	6.0
I(A)	2.0	3.0
Mass of water m (g) collected in 500s	14.9	29.8

Calculate

- (i) Specific latent heat of fusion of ice (04marks)
Specific latent heat $c_l = \frac{(VI - V_1 I_1)}{(m - m_1)} = \frac{4 \times 2 - 6 \times 3}{\frac{14.9}{500 \times 10^3} - \frac{29.8}{500 \times 10^3}} = 3.36 \times 10^5 \text{ J/kg}$
- (ii) Energy gained in the course of obtaining the first set of readings (03marks)
 $I_1 V_1 = m_1 c_l + h$
 $4 \times 2 = \frac{14.9}{500 \times 10^3} \times 3.36 \times 10^5 + h$
 $h = -2W$
Energy gained from surrounding = $h \times t = 2 \times 500 = 1000J$

(e) Why are two sets of reading necessary in (d) above. (01mark)

To account for heat gained from surrounding

11. (a) (i) State Dalton's law of partial pressures. (01marks)

Dalton's law of partial pressures states that the total pressure of a mixture of gases that do not react chemically is equal to the sum of partial pressures

(ii) Using the expression $p = \frac{1}{3} \rho c^2$, where p is the pressure of a gas of density ρ and mean square speed c^2 , derive Daltons law of partial pressures for two gases. (05marks)

$$P = \frac{1}{3} N \frac{m}{V} c^2 = \frac{2}{3} N \left(\frac{1}{2} m c^2 \right)$$

For gas 1, $P_1 V_1 = \frac{2}{3} N_1 \left(\frac{1}{2} m_1 c_1^2 \right)$
 $\Rightarrow N_1 = \frac{3}{2} P_1 V_1 \cdot \frac{1}{K_1}$

Similarly for gas 2

$$N_2 = \frac{3}{2} P_2 V_2 \cdot \frac{1}{K_2}$$

For a mixture of gases, $N = \frac{3}{2} P V \cdot \frac{1}{K}$; but $N = N_1 + N_2$

$$\frac{3}{2} P V \cdot \frac{1}{K} = \frac{3}{2} P_1 V_1 \cdot \frac{1}{K_1} + \frac{3}{2} P_2 V_2 \cdot \frac{1}{K_2}$$

Since temperature is constant, $K_1 = K_2 = K$

$$- \quad PV = P_1 V_1 + P_2 V_2$$

$$- \quad \text{But } V = V_1 = V_2$$

$$- \quad \therefore P = P_1 + P_2$$

(b) (i) What is meant by isothermal process and adiabatic process. (02marks)

Isothermal process is the expansion or compression of a gas at constant temperature.

Adiabatic process is the expansion or compression of a gas where there is no heat loss or gain into the gas.

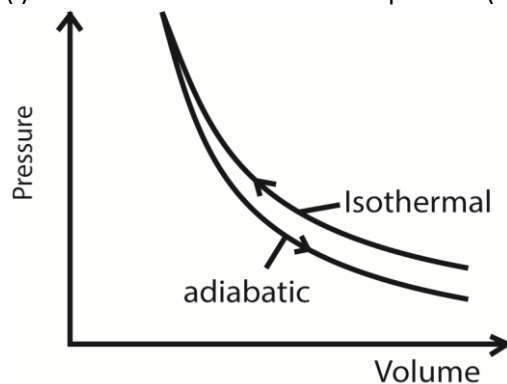
(ii) Explain why adiabatic expansion of a gas causes cooling (03marks)

During an adiabatic expansion of a gas, no heat is supplied to the gas. Molecules strike the receding piston and bounce off with reduced velocities and hence lower kinetic energy.

Since kinetic energy is proportional to temperature, the gas cools during the expansion

(c) A gas at a temperature of 17°C and pressure $1.0 \times 10^5 \text{ Pa}$ compressed isothermally to half its original volume. It is then allowed to expand adiabatically to its original volume

(i) Sketch a P-V curve the above process (02marks)



(ii) If the specific heat capacity at constant pressure is $2100 \text{ J mol}^{-1} \text{ K}^{-1}$ and at constant volume is $1500 \text{ J mol}^{-1} \text{ K}^{-1}$, find the final temperature of the gas (04marks)

$$\gamma = \frac{2100}{1500} = 1.4$$

$$T_2 V_2^{\gamma-1} = T_3 V_3^{\gamma-1}$$

$$290 \left(\frac{V}{2} \right)^{0.4} = T_3 V^{0.4}$$

$$T_3 = 219.8 \text{ K}$$

(d) (i) What is meant by saturated vapour? (01mark)

A saturated vapour is a vapour in dynamic equilibrium with its own liquid.

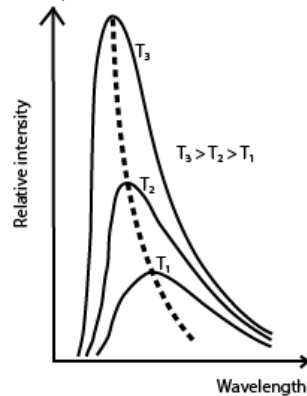
(ii) Explain briefly the effect of altitude on the boiling point of a liquid (02marks)

A liquid boils when its saturated vapour pressure is equal to the external vapour pressure. Atmospheric pressure decreases with increasing altitude, hence the boiling point of a liquid reduces as the altitude increases.

12. (a)(i) Define a black body. (01mark)

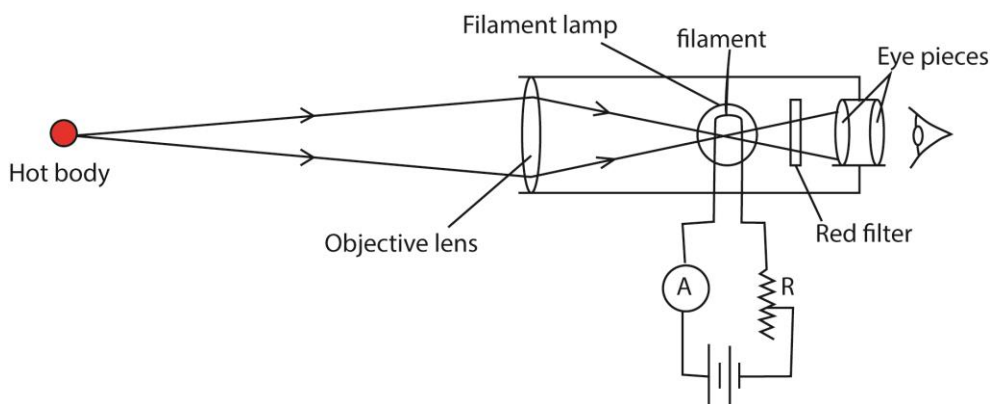
A black body is a body which absorbs all the radiations incident on it and does not reflect or transmit any.

(ii) Sketch and explain graphs of intensity versus wavelength for three different temperatures of a black body. (03marks)



- For every wave length, relative intensity increases as temperature is increased.
- The wavelength at which maximum intensity occur shifts to the shorter wavelength as temperature is increased.
- $\lambda_{\max}$ is the wavelength of radiation emitted at maximum intensity/emission of a black body at a particular temperature.

(b) Describe with the aid of a diagram how an optical radiation pyrometer is used to measure temperature. (06marks)



- the filament is focused on the eye piece and the objective focuses the object so that the image of the object lies in the same plane as the filament
- Light from the hot object and the filament is passed through the red filter and viewed by the eyepiece.
- Current is adjusted by the rheostat R until the filament and the object are equally bright.
- The temperature of the hot body is then read from the calibrated ammeter, A.

(c) (i) State Prevost's theory of heat exchanges (01marks)

When a body is in thermal equilibrium with its surrounding, its rate of emission of radiation to surrounding is equal to the rate of absorption of the radiation from the surrounding.

(ii) Metal sphere of radius 1.5cm is suspended within an evacuated enclosure whose walls are at 320K. The emissivity of the metal is 0.40. Find the power input required to maintain the sphere at a temperature of 320K, if heat conduction along the support is negligible. (04marks)

$$P = \epsilon A \sigma (T_4 - T_0^4)$$

$$= 0.4 \times 4\pi (1.5 \times 10^{-2})^2 \times 5.67 \times 10^{-8} (320^4 - 320^4) = 0$$

(d) A metal boiler is 1.5cm thick. Find the difference in temperature between the inner and outer surfaces if 40kg of water evaporate from the boiler per meter squared per hour. [Latent heat of vaporization of water = 2268 kJ kg⁻¹, Thermal conductivity of the metal of the boiler = 63 W m⁻¹ K⁻¹] (05marks)

$$\frac{dQ}{dt} = \frac{40}{3600} \times 2268000 = 22500$$

$$\text{From } \frac{dQ}{dt} = \frac{kA(\theta_2 - \theta_1)}{l}$$

$$22500 = \frac{63 \times 1 \times \Delta Q}{1.5 \times 10^{-2}}$$

$$\Delta Q = 6.0K$$

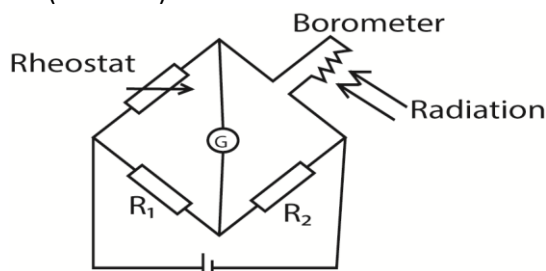
13.(a) (i) State four desirable properties a material must have to be used as a thermometric substance. (02marks)

- The property must vary linearly with temperature
- The property must vary continuously with temperature
- The property must be easily measurable
- The property must be safe to handle

(ii) State why scales of temperature based on different thermometric properties may not agree. (01mark)

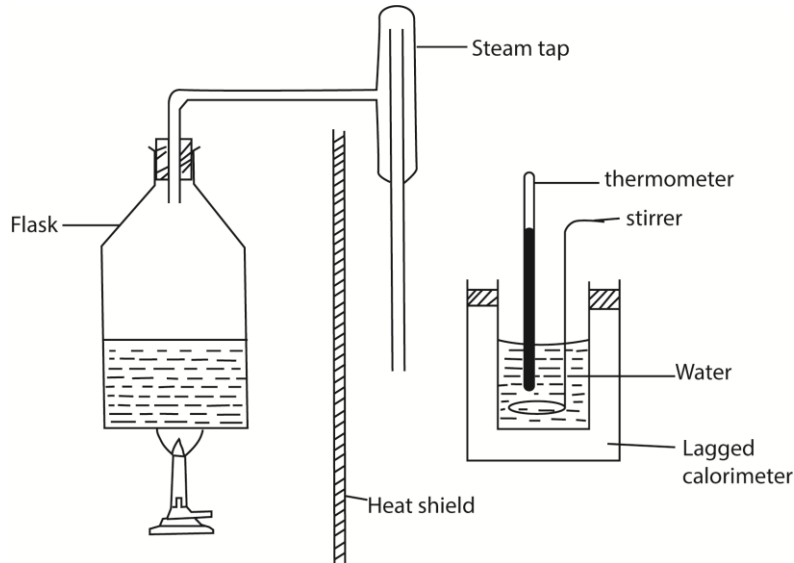
It is because different thermometric properties vary differently with temperature but only agree at the fixed points.

(b) With the aid of diagram explain how a bolometer is used to detect thermal radiation. (06marks)



The bolometer strip is connected to Wheatstone bridge circuit above. The rheostat is adjusted until the galvanometer shows no deflection. When the radiations fall on the strip, they are absorbed and its temperature rises leading to an increase in resistance. The galvanometer deflects showing the presence of radiations.

(c) Describe, with the aid of a diagram an experiment to determine specific heat of vaporization of steam using the method of mixtures. (07marks)



- The initial temperature θ_0 and mass, m of water in the calorimeter are measured
 - Steam from boiling water is passed into water in a calorimeter and after a reasonable temperature rise, flow of steam is stopped and final temperature, θ_f is recorded.
 - Mass m_2 of water in the calorimeter is then taken
 - The mass of steam condensed, $m_s = (m_2 - m)$
- Given that the heat capacity of the calorimeter = C
 Heat gained by steam = heat gained by water and calorimeter
 $m_s c_v + m_s c(100 - \theta_f) = (m_2 - m)c(\theta_f - \theta_0) + C(\theta_f - \theta_0)$
 c_v = specific latent heat of vaporization
 c = specific heat capacity of water

(d) A 600W electricity heater is used to raise the temperature of a certain mass of water in a thermos flask from room temperature to 80°C . The same temperature rise is obtained when steam from a boiler is passed into an equal mass of water at room temperature in the same time. If 16g of water were being evaporated every minute in the boiler, find the specific latent heat of vaporization of steam, assuming no heat losses. (04marks)

Rate of evaporation = 0.016kg per minute

$$= \frac{0.016}{60} \text{ kgs}^{-1}$$

Let L_v be specific latent heat of vaporization

$$P = mL_v + mc\theta$$

$$600 = \frac{0.016}{60} c_v + \frac{0.016}{60} \times 4200 \times (100 - 80)$$

$$L_v = 2.2 \times 10^6 \text{ Jkg}^{-1}$$

14.(a) Define the following

(i) Absolute zero (01marks)

It is the temperature attained when molecules slow down and acquire the least possible energy

(ii) Cooling correction (01marks)

It is the temperature added to experimentally observed maximum temperature to cater for heat lost to the surroundings.

(b) (i) State Dalton's law of partial pressures (01mark)

Dalton's law of partial pressures states that the total pressure of a mixture of gases that do not react chemically is equal to the sum of partial pressures

(ii) Using the expression $p = \frac{1}{3} \rho \overline{c^2}$, where p is the pressure of a gas of density ρ and mean square speed $\overline{c^2}$, derive Daltons law of partial pressures for two gases. (05marks)

$$P = \frac{1}{3} N \frac{m}{V} \overline{c^2} = \frac{2}{3} N \left(\frac{1}{2} m \overline{c^2} \right)$$

$$\text{For gas 1, } P_1 V_1 = \frac{2}{3} N_1 \left(\frac{1}{2} m_1 \overline{c_1^2} \right)$$

$$\Rightarrow N_1 = \frac{3}{2} P_1 V_1 \cdot \frac{1}{K_1}$$

Similarly for gas 2

$$N_2 = \frac{3}{2} P_2 V_2 \cdot \frac{1}{K_2}$$

For a mixture of gases, $N = \frac{3}{2} P V \cdot \frac{1}{K}$; but $N = N_1 + N_2$

$$\frac{3}{2} P V \cdot \frac{1}{K} = \frac{3}{2} P_1 V_1 \cdot \frac{1}{K_1} + \frac{3}{2} P_2 V_2 \cdot \frac{1}{K_2}$$

Since temperature is constant, $K_1 = K_2 = K$

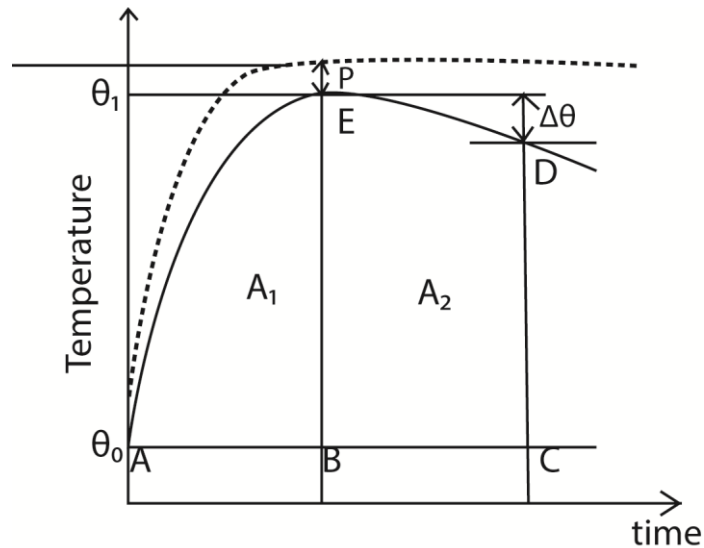
$$- \quad PV = P_1 V_1 + P_2 V_2$$

$$- \quad \text{But } V = V_1 = V_2$$

$$- \quad \therefore P = P_1 + P_2$$

(c) Explain clearly the steps taken to determine the cooling correction when measuring the specific heat capacity of a poor conductor by the method of mixtures. (07marks)

- Pour a liquid in a calorimeter and place it on a table
- Place a thermometer into the liquid and after sometime, record the temperature of the surroundings, θ_0 .
- Gently place a hot solid into the liquid and stir.
- Record the temperature of the mixture at suitable interval until the temperature of the mixture has fallen by about 1°C below the observed maximum temperature, θ_1 .
- Plot a graph of temperature against time



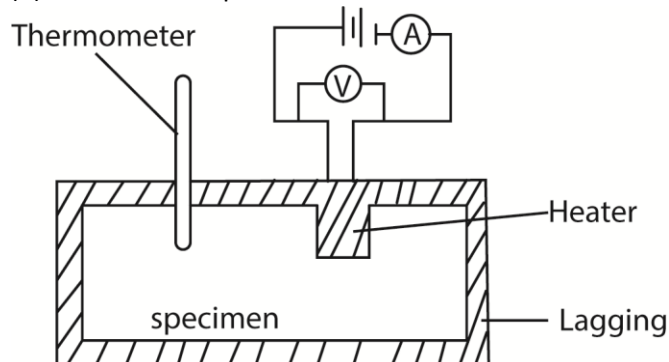
- The broken line shows how we would expect the temperature to rise if no heat were lost and the difference, P, between the plateau of this imaginary curve, and the crest of the experimental curve, E, is known as the 'cooling correction'
- Draw a line AC through θ_0 parallel to the time axis.
- Draw a line BE through θ_1 parallel to the temperature axis.
- Draw a line CD beyond BE parallel to the temperature axis and note $\Delta\theta$
- Estimate the area A_1 and A_2 under the graph by counting the square on the graph paper
- Cooling correction, P s given by the graph

$$\text{Cooling correction, } P = \frac{A_1}{A_2} \times \Delta\theta^\circ\text{C}$$

15.(a) Define thermal conductivity of material and state its units. (02marks)

Thermal conductivity is the rate of heat flow per unit area of cross section area per temperature gradient. Units are $\text{Wm}^{-1}\text{K}^{-1}$

(b) Describe an experiment to determine the thermal conductivity of copper. (06marks)



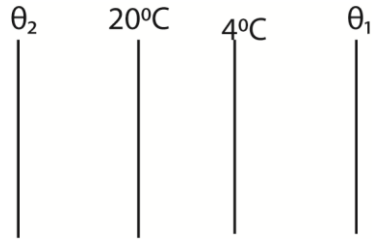
- Two holes are drilled into the specimen solid of copper of mass m.
- A thermometer is inserted in one of the holes and an electric heater into the other hole. The holes are then filled with a good conducting fluid, e.g. oil to ensure thermal contact.
- The apparatus is insulated and initial temperature θ_0 is recorded.
- The heater is switched on at the same time a stop clock is started.

- The steady values of ammeter reading, I and voltmeter reading, V are recorded.
- After considerable temperature rise, the heater is switched off and stop clock stopped.
- The highest temperature θ_1 recorded and time t taken noted.
- The specific heat capacity, c, of the conducting solid is calculated from

$$c = \frac{IVt}{m(\theta_1 - \theta_0)}$$

(c) A double glazed window has two glasses each of thickness 4.0mm separated by a layer of air of thickness 1.5mm. If the two inner air-glass surfaces have steady temperature of 20°C and 4°C respectively. Find the

(i) temperatures of the outer air-glass surfaces (03marks)



$$\frac{Q}{t} = \frac{0.72A(\theta_2 - 20)}{4 \times 10^{-3}} = \frac{0.025A(20 - 4)}{1.5 \times 10^{-3}} = \frac{0.72A(4 - \theta_1)}{4 \times 10^{-3}}$$

$$\theta_2 = 21.48^\circ\text{C} ; \theta_1 = 2.52^\circ\text{C}$$

(ii) the amount of heat that flows across an area of the window of 2m² in 2hours.

$$\frac{Q}{t} = \frac{0.025 \times 16 \times 2}{1.5 \times 10^{-3}} = 533.3\text{Js}^{-1}$$

$$\text{Heat flow in two hours} = 533.3 \times 2 \times 3600 = 3.84 \times 10^6\text{J}$$

[Conductivity of glass = 0.72Wm⁻¹k⁻¹ and that of air = 0.025Wm⁻¹k⁻¹]

(d)(i) What is a black body? (01mark)

A black body is one that absorbs all incident radiation falling on it and transmits or reflects none.

(ii) Explain how a welder can protect the eyes from damage. (03marks)

A welder puts on dark shades that absorb ultraviolet light which damages the eyes.

(iii) Calculate the wavelength of the radiation emitted by a black body at 6000K

[Wien's displacement constant = 2.9 × 10⁻³mK] (02marks)

$$\lambda T = 2.9 \times 10^{-3}$$

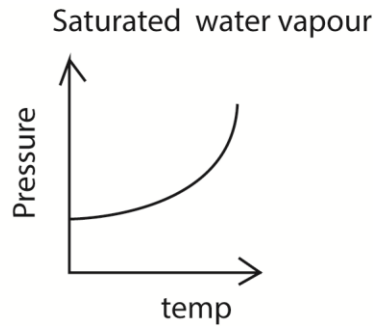
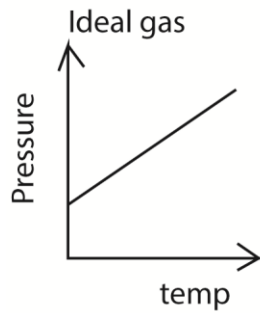
$$6000\lambda = 2.9 \times 10^{-3}$$

$$\lambda = 4.8 \times 10^{-7}\text{m}$$

16.(a) (i) State two differences between saturated and unsaturated vapours. (02marks)

- A saturated vapour pressure is one which is in dynamic equilibrium with its own liquid and an unsaturated vapour is one that is not in dynamic equilibrium with its own liquid.
- A saturated vapour pressure does not obey gas laws whereas unsaturated vapour approximately obeys gas laws.

(ii) Sketch graphs of pressure against temperature for an ideal gas and for saturated water vapour originally at 0°C (03marks)



- (b) The specific heat capacity of oxygen at constant volume is $719 \text{ J kg}^{-1} \text{ K}^{-1}$ and its density at standard temperature and pressure is 1.429 kg m^{-3} . Calculate the specific heat capacity of oxygen at constant pressure (04marks)

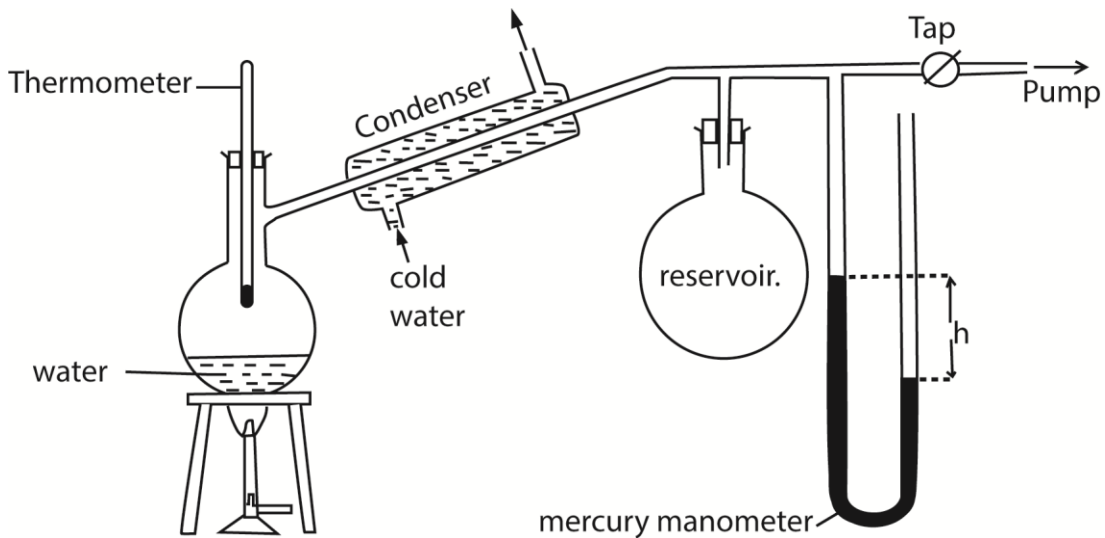
$$PV = nrT$$

$$r = \frac{P}{T} \left(\frac{V}{m} \right) = \frac{1.01 \times 10^5}{273 \times 1.429} = 258.9 \text{ J kg}^{-1} \text{ K}^{-1}$$

$$c_p - c_v = r$$

$$c_p = 719 + 258.9 = 977.9 \text{ J kg}^{-1} \text{ K}^{-1}$$

- (c) (i) With the aid of a labelled diagram, describe an experiment to determine standard saturated vapour pressure of water. (05marks)



- The pressure of the air in R is shown by the mercury manometer; if its height is h , the pressure in mm mercury is $P = H - h$, where H is the barometer height.
- The tap is opened and the pressure above water varied using the pump to a suitable value.
- The tap is closed and water in the flask is heated until it boils.
- The temperature θ and difference in mercury levels, h , are noted and recorded.
- The saturated vapour pressure, $P = (H \pm h)$ is calculated
- The procedure is repeated for other values of θ and h

- A graph of P versus θ is plotted and the saturated vapour pressure at a particular temperature is obtained.

(ii) State how the experiment set up in (c) (i) may be modified to determine a saturated vapour pressure of above atmospheric pressure (01marks)

By replacing the vacuum pump with a bicycle pump

(d)(i) Define ideal gas (01mark)

An Ideal gas is one that obeys Boyle's law under all conditions

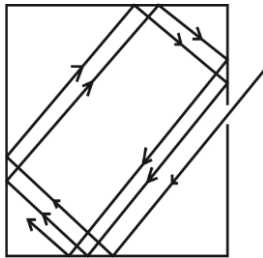
(ii) State and explain the conditions under which real gases behave as ideal gases. (04marks)

- At higher temperature, the intermolecular spacing increases and intermolecular forces become negligible
- At very low pressure, the gas occupies negligible volume of the container.

17. (a) (i) What is a black body?(01marks)

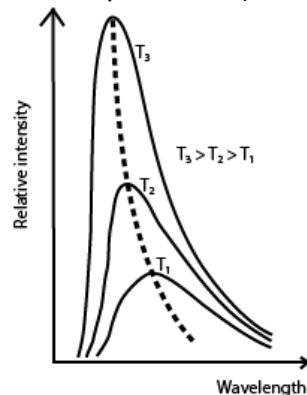
A black body is one which absorbs all the radiation that falls upon it, and reflects or transmits none.

(ii) Explain with the aid of a diagram how black body can be approximated. (03marks)



When radiation enters a black container through a hole, it undergoes multiple reflections. At each reflection, part of the radiation is absorbed. After several reflections, all the radiation is retained inside the container. Hence it approximates to a black body.

(iii) With the aid of sketch graphs explain the salient features of the spectral distribution of black body radiation (04 marks)



- For every wave length, relative intensity increases as temperature is increased.
- The wavelength at which maximum intensity occur shifts to the shorter wavelength as temperature is increased.

- λ_{max} is the wavelength of radiation emitted at maximum intensity/emission of a black body at a particular temperature.

(b) Give four properties of ultraviolet radiation. (02marks)

- produce ionization and fluorescence
- affect photographic plates
- produces photoelectric effect
- promotes chemical reaction
- can be reflected and refracted.

(c) Describe an experiment to compare the energy radiated by two surfaces at different temperatures (04marks)

- A metal cube whose sides have a variety of finishes; dull black, white, highly polished is filled with water and this water is kept boiling by a constant heat supply.
- A thermopile is made to face the various finishes of the cube at equal distances and each time the deflection on the galvanometer is noted.
- The deflection of the galvanometer is greatest when the thermopile is facing the dull-black surface and least when facing the highly polished surface.
- This implies that the dull-black surface is a better radiator.

(d) (i) State Stefan's law. (01mark)

Stefan's law states that the total power radiated by a black body per unit surface area is proportional to the fourth power of its absolute temperature. i.e. $\frac{P}{A} \propto T^4$

(ii) The earth receives energy from the sun at the rate of $1.4 \times 10^3 \text{ Wm}^{-2}$. If the ratio of the earth's orbit to the sun's radius is 216, calculate the surface temperature of the sun. (05marks)

$$\text{Power radiated by the sun} = 4\pi r^2 \sigma T^4$$

$$\text{Energy intensity} = \frac{4\pi r^2 \sigma T^4}{4\pi R^2}$$

$$\therefore \frac{4\pi r^2 \sigma T^4}{4\pi R^2} = 1.4 \times 10^3$$

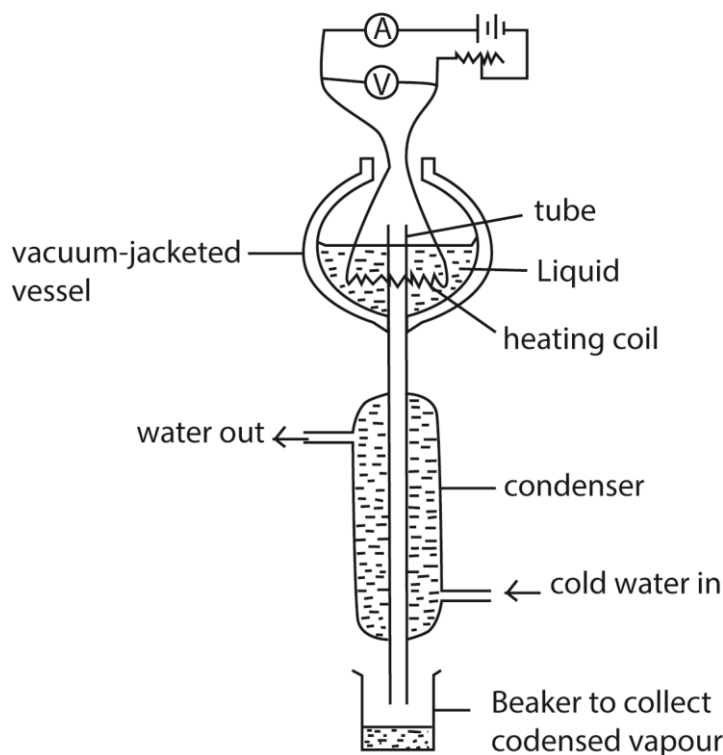
$$T^4 = \frac{1.4 \times 10^3}{5.7 \times 10^{-8}} \left(\frac{R}{r}\right)^2 = \frac{1.4 \times 10^3}{5.7 \times 10^{-8}} \times 216^2$$

$$T = 5.82 \times 10^3 \text{ K}$$

18. (a) Define specific latent heat of vaporization. (01mark)

Specific latent heat of vaporization is the amount of heat required to change 1kg mass of a liquid into vapour at constant temperature.

(b) With the aid of labelled diagram, describe an experiment to measure the specific latent heat of vaporization of a liquid using an electrical method. (07marks)



- Put the liquid whose specific latent heat of vaporization is required in a vacuum jacketed vessel as shown above.
- The liquid is heated to boiling point.
- The current, I , and voltage, V are recorded.
- The mass of liquid, m , condensed in time, t , is determined.
- Then $IV = \frac{m}{t}L + h$, where h is the rate of heat loss to the surroundings
- To eliminate, h , the experiment is repeated for different values of I' and V' and the mass of the liquid, m' condensed in time t is determined.
- Again $I'V' = \frac{m'}{t}L + h$

$$\text{Latent heat of vaporization, } L = \frac{(I'V' - IV)t}{(m' - m)}$$

(c) Explain the effect of pressure on the boiling point of a liquid. (02marks)

- Since a liquid boils when its saturated vapour pressure is equal to external pressure.
- Increasing the external pressure increases the boiling point of a liquid because the liquid has to be heated to a higher temperature to make its saturated vapour pressure equal to external pressure

(d) A liquid of specific heat capacity $2.8 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$ and specific latent heat of vaporization $9.00 \times 10^5 \text{ J kg}^{-1}$ is contained in a flask of heat capacity 800 J K^{-1} at a temperature of 32°C . An electric heater rated 1 kW is immersed in 2.5 kg of the liquid and switched on for 12 minutes, calculate the amount of liquid that boiled off, given that the boiling point of the liquid is 80°C . (06marks)

Heat supplied by the heater = $mc\theta + C\theta + m_1L$

$$1000 \times 12 \times 60 = 2.5 \times 2.8 \times 10^3(80-32) + 800 \times (80-32) + 9.00 \times 10^5 m_1$$

Mass of the liquid evaporates, $m_1 = 0.384\text{kg}$

- (e) (i) Two thermometers are used to measure the temperature of a body. Explain why the temperatures may be different. (02marks)

Because thermometric properties vary differently with temperature and only agree at fixed points.

- (ii) A platinum resistance thermometer has a resistance of 5.42Ω at the triple point of water. Calculate the resistance at a temperature of 50.0°C . (02marks)

$$T = \frac{R_T}{R_{tr}} \times 273.16$$

$$(273 + 50) = \frac{R_{50}}{5.42} \times 273.16$$

$$R_{50} = 6.41\Omega$$

19. (a) Define

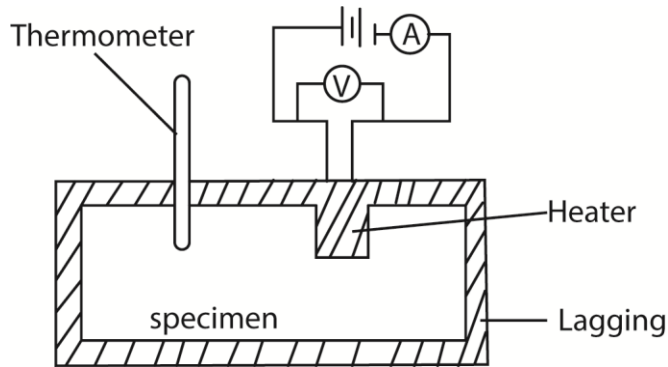
- (i) Specific heat capacity (01mark)

Specific heat capacity is the amount of heat required to rise the temperature of 1kg mass of a substance by 1K.

- (ii) Specific latent heat of vaporization of a liquid. (01 mark)

Specific latent heat of vaporization is amount of heat required to convert 1kg of a liquid substance at its boiling point into vapor at constant temperature.

- (b) With the aid of a labelled diagram, describe the electrical method of determining the specific heat capacity of a solid (07marks)



- Two holes are drilled into the specimen solid of mass m .
- A thermometer is inserted in one of the holes and an electric heater into the other hole. The holes are then filled with a good conducting fluid, e.g. oil to ensure thermal contact.
- The apparatus is insulated and initial temperature θ_0 is recorded.
- The heater is switched on at the same time a stop clock is started.
- The steady values of ammeter reading, I and voltmeter reading, V are recorded.
- After considerable temperature rise, the heater is switched off and stop clock stopped.
- The highest temperature θ_1 recorded and time t taken noted.
- The specific heat capacity, c , of the conducting solid is calculated from

$$c = \frac{IVt}{m(\theta_1 - \theta_0)}$$

- (c) An electrical heater rated 48W, 12V is placed in a well-insulated metal of mass 1.0kg at a temperatures of 18°C. When power is switched on for 5minutes, the temperature of the metal rises to 34°C. Find the specific heat capacity of the metal (04marks)

Heat supplied by the heater, $IVt = mc\theta$

$$48 \times 5 \times 60 = 1 \times c \times (34-18)$$

$$\text{Specific heat capacity, } c = 900 \text{ J kg}^{-1} \text{ K}^{-1}$$

- (d) (i) State Newton's law of cooling (01marks)

The rate of loss of heat is proportional to the excess temperature over the surroundings under conditions of forced convection.

(ii) Use Newton's law of cooling to show that $\frac{d\theta}{dt} = -k(\theta - \theta_R)$

Where $\frac{d\theta}{dt}$ is the rate of fall of temperature and θ_R is the temperature of the surrounding.

From the above law, $\frac{dQ}{dt} \propto (\theta - \theta_R)$

$$\Rightarrow \frac{dQ}{dt} = k(\theta - \theta_R)$$

But $\frac{dQ}{dt} = mc \frac{d\theta}{dt}$

$$\Rightarrow \frac{d\theta}{dt} = k(\theta - \theta_R)$$

Since for a given body, m and c are constant.

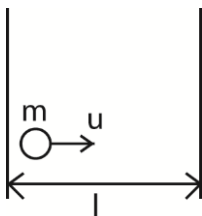
- (e) Explain why evaporation causes cooling. (03marks)

During evaporation the most energetic molecules at the liquid surface escape leaving molecules with low kinetic energy. Since mean kinetic energy of molecules is directly proportional to absolute temperature, the liquid cools.

20. (a) The pressure, P, of an ideal gas is given by $P = \frac{1}{3} \rho \overline{c^2}$, where ρ is the density of the gas and $\overline{c^2}$ its mean square speed.

- (i) Show clearly the steps taken to derive this expression (06marks)

Consider a molecule of mass, m, moving in a cube of length, l and velocity, u.



Change in momentum = $mu - (-mu) = 2mu$

Rate of change of momentum = $\frac{2mu}{t}$

Time, t , between collision = $\frac{2l}{u}$

$$F_1 = 2mu \div \frac{2l}{u} = \frac{mu^2}{l}$$

For N molecules, force on the wall,

$$F = \frac{mu_1^2}{l} + \frac{mu_2^2}{l} + \frac{mu_3^2}{l} + \dots + \frac{mu_N^2}{l}$$

Pressure, $P = \frac{F}{A} = \frac{m}{l^3} (u_1^2 + u_2^2 + u_3^2 + \dots + u_N^2)$ since $A = l^2$

$$u^2 = \frac{u_1^2 + u_2^2 + u_3^2 + \dots + u_N^2}{N}$$

$$Nu^2 = u_1^2 + u_2^2 + u_3^2 + \dots + u_N^2$$

$$\therefore P = \frac{Nmu^2}{l^3} = \rho u^2; \text{ since } \rho = \frac{Nm}{l^3}$$

$$c^2 = u^2 + v^2 + w^2 \text{ and } u^2 = v^2 + w^2$$

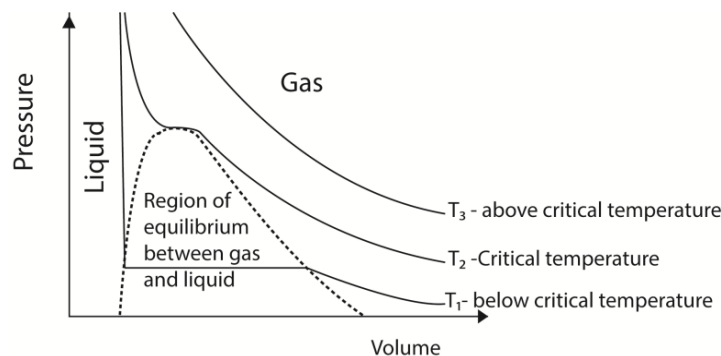
$$\therefore c^2 = 3u^2 \Rightarrow u^2 = \frac{1}{3}c^2$$

$$\therefore P = \frac{1}{3}\rho c^2$$

(ii) State the assumptions made in deriving this expression (02marks)

- Intermolecular forces of attraction are negligible
- The volume of the gas molecules are negligible compared to that of the container
- Molecules make perfectly elastic collision
- The duration of collision is negligible compared to the time between collisions

(b) Sketch the pressure versus volume curve for a real gas for temperatures above and below the critical temperature. (03marks)



- Above the critical temperature a gas obeys Boyle's law.

- Below the critical temperature a gas exist as unsaturated vapour at low pressure when the pressure is increase it condenses until all the gas is turned into a liquid.

(c) For 1 mole of a real gas, the equation of state is $\left(P + \frac{a}{V^2}\right)(V - b) = RT$

Explain the significance of the terms $\frac{a}{V^2}$ and b. (02marks)

$\frac{a}{V^2}$ - corrects deficit in pressure due to intermolecular attractions of gas molecules

b – accounts for the finite volume of molecules themselves.

(d) A balloon of volume $5.5 \times 10^{-2} \text{m}^3$ is filled with helium to a pressure of $1.10 \times 10^5 \text{Nm}^{-2}$ at a temperature of 20°C . Calculate the

(i) the number of helium atoms in the balloon (03marks)

From $PV = nRT$

$$n = \frac{1.10 \times 10^5 \times 5.5 \times 10^{-2}}{8.31 \times 293} = 2.48 \text{ moles}$$

$$\text{Number of atoms} = 2.48 \times 6.02 \times 10^{23} = 1.49 \times 10^{24}.$$

(ii) net force acting on the square meter of material of the balloon if the atmospheric temperature is $1.01 \times 10^5 \text{Nm}^{-2}$ (04marks)

$$F = PA$$

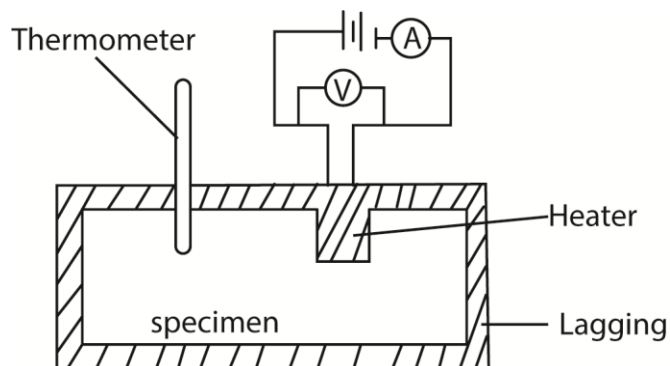
Net force = internal force in the bulb – external force on the bulb

$$= (1.10 \times 10^5 - 1.01 \times 10^5) \times 1.0 = 9.0 \times 10^3 \text{N}$$

21. (a) (i) Define thermal conductivity of a material (01mark)

Thermal conductivity is the rate of heat flow through a material per unit cross sectional area per unit temperature gradient.

(ii) Describe an experiment to determine the thermal conductivity of copper. (06marks)



- Two holes are drilled into the specimen solid of copper of mass m.
- A thermometer is inserted in one of the holes and an electric heater into the other hole. The holes are then filled with a good conducting fluid, e.g. oil to ensure thermal contact.

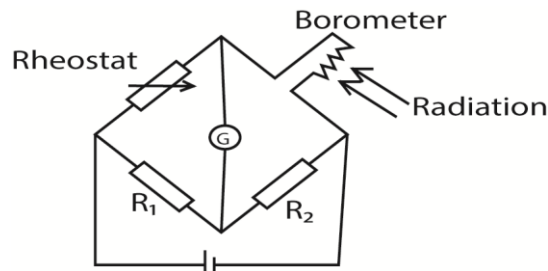
- The apparatus is insulated and initial temperature θ_0 is recorded.
- The heater is switched on at the same time a stop clock is started.
- The steady values of ammeter reading, I and voltmeter reading, V are recorded.
- After considerable temperature rise, the heater is switched off and stop clock stopped.
- The highest temperature θ_1 recorded and time t taken noted.
- The specific heat capacity, c , of the conducting solid is calculated from

$$c = \frac{IVt}{m(\theta_1 - \theta_0)}$$

(b) (i) What is a black body? (01 marks)

A black body is one which absorbs all the radiation of every wavelength falling on it, reflects and transmits none.

(ii) Describe how infrared radiation can be detected using a bolometer. (03marks)



The bolometer strip is connected to Wheatstone bridge circuit above. The rheostat is adjusted until the galvanometer shows no deflection. When the radiations fall on the strip, they are absorbed and its temperature rises leading to an increase in resistance. The galvanometer deflects showing the presence of radiations.

(iii) Give one characteristic property of infrared radiation. (01mark)

Causes sensation of warmth (increases body temperature).

(c) (i) A spherical black body of radius 2.0cm at -73°C is suspended in an evacuated enclosure whose walls are maintained at 27°C . If the rate of exchange of thermal energy is equal to 1.85Js^{-1} , find the value of Stefan's constant, (05marks)

$$T_1 = 27 + 273 = 300\text{K}$$

$$T_2 = -73 + 273 = 200\text{K}$$

$$P = A\sigma(T_1^4 - T_2^4)$$

$$1.85 = 4\pi(0.02)^2\sigma(300^4 - 200^4)$$

$$\sigma = 5.66 \times 10^{-8}\text{Wm}^{-2}\text{K}^{-4}$$

(ii) Calculate the wavelength at which the radiation emitted by the enclosure has maximum intensity (03mark)

$$\lambda_{\text{max}}T = 2.9 \times 10^{-3}$$

$$\lambda_{\text{max}} = \frac{2.9 \times 10^{-3}}{300} = 9.7 \times 10^{-6}\text{m}$$

22. (a)(i) Define the terms specific heat capacity and specific latent heat of fusion (02marks)

Specific heat capacity is the amount of heat required to raise the temperature of 1kg mass of a substance by 1K of 1°C.

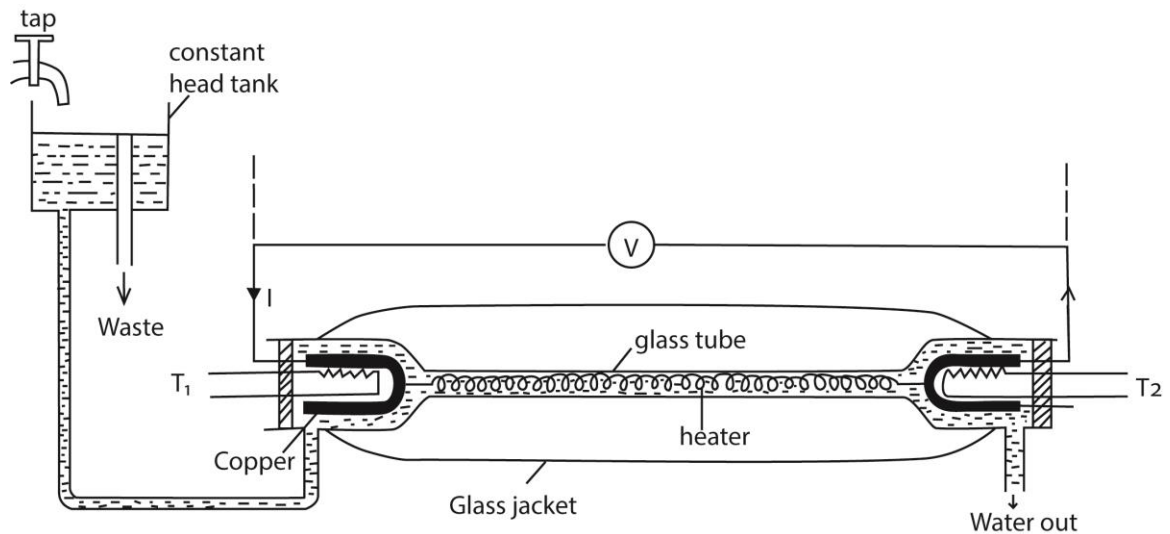
Specific latent heat of fusion is the amount of heat required to change 1kg of solid substance to a liquid at constant temperature.

(ii) Explain the changes that take place in the molecular structure of substances during fusion and evaporation (04marks)

Heat supplied during fusion breaks down the forces that keep ordered pattern of molecules in solid crystalline structure to form a liquid. The potential energy of the molecules increases but the average kinetic energy and temperature of the molecules remain unchanged.

Heat supplied during evaporation breaks molecular bonds in liquids and allows gas molecules to expand against atmospheric pressure which allows them to move independently.

(b) With the aid of a labelled diagram describe an experiment to determine the specific heat capacity of a liquid using the continuous flow method. (08marks)



- A liquid is allowed to flow at constant rate
- Power is switched on and the liquid is heated until temperatures registered by T_1 and T_2 are steady and the values θ_1 and θ_2 respectively are recorded.
- The p.d V and current I are recorded from the voltmeter and ammeter respectively
- The mass, m of a liquid collected in time t is recorded
- At steady state; $VIt = mc(\theta_2 - \theta_1) + h$ (i)
where h is heat lost to the surrounding
- The rate of flow is changed and the voltage and current are adjusted until the steady readings of T_1 and T_2 are θ_1 and θ_2 respectively

- If m_1 , V_1 and I_1 are the values mass of liquid collected in time t , voltmeter and ammeter readings respectively, then

$$V_1 I_1 t = m_1 c (\theta_2 - \theta_1) + h \dots\dots\dots (ii)$$

Subtracting (ii) from (i)

$$c = \frac{(VI - V_1 I_1)t}{(m - m_1)(\theta - \theta_1)}$$

(c) Steam at 100°C is passed into a copper calorimeter of mass 150g containing 340g of water at 15°C . This is done until the temperature of the calorimeter and its content is 71°C . If the mass of the calorimeter and its content is found to be 525g, calculate the specific latent heat of vaporization of water. (06marks)

Mass of condensed steam = $525 - (340 + 150) = 35\text{g}$

Heat lost by steam = heat gained water and calorimeter

$$Ml_v + mc\Delta\theta = m_1c\Delta\theta + C\Delta\theta$$

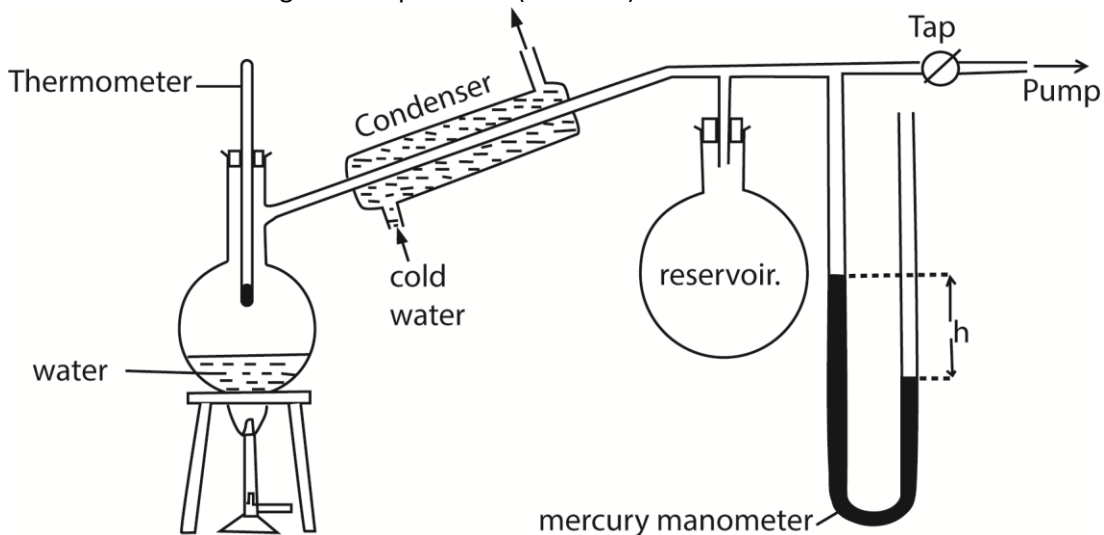
$$0.035l = 0.340(100 - 71) + 0.150 (100 - 71)$$

Specific latent heat capacity, $l_v = 2.259 \times 10^6 \text{Jkg}^{-1}$.

23. (a) (i) Define saturated vapour pressure. (01mark)

Saturated vapour pressure of a liquid is the pressure exerted by vapour in dynamic equilibrium with its liquid

(ii) Describe with the aid of a diagram, how saturated vapour pressure of a liquid can be determined at a given temperature. (06marks)



- The pressure of the air in R is shown by the mercury manometer; if its height is h , the pressure in mm mercury is $P = H - h$, where H is the barometer height.
- The tap is opened and the pressure above water varied using the pump to a suitable value.
- The tap is closed and water in the flask is heated until it boils.
- The temperature θ and difference in mercury levels, h , are noted and recorded.

- The saturated vapour pressure, $P = (H \pm h)$ is calculated
- The procedure is repeated other values of θ and h
- A graph of P versus θ is plotted and the saturated vapour pressure at a particular temperature is obtained.

(b) Use the kinetic theory to explain the following observations

(i) Saturated vapour pressure of a liquid increases with temperature. (03marks)

If a liquid is in dynamic equilibrium with its vapour, an increase in temperature increases mean kinetic energy of the molecules and hence the rate at which molecules escape from the liquid.

The density of the vapour increases implying increase in the rate of condensation until dynamic equilibrium is restored. There are now more molecules in the vapour phase than previously that are moving faster and hence higher pressure.

(ii) Saturated vapour pressure is not affected by decrease in volume at constant pressure. (03marks)

A decrease in volume leads to a momentary increase in vapour density. Consequently, the rate of condensation increases while the rate of evaporation rate is constant. When the vapour density reduces, the condensation rate also reduces. So the dynamic equilibrium is restored to the initial value.

(c) When hydrogen gas is collected over water, the pressure in the tube at 15°C and 75°C are 65.5cm and 105.6cm of mercury respectively. If the saturated vapour pressure at 15°C is 1.42cm of mercury, find its value at 75°C (04marks)

$$P_1 = 65.5 - 1.42 = 62.08 \text{ and } T_1 = 273 + 15 = 288\text{K}$$

$$P_2 = 105.6 - P, \text{ and } T_2 = 273 + 75 = 348\text{K}$$

$$\text{From } \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$P_2 = \left(\frac{P_1}{T_1}\right) T_2 = 105.6 - \frac{64.08}{288} \times 348 = 28.12\text{cmHg}$$

(d) Explain why the molar heat capacity of an ideal gas at constant pressure differs from the molar heat capacity at constant volume (03marks)

At constant volume, all the heat supplied goes to raising temperature (increasing internal energy of the gas) while at constant pressure, heat is used to raise the temperature of the gas (internal energy) and do external work in expansion to keep the pressure constant.

Therefore the molar heat capacity at constant pressure is more than the molar heat capacity at constant volume.

24. (a) (i) Define thermal conductivity. (01mark)

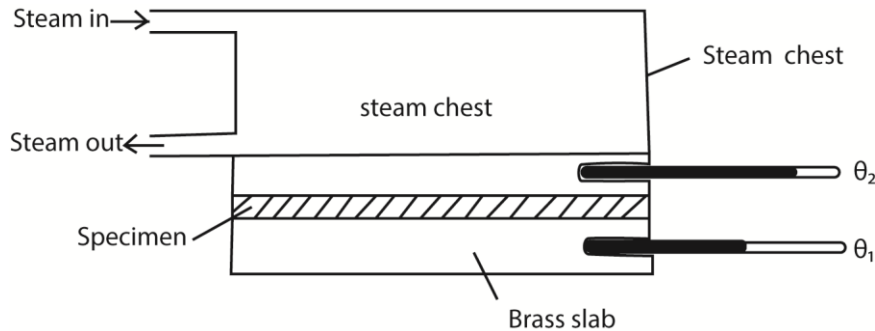
Thermal conductivity is the rate of heat transfer per unit cross section area per unit temperature gradient.

(ii) Compare the mechanism of heat transfer in poor conductor and good conductor. (05marks)

When one end of a poor conductor is heated, the atoms at the hot end vibrate with increased amplitude, collide with neighboring atoms and lose energy to them. The neighboring atoms also vibrate with increased amplitude, collide with adjacent atoms and lose energy to them. In this way, heat is transferred from one end to another.

Good conductors contain free electron. When heated, the electrons at hot end gain more energy and transfer the energy as they collide with atoms in solid lattice. Also, when one end of a good conductor is heated, the atoms at the hot end vibrate with increased amplitude, collide with neighboring atoms and lose energy to them. The neighboring atoms also vibrate with increased amplitude, collide with adjacent atoms and lose energy to them. In this way, heat is transferred from one end to another.

(b) Describe, with the aid of a diagram how you would measure the thermal conductivity of a poor conductor, stating the necessary precautions (08marks)



- Glass is cut in form of a thin disc of cross section area, A and thickness, x .
- The disc is sandwiched between a steam chest and brass slab of mass, m and specific heat capacity, c .
- Steam is passed through the chest until the thermometers register steady temperatures, θ_1 and θ_2 .
- Then, $\frac{\theta}{t} = kA \left(\frac{\theta_2 - \theta_1}{x} \right)$
- The glass disc is removed and brass slab is heated directly by steam chest, until its temperature is about 10°C above θ_1 .
- Steam chest is removed and the top of the glass slab is covered by the glass disc.
- The temperature of the slab is recorded at suitable time interval until its temperature is about 10°C below θ_1 .
- A graph of temperature against time is plotted and its slope is determined at θ_1

$$\frac{\theta}{t} = mcs$$

$$\therefore kA \left(\frac{\theta_2 - \theta_1}{x} \right) = mcs$$

$$k = \frac{mcsx}{A(\theta_2 - \theta_1)} \text{ but } A = \frac{\pi D^2}{4}$$

$$\therefore k = \frac{4mcsx}{\pi D^2(\theta_2 - \theta_1)}$$

Precautions

- Sample in a thin disc
- Faces of the disc highly polished to ensure tight uniform contacts

- A thin layer of grease is smeared on faces for good thermal contact.
- (c) A cylindrical iron vessel with a base of diameter 15cm and thickness 0.30cm has its base coated with a thin film of soot of thickness 0.10cm. It is then filled with water at 100°C and placed on a large block of ice at 0°C. Calculate the initial rate at which the ice will melt

(06marks) (thermal conductivity of soot=0.12Wm⁻¹K⁻¹)

$$\frac{Q}{t} = kA \left(\frac{\theta_2 - \theta_1}{x} \right) = k_1 A \left(\frac{\theta_2 - \theta_1}{x} \right) = ml_f \text{ where } m \text{ is mass that melt per second and } l_f = \text{latent heat of fusion}$$

Thermal conductivity of iron, $k = 75 \text{Wm}^{-1}\text{K}^{-1}$. A in the equation cancel

$$= 75A \left(\frac{100 - \theta_1}{0.3 \times 10^{-2}} \right) = 0.12A \left(\frac{\theta_1 - 0}{0.1 \times 10^{-2}} \right)$$

$$\theta_1 = 99.52^\circ\text{C}$$

$$\text{Also, } kA \left(\frac{\theta_2 - \theta_1}{x} \right) = ml_f$$

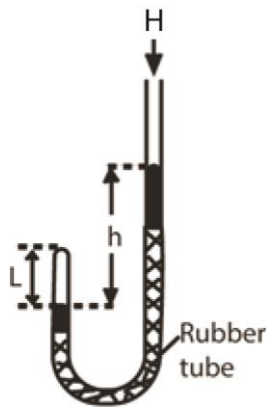
$$75 \times \pi \times \frac{(0.15)^2}{4} \left(\frac{100 - 99.52}{0.3 \times 10^{-2}} \right) = m \times 3.3 \times 10^5$$

$$m = 6.42 \times 10^{-4} \text{kg s}^{-1}$$

25. (a)(i) State Boyles law (01mark)

Boyles law states that for a fixed mass of a gas at constant temperature, pressure is inversely proportional to volume.

(ii) Describe an experiment to verify Boyles' law (06mark)



- air in the closed limb of a U-tube barometer as shown above
- mercury is poured to a height, h , and the length of the air column, L is noted.
- the length h is varied to obtain different sets of values of h and L
- Pressure of the gas is calculated from $P = (H + h)\rho g$ where H = height of barometer corresponding to atmospheric pressure, ρ = density of mercury, g = acceleration due to gravity. Note that h can be positive or negative.
- If A is the cross section area, $V = AL$
- Values of h , L , P , V and $1/V$ are tabulated
- A plot of P against $1/V$ gives a straight line through the origin which verifies Boyle's law.

- (iii) Explain why the pressure of a fixed mass of a gas rises if its temperature is increased. (02marks)

When the temperature of a fixed mass of a gas is increased, at constant volume, the velocities and kinetic energy of molecules is increased. They bombard the walls of the container more frequently with increased force. This increases pressure since pressure is proportional to force.

- (b) (i) Define the term thermometric property and give four examples (03marks)

Thermometric property is a physical property whose value varies uniformly and continuously with change in temperature.

Examples

- Volume of constant mass of a gas at constant pressure
- Pressure of a gas at constant volume
- Electrical resistance of a platinum wire
- e.m.f of a thermocouple
-

- (ii) State two qualities of a good thermometric property. (01mark)

- Should vary linearly and continuously with temperature
- Should be sensitive to temperature change
- Should vary over a wide range of temperature.

- (c) (i) With reference to a liquid in glass thermometer, describe the step involved in setting up a Kelvin scale of temperature (03marks)

Length l_{tr} of a liquid column is measured at the triple point of water

Length l_T of liquid column is measured at unknown temperature, T

$$T = \frac{l_T}{l_{tr}} \times 273.16K$$

- (ii) State one advantage and one disadvantage of the resistance thermometer. (01mark)

Advantage

- measures a wide range of temperatures
- very accurate

Disadvantage

- unsuitable for rapidly changing temperatures
- Cannot measure temperature at a point
- Does not give direct readings

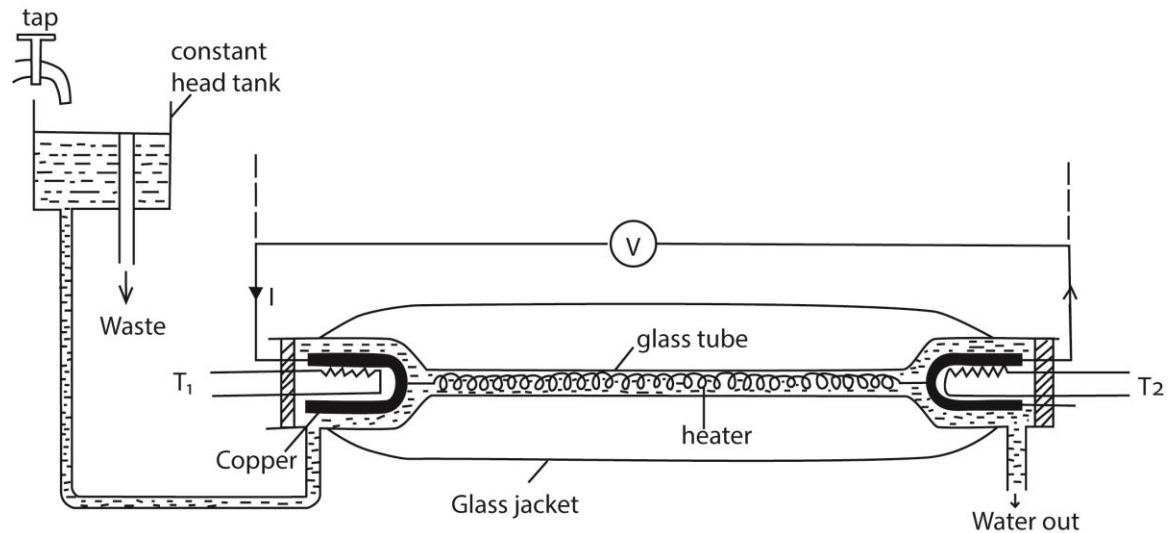
- (d) A resistance thermometer has resistance of 21.42Ω at the ice point, 29.10Ω at steam point and 28.11Ω at some unknown temperature θ . Calculate θ on the scale of this thermometer. (03marks)

$$\theta = \frac{R_\theta - R_0}{R_{100} - R_0} \times 100^\circ C = \frac{28.11 - 21.42}{29.10 - 21.42} \times 100^\circ C = 87.11^\circ C$$

26. (a) Define specific heat capacity of a substance and state its units (02marks)

Specific heat capacity is the amount of heat required to raise the temperature of 1kg mass of a substance by 1K of 1°C. Units $\text{JKg}^{-1}\text{K}^{-1}$.

(b) (i) Describe how specific heat capacity of a liquid can be obtained by continuous flow method. (07marks)



- A liquid is allowed to flow at constant rate
- Power is switched on and the liquid is heated until temperatures registered by T_1 and T_2 are steady and the values θ_1 and θ_2 respectively are recorded.
- The p.d V and current I are recorded from the voltmeter and ammeter respectively
- The mass, m of a liquid collected in time t is recorded
- At steady state; $VIt = mc(\theta_2 - \theta_1) + h$ (i)
where h is heat lost to the surrounding
- The rate of flow is changed and the voltage and current are adjusted until the steady readings of T_1 and T_2 are θ_1 and θ_2 respectively
- If m_1 , V_1 and I_1 are the values mass of liquid collected in time t , voltmeter and ammeter readings respectively, then

$$V_1 I_1 t = m_1 c (\theta_2 - \theta_1) + h \text{ (ii)}$$

Subtracting (ii) from (i)

$$c = \frac{(VI - V_1 I_1)t}{(m - m_1)(\theta - \theta_1)}$$

(ii) State one disadvantage of this method. (01mark)

- A large quantity of liquid is required
- Not suitable for all liquids

(c) An electric kettle rated 1000W, 240V is used on 220V mains to boil 0.52kg of water. If the heat capacity of the kettle is 400JK^{-1} and the initial temperature of water is 20°C , how long will the water take to boil? (04marks)

$$P = \frac{V^2}{R}$$

$$\Rightarrow 1000 = \frac{240^2}{R}; R = 57.6\Omega$$

$$P \times t = mc\theta + C\theta$$

$$\frac{220^2}{57.6} = 0.52 \times 4200(100 - 20) + 400(100 - 20)$$

$$t = 246s$$

(d) (i) Distinguish between isothermal and adiabatic changes (02marks)

Isothermal change is a process which takes place at constant temperature while adiabatic change is a change which takes place in such a way that no heat enters or leaves the system

(ii) An ideal gas at 18°C is compressed adiabatically until the volume is halved. Calculate the final temperature of the gas. [Assume specific heat capacities of the gas at constant pressure and volume are 2100Jkg⁻¹K⁻¹ and 1500Jkg⁻¹K⁻¹] respectively. (04marks)

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

$$\gamma = \frac{2100}{1500} = 1.40$$

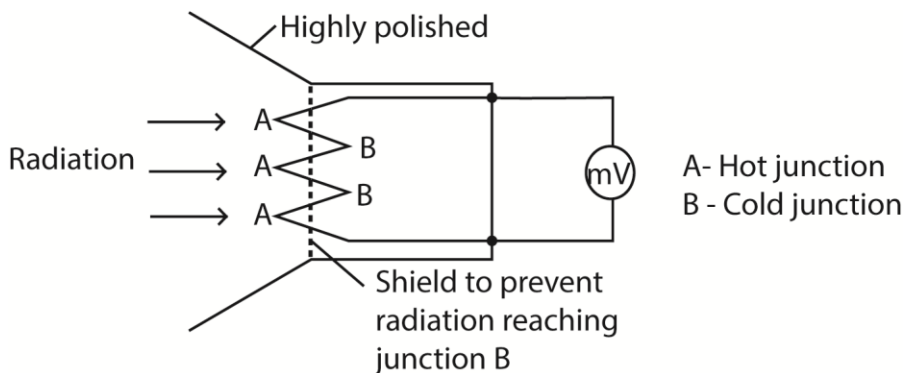
$$\Rightarrow 291(V)^{1.4-1} = T_2 \left(\frac{V}{2}\right)^{1.4-1}$$

$$T_2 = 384K$$

27. (a) State Stefan's law of black body radiation. (01marks)

Stefan's law states that the energy radiated per second per unit area of black body is proportional to the fourth power of the temperature of the body in Kelvin.

(b) Briefly describe how a thermopile can be used to detect thermal radiation. (05marks)



Radiation falling on junction A is absorbed and temperature rises above that of junction B. An e.m.f is generated and is measured by millivolt meter which deflects as a result.

(c) Explain the temperature distribution along

(i) a perfectly lagged metal bar (02marks)

When a metal is fully lagged, no heat is lost to the surroundings. The rate of heat flow along the metal bar is the same making the fall in temperature along the bar is uniform,

(ii) an unlagged metal bar. (02marks)

For a fully unlagged metal, heat lost to the surroundings. The rate of heat flow along the bar is not the same. Hence temperature gradient along the bar decreases with distance from the hot end to the cold end.

(d) The wall of a furnace is constructed with two layers. The inner layer is made of bricks of thickness 10.0cm and thermal conductivity $0.8 \text{ Wm}^{-1}\text{K}^{-1}$ and the outer layer is made of material of thickness 10.0 cm and thermal conductivity $1.6 \text{ Wm}^{-1}\text{K}^{-1}$.

The temperatures of the inner and outer surfaces are 600°C and 460°C respectively.

(i) Explain why in steady state, the rate of thermal energy transfer must be the same in both layers. (01mark)

Rate of the thermal energy transfer is the same because no heat is lost transverse to the direction of heat flow.

(ii) Calculate the rate of heat flow per square meter through the wall. (05marks)

$$\frac{Q}{t} = kA \left(\frac{\theta_2 - \theta_1}{l} \right)$$

$$\frac{0.8A(600 - \theta)}{10 \times 10^{-2}} = \frac{1.6A(\theta - 460)}{10 \times 10^{-2}}$$

$$\theta = 506.7^\circ$$

$$\frac{QIt}{A} = \frac{0.8A(600 - 506.7)}{10 \times 10^{-2}} = 746.4 \text{ Wm}^{-2}$$

(e) Explain the greenhouse effect and how it is related to global warming. (04marks)

Short wavelength radiation from the sun passes through glass of green house. This is absorbed by plants and soil leading to increase in temperature. Plants and soil reradiate long wavelength radiations which cannot penetrate the glass and trapped in the greenhouse leading to higher temperature inside the greenhouse.

Water vapour, carbon dioxide, CFC and other greenhouse gases exhibit the same selective absorption effect in the temperature, making the earth to high temperature by absorbing short wavelength radiation.

The earth reradiates long wavelength radiation which is absorbed by the layers of greenhouse gases. This leads to increased temperature over the earth and after a long time may lead to global warming.

28. (a) (i) Define the term specific heat capacity and internal energy and state their units. (03marks)

Specific heat capacity is the amount of heat required to raise the temperature of 1kg mass of a substance by 1K or 1°C .

Internal energy is the total of the kinetic energy of atoms and molecules and the potential energy due to mutual interactions of these atoms. Units: joules.

(ii) Why is the distinction between specific heat capacity at constant pressure and that at constant volume important for gases, but less important for solids and liquids? (04marks)

The volume of solids and liquids change very little when heated at constant pressure compared with volume changes for gas for the same temperature changes. Thus solid and liquids do very

little work against atmospheric pressure. This implies that there is very little difference in energy when they expand and when they are allowed to expand.

(b) Explain why the temperature of a liquid does not change when the liquid is boiling?

(02marks)

When the liquid boils, there is change in a state to vapour and all the heat supplied is used to do work by breaking the molecular bonds of the liquid. The temperature will not change until all the bonds broken.

(c) One kilogram of water is converted to steam at a temperature of 100°C and a pressure of $1.0 \times 10^5 \text{Pa}$. If the density of steam is 0.58kgm^{-3} and specific heat of vaporization of water is $2.3 \times 10^6 \text{Jkg}^{-1}$, calculate the

(i) external work done (04marks)

$$\text{Volume of 1kg of steam} = \frac{m}{\rho} = \frac{1}{0.58} = 1.724 \text{m}^3$$

$$\text{Volume of 1kg of steam} = \frac{m}{\rho} = \frac{1}{1000} = 0.001 \text{m}^3$$

$$\text{Change in volume} = 1.724 - 0.001 = 1.723 \text{m}^3$$

$$\text{Work} = p dV = 1.0 \times 10^5 \times 1.723 = 1.723 \times 10^5 \text{J}$$

(ii) internal energy (03marks)

$$\Delta u = \Delta Q - \Delta w$$

$$= 2.3 \times 10^6 - 1.723 \times 10^5$$

$$= 2.13 \times 10^6 \text{J}$$

(d) Explain why the specific latent heat of fusion and specific latent heat of vaporization of a substance at the same pressure are different. (04marks)

Change from solid to liquid, intermolecular bonds are weakened and there is a small increase in volume. This implies there negligible change in volume and thus little work done against atmospheric pressure.

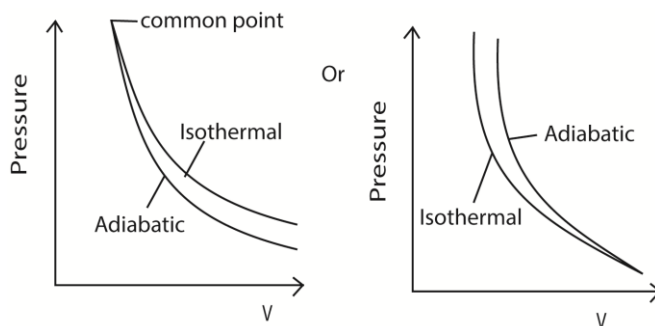
During vaporization, a lot of heat is required to break molecular bonds in a liquid and to enable expansion to larger volume of a gas against atmospheric pressure.

(a) (i) Explain the difference between isothermal and adiabatic expansion of a gas. (02marks)

Isothermal expansion takes place at constant temperature.

Adiabatic expansion takes place at constant heat.

(ii) Using same axes and point, sketch graphs of pressure versus volume for fixed mass of a gas undergoing isothermal and adiabatic changes. (03marks)



(b) Show that work, W , done by a gas which expands reversibly from V_0 to V_1 is given by

$$W = \int_{V_0}^{V_1} P dv \quad (04\text{marks})$$

If the piston is moved through a small distance dx , so that the pressure P is constant then

$$dw = Fdx$$

$$\text{but } F = PA; \Rightarrow dw = PAdx; \text{ also, } Adx = dv$$

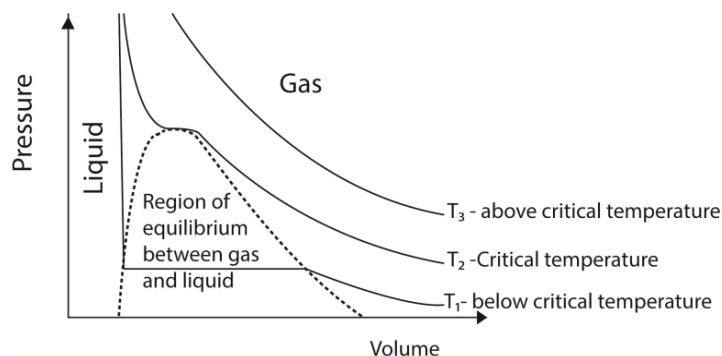
$$\therefore dw = Pdv$$

$$\Rightarrow W = \int_{V_0}^{V_1} Pdv$$

(c) (i) State two differences between real and ideal gases (02marks)

Real gas	Ideal gas
Intermolecular force are appreciable	Intermolecular forces are negligible
Volume of molecules compared to the volume of the container is not negligible	Volume of molecules compared to the volume of container is negligible
Obey Boyle's law at high temperature and very low pressure	Obey Boyle's law at all temperatures and pressures.

(ii) Draw a labelled diagram showing P-V isotherms for a real gas above and below the critical temperature. (03marks)



- Above the critical temperature a gas obeys Boyle's law.
- Below the critical temperature a gas exist as unsaturated vapour at low pressure when the pressure is increase it condenses until all the gas is turned into a liquid.

- (d) Ten moles of a gas, initially at 27°C are heated at constant pressure of $1.01 \times 10^5 \text{Pa}$ and volume increased from 0.25m^3 to 0.375m^3 . Calculate the increase in internal energy.

[Assume $C_p = 28.5 \text{Jmol}^{-1}\text{K}^{-1}$] (06marks)

$$T_1 = 27^{\circ}\text{C} = 300\text{K}$$

$$\text{Using } \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{0.250}{300} = \frac{0.375}{T_2}; T_2 = 450\text{K}$$

$$\Delta T = 450 - 300 = 150\text{K}$$

$$\Delta Q = \Delta U + \Delta w$$

$$nC_p \Delta T = nC_v \Delta T + nR \Delta T$$

$$nC_v \Delta T = nC_p \Delta T - nR \Delta T$$

$$= 10 \times 28.5 \times 150 - 10 \times 8.31 \times 150$$

$$= 3.03 \times 10^4 \text{J}$$

- 29.(a) What is meant by the following?

- (i) Conduction

Conduction is the process of heat transfer through a substance from a region of high temperature to a region of low temperature without bulk movement of the medium; mainly by collision between atoms that vibrate about equilibrium positions.

- (ii) Convection

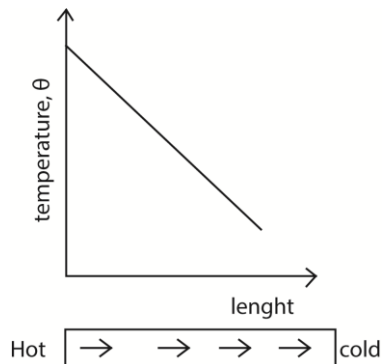
Convection is a process of heat transfer in fluids from a region of high temperature to a region of low temperature, due to movement of the medium. Heated fluid become less dense and rises up and is replaced by cold denser fluid.

- (iii) Greenhouse effect (06marks)

Solar radiation of short wavelengths is absorbed by the earth's surface. The earth radiates long wavelength radiations which are trapped by the atmosphere leading to global warming.

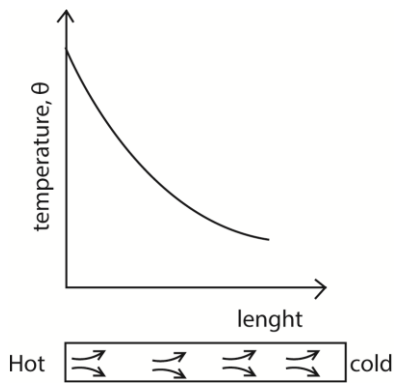
- (b) One end of a long copper bar is heated in a steam chest and the other end is kept cool by current of circulating water. Explain with the aid of sketch graphs, the variation of temperature along the bar, when steady state has been attained if the bar is

- (i) lagged (02marks)



The rate of heat flow along the bar is constant since heat loss is negligible.

(ii) exposed to the surrounding (02marks)

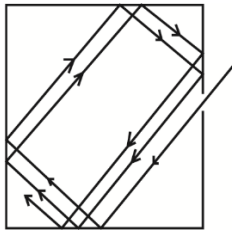


The rate of heat flow decrease with length due to heat losses

(c) (i) What is meant by a black body? (01mark)

A black body is one that absorbs all the radiations incident on it, reflects none and transmits none.

(ii) Describe how a black body can be approximated in practice. (04marks)

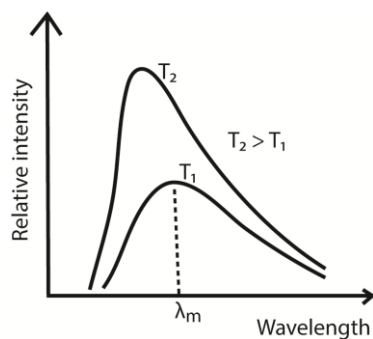


When radiation enters a black container through a hole, it undergoes multiple reflections. At each reflection, part of the radiation is absorbed. After several reflections, all the radiation is retained inside the container. Hence it approximates to a black body.

(d) (i) State Prevost's theory of heat exchange. (01mark)

A body at constant temperature is in of dynamic equilibrium with its surroundings. The rate of radiation being equal to the rate of absorption.

(ii) Sketch the variation with wavelength of the intensity of radiation emitted by a black body at two different temperatures. (01mark)



- For every wave length, relative intensity increases as temperature is increased.
- The wavelength at which maximum intensity occur shifts to the shorter wavelength as temperature is increased.
- $\lambda_{\max}$ is the wavelength of radiation emitted at maximum intensity/emission of a black body at a particular temperature.

(e) A cube of side 1.0cm has a grey surface that emits 50% of the radiation emitted by a black body at the same temperature. If the cube's temperature is 700°C, calculate the power radiated by the cube. (03marks)

$$P = \sigma AT^4$$

$$T = 700 + 273 = 973\text{K}$$

$$\therefore P = 0.5 \times 5.67 \times 10^{-8} \times (6 \times 10^{-4}) \times 973^4 = 15.25\text{W}$$

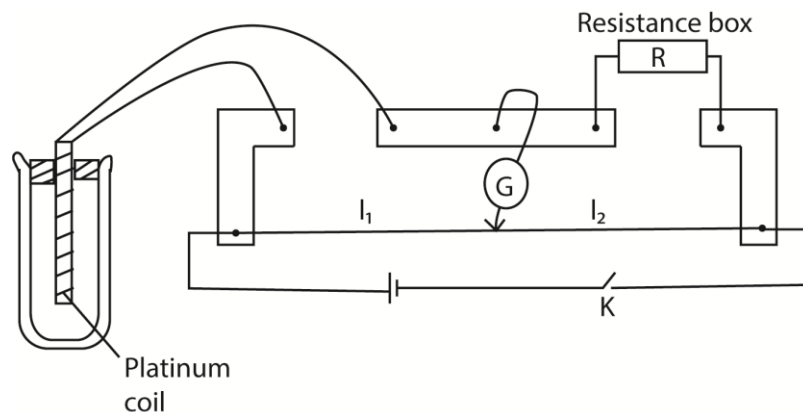
30. (a) (i) Define the term thermometric property. (01mark)

Thermometric property is a physical property that vary uniformly and continuously with temperature.

(iii) State two thermometric properties. (01mark)

- Volume of constant mass of a gas at constant pressure
- Pressure of a gas at constant volume
- Electrical resistance of a platinum wire
- e.m.f of a thermocouple

(iv) With the aid of a labelled diagram, describe how the room temperature can be measured using uncalibrated resistance thermometer. (06marks)



- Place the resistance thermometer in a funnel with crushed ice and leave it for some time.
- Close the switch and obtain a balance point by adjusting the resistance box,
- Determine the resistance R_0 at 0°C from $R_0 = \left(\frac{l_1}{l_2}\right) R$
- Transfer the resistance thermometer a beaker containing boiling water and after some time, determine resistance R_{100} .
- Place the resistance thermometer in water at room temperature and determine resistance R_θ .
- Temperature of the room temperature, $\theta = \left(\frac{R_\theta - R_0}{R_{100} - R_0}\right) \times 100^\circ\text{C}$

(b) (i) Define specific heat capacity of a substance. (01mark)

Specific heat capacity is the amount of heat required to raise the temperature of 1kg mass of a substance by 1K or 1°C.

(ii) Hot water at 85°C and cold water 10°C are ran into a bath at a rate of $3.0 \times 10^{-2} \text{m}^3 \text{min}^{-1}$ and V , respectively. At the point of filling the bath, the temperature of the mixture of water 40°C. Calculate the time taken to fill the bath is its capacity is 1.5m^3 .

$$V \rho c (40 - 10) = 3.0 \times 10^{-2} \rho c (85 - 40)$$

$$30V = 3.0 \times 10^{-2} \times 45$$

$$V = 4.5 \times 10^{-2} \text{m}^3 \text{min}^{-1}$$

At time of filling; total volume = volume of hot water + volume of cold water.

$$1.5 = 4.5 \times 10^{-2} \times t + 3.0 \times 10^{-2} \times t$$

Time, $t = 20$ minutes.

(c) The specific latent heat of fusion of a substance is significantly different from its specific latent heat of vaporization at the same pressure. Explain how the difference arises. (04marks)

During evaporation, more energy is need to break intermolecular forces of attraction to form a gas and work done is done against atmospheric pressure by the expanding gas.

During fusion, energy is supplied to weaken the molecular bonds in solids accompanied by a small increase in volume. This implies negligible work done against atmospheric pressure.

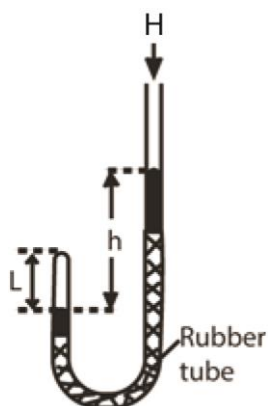
(d) Explain in terms of specific heat capacity why water is used in a car radiator other than any other liquid. (02mark)

Water has very high specific heat capacity, hence high amount of heat lead to small increase in temperature of water compared to the change in temperatures in equal masses other liquids with low specific heat capacities.

31. (a) (i) state Boyles law. (01mark)

Boyle's law states that the pressure of a fixed mass of a gas at constant temperature is inversely proportional to the volume of the gas.

(ii) Describe an experiment that can be used to verify Boyles' law. (06marks)



- air in the closed limb of a U-tube barometer as shown above
- mercury is poured to a height, h , and the length of the air column, L is noted.
- the length h is varied to obtain different sets of values of h and L
- Pressure of the gas is calculated from $P = (H + h)\rho g$ where H = height of barometer corresponding to atmospheric pressure, ρ = density of mercury, g = acceleration due to gravity. Note that h can be positive or negative.
- If A is the cross section area, $V = AL$
- Values of h , L , P , V and $1/V$ are tabulated
- A plot of P against $1/V$ gives a straight line through the origin which verifies Boyle's law.

(b) Explain the following observations using the kinetic theory.

(i) A gas fills any container in which it is placed and exerts pressure on its walls. (03marks)

A gas contains molecules with negligible intermolecular forces and free to move in all directions. As they move, they collide with each other and with the walls of the container. The unrestricted movements make them to fill the available space and collisions with the walls contributes to the pressure exerted on the wall.

(ii) The pressure of a fixed mass of a gas rises when temperature is increased at constant volume. (02 marks)

When the temperature of a gas increases, the kinetic energy of the gas molecules increases. This increases the frequency and force of collision against the wall leading to increase in pressure.

(c) (i) What is meant by a reversible process. (01marks)

A reversible process is one that takes place in reverse direction through the same values of pressure, volume and temperature in small changes or steps.

(ii) State the conditions necessary for isothermal and adiabatic processes to occur, (04marks)

Isothermal process occurs at constant temperature and therefore the gas must be enclosed in a thin walled container placed in a temperature reservoir and occurs slowly.

Adiabatic process requires no heat input or out and therefore should occur rapidly in a well insulated container like a thermos flask.

(d) A mass of an ideal gas of volume 200cm^3 at 144K expands adiabatically to a temperature of 137K . Calculate its new volume. (Take $\gamma = 1.40$)

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

$$\gamma = \frac{2100}{1500} = 1.40$$

$$\Rightarrow 144(200)^{1.4-1} = 137(V)^{1.4-1}$$

$$V = 226.5\text{cm}^3$$

32. (a) Define thermal conductivity. (01mark)

Thermal conductivity is the rate of heat flow per unit area per unit temperature gradient.

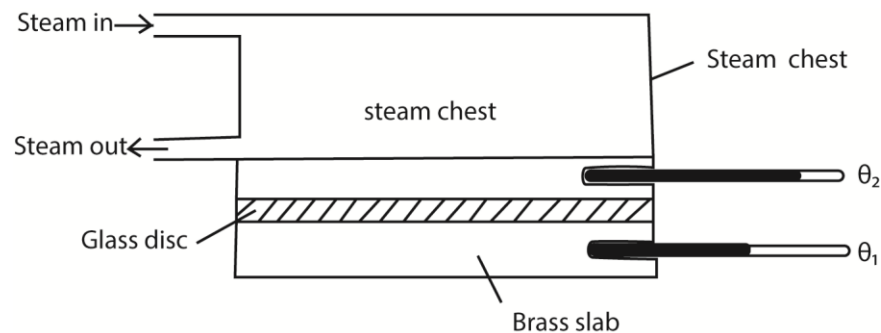
(b)(i) Explain the mechanism of thermal conduction in nonmetallic solids. (03marks)

In solids the atoms are loosely packed and have strong intermolecular forces as they vibrate within a fixed lattice. When one end is heated, the atoms vibrate with bigger amplitudes, collide with the neighboring atoms and lose their vibration energy to them. These also vibrate more vigorously and collide and lose their vibration energy to them. In this way, heat is propagated throughout the solids.

(ii) Why are metal better thermal conductors than nonmetallic solids? (02marks)

In metals there are free electrons which gain kinetic energy when heat and move faster and for a longer distance to pass over their energy to other atoms they collide with. This occurs in addition to the transfer of heat by vibrating atoms as it occurs in nonmetallic solids.

(c) With the aid of a diagram, describe an experiment to determine the thermal conductivity of a poor conductor. (06marks)



- Glass is cut in form of a thin disc of cross section area, A and thickness, x.
- The disc is sandwiched between a steam chest and brass slab of mass, m and specific heat capacity, c.
- Steam is passed through the chest until the thermometers register steady temperatures, θ_1 and θ_2 .
- Then, $\frac{\theta}{t} = kA \left(\frac{\theta_2 - \theta_1}{x} \right)$
- The glass disc is removed and brass slab is heated directly by steam chest, until its temperature is about 10°C above θ_1 .
- Steam chest is removed and the top of the glass slab is covered by the glass disc.
- The temperature of the slab is recorded at suitable time interval until its temperature is about 10°C below θ_1 .
- A graph of temperature against time is plotted and its slope is determined at θ_1

$$\frac{\theta}{t} = mcs$$

$$\therefore kA \left(\frac{\theta_2 - \theta_1}{x} \right) = mcs$$

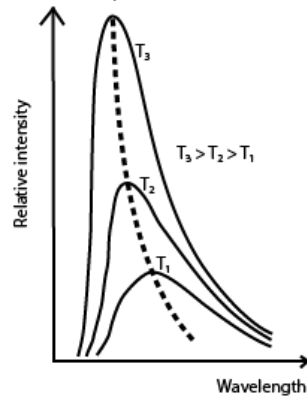
$$k = \frac{mcsx}{A(\theta_2 - \theta_1)} \text{ but } A = \frac{\pi D^2}{4}$$

$$\therefore k = \frac{4mcsx}{\pi D^2(\theta_2 - \theta_1)}$$

(d) (i) What is meant by a black body? (01mark)

A black body is one that absorbs all incident radiations on it, transmits and reflects none.

(ii) Sketch curves showing the spectral distribution of energy radiated by a black body at three different temperatures. (02marks)



(iii) Describe the main features of the curves you have drawn in (d)(ii) (02marks)

- For every wave length, relative intensity increases as temperature is increased.
- The wavelength at which maximum intensity occur shifts to the shorter wavelength as temperature is increased.
- λ_{max} is the wavelength of radiation emitted at maximum intensity/emission of a black body at a particular temperature.

(e) A small blackened solid copper sphere of radius 2cm is placed in an evacuated enclosure whose wall are kept at 100°C. Find the rate at which energy must be supplied to the sphere to keep its temperature at 127°C. (03marks)

$$P = \sigma A(T_2^4 - T_1^4)$$

$$= \sigma 4\pi r^2(T_2^4 - T_1^4)$$

$$= 5.67 \times 10^{-8} \times 4\pi (2 \times 10^{-2})^2(400^4 - 372^4)$$

$$= 1.78W$$

33. (a) Define the following terms

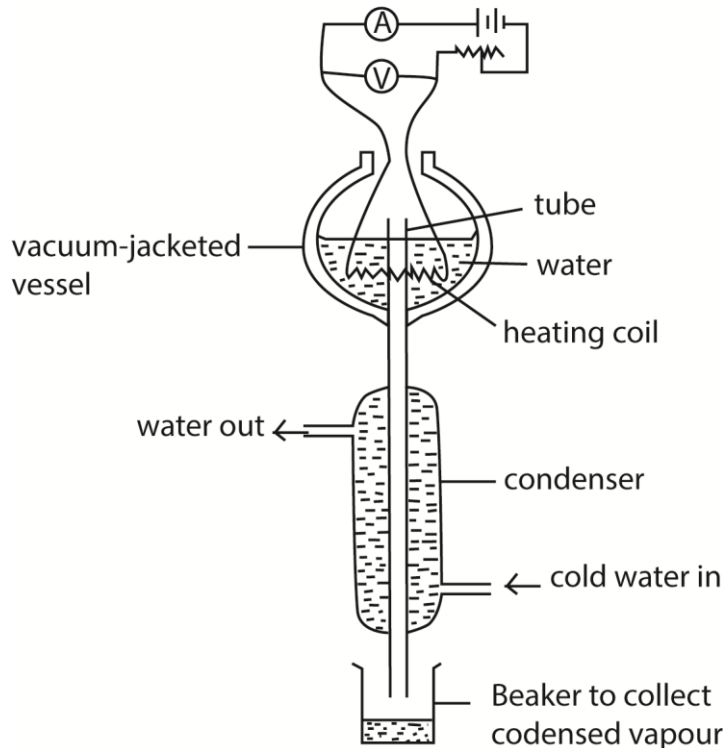
(i) Specific latent heat of vaporization (01mark)

Specific latent heat of vaporization is the amount of heat energy required to change 1kg mass of a liquid to vapour at constant temperature.

(ii) Coefficient of thermal conductivity

Thermal conductivity is heat flow per second per unit area per unit temperature gradient.

- (b) With the aid of a labelled diagram, describe an experiment to measure the specific latent heat of vaporization of water by electrical method (07marks)



- Put the liquid whose specific latent heat of vaporization is required in a vacuum jacketed vessel as shown above.
- The liquid is heated to boiling point.
- The current, I , and voltage, V are recorded.
- The mass of condensed water, m , condensed in time, t , is determined.
- Then $IV = \frac{m}{t}L + h$, where h is the rate of heat loss to the surroundings
- To eliminate, h , the experiment is repeated for different values of I' and V' and the mass of the condensed water, m' condensed in tie t is determined.
- Again $I'V' = \frac{m'}{t}L + h$

$$\text{Latent heat of vaporization, } L = \frac{(I'V' - IV)t}{(m' - m)}$$

- (c) An appliance rated 240V, 200W evaporates 20g of water in 5 minutes. Find the heat loss if specific latent heat of vaporization is $2.26 \times 10^6 \text{ Jkg}^{-1}$. (03marks)

$$\text{Electrical energy supplied} = mlv + h$$

$$\text{Power} \times \text{time} = mlv + h$$

$$200 \times 5 \times 60 = 20 \times 10^{-3} \times 2.26 \times 10^6 + h$$

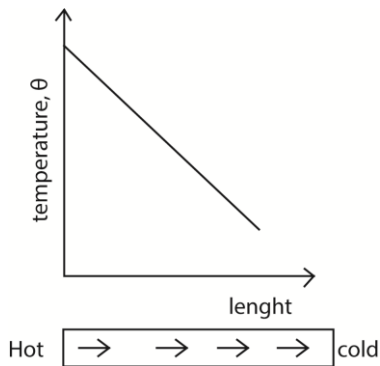
$$h = 14800\text{J}$$

(d) Explain why at a given external pressure a liquid boils at constant temperature. (04marks)

A liquid boils when its saturated vapour pressure equals the external pressure. Since saturated vapour pressure depends on temperature of a liquid, it implies that for a given external pressure, boiling occurs at constant temperature.

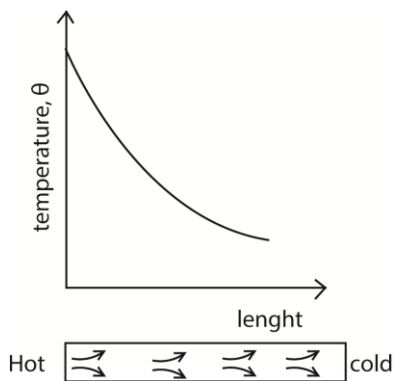
(e) With the aid of a suitable sketch graphs, explain the temperature distribution along lagged and unlagged metal rods, heated at one end. (04marks)

(i) lagged



The rate of heat flow along the bar is constant since heat loss is negligible.

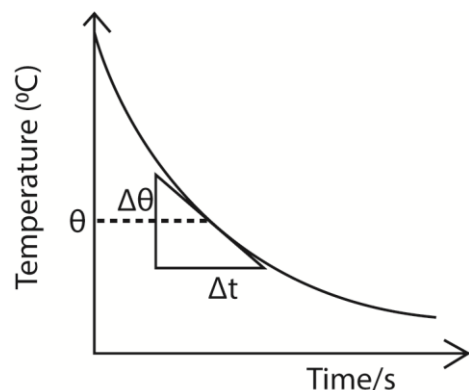
(ii) unlagged bar



The rate of heat flow decrease with length due to heat losses

34. (a) Describe an experiment to verify Newton's law of cooling. (05marks)

- Hot water is placed in a calorimeter that is standing on an insulating surface and is put in a draught.
- The temperature, θ , of the water is recorded at suitable intervals.
- The room temperature θ_R is recorded.
- Plot a graph of temperature against time to get a graph similar to the one below.



-
- Draw tangent at various temperatures, θ and obtain their slopes. These slopes give the rate of temperature fall.
- Plot these slopes with corresponding excess temperatures ($\theta - \theta_R$)
- A straight line graph is obtained implying that the rate of heat loss is proportional to excess temperature.

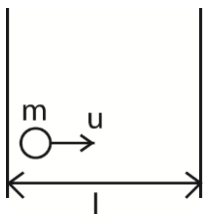
(b) (i) Distinguish between a real and an ideal gas. (03marks)

Real gas	Ideal gas
Intermolecular force are appreciable	Intermolecular forces are negligible
Volume of molecules compared to the volume of the container is not negligible	Volume of molecules compared to the volume of container is negligible
Obey Boyle's law at high temperature and very low pressure	Obey Boyle's law at all temperatures and pressures.

(ii) Derive the expression

$$P = \frac{1}{3} \rho \bar{c}^2 \text{ for the pressure of an ideal gas of density, } \rho, \text{ and mean square speed } \bar{c}^2$$

Consider a molecule of mass, m , moving in a cube of length, l and velocity, u .



$$\text{Change in momentum} = mu - (-mu) = 2mu$$

$$\text{Rate of change of momentum} = \frac{2mu}{t}$$

$$\text{Time, } t, \text{ between collision} = \frac{2l}{u}$$

$$F_1 = 2mu \div \frac{2l}{u} = \frac{mu^2}{l}$$

For N molecules, force on the wall,

$$F = \frac{mu_1^2}{l} + \frac{mu_2^2}{l} + \frac{mu_3^2}{l} + \dots + \frac{mu_N^2}{l}$$

Pressure, $P = \frac{F}{A} = \frac{m}{l^3} (u_1^2 + u_2^2 + u_3^2 + \dots + u_N^2)$ since $A = l^2$

$$\bar{u^2} = \frac{u_1^2 + u_2^2 + u_3^2 + \dots + u_N^2}{N}$$

$$N\bar{u^2} = u_1^2 + u_2^2 + u_3^2 + \dots + u_N^2$$

$$\therefore P = \frac{Nm\bar{u^2}}{l^3} = \rho\bar{u^2}; \text{ since } \rho = \frac{Nm}{l^3}$$

$$c^2 = \bar{u^2} + \bar{v^2} + \bar{w^2} \text{ and } \bar{u^2} = \bar{v^2} + \bar{w^2}$$

$$\therefore c^2 = 3\bar{u^2} \Rightarrow \bar{u^2} = \frac{1}{3}c^2$$

$$\therefore P = \frac{1}{3}\rho c^2$$

(c) (i) Explain why the pressure of a fixed mass of a gas in a closed container increases when the temperature of the container is raised. (02marks)

When the temperature of the container increases, the average velocity of the molecules increases. So the number and force of collisions with the walls of the container per second increases. Consequently the momentum change per second increases as they bombard the walls. This leads to increase in the impulsive force exerted on the walls causing increase in pressure.

(ii) Nitrogen gas is trapped in a container by a movable piston. If the temperature of the gas is raised from 0°C to 50°C at constant pressure of $4.0 \times 10^5 \text{ Pa}$ and the total heat added is $3.0 \times 10^4 \text{ J}$, calculate the work done by the gas. [The molar heat capacity of nitrogen at constant pressure is $29.1 \text{ J mol}^{-1} \text{ K}^{-1}$, $C_p/C_v = 1.4$]

$$\Delta Q = \Delta U + \Delta w \dots\dots\dots(i)$$

$$C_v = \frac{C_p}{1.4} = \frac{29.1}{1.4} = 20.79 \text{ J mol}^{-1}$$

$$\Delta Q = nC_v \Delta T$$

$$n = \frac{\Delta Q}{C_v \Delta T} = \frac{3 \times 10^4}{20.79 \times 50} = 20.62$$

From equation (i)

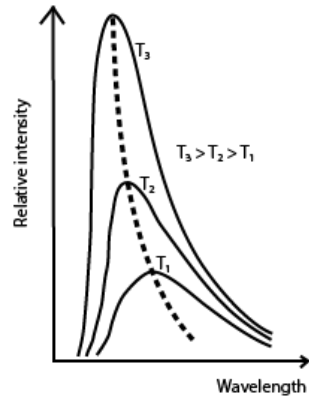
$$3 \times 10^4 = 20.62 \times 20.79 (50-0) + \Delta w$$

$$\Delta w = 8.57 \times 10^3 \text{ J}$$

35. (a) (i) State the laws of black body radiation (02marks)

- The wavelength λ_m at which maximum energy is radiated for temperature, T is such that $\lambda_m T = \text{constant}$. (Wien's displacement law)
- If E_{λ_m} is the height of the peak of the curve for a temperature T, then $E_{\lambda_m} \propto T^6$
- The total energy radiated per square meter per second by a black body at temperature, T, is proportional to T^4 (Stefan's Boltzmann law)

(ii) Sketch the variation of intensity with wavelength in a black for different temperatures. (03marks)

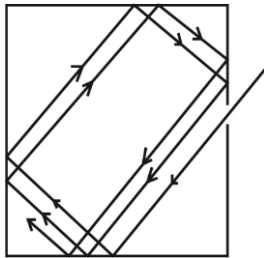


- For every wave length, relative intensity increases as temperature is increased.
- The wavelength at which maximum intensity occur shifts to the shorter wavelength as temperature is increased.
- $\lambda_{\max}$ is the wavelength of radiation emitted at maximum intensity/emission of a black body at a particular temperature.

(b) (i) What is a perfectly black body? (01marks)

A perfect black body is one that absorbs all the radiation incident on it, but reflects and transmits none.

(ii) How can a perfectly black body be approximated in reality? (04marks)



When radiation enters a black container through a hole, it undergoes multiple reflections. At each reflection, part of the radiation is absorbed. After several reflections, all the radiation is retained inside the container. Hence it approximates to a black body.

(c)(i) The energy intensity received by a spherical planet from a star is $1.4 \times 10^3 \text{ Wm}^{-2}$. The star is of radius $7.0 \times 10^5 \text{ km}$ and is $14.0 \times 10^7 \text{ km}$ from the planet.

(i) Calculate the surface temperature of the star. (04marks)

$$\begin{aligned} \text{Incident energy per second (power) on a unit of planet} &= \frac{4\pi r_s^2 \sigma T^4}{4\pi R^2} \\ &= \left(\frac{r_s}{R}\right)^2 \sigma T^4 \end{aligned}$$

Where r_s and R are the radii of the star and the distance of the star from the planet respectively.

$$1.4 \times 10^3 = \left(\frac{r_s}{R}\right)^2 \sigma T^4$$

$$T = \left[\frac{1.4 \times 10^3}{\sigma} \times \left(\frac{R}{r_s}\right)^2 \right]^{\frac{1}{4}} = \left[\frac{1.4 \times 10^3}{5.67 \times 10^{-8}} \times \left(\frac{14 \times 10^{10}}{7 \times 10^8}\right)^2 \right]^{\frac{1}{4}} = 5605.98 \text{ K}$$

(ii) State any assumptions you have made in (c)(i) above (01marks)

- The star is spherical
- The star radiates as a black body
- There is no heat loss to the sphere

(d) (i) What is convection? (01mark)

Convection is the transfer of heat in fluids by bulk movement of the fluid its self.

(ii) Explain the occurrence of land and sea breeze. (04marks)

During day, the land is heated to a high temperature than the sea. Hot air expands and rises from land. A stream of cool air from the sea blows towards the land to replace the uprising air, hence sea breeze occurs.

At night the land cools faster because it is no longer heated by the sun. The sea retains the warmth because it is heated deeply. Warm less dense air rises from the sea surface and air from land blows to replace it leading to land breeze.

36. (a) (i) Define a thermometric property and give two examples (02marks)

Thermometric property is a physical measurable property that varies linearly and continuously with temperature and is constant at constant temperature.

Examples

- Volume of constant mass of a gas at constant pressure
- Pressure of a gas at constant volume
- Electrical resistance of a platinum wire
- e.m.f of a thermocouple

(ii) When is the temperature of 0K attained? (02marks)

Ok is when molecules of a substance slow down and attain their minimum total energy

(b)(i) With reference to constant-volume gas thermometer, define temperature on the Celsius scale (02marks)

$\theta = \frac{P_\theta - P_0}{P_{100} - P_0}$ where θ is unknown temperature, P_θ is the pressure at unknown temperature, P_0 is the pressure at ice point and P_{100} is the pressure at steam point.

(ii) State two advantages and two disadvantages of the constant-volume gas thermometer. (02marks)

Advantages

- it has a wide range
- very accurate

Disadvantages

- it does not give direct reading
- cannot measure rapidly changing temperatures.

(c) (i) Define triple point of water (01mark)

Triple point of water is the temperature and pressure at which saturated water vapour, pure water and ice coexist in equilibrium.

- (ii) Describe how you would measure the temperature of a body on the thermodynamic scale using a thermocouple. (03marks)

The e.m.f, E_{Tr} is obtained when a hot junction is placed in water at triple point. E.m.f, E_T is obtained at unknown temperature T .

$$T = \frac{E_T}{E_{Tr}} \times 273.16K$$

- (d) The resistance, R_θ of platinum varies with the temperature $^\circ C$ as measured by the constant-volume gas thermometer according to the equation

$$R_\theta = 50.0 + 0.17\theta + 3.0 \times 10^{-4}\theta^2$$

- (i) Calculate the temperature on the platinum scale corresponding to $60^\circ C$ on the gas scale. (06marks)

$$R_0 = 50\Omega$$

$$R_{60} = 50 + 0.17 \times 60 + 3.0 \times 10^{-4} \times 60^2 = 61.28\Omega$$

$$R_{100} = 50 + 0.17 \times 100 + 3.0 \times 10^{-4} \times 100^2 = 70.00\Omega$$

$$\begin{aligned} \theta &= \frac{R_\theta - R_0}{R_{100} - R_0} \times 100^\circ C \\ &= \frac{61.28 - 50}{70 - 50} \times 100 \\ &= 56.4^\circ C \end{aligned}$$

- (ii) Account for the difference between the two values and state the temperatures at which they agree. (02marks)

Difference thermometric properties vary differently with temperature.

37. (a) (i) Define latent heat (01mark)

Latent heat is the amount of heat required to change a unit mass of a substance from one state to another at constant temperature.

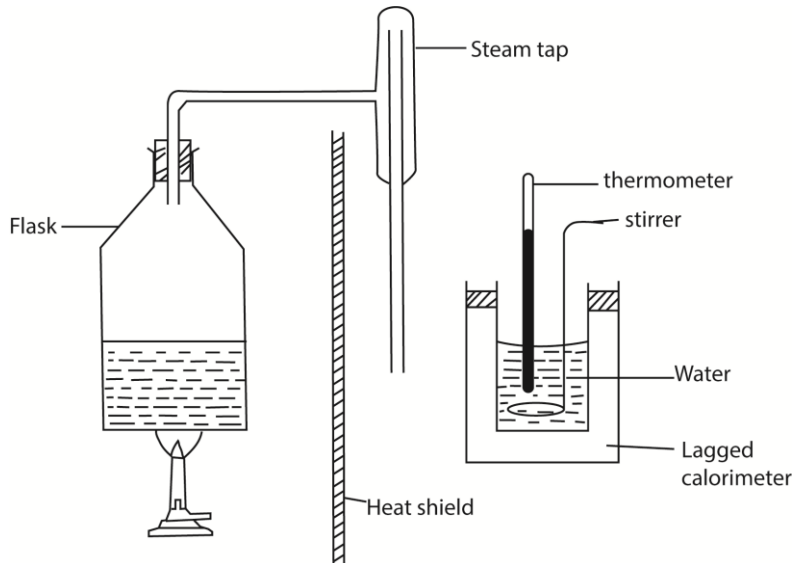
- (ii) Explain the significance of latent heat in regulation of body temperature (03marks)

On a hot day, the body sweats. Evaporation occurs at the surface of the body leading to the cooling of the body since the evaporating water draws heat from the body.

- (b) (i) using kinetic theory, explain boiling of a liquid (03mark)

Molecules of a liquid through moving randomly have attractive forces between them. When a liquid is heated, the molecules move faster and forces of attraction weakened until they are overcome at the boiling temperature. At this point, saturated vapour pressure (SVP) of liquids is equal to external pressure. Liquid molecules with enough energy escape from the bulk to the atmosphere.

(ii) Describe how you would determine the specific latent heat of vaporization of water by the method of the mixtures (05marks)



- The initial temperature θ_0 and mass, m of water in the calorimeter are measured
- Steam from boiling water is passed into water in a calorimeter and after a reasonable temperature rise, flow of steam is stopped and final temperature, θ_f is recorded.
- Mass m_2 of water in the calorimeter is then taken
- The mass of steam condensed, $m_s = (m_2 - m)$

Given that the heat capacity of the calorimeter = C

Heat gained by steam = heat gained by water and calorimeter

$$m_s c_v + m_s c(100 - \theta_f) = (m_2 - m)c(\theta_f - \theta_0) + C(\theta_f - \theta_0)$$

c_v = specific latent heat of vaporization

c = specific heat capacity of water

(iii) Explain why latent heat of vaporization is always greater than that of fusion. (02marks)

In evaporation energy is needed to break intermolecular forces of attraction and to expand against atmospheric pressure while in fusion, energy is needed to weaken molecular attraction only.

(c) In an experiment to determine the specific latent heat of vaporization of a liquid using the continuous flow calorimeter, the following results were obtained.

Voltage, V/V	Current, I/A	Mass collected in 300s/g
7.4	2.6	5.8
10.0	3.6	11.3

Calculate the power of the heater required to evaporate 3.0g of water in 2 minutes (06marks)

$$I_1 V_1 = m_1 l + h \dots\dots\dots(i)$$

$$I_2 V_2 = m_2 l + h \dots\dots\dots(ii)$$

From (i) and (ii)

$$I = \frac{I_2 V_2 - I_1 V_1}{m_2 - m_1} = \frac{10 \times 3.6 - 7.4 \times 2.6}{(11.3 \times 10^{-3} - 5.8 \times 10^{-3})/300} = 9.14 \times 10^5 \text{ J kg}^{-1}$$

$$m_3 = \frac{3.0 \times 10^{-3}}{2 \times 60} = 2.5 \times 10^{-5} \text{ kg s}^{-1}$$

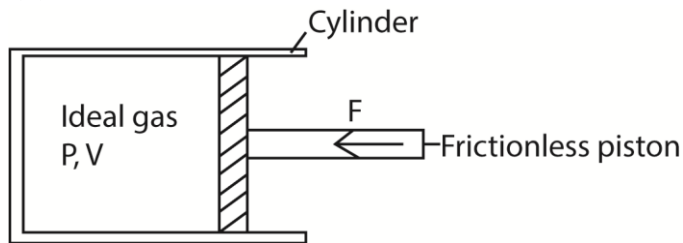
$$I = \frac{I_2 V_2 - I_3 V_3}{m_2 - m_3}$$

$$9.14 \times 10^5 \text{ n} = (10 \times 3.6 - I_3 V_3) \div \left(\frac{11.3 \times 10^{-3}}{300} - 2.5 \times 10^{-5} \right)$$

$$11.59 = 36 - I_3 V_3$$

$$\text{Power} = I_3 V_3 = 36 - 11.59 = 24.41 \text{ W}$$

38. (a)



A fixed mass of an ideal gas is confined in a cylinder by frictionless piston of cross section area A . the piston is in equilibrium under the action of force, F as shown in the figure above. Show that the work done, W , by the gas when it expands from V_1 to V_2 is given by

$$W = \int_{V_1}^{V_2} P dV \quad (03 \text{ marks})$$

Suppose the gas expands by dv so that the piston moves out through a small distance dx .

Work done by the gas, $dW = F dx$

$$= P A dx$$

$$= P dv$$

Total work done during expansion from v_1 to v_2 is given by

$$W = \int_{v_1}^{v_2} P dv$$

(b) State the first law of thermodynamics and use it to distinguish between Isothermal and adiabatic changes in a gas. (05 marks)

$$\Delta Q = \Delta U + \Delta W = n C_v \Delta T + \Delta W$$

During isothermal expansion, $\Delta T = 0$. Therefore all the energy supplied is equal to the work done by the gas during expansion.

In adiabatic expansion, no heat enters or leaves the gas. Therefore $\Delta Q = 0$ and $\Delta U = -\Delta W$.

In adiabatic expansion, work is done at the expense of its internal energy. Therefore the gas cools.

(c) The temperature of 1 mole of helium gas at a pressure of $1.0 \times 10^5 \text{ Pa}$ increases from 20°C to 100°C when the gas is compressed adiabatically.

Find the final pressure of the gas. (Take $\gamma = 1.67$) (04 marks)

$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

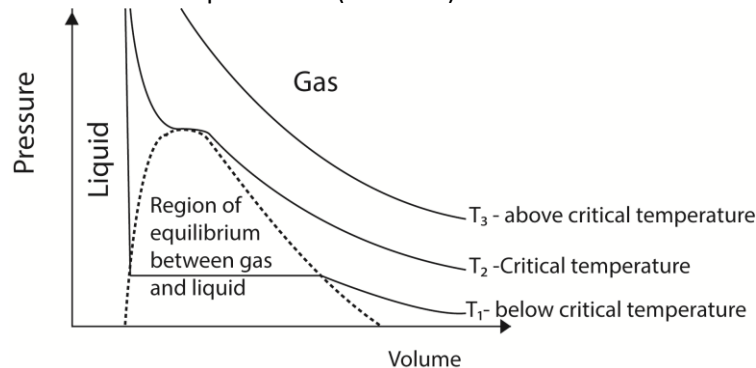
$$\text{but } V = \frac{nRT}{P} \Rightarrow \frac{P_1 T_1^\gamma}{P_1} = \frac{P_2 T_2^\gamma}{P_2}$$

$$\Rightarrow \frac{T_1^\gamma}{P_1^{\gamma-1}} = \frac{T_2^\gamma}{P_2^{\gamma-1}}$$

$$\frac{(293)^{1.67}}{(1.0 \times 10^5)^{0.67}} = \frac{(373)^{1.67}}{(P)^{0.67}}$$

$$P = 1.87 \times 10^5 \text{ Pa}$$

(d) With the aid of a P-V diagram, explain what happens when a real gas is compressed at different temperatures. (04marks)



- Above the critical temperature a gas obeys Boyle's law.
- Below the critical temperature a gas exist as unsaturated vapour at low pressure when the pressure is increase it condenses until all the gas is turned into a liquid.

(e) The root-mean square speed of the molecules of a gas is 44.72 ms^{-1} . Find the temperature of the gas if its density is $9.0 \times 10^{-2} \text{ kg m}^{-3}$ and the volume is 42.0 m^3 . (04marks)

$$P = \frac{1}{3} \rho c^2$$

$$\Rightarrow \frac{RT}{V} = \frac{1}{3} \rho c^2$$

$$T = \frac{1}{3} \rho c^2 \times \frac{V}{R} = \frac{1}{3} \times 9.0 \times 10^{-2} \times (44.72)^2 \times \frac{42}{8.31} = 303.2 \text{ K}$$

39. (a) Define saturated vapour pressure (S.V.P) (01mark)

Saturated vapour pressure is the one in dynamic equilibrium with its own liquid

(b) Use the kinetic theory of matter to explain the following observations

(i) saturated vapour pressure of a liquid increases with temperature. (03marks)

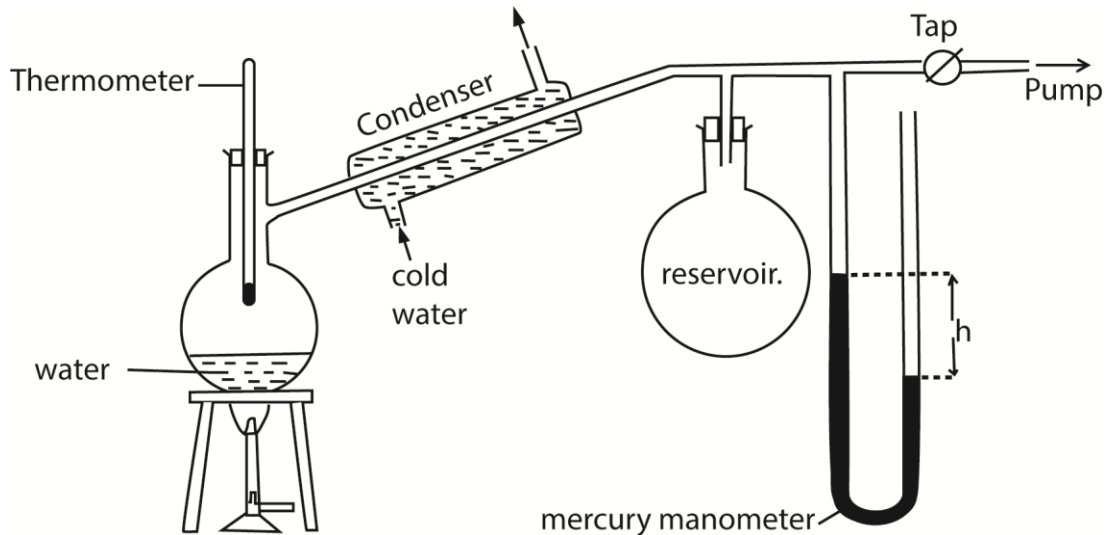
Increase in temperature increases the kinetic energy of the liquid molecules and the rate of evaporation increases. Therefore the pressure of the vapour rises. As the rate at which the molecules bombard the liquid surface increases, dynamic equilibrium is restored at a higher saturated vapour pressure.

(ii) saturated vapour pressure is not affected by decrease in volume at constant temperature.

(03marks)

A decrease in volume leads to momentary increase in the density of the vapour. The rate of condensation increase than the rate of evaporation. As the density of the vapour falls the rate of condensation also falls. Dynamic equilibrium is re-established to original values of density and pressure of vapour. Therefore no increase in saturated vapour pressure.

(c) Describe how saturated vapour pressure of a liquid at various temperatures can be determined. (07marks)



- The pressure of the air in R is shown by the mercury manometer; if its height is h , the pressure in mm mercury is $P = H - h$, where H is the barometer height.
- The tap is opened and the pressure above water varied using the pump to a suitable value.
- The tap is closed and water in the flask is heated until it boils.
- The temperature θ and difference in mercury levels, h , are noted and recorded.
- The saturated vapour pressure, $P = (H \pm h)$ is calculated
- The procedure is repeated for other values of θ and h
- A graph of P versus θ is plotted and the saturated vapour pressure at a particular temperature is obtained.

(d) (i) State Dalton's law of partial pressures (01mark)

Dalton's law of partial pressures states that the pressure of a mixture of gases that do not react chemically is the sum of partial pressures of its components.

(ii) A horizontal tube of uniform bore, closed at one end, has some air trapped by a small quantity of water. The length of the enclosed air column is 20cm at 12°C.

Find stating any assumptions made, the length of air column when the temperature is raised to 38°C.

[S.V.P of water at 12°C and 38°C are 10.5mmHg and 49.5mmHg respectively. Atmospheric pressure = 75cmHG] (05marks)

$T_1 = 273 + 12 = 285\text{K}$, $T_2 = 273 + 38 = 311\text{K}$; $P_1 = 750 - 10.5 = 739.5\text{mmHg}$, $P_2 = 750 - 49.5 = 700.5\text{mmHg}$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{739.5 \times 20A}{285} = \frac{700.5 \times hA}{311}$$

$$h = 23.04\text{cm}$$

Assumption: the tube does not expand when the temperature increases.

40.(a) (i) Define specific heat capacity of a substance. (01mark)

Specific heat capacity is the energy required to raise the temperature of 1kg mass of a substance by 1K.

(ii) State three advantages of the continuous flow method over the method of mixtures in determination of the specific heat capacity of a liquid. (03marks)

- The heat capacity of the apparatus is not required.
- Heat loss is eliminated in the calculation
- Resistance thermometer can be used.
- Temperatures are read at leisure

(b) In a continuous flow experiment, a steady difference of temperature of 1.5°C is maintained when the rate of liquid flow is 4.5gs^{-1} and the rate of electrical heating is 60.5W . On reducing the liquid flow rate to 1.5gs^{-1} , 36.5W is required to maintain the same temperature difference.

Calculate the

(i) Specific heat capacity of the liquid. (04marks)

$$P = \frac{m}{t}c\theta + h$$

$$60.5 = 4.5 \times 10^{-3} \times c \times 1.5 + h \dots\dots\dots (i)$$

$$36.5 = 1.5 \times 10^{-3} \times c \times 1.5 + h \dots\dots\dots (ii)$$

Subtracting (ii) from (i)

$$24 = 3 \times 10^{-3} \times c \times 1.5$$

$$c = 5,333\text{Jkg}^{-1}\text{K}^{-1}$$

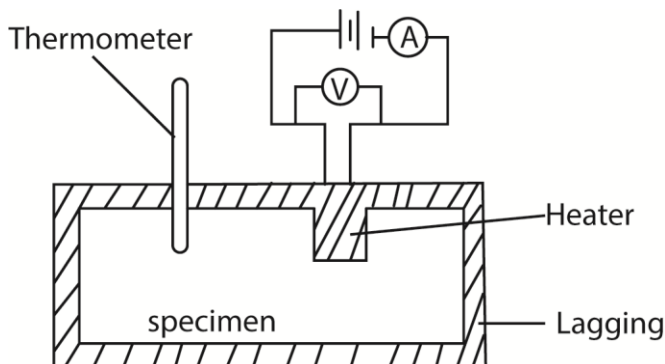
(ii) Rate of heat loss to the surroundings (03marks)

Substituting c in (i)

$$60.5 = 4.5 \times 10^{-3} \times 5333 \times 1.5 + h$$

$$h = 24.5\text{W}$$

(c) (i) Describe an electrical method for determination of the specific heat capacity of a metal. (06marks)



- Two holes are drilled into the specimen solid of mass m.
- A thermometer is inserted in one of the holes and an electric heater into the other hole. The holes are then filled with a good conducting fluid, e.g. oil to ensure thermal contact.
- The apparatus is insulated and initial temperature θ_0 is recorded.

- The heater is switched on at the same time a stop clock is started.
- The steady values of ammeter reading, I and voltmeter reading, V are recorded.
- After considerable temperature rise, the heater is switched off and stop clock stopped.
- The highest temperature θ_1 recorded and time t taken noted.
- The specific heat capacity, c, of the conducting solid is calculated from

$$c = \frac{IVt}{m(\theta_1 - \theta_0)}$$

(ii) State the assumptions made in the above experiment. (02marks)

- All heat supplied by the heater is gained by the metal block
 - The volume of the metal does not change.
- (iii) Comment about the accuracy of the results of the experiment in (c)(i) above. (01marks)
- The value of specific heat capacity is accurate as long as there is not heat losses to the surrounding.

41. (a)(i) Define thermal conductivity. (01mark)

Thermal conductivity is the rate of heat flow per unit cross section area per unit temperature gradient.

(ii) Explain the mechanism of heat transfer in metals (03marks)

When one end of a metal is heated, the metal atoms gain energy and their vibration increase. These collide with the neighboring atoms giving them some of the energy. The neighboring atoms also vibrate with higher amplitudes and collide with their neighboring atom to which they give some of their energy. In this way heat is transferred from atom to atom.

Secondly, electrons gain kinetic energy and move and collide other electrons and atom delivering heat energy.

(b) Two brick walls each of thickness 10cm are separated by an air-gap of thickness 10cm. the outer faces of the brick walls are maintained at 20°C and 5°C respectively.

(i) Calculate the temperatures of the inner surfaces of the walls. (06marks)

$$\text{From } \frac{\Delta Q}{\Delta t} = kA \frac{\Delta \theta}{\Delta x}$$

$$k_b A \frac{(20 - \theta_1)}{0.1} = k_a A \frac{(\theta_1 - \theta_2)}{0.1} = k_b A \frac{(\theta_2 - 5)}{0.1}$$

$$0.6A \frac{(20 - \theta_1)}{0.1} = 0.2A \frac{(\theta_1 - \theta_2)}{0.1} = 0.6A \frac{(\theta_2 - 5)}{0.1}$$

$$\theta_1 = 19.5^\circ \text{ and } \theta_2 = 5.5^\circ \text{C}$$

(ii) Compare the rate of heat loss through the layer of air with that through a single brick wall. (03marks)

The rate of heat loss from a single brick wall is higher than that of the air because a brick is a better conductor.

[Thermal conductivity of air is $0.02 \text{ Wm}^{-1}\text{K}^{-1}$, and that of bricks is $0.6 \text{ Wm}^{-1}\text{K}^{-1}$]

(c)(i) State Stefan's law of black body radiation. (01mark)

The total energy radiated by a black body per unit area of the surface per unit time is proportional to the fourth power of the body's absolute temperature.

- (ii) The average distance of Pluto from the sun is about 40 times that of the Earth from the sun. If the sun radiated as a black body at 600K, and is $1.5 \times 10^{11}\text{m}$ from the Earth, Calculate the temperature of Pluto. (06marks)

$$\text{Power radiated by the sun} = 4\pi r_s^2 \sigma T_s^4$$

$$\text{Power radiated by Pluto} = \frac{\pi r_p^2}{4\pi R^2} \times 4\pi r_s^2 \sigma T_s^4$$

$$\text{Power radiated by Pluto assuming it is a black body} = 4\pi r_p^2 \sigma T_p^4$$

$$\text{At equilibrium, } 4\pi r_p^2 \sigma T_p^4 = \frac{\pi r_p^2}{4\pi R^2} \times 4\pi r_s^2 \sigma T_s^4$$

$$T_p = \left(\frac{T_s^4 r_s^2}{4R^2} \right)^{\frac{1}{4}} = \left(\frac{6000^4 \times (7 \times 10^8)^2}{4 \times (40 \times 1.5 \times 10^{11})^2} \right)^{\frac{1}{4}} = 45.8\text{K}$$

42. (a)(i) What is meant by term fixed point in thermometry? Give two examples (02marks)

Fixed points are temperatures at which water changes from one phase to the other, i.e. melting and boiling points.

- (ii) How is temperature on Celsius scale defined on a platinum resistance thermometer? (02marks)

$$\theta = \frac{R_\theta - R_0}{R_{100} - R_0} \text{ where } R_\theta \text{ is the resistance at unknown temperature, } R_0 \text{ and } R_{100} \text{ are resistances at ice and steam points respectively}$$

- (b) Explain the extent to which two thermometers based on different properties but calibrated using the same fixed points are likely to agree when used to measure temperature.

- (i) near one of the fixed point (02marks)

They do not agree since different thermometric properties vary differently with temperature changes

- (ii) mid-way between two fixed points (02marks)

They agree because the choice of fixed points is definite.

- (c) The continuous flow method is used in determination of the specific heat capacity of liquids.

- (i) What are the principal advantages of this method compared to the method of mixtures? (03marks)

- The heat capacity of the apparatus is not required in the apparatus
- Heat losses are not required in the calculation
- Temperatures read at leisure.

(ii) In such a method, 50g of water is collected in 1 minute. The voltmeter and ammeter readings are 12.0V and 2.50A respectively, while the inflow and outflow temperatures are 20°C and 28°C respectively. When the flow rate is reduced to 25gmin⁻¹, the voltmeter and ammeter read 8.8V and 1.85A respectively while the temperatures remain constant. Calculate the specific heat capacity of water. (05marks)

From $VIt = mc\theta + h$

$$12 \times 2.5 \times 1 \times 60 = 50 \times 10^{-3} \times c \times (28 - 20) + h \dots\dots\dots (i)$$

$$8.8 \times 1.85 \times 1 \times 10 = 25 \times 10^{-3} \times c \times (28 - 20) + h \dots\dots\dots (ii)$$

Subtracting (ii) from (i)

$$c = 4.1 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$$

(d) What are the advantages of a thermocouple over a constant volume thermometer for measuring temperature? (04marks)

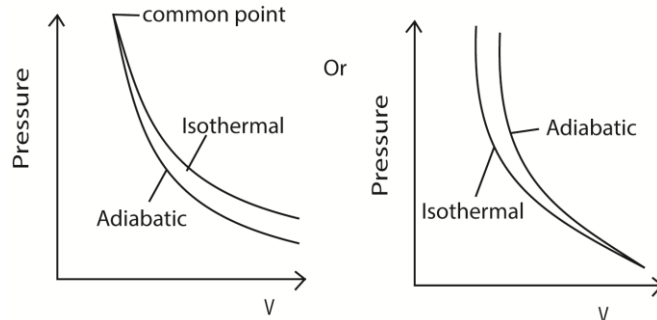
- Use to measure rapidly changing temperature
- It can give direct readings
- It is not bulky
- It can measure temperature at a point

43.(a)(i) What is meant by isothermal and adiabatic changes? (02marks)

Isothermal expansion takes place at constant temperature.

Adiabatic expansion takes place at constant heat.

(ii) Using same axes and point, sketch graphs of pressure versus volume for fixed mass of a gas undergoing isothermal and adiabatic changes. (03marks)



(b) An ideal gas is trapped in a cylinder by a movable piston. Initially it occupies a volume of $8 \times 10^{-3} \text{ m}^3$ and exerts a pressure of 108kPa. The gas undergoes an isothermal expansion until its volume is $27 \times 10^{-3} \text{ m}^3$. It is then compressed adiabatically to the original volume of the gas.

(i) Calculate the final pressure of the gas (06marks)

Under isothermal, $P_1 V_1 = P_2 V_2$

$$108 \times 10^3 \times 8 \times 10^{-3} = P_2 \times 27 \times 10^{-3}$$

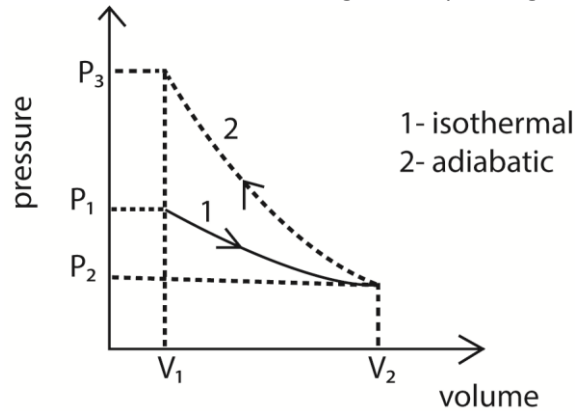
$$P_2 = 3.2 \times 10^3 \text{ Pa}$$

Under adiabatic, $P_3 V_3^\gamma = P_2 V_2^\gamma$

$$P_3 (8 \times 10^{-3})^{\frac{5}{3}} = 3.2 \times 10^3 \times (27 \times 10^{-3})^{\frac{5}{3}}$$

$$P_3 = 243 \times 10^3 \text{ Pa}$$

(iii) Sketch and label the two stages on a p-v diagram. (02marks)



[The ratio of the principal molar heat capacities of the gas = 5:3]

(c) (i) Define molar heat capacities at constant pressure. (01mark)

The specific heat capacity of a gas at constant pressure is the heat required to warm unit mass of it by one degree, when its pressure is kept constant.

(ii) Derive the expression $C_p - C_v = R$, for 1mole of a gas (05marks)

From $dQ = dU + dW$ (i)

But $dQ = C_p dT$, $dU = C_v dT$ and $dW = PdV = RdT$

Substituting in (i)

$$C_p dT = C_v dT + RdT$$

$$\therefore C_p - C_v = R$$

(iii) In which ways does a real gas differ from an ideal gas? (02marks)

Real gas	Ideal gas
Intermolecular force are appreciable	Intermolecular forces are negligible
Volume of molecules compared to the volume of the container is not negligible	Volume of molecules compared to the volume of container is negligible
Obey Boyle's law at high temperature and very low pressure	Obey Boyle's law at all temperatures and pressures.

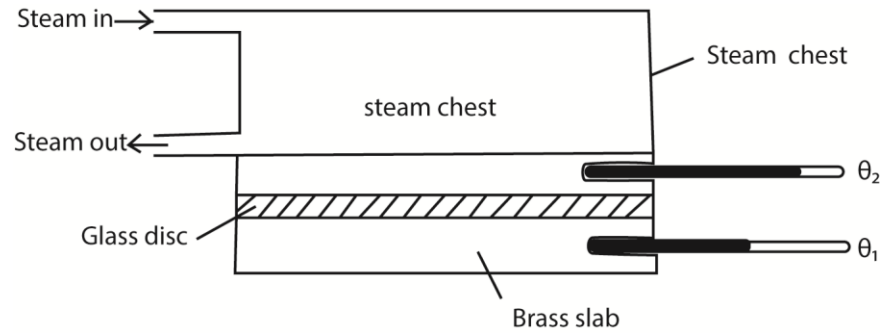
44. (a) (i) Define thermal conductivity. (01mark)

Thermal conductivity is the rate of heat flow per unit cross section area per unit temperature gradient.

(ii) State two factors which determine the rate of heat transfer through a material (02marks)

- Temperature gradient
- Thermal conductivity of a material
- Cross section area.

(b)(i) Describe with the aid of a diagram an experiment to measure the thermal conductivity of glass. (08marks)



- Glass is cut in form of a thin disc of cross section area, A and thickness, x .
- The disc is sandwiched between a steam chest and brass slab of mass, m and specific heat capacity, c .
- Steam is passed through the chest until the thermometers register steady temperatures, θ_1 and θ_2 .
- Then, $\frac{\theta}{t} = kA \left(\frac{\theta_2 - \theta_1}{x} \right)$
- The glass disc is removed and brass slab is heated directly by steam chest, until its temperature is about 10°C above θ_1 .
- Steam chest is removed and the top of the glass slab is covered by the glass disc.
- The temperature of the slab is recorded at suitable time interval until its temperature is about 10°C below θ_1 .
- A graph of temperature against time is plotted and its slope is determined at θ_1

$$\frac{\theta}{t} = mcs$$

$$\therefore kA \left(\frac{\theta_2 - \theta_1}{x} \right) = mcs$$

$$k = \frac{mcsx}{A(\theta_2 - \theta_1)} \text{ but } A = \frac{\pi D^2}{4}$$

$$\therefore k = \frac{4mcsx}{\pi D^2(\theta_2 - \theta_1)}$$

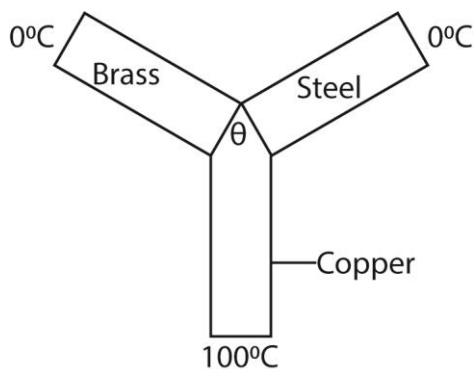
(ii) Briefly discuss the advantages of the apparatus in (b)(i). (02marks)

- Temperature read at steady state
- The heat capacity of the apparatus not required

(c) Metal rods of copper, brass are welded together to form Y shaped figure.

The cross-section area of each rod is 2cm^2 . The free end of copper rod are maintained at 100°C , while the free ends of brass and steel rods are maintained at 0°C . If there is no heat loss from the surfaces of the rods and the length of the rods are 0.46m , 0.13m and 0.12m respectively.

(i) Calculate the temperature of the junction (05marks)



At the junction, $\frac{Q}{t} = kA \left(\frac{\theta_2 - \theta_1}{l} \right)$

$$\frac{dQ}{dt} = \frac{k_1 A}{l_1} (100 - \theta) = \frac{k_2 A}{l_2} (\theta - 0)$$

$$\frac{dQ}{dt} = \frac{k_1 A}{l_1} (100 - \theta) = \frac{k_3 A}{l_3} (\theta - 0)$$

Eqn. (i) and Eqn. (ii)

$$\frac{k_1 A}{l_1} (100 - \theta) = A \theta \left(\frac{k_2}{l_2} + \frac{k_3}{l_3} \right)^{-1}$$

$$\theta = \frac{200k_1}{l_1} \left(\frac{2k_1}{l_1} + \frac{k_2}{l_2} + \frac{k_3}{l_3} \right)^{-1} = \frac{200 \times 385}{0.46} \left(\frac{2 \times 385}{0.46} + \frac{109}{0.13} + \frac{50.2}{0.12} \right)^{-1} = 57.11^\circ\text{C}$$

- (ii) Find the heat current in the copper rod. (02marks)

$$\frac{dQ}{dt} = \frac{kA}{l_1} (100 - \theta) = \frac{385 \times 10^{-4} (100 - 57.11)}{0.46} = 7.2 \text{ Js}^{-1}$$

[Thermal conductivities of copper, brass and steel are $385 \text{ Wm}^{-1}\text{K}^{-1}$, $109 \text{ Wm}^{-1}\text{K}^{-1}$ and $50.2 \text{ Wm}^{-1}\text{K}^{-1}$ respectively.]

45. (a) What is meant by:

- (i) Thermometric property (01mark)

Thermometric property is a physical property that vary uniformly and continuously with temperature.

- (ii) Triple point (01mark)

It the temperature and pressure at which a vapour, liquid and solid of a substance coexist at equilibrium.

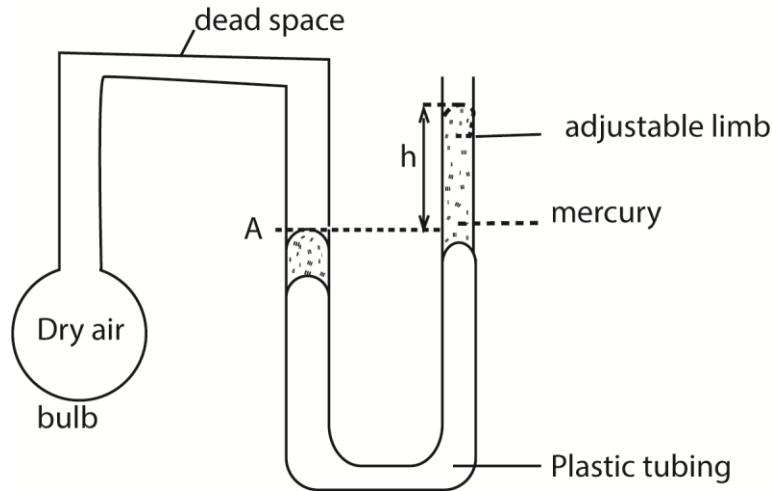
(b) (i) Describe the steps taken to establish a temperature scale. (05marks)

- Choose a thermometric property
- Find its value, x_{100} at steam point and value x_0 at ice point.
- If the value of thermometric property is x_θ at temperature θ
- Then $\theta = \frac{x_\theta - x_0}{x_{100} - x_0}$

- (ii) Explain why two thermometers may give different values for the same unknown temperature. (02marks)

Two thermometers based on different thermometric property may show different temperatures because thermometric properties vary differently with change in temperature.

- (c) (i) Describe, with the aid of a diagram, how a constant-volume gas thermometer may be used to measure temperature. (06mrks)



- Place the bulb inside whose temperature is to be measured.
- Allow some time for the gas to acquire the temperature of the enclosure. The gas in the bulb may expand and forces mercury up the adjustable tube.
- Adjust the adjustable limb to bring back mercury to constant volume at A and record the height of mercury, h_θ .
- The Celsius scale is given by $\theta = \left(\frac{h_\theta - h_0}{h_{100} - h_0} \right) \times 100^\circ \text{C}$ where h_{100} and h_0 are the heights at steam and ice points

- (ii) State three corrections that need to be made when using the thermometer in (c)(i) above. (03marks)

- The bulb should be made of glass with low thermal expansivity
- Dead space should be narrowed
- The bulb should be thin to allow easy penetration of heat

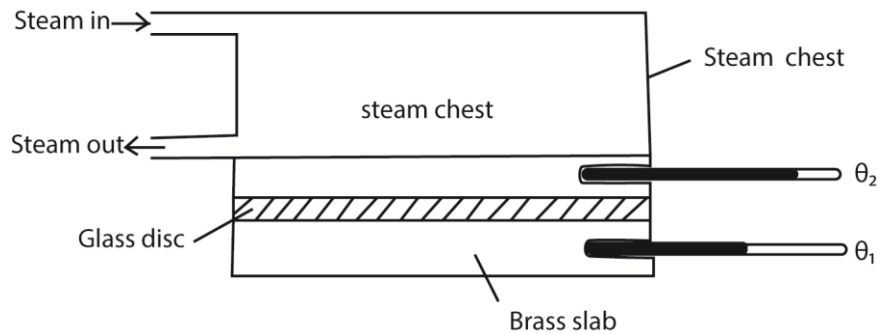
- (iii) State and explain the sources of inaccuracies in using mercury in glass thermometer, (02marks)

- Non uniformity the mercury tube
- Temperature of air in dead space being different from that in the bulb

46. (a) Define thermal conductivity of a material and state its units (02marks)

Thermal conductivity is the rate of heat flow per unit cross section area per unit temperature gradient. Units $\text{Wm}^{-1}\text{K}^{-1}$

- (b) Describe with the aid of a diagram how the thermal conductivity of a poor conductor can be determined. (07marks)



- Glass is cut in form of a thin disc of cross section area, A and thickness, x .
- The disc is sandwiched between a steam chest and brass slab of mass, m and specific heat capacity, c .
- Steam is passed through the chest until the thermometers register steady temperatures, θ_1 and θ_2 .
- Then, $\frac{\theta}{t} = kA \left(\frac{\theta_2 - \theta_1}{x} \right)$
- The glass disc is removed and brass slab is heated directly by steam chest, until its temperature is about 10°C above θ_1 .
- Steam chest is removed and the top of the glass slab is covered by the glass disc.
- The temperature of the slab is recorded at suitable time interval until its temperature is about 10°C below θ_1 .
- A graph of temperature against time is plotted and its slope is determined at θ_1

$$\frac{\theta}{t} = mcs$$

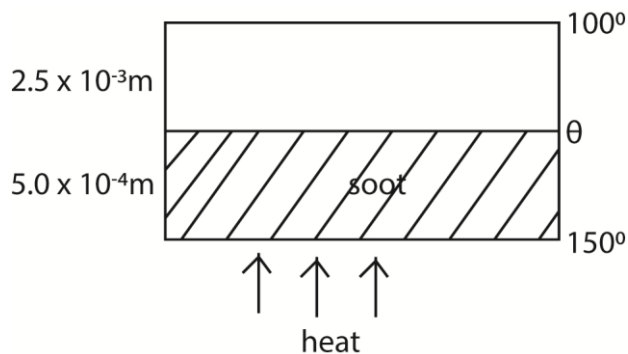
$$\therefore kA \left(\frac{\theta_2 - \theta_1}{x} \right) = mcs$$

$$k = \frac{mcsx}{A(\theta_2 - \theta_1)} \text{ but } A = \frac{\pi D^2}{4}$$

$$\therefore k = \frac{4mcsx}{\pi D^2(\theta_2 - \theta_1)}$$

- (c) A cooking saucepan made of iron has a base area of 0.05m^2 and thickness of 2.5mm . It has a thin layer of soot of average thickness 0.5mm on its bottom surface. Water in the saucepan is heated until it boils at 100°C . The water boils away at a rate of 0.60kg per minute and the side of the soot nearest to the heat source is at 150°C . Find the thermal conductivity of soot.

[Thermal conductivity of iron = $66\text{Wm}^{-1}\text{K}^{-1}$ and specific latent heat of vaporization = 2200kJ/kg]



At steady state

$$\frac{dQ}{dt} = \frac{k_1 A (150 - \theta)}{l_1} = \frac{k_2 A (\theta - 100)}{l_2} = \frac{0.6}{60} \times 2.2 \times 10^6$$

$$\Rightarrow k_1(150 - \theta) = k_2(\theta - 100) \times \frac{l_1}{l_2} = k_1(150 - \theta) = 66(\theta - 100) \times 0.2 \dots\dots(i)$$

Also,

$$k_2 A (\theta - 100) = 2.2 \times 10^4 \times l_2$$

$$66 \times 0.05 (\theta - 100) = 2.2 \times 10^4 \times 2.5 \times 10^{-3}$$

$$\theta = 116.67^\circ\text{C}$$

Substituting θ in equation (ii)

$$k_1(150 - 116.67) = 66(116.67 - 100) \times 0.2$$

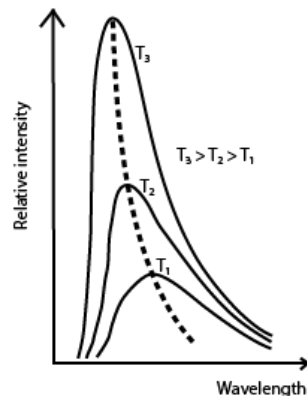
$$k_1 = 6.6 \text{ Wm}^{-1}\text{K}^{-1}$$

Hence thermal conductivity of shoot = $6.6 \text{ Wm}^{-1}\text{K}^{-1}$

(d) (i) What is a black body? (01mark)

A black body is one that absorbs all the radiations falling on it, transmits and reflects none.

(ii) Sketch the spectral distribution of black body radiation for three different temperatures and describe their main features. (04marks)



As temperature increases, the intensity increases. The intensity of shorter wavelengths increase more rapidly. The wavelength of the most intense radiation decreases as temperature increases.

47. (a) Derive the expression $P = \frac{1}{3} \rho c^2$ for the pressure, P , of an ideal gas of density ρ and mean square speed, c^2 . State any assumptions made (07marks)

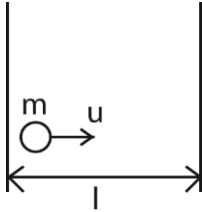
Assumptions

- The intermolecular forces are negligible

- The volume of the gas is negligible compared the volume of the container
- Collision are perfectly elastic
- The duration of collision is negligible

Derivation

Consider a molecule of mass, m , moving in a cube of length, l and velocity, u .



$$\text{Change in momentum} = mu - (-mu) = 2mu$$

$$\text{Rate of change of momentum} = \frac{2mu}{t}$$

$$\text{Time, } t, \text{ between collision} = \frac{2l}{u}$$

$$F_1 = 2mu \div \frac{2l}{u} = \frac{mu^2}{l}$$

For N molecules, force on the wall,

$$F = \frac{mu_1^2}{l} + \frac{mu_2^2}{l} + \frac{mu_3^2}{l} + \dots + \frac{mu_N^2}{l}$$

$$\text{Pressure, } P = \frac{F}{A} = \frac{m}{l^3} (u_1^2 + u_2^2 + u_3^2 + \dots + u_N^2) \text{ since } A = l^2$$

$$u^2 = \frac{u_1^2 + u_2^2 + u_3^2 + \dots + u_N^2}{N}$$

$$Nu^2 = u_1^2 + u_2^2 + u_3^2 + \dots + u_N^2$$

$$\therefore P = \frac{Nmu^2}{l^3} = \rho u^2; \text{ since } \rho = \frac{Nm}{l^3}$$

$$c^2 = u^2 + v^2 + w^2 \text{ and } u^2 = v^2 + w^2$$

$$\therefore c^2 = 3u^2 \Rightarrow u^2 = \frac{1}{3}c^2$$

$$\therefore P = \frac{1}{3}\rho c^2$$

(b) A gas is confined in a container of volume 0.1m^3 at a pressure of $1.0 \times 10^5\text{Nm}^{-2}$ and temperature of 300K . If the gas is assumed to be ideal, calculate the density of the gas.

(The relative molecular mass of the gas is 32) (05marks)

$$PV = nRT$$

$$n = \frac{1.0 \times 10^5 \times 0.1}{8.31 \times 300} = 4$$

mass of gas, $m = nM = 4 \times 32 \times 10^{-3} = 0.128\text{kg}$

$$\text{Density} = \frac{m}{V} = \frac{0.128}{0.1} = 1.28\text{kgm}^{-3}$$

(c) What is meant by

(i) isothermal change

Isothermal expansion takes place at constant temperature.

(ii) adiabatic change (02marks)

Adiabatic expansion takes place at constant heat.

(d) A gas at a pressure of $1.0 \times 10^6\text{Pa}$ is compressed adiabatically to half its volume and then allowed to expand isothermally to its original volume. Calculate the final pressure of the gas.

[Assume the ratio of the principal specific heat capacities $c_p/c_v, \gamma = 1.4$] (06marks)

For adiabatic change

$$PV^\gamma = \text{constant}$$

$$\Rightarrow 1.0 \times 10^6 \times V^{1.4} = P \times \left(\frac{V}{2}\right)^{1.4}$$

$$P = 2.64 \times 10^6\text{Pa}$$

For isothermal change

$$PV = \text{constant}$$

$$2.64 \times 10^6 \times \frac{V}{2} = PV$$

$$P = 1.32 \times 10^6\text{Pa}$$

48. (a) (i) Define molar heat capacity of a gas at constant volume. (01mark)

Molar heat capacity of a gas at constant volume is the amount of heat required to raise 1 mole of the gas through 1K at constant volume.

(ii) The specific heat capacity of oxygen at constant volume is $719\text{Jkg}^{-1}\text{K}^{-1}$. If the density of oxygen at s.t.p is 1.429kgm^{-3} , calculate the specific heat capacity of oxygen at constant pressure. (04marks)

$$PV = nRT$$

$$\text{At s.t.p } 1 \times 10^{-5}V = 273R$$

$$V = 273R \times 10^{-5}\text{m}^3$$

$$\text{Since } \rho = \frac{m}{V}; m = \rho V \dots\dots\dots(i)$$

$$\text{But } mC_p - mC_v = R \dots\dots\dots(ii)$$

Where C_p and C_v are specific heat capacities at constant pressure and volume respectively

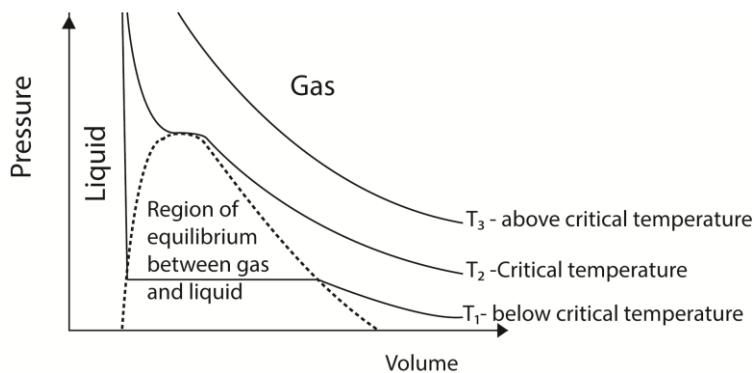
From equation (ii)

$$C_p = \frac{R + mC_v}{m} \dots\dots\dots(iii)$$

Substituting for m from equation (i) into equation (iii)

$$C_p = \frac{R + \rho(273R \times 10^{-5})C_v}{273\rho R \times 10^{-5}} = \frac{1 + 273\rho C_v \times 10^{-5}}{273\rho \times 10^{-5}} = \frac{1 + (273 \times 1.429 \times 719 \times 10^{-5})}{273 \times 1.429 \times 10^{-5}} = 975.5\text{Jkg}^{-1}\text{K}^{-1}$$

(b) Indicate the different states of a real gas at different temperatures and pressure versus volume sketch graph.



(c) (i) In deriving the expression $P = \frac{1}{3} \rho \overline{c^2}$ for the pressure of an ideal gas, two of the assumptions made are not valid for a real gas. State these assumptions. (02marks)

- The intermolecular forces are negligible
- The volume of the gas is negligible compared the volume of the container
- Collision are perfectly elastic
- The duration of collision is negligible

(ii) The equation of state of one mole of a real gas is $\left(P + \frac{a}{v^2}\right)(v - b) = RT$

Account for the terms $\frac{a}{v^2}$ and b (02marks)

The molecules that strike the walls of the container are retarded by unbalances forces due to the molecules behind them. So the observed pressure is less than what it would be without these forces. Hence $\frac{a}{v^2}$ corrects deficit in pressure due to intermolecular attractions of gas molecules

The volume of the molecules compared to the volume of the container occupied by the gas. Therefore, b, called the co-volume accounts for the finite volume of molecules themselves

(d) Use the expression $P = \frac{1}{3} \rho \overline{c^2}$; for the pressure of an ideal gas to derive Dalton's law of partial pressures (04marks)

$$P = \frac{1}{3} N \frac{m}{V} \overline{c^2} = \frac{2}{3} N \left(\frac{1}{2} m \overline{c^2} \right)$$

$$\text{For gas 1, } P_1 V_1 = \frac{2}{3} N_1 \left(\frac{1}{2} m_1 \overline{c_1^2} \right)$$

$$\Rightarrow N_1 = \frac{3}{2} P_1 V_1 \cdot \frac{1}{K_1}$$

Similarly for gas 2

$$N_2 = \frac{3}{2} P_2 V_2 \cdot \frac{1}{K_2}$$

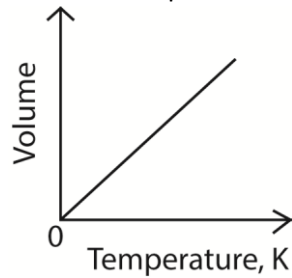
For a mixture of gases, $N = \frac{3}{2} PV \cdot \frac{1}{K}$; but $N = N_1 + N_2$

$$\frac{3}{2} PV \cdot \frac{1}{K} = \frac{3}{2} P_1 V_1 \cdot \frac{1}{K_1} + \frac{3}{2} P_2 V_2 \cdot \frac{1}{K_2}$$

Since temperature is constant, $K_1 = K_2 = K$

- $PV = P_1 V_1 + P_2 V_2$
- But $V = V_1 = V_2$
- $\therefore P = P_1 + P_2$

- (e) Explain, with the aid of a volume versus temperature sketch graph, what happens to a gas cooled at constant pressure from room temperature to zero Kelvin. (04marks)

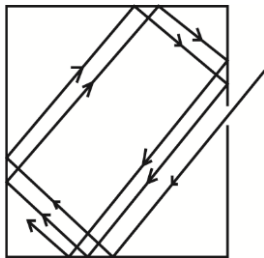


As the gas cools, the kinetic energy of its molecules reduce, implying that the internal energy of the molecules reduce until zero K where the volume is assumed to be zero and Charles laws ceases to apply.

49. (a) What is meant by black body? (01mark)

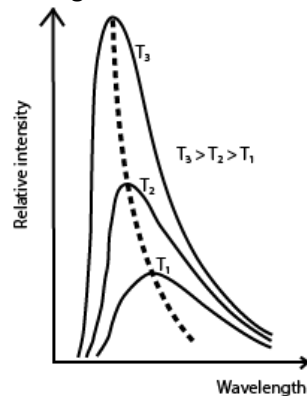
A black body is one that absorbs all incident radiation, but reflects and transmits none.

- (b) Describe how an approximate black body can be realized in practice. (02marks)



When radiation enters a black container through a hole, it undergoes multiple reflections. At each reflection, part of the radiation is absorbed. After several reflections, all the radiation is retained inside the container. Hence it approximates to a black body.

- (c)(i) Draw sketch graphs to show how variation of relative intensity of black body radiation with wavelength for three different temperatures. (02marks)



- (ii) Describe the features of the sketch in (c)(i) above. (03marks)

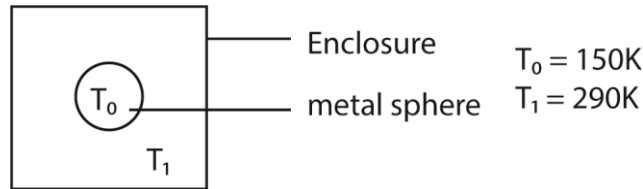
As temperature increases, the intensity increases. The intensity of shorter wavelengths increase more rapidly. The wavelength of the most intense radiation decreases as temperature increases.

- (d)(i) State Stefan's law (01mark)

Stefan's law states that the total power radiated by a black body is directly proportional to the fourth power of its absolute temperature.

- (ii) A solid copper sphere of diameter 10 mm and temperature of 150K is placed in an enclosure maintained at a temperature of 290K. Calculate, stating assumptions made, the initial rate of rise of temperature of the sphere.

[Density of copper = $8.93 \times 10^3 \text{ kg m}^{-3}$, specific heat capacity of copper = $3.7 \times 10^2 \text{ J kg}^{-1} \text{ K}^{-1}$]
(07marks)



$$\text{Power radiated by the sphere} = 4\pi r^2 \sigma T_0^4$$

$$\text{Power absorbed by the sphere} = 4\pi r^2 \sigma T_1^4$$

$$\text{Net power absorbed, } P = 4\pi r^2 \sigma (T_1^4 - T_0^4)$$

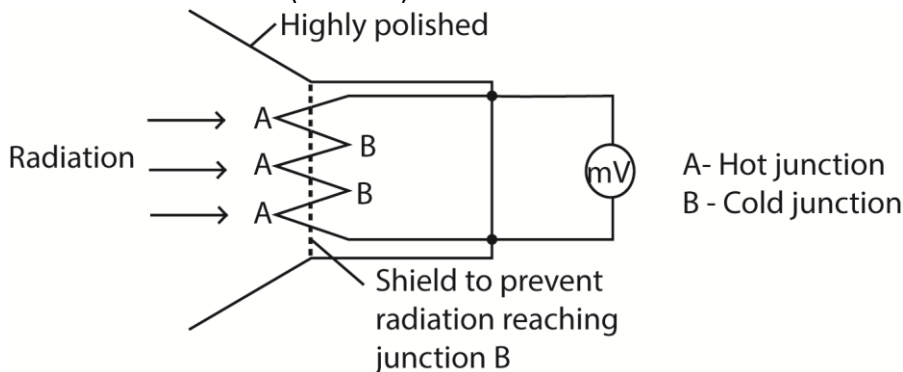
$$\text{But also, } P = mc \frac{d\theta}{dt} = \frac{4}{3} \pi r^3 \rho c \frac{d\theta}{dt}$$

At equilibrium

$$\frac{4}{3} \pi r^3 \rho c \frac{d\theta}{dt} = 4\pi r^2 \sigma (T_1^4 - T_0^4)$$

$$\frac{d\theta}{dt} = \frac{3\sigma}{\rho cr} (T_1^4 - T_0^4) = \frac{3 \times 5.67 \times 10^{-8}}{8.93 \times 10^3 \times 3.7 \times 10^2 \times 5 \times 10^{-3}} = 0.068 \text{ K s}^{-1}$$

- (e) With the aid of a labelled diagram, describe how a thermopile can be used to determine infrared radiation. (04marks)



Radiation falling on junction A is absorbed and temperature rises above that of junction B. An e.m.f is generated and is measured by millivolt meter which deflects as a result.

50. (a) (i) What is meant by kinetic theory of gases? (03marks)

Gases are composed of molecules which are in continuous random motion. The molecules collide elastically with one another and also with the walls of the container. When heat energy is supplied, their kinetic energy increases.

- (ii) Define an ideal gas (01mark)

An ideal gas is one which exactly obeys Boyle's law at all conditions

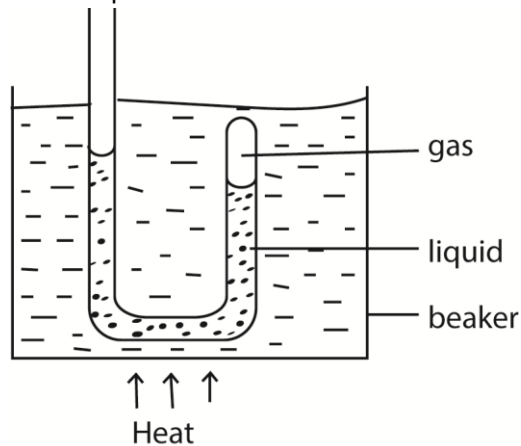
(iii) State and explain conditions under which real gases behave like ideal gases. (04mark)

At very high temperature, the intermolecular forces of attraction become negligible.

At low pressure, the volume of gas molecules become negligible compared to the volume of the container.

(b) (i) Describe an experiment to show that a liquid boils only when its saturated vapor pressure is equal to external pressure (05marks)

Experiment to show that a liquid boils off when its saturated vapour pressure equals the external pressure



- Air is trapped in the closed limb of the tube by water column.
- The tube is heated in water bath.
- When the water bath begins to boil, the water in the tube comes to the same level in each limb.
- This shows that the vapor pressure in closed limb is equal to external pressure.

(ii) Explain how cooking at a pressure of 76cm of mercury and temperature of 100°C may be achieved on top of high mountains. (03marks)

Cooking pans are fitted with lids that possess safety valves that open when the pressure exceeds 76cmHg. During cooking the vapour pressure inside the cooking pan increase and the temperature increases to 100°C. the safety valves prevents pressure to exceed 76cmHg and therefore boiling occurs at 100°C.

(c) (i) Define root-mean-square speed of molecules of a gas. (01mark)

Root mean square speed of the gas is the average of the square speeds of individual molecules of a gas.

(ii) The mass of hydrogen and oxygen atoms are $1.66 \times 10^{-27}\text{kg}$ and $2.66 \times 10^{-26}\text{kg}$ respectively.

What is the ratio of the root mean square speed of hydrogen to that of oxygen molecules at the same temperature? (03marks)

$$\text{From } \frac{1}{3} N m c^2 = RT$$

$$\frac{1}{3} N \times 1.66 \times 10^{-27} \times c_H^2 = \frac{1}{3} N \times 2.66 \times 10^{-26} \times c_O^2$$

$$\frac{c_H^2}{c_O^2} = \frac{2.66 \times 10^{-26}}{1.66 \times 10^{-27}} = 16$$

51. (a) State the assumption made in the derivation of the expression $P = \frac{1}{3} \rho \overline{c^2}$ for pressure of an ideal gas (02marks)

- The intermolecular forces are negligible
- The volume of the gas is negligible compared the volume of the container
- Collision are perfectly elastic
- The duration of collision is negligible

(b) Use the expression in (a) above to deduce Dalton's law of partial pressures. (03marks)

$$P = \frac{1}{3} N \frac{m}{V} \overline{c^2} = \frac{2}{3} N \left(\frac{1}{2} m \overline{c^2} \right)$$

$$\text{For gas 1, } P_1 V_1 = \frac{2}{3} N_1 \left(\frac{1}{2} m_1 \overline{c_1^2} \right)$$

$$\Rightarrow N_1 = \frac{3}{2} P_1 V_1 \cdot \frac{1}{K_1}$$

Similarly for gas 2

$$N_2 = \frac{3}{2} P_2 V_2 \cdot \frac{1}{K_2}$$

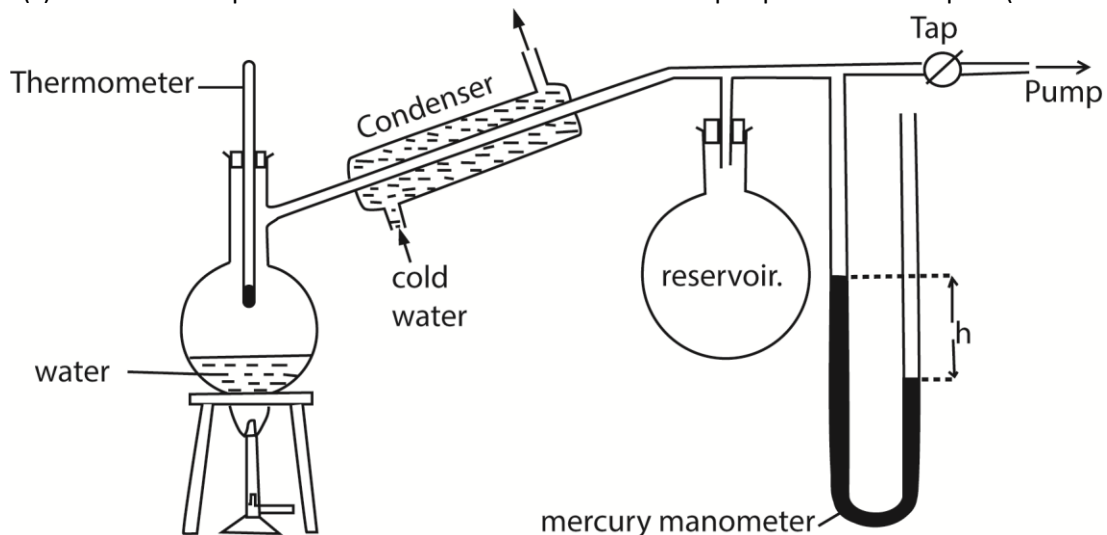
For a mixture of gases, $N = \frac{3}{2} P V \cdot \frac{1}{K}$; but $N = N_1 + N_2$

$$\frac{3}{2} P V \cdot \frac{1}{K} = \frac{3}{2} P_1 V_1 \cdot \frac{1}{K_1} + \frac{3}{2} P_2 V_2 \cdot \frac{1}{K_2}$$

Since temperature is constant, $K_1 = K_2 = K$

- $PV = P_1 V_1 + P_2 V_2$
- But $V = V_1 = V_2$
- $\therefore P = P_1 + P_2$

(c) Describe an experiment to determine the saturation vapor pressure of a liquid. (06marks)



- The pressure of the air in R is shown by the mercury manometer; if its height is h, the pressure in mm mercury is $P = H - h$, where H is the barometer height.
- The tap is opened and the pressure above water varied using the pump to a suitable value.
- The tap is closed and water in the flask is heated until it boils.

- The temperature θ and difference in mercury levels, h , are noted and recorded.
- The saturated vapour pressure, $P = (H \pm h)$ is calculated
- The procedure is repeated other values of θ and h
- A graph of P versus θ is plotted and the saturated vapour pressure at a particular temperature is obtained.

(d) (i) What is meant by a reversible isothermal change? (02marks)

The change taking place at constant temperature and can be taken back from the final to initial states through exactly the same values of pressure and volume at every stage.

(ii) State the conditions for achieving a reversible isothermal change. (02marks)

Use vessels with thin good conducting walls having a frictionless piston, surrounded by constant temperature bath and the process must occur slowly.

(e) An ideal gas at 27°C and at a pressure of $1.01 \times 10^5 \text{Pa}$ is compressed reversibly and isothermally until its volume is halved. It is then expanded reversibly and adiabatically to twice its original volume. Calculate the final pressure and temperature of the gas if $\gamma = 1.4$ (05marks)

For isothermal: $P \frac{V}{2} = 1.01 \times 10^5 V$; $P = 2.02 \times 10^5 \text{Pa}$

For adiabatic; $2.02 \times 10^5 \left(\frac{V}{2}\right)^{1.4} = P_1 (2V)^{1.4}$; $P_1 = 2.9 \times 10^4 \text{Pa}$

Final pressure = $2.9 \times 10^4 \text{Pa}$

Also,

$TV^{\gamma-1} = \text{constant}$.

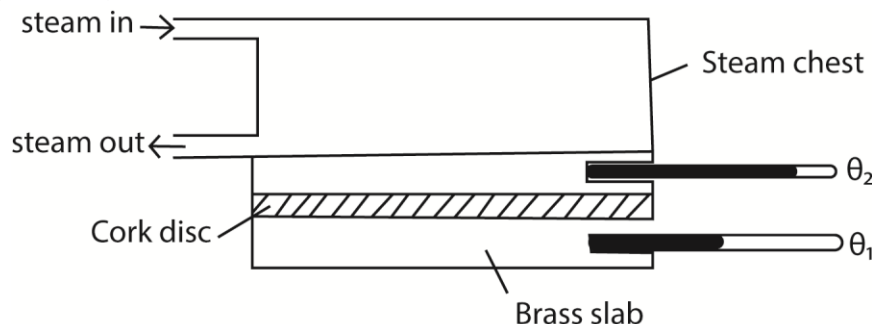
$$\Rightarrow (300.15) \left(\frac{V}{2}\right)^{0.4} = (2V)^{0.4}; T = 172\text{K}$$

52. (a) Explain the mechanism of heat conduction in solids. (03marks)

Atoms or molecules at the heated end vibrate more vigorously about their fixed positions. They collide and pass on heat to the neighboring atoms which in turn vibrate vigorously; collide and pass on heat to their neighboring atoms. In this way heat is transferred from the hot end to the cold end.

Also, good conductors have free electrons that acquired high kinetic energy when heat, move and transfer heat collide with atoms in the cold

(b) Describe a method of determining the thermal conductivity of cork in form of a thin sheet. (06marks)



- Cock disc cut in form of a thin disc of cross section area, A and thickness, x.
- The disc is sandwiched between a steam chest and brass slab of mass, m and specific heat capacity, c.
- Steam is passed through the chest until the thermometers register steady temperatures, θ_1 and θ_2 .
- Then, $\frac{\theta}{t} = kA \left(\frac{\theta_2 - \theta_1}{x} \right)$
- The glass disc is removed and brass slab is heated directly by steam chest, until its temperature is about 10°C above θ_1 .
- Steam chest is removed and the top of the glass slab is covered by the glass disc.
- The temperature of the slab is recorded at suitable time interval until its temperature is about 10°C below θ_1 .
- A graph of temperature against time is plotted and its slope s determined at θ_1

$$\frac{\theta}{t} = mcs$$

$$\therefore kA \left(\frac{\theta_2 - \theta_1}{x} \right) = mcs$$

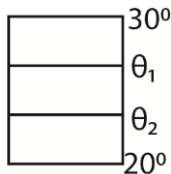
$$k = \frac{mcsx}{A(\theta_2 - \theta_1)} \text{ but } A = \frac{\pi D^2}{4}$$

$$\therefore k = \frac{4mcsx}{\pi D^2(\theta_2 - \theta_1)}$$

(c) A window of height 1.0m and width 1.5m contains a double glazed unit consisting of two single glass panes, each of thickness 4.0mm separated by an air gap of 2.0mm. Calculate the rate at which heat is conducted through the window if the temperatures of external surfaces of glass are 20°C and 30°C respectively.

[Thermal conductivities of glass and air are $0.72\text{Wm}^{-1}\text{K}^{-1}$ and $0.025\text{Wm}^{-1}\text{K}^{-1}$ respectively]

(07marks)



$$\frac{dQ}{dT} = \frac{kA(\theta_2 - \theta_1)}{L} = mc \times \text{slope}$$

$$\frac{k_1 A (30 - \theta_1)}{4 \times 10^{-3}} = \frac{k_2 A (\theta_2 - \theta_1)}{2 \times 10^{-3}} = \frac{k_1 A (\theta_1 - 20)}{4 \times 10^{-3}}$$

$$\Rightarrow \theta_1 + \theta_2 = 50$$

$$\frac{0.72A(30 - \theta_1)}{4 \times 10^{-3}} = \frac{0.025A(\theta_1 - \theta_2)}{2 \times 10^{-3}}$$

$$\frac{0.72A(30 - \theta_1)}{4 \times 10^{-3}} = \frac{0.025A(\theta_1 - (50 - \theta_1))}{2 \times 10^{-3}}$$

$$\theta_1 = 29.4^\circ\text{C}$$

$$\text{Hence } \frac{dQ}{dT} = \frac{0.72A(30 - 29.4)}{4 \times 10^{-3}} = 162\text{W}$$

(d) (i) State Stefan's law. (01mark)

Stefan's law states that the total energy radiated per square meter per second by a black body is directly proportional to the fourth power of its absolute temperature.

(ii) The element of a 1.0kW electric fire is 30.0cm long and 1.0cm in diameter. If the temperature of the surroundings is 20°C, estimate the working temperature of the element.

[Stefan's constant, $\sigma = 5.7 \times 10^{-8} \text{Wm}^{-2}\text{K}^{-4}$] (03marks)

$$P = A\sigma T^4$$

$$= 2\pi r l \sigma (T^4 - T_s^4)$$

$$= 2\pi r l \sigma T^4 - 2\pi r^2 l \sigma T_s^4$$

$$T = \sqrt[4]{\frac{1 \times 10^3 + 2\pi (0.5 \times 10^{-2})(30 \times 10^{-2}) \times 5.67 \times 10^{-8} \times 273^4}{2\pi (0.5 \times 10^{-2})(30 \times 10^{-2}) \times 5.67 \times 10^{-8}}} = 1169\text{K}$$

53. (a) (i) Define specific heat capacity of a substance (01mark)

Specific heat capacity is the quantity of heat required to raise the temperature of 1kg mass of a substance by 1K without change of state

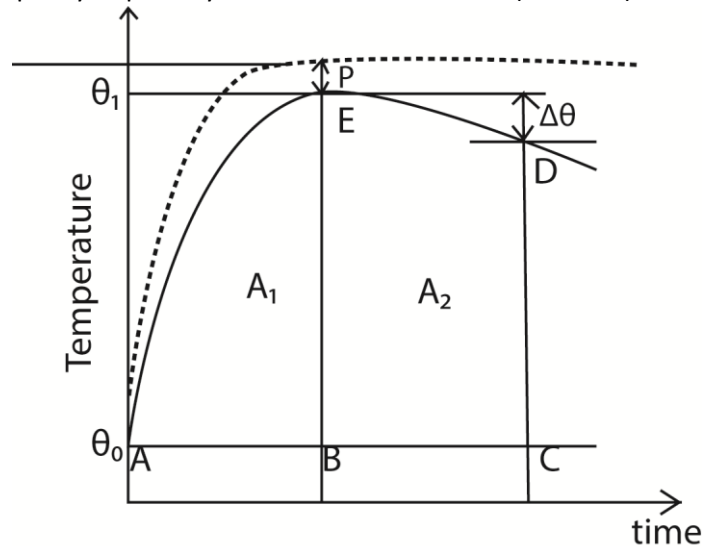
(ii) State how heat losses are minimized in calorimetry (02mark)

- Surrounding the calorimeter vacuum
- Using a highly polished surface
- By lagging the calorimeter using insulating material
- Surrounding the calorimeter with a layer of still air.

(b) (i) What is meant by cooling correction? (01marks)

This is the extra temperature difference to be added to the observed maximum temperature of the mixture to make up for the heat lost to the surrounding during the experiment.

(ii) Explain how the cooling correction may be estimated in the determination of the heat capacity of poor by the method of mixtures (05marks)



- The broken line shows how we would expect the temperature to rise if no heat were lost and the difference, P, between the plateau of this imaginary curve, and the crest of the experimental curve, E, is known as the 'cooling correction'

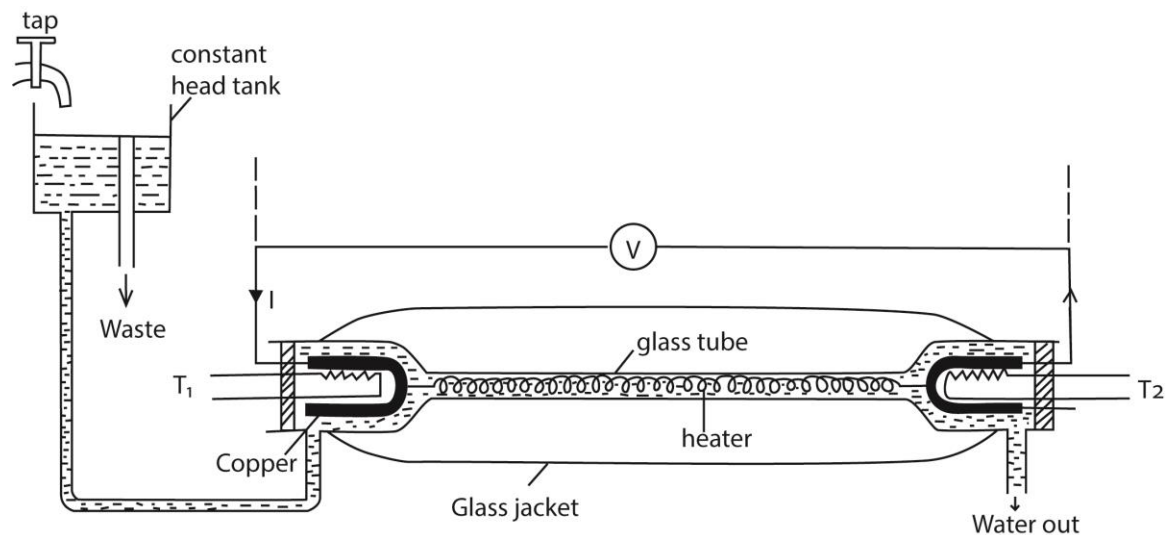
- Draw a line AC through θ_0 parallel to the time axis.
- Draw a line BE through θ_1 parallel to the temperature axis.
- Draw a line CD beyond BE parallel to the temperature axis and note $\Delta\theta$
- Estimate the area A_1 and A_2 under the graph by counting the square on the graph paper
- Cooling correction, P s given by the graph

$$\text{Cooling correction, } P = \frac{A_1}{A_2} \times \Delta\theta^\circ\text{C}$$

(iii) Explain why a small body cools faster than a larger one of the same material. (04marks)

Small body has a large surface area to volume ratio and small quantity of heat compare to the bod body. And the rate of heat is proportional to the surface area while the rate of temperature fall is inversely proportional to the quantity of heat held by the body

(c) Describe how you would determine the specific heat capacity of a liquid by the continuous flow method. (07marks)



- A liquid is allowed to flow at constant rate
- Power is switched on and the liquid is heated until temperatures registered by T_1 and T_2 are steady and the values θ_1 and θ_2 respectively are recorded.
- The p.d V and current I are recorded from the voltmeter and ammeter respectively
- The mass, m of a liquid collected in time t is recorded
- At steady state; $VIt = mc(\theta_2 - \theta_1) + h$ (i)
where h is heat lost to the surrounding
- The rate of flow is changed and the voltage and current are adjusted until the steady readings of T_1 and T_2 are θ_1 and θ_2 respectively
- If m_1 , V_1 and I_1 are the values mass of liquid collected in time t , voltmeter and ammeter readings respectively, then

$$V_1 I_1 t = m_1 c (\theta_2 - \theta_1) + h \text{ (ii)}$$

Subtracting (ii) from (i)

$$c = \frac{(VI - V_1 I_1)t}{(m - m_1)(\theta_2 - \theta_1)}$$

54. (a) Define thermal conductivity of a substance and state its units. (02marks)

Thermal conductivity is the rate of heat flow through a unit cross section area at per unit temperature gradient.

- (b) Flux of solar energy incident on the earth's surface is $1.36 \times 10^3 \text{ Wm}^{-2}$.

Calculate

- (i) The temperature of the surface of the sun (04marks)

$$\frac{4\pi r_s^2 \sigma T_s^4}{4\pi R^2} = 1.36 \times 10^3$$

$$T_s = \sqrt[4]{\frac{1.36 \times 10^3 \times (1.5 \times 10^{11})^2}{(6.96 \times 10^8)^2 \times 5.67 \times 10^{-8}}} = 5777\text{K}$$

- (ii) The total power emitted by the sun (03marks)

Power emitted by the sun = Power radiated by the sun

$$= A\sigma T_s^4$$

$$= 4\pi r_s^2 \sigma T_s^4$$

$$= 4\pi (6.96 \times 10^8)^2 \times 5.67 \times 10^{-8} \times 5777^4$$

$$= 3.85 \times 10^{26} \text{ W}$$

- (iii) The rate of loss of mass by the sun (03marks)

From $E = mc^2$

$$\frac{dm}{dt} = \frac{P}{c^2} = \frac{3.85 \times 10^{26}}{(3 \times 10^8)^2} = 4.3 \times 10^9 \text{ kgs}^{-1}$$

- (c)(i) Explain how heat is conducted through a glass rod. (03marks)

Atoms or molecules at the heated end vibrate more vigorously about their fixed positions. They collide and pass on heat to the neighboring atoms which in turn vibrate vigorously; collide and pass on heat to their neighboring atoms. In this way heat is transferred from the hot end to the cold end.

- (ii) Why is a metal a better conductor of heat than glass? (02marks)

In addition to conduction of heat as in glass metal have free electrons that acquired high kinetic energy when heat, move and transfer heat collide with atoms in the cold

- (iii) Explain briefly why it is necessary to use a thin specimen of large cross-section area in determining thermal conductivity of a poor conductor of heat. (03marks)

To ensure steep temperature gradient.

55. (a) (i) Explain what happens when a quantity of heat is applied to a fixed mass of a gas (02marks)

Heat supplied increase internal energy of the gas and used to overcome external pressure during the expansion.

- (ii) Derive the relationship between the principal molar heat capacities C_p and C_v for an ideal gas. (05marks)

From $dQ = dU + dW$ (i)

But $dQ = C_p dT$, $dU = C_v dT$ and $dW = PdV = RdT$

Substituting in (i)

$$C_p dT = C_v dT + R dT$$

$$\therefore C_p - C_v = R$$

(b) (i) What is adiabatic process? (01mark)

An adiabatic process is one in which no heat is added or removed from the system.

(ii) A bicycle pump contains air at 290K. The piston of the pump is slowly pushed in until the volume of the air enclosed is one fifth of the total volume of the pump. The outlet is sealed off and the piston suddenly pulled out to full extension. If no air escapes, find its temperature immediately after pulling the piston. (Take $C_p/C_v = 1.4$) (03marks)

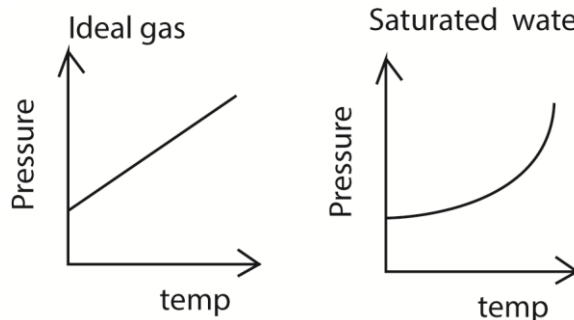
$$T_2 V_2^{\gamma-1} = T_1 V_1^{\gamma-1}$$

$$T_2 = 290 \left(\frac{5V}{V} \right)^{0.4} = 152K$$

(c) (i) Distinguish between unsaturated and saturated vapors. (02marks)

Unsaturated vapour is a vapour that is not in dynamic equilibrium with its own liquid while saturated vapour is a vapour that is in dynamic equilibrium with its own liquid.

(ii) Draw graphs to show the relationship between pressure and temperature for ideal gas and for saturated water vapour originally at 0°C. (03marks)



(d) In an experiment, the pressure of a fixed mass of air at constant temperature is 10.4kPa. When the volume is halved, keeping the temperature constant, the pressure becomes 19.0kPa. Discuss the applicability of the above results in verifying Boyle's law. (04marks)

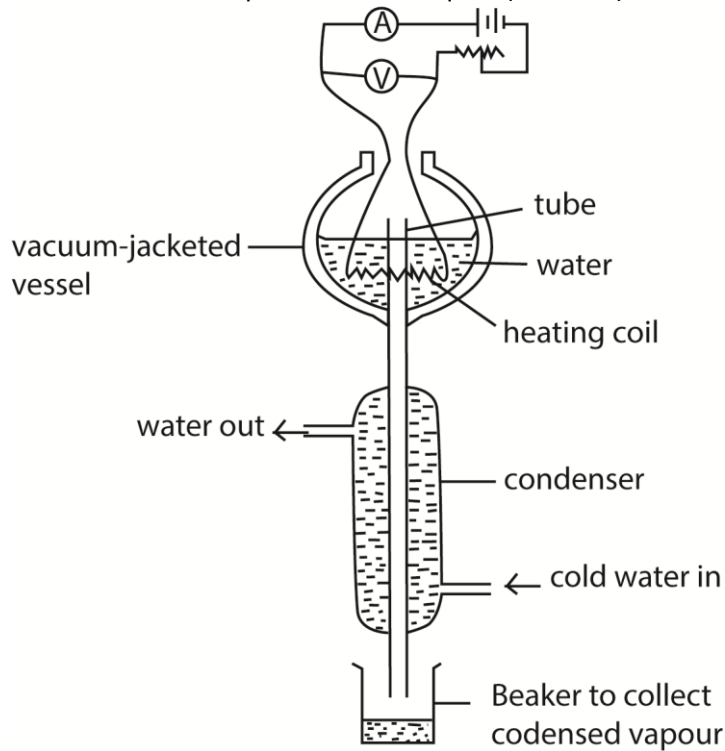
From $PV = \text{constant}$

Halving the volume at constant temperature doubles pressure. Since pressure was not doubled, Boyle's law is not verified.

56. (a) Explain why temperature remains constant during change of phase. (04marks)

The energy supplied goes into increasing the amplitude of oscillation of atoms which become so large that the regular arrangement of these atoms collapses. Until the process is complete, the temperature remains constant, hence no increase in temperature.

(b) Describe with the aid of labelled diagram, an electrical method for determination of specific latent heat of vaporization of a liquid. (07marks)

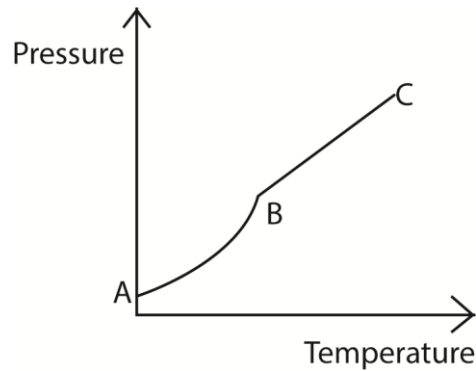


- Put the liquid whose specific latent heat of vaporization is required in a vacuum jacketed vessel as shown above.
- The liquid is heated to boiling point.
- The current, I , and voltage, V are recorded.
- The mass of condensed water, m , condensed in time, t , is determined.
- Then $IV = \frac{m}{t}L + h$, where h is the rate of heat loss to the surroundings
- To eliminate, h , the experiment is repeated for different values of I' and V' and the mass of the condensed water, m' condensed in time t is determined.
- Again $I'V' = \frac{m'}{t}L + h$

$$\text{Latent heat of vaporization, } L = \frac{(I'V' - IV)t}{(m' - m)}$$

(c) Water vapour and liquid water are confined in an air tight vessel. The temperature of the water is raised until all the water has evaporated.

Draw a sketch graph to show how the pressure of water vapour changes with temperature and account for its main features. (06marks)



- Water vapor is saturated up to B; i.e. between A and B, increase in temperature increases the kinetic energy of the liquid molecules. The fastest molecules leave the liquid hence the liquid evaporates.
 - The density of the vapour above the liquid increases implying that saturated vapour pressure increases.
 - Beyond B, the unsaturated vapour obeys gas laws and hence the graph is linear.
- (d) Calculate the work done against the atmosphere when 1kg of water turns into vapour at atmospheric pressure of $1.01 \times 10^5 \text{ Pa}$.

[Density of water vapour $= 0.598 \text{ kg m}^{-3}$] (03 marks)

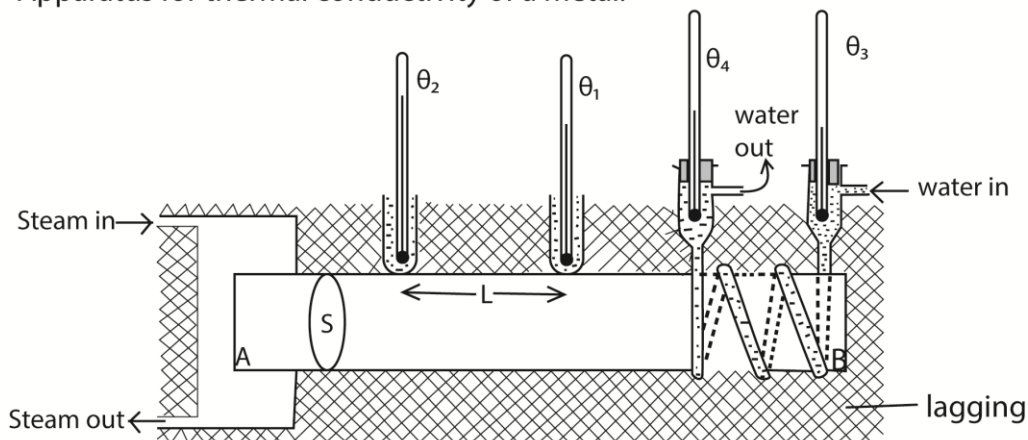
Work done $= Pdv = P(V_2 - V_1)$ where V_2 = volume of the vapor, V_1 = volume of water

$$\text{Volume} = \frac{\text{mass}}{\text{density}}$$

$$\therefore \text{Work done} = 1.01 \times 10^5 \left(\frac{1}{0.598} - \frac{1}{1000} \right) = 1.69 \times 10^5 \text{ J}$$

57. (a)(i) Describe Searle's method of determining the thermal conductivity of a good conductor of heat. (07 marks)

Apparatus for thermal conductivity of a metal.



- Specimen bar AB of mean diameter, d , is heated by steam at end A and cooled by water at end B as shown above
- The lagging ensure a constant rate of heat flow

- The setup is left to run for some time until steady temperatures θ_1 , θ_2 , θ_3 and θ_4 are obtained.
- The rate water flow $m \text{ kgs}^{-1}$ is measured using a cylinder and stop clock.
- Cross section area $A = \frac{\pi d^2}{4}$
- The rate of heat flow is given by

$$\frac{Q}{t} = kA \left(\frac{\theta_2 - \theta_1}{L} \right) = mc_w(\theta_4 - \theta_3)$$

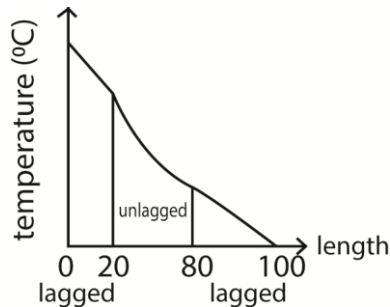
where k = thermal conductivity of the metal and c_w is specific heat capacity of water

(ii) Why is the method in (a)(i) best suited for a good conductor of heat? (02marks)

- Rate of heat flow through the conductor is measurable
- There is a steep temperature gradient.

(b) The two ends of a metal bar of length 1.0m are perfectly lagged up to 20cm from either end. The ends of the bar maintained at 100°C and 0°C respectively.

(i) Sketch a graph of temperature versus distance of a bar. (02marks)



(ii) Explain the features of the graph in (b)(i) (03marks)

- In lagged portions there is constant heat flow because there is no heat loss to the surroundings
- In unlagged portion heat flow is not uniform due to heat loss to the environment.

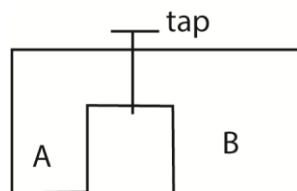
58. (a) (i) State Boyle's law. (01mark)

The pressure of a fixed mass of a gas is inversely proportional to volume.

(ii) What is meant by partial pressure of a gas? (01 mark)

Partial pressure is the pressure that would be exerted by a gas if it alone occupied the volume of the mixture.

(iii)



Two cylinders A and B of volumes V and $3V$ respectively are separately filled with a gas. The cylinders are connected as shown above with the tap closed. The pressures of A and B

are P and 4P respectively. When the tap is opened the common pressure becomes 60Pa. Assuming isothermal conditions find the value of P. (04marks)

Solution

From $PV = nRT$

Moles n_1 of the gas in A before mixing = $\frac{PV}{RT}$

Moles n_2 of the gas in B before mixing = $\frac{4P \times 3V}{RT} = \frac{12PV}{RT}$

Moles n_3 of the gas when tap is opened = $\frac{60 \times 4V}{RT}$

But moles of the gas before mixing = mole of the gas after mixing

$$\Rightarrow n_1 + n_2 = n_3$$

$$\frac{PV}{RT} + \frac{12PV}{RT} = \frac{60 \times 4V}{RT}$$

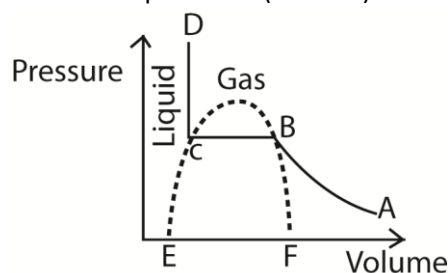
$$13P = 240$$

$$P = 18.46\text{Pa}$$

(b) (i) State three differences between ideal and real gases. (03marks)

Real gas	Ideal gas
Intermolecular force are appreciable	Intermolecular forces are negligible
Volume of molecules compared to the volume of the container is not negligible	Volume of molecules compared to the volume of container is negligible
Obey Boyle's law at high temperature and very low pressure	Obey Boyle's law at all temperatures and pressures.

(ii) Sketch a pressure versus volume curve for a real gas undergoing compression below its critical temperature. (01mark)



(iii) Explain the main features of the curve in (b)(ii) above (03marks)

- AB represents unsaturated vapour that approximately obey Boyle's law.
- BC represents saturated vapour, the gas turns into a liquid at constant pressure.
- CD is a liquid, small decrease in volume leads to a big increase in pressure because liquids are incompressible

(c) Two similar cylinders P and Q contain different gases at the same pressure. When gas is released from P the pressure remains constant for some time before it starts dropping. When gas is released from Q the pressure continuously drops. Explain the observation above. (05marks)

- The gas in P is in form of a saturated vapour; that is, in dynamic equilibrium with a liquid. As the gas is released, more liquid turns into a gas to restore pressure until the gas becomes unsaturated and the pressure begins to drop as the moles of the gas decrease
- The gas in Q is unsaturated, and thus pressure reduces as the moles of the gas reduces up on release.

(d) Using the expression for the kinetic pressure of an ideal gas, deduce the ideal gas equation of

$$\frac{1}{2}mc^2 = \frac{3}{2}K_B T \text{ (02marks)}$$

Given $\frac{1}{2}mc^2 = \frac{3}{2}K_B T$

From $P = \frac{1}{3}\rho c^2 = \frac{1}{3}\chi \frac{M}{V} c^2$

$$PV = \frac{1}{3}Mc^2 = \left(\frac{1}{2}Mc^2\right) \chi \frac{2}{3} = \frac{3}{2}K_B T \chi \frac{2}{3} = K_B T = \text{Constant}$$

$\therefore PV = \text{constant}$

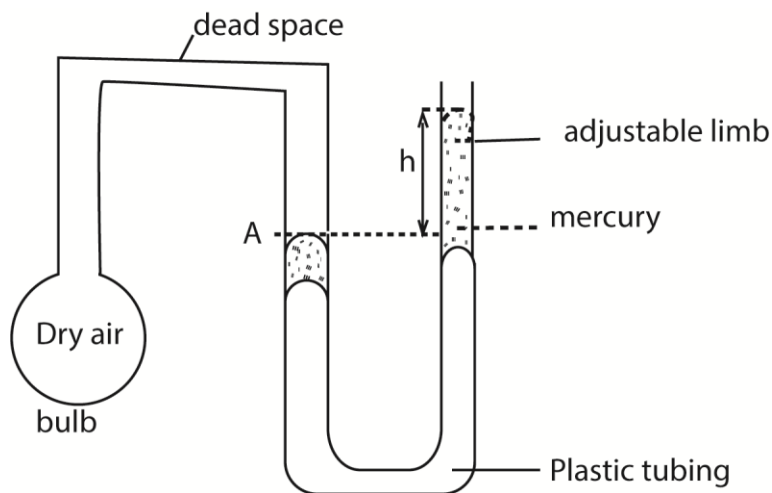
59. (a)(i) State the desirable properties of a material must have to be used as thermometric substance, (02marks)

- Should change considerably for a small change in temperature
- Should vary linearly and continuously with temperature.

(ii) Explain why scales of temperature based on different thermometric properties may not agree. (01marks)

Because different thermometric properties respond differently to temperature

(b) (i) Draw a labelled diagram to show a simple constant volume gas thermometer. (03marks)



(ii) Describe how a simple constant volume gas thermometer can be used to establish a Celsius scale of temperature. (05marks)

- Place the bulb inside whose temperature is to be measured.
- Allow some time for the gas to acquire the temperature of the enclosure. The gas in the bulb may expand and forces mercury up the adjustable tube.
- Adjust the adjustable limb to bring back mercury to constant volume at A and record the height of mercury, h_θ .
- The Celsius scale is given by $\theta = \left(\frac{h_\theta - h_0}{h_{100} - h_0} \right) \times 100^\circ \text{C}$ where h_{100} and h_0 are the heights at steam and ice points

(iii) State the advantages and disadvantages of mercury in glass thermometer and constant-volume gas thermometer. (03marks)

Advantages of mercury in glass

- Give direct reading
- Cheap
- Portable

Disadvantage of mercury in glass

- Have limited temperature range
- Not very accurate

Advantages of constant volume gas thermometer

- Very sensitive to temperature change
- Has wide range
- Very accurate

Disadvantage of constant volume gas thermometer

- It is bulky
- Cannot measure temperature at a point
- Slow to respond to rapidly changing temperature
- Does not give direct readings

(c) The resistance of the element of platinum resistance thermometer is 4.00Ω at ice point and 5.46Ω at steam point. What is the temperature on the platinum resistance scale would correspond to a resistance of 9.84Ω . (03marks)

$$\theta = \frac{R_\theta - R_0}{R_{100} - R_0} \times 100^\circ \text{C} = \frac{9.84 - 4.0}{5.46 - 4.00} \times 100 = 400^\circ \text{C}$$

(d) The mean kinetic energy of one mole of helium gas at room temperature is $3.74 \times 10^3 \text{J}$. Calculate room temperature.

$$\frac{1}{2}mc^2 = \frac{3}{2}K_B T$$

$$\text{Mean kinetic energy} = \frac{3}{2}K_B T$$

$$3.74 \times 10^3 = \frac{3}{2} \times 8.31 \times T$$

$$T = 300.04\text{K}$$

Thank you

Compiled by Dr. Bbosa Science



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Based on, best for sciences

1. (a) (i) What are cathode rays? (01marks)
(ii) State two properties of cathode rays (01mark)
(iii) Explain two disadvantages of using the discharge tube in producing cathode rays.
(02marks)
- (b) With the aid of a diagram, describe Millikan's experiment to determine the charge on an oil drop (07marks)
- (c) A beam of electrons is accelerated through a potential difference of 1.98kV and directed mid-way between two horizontal plates of length 4.8cm and separated by a distance of 2.0cm. the potential difference applied across the plates is 80.0V.
(i) Calculate the speed of the electrons as they enter the region between the plates (03marks)
(ii) Explain the motion of the electrons between the plates (02marks)
(iii) Find the speed of electrons as they emerge from the region between the plates (04marks)
2. (a)(i) what is meant by thermionic emission? (01marks)
(ii) Describe how full-wave rectification of a.c can be achieved using four semiconductor diodes. (04marks)
- (b) (i) Draw a labelled diagram to show the main parts of a cathode ray oscilloscope (C.R.O) (03marks)
(ii) Describe how a C.R.O can be used as an a.c voltmeter. (02marks)
- (c) (i) an electron of charge $-e$ and mass m moves in circular orbit round a central hydrogen nucleus of charge $+e$. Derive an expression for total energy of electron in an orbit of radius r . (05 marks)
(ii) Why is this energy always negative (01marks)
- (d) (i) what is meant by excitation potential of an atom? (01marks)
(ii) Some of the energy levels in mercury spectrum are shown in the figure below.

A ————— 0

B ————— 5.5eV

C ————— 10.4eV

Calculate the wavelength of the radiation emitted when electron makes a transition from level A to level C. (03marks)

3. (a) What is meant by the following as applied to radioactivity?

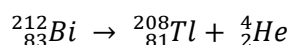
- (i) Activity (01marks)
- (ii) Half-life of a radioactive material (01marks)

(b) Using the radioactive decay law $N = N_0 e^{-\lambda t}$, show that the half-life $T_{\frac{1}{2}} = \frac{1}{\lambda}$ (02marks)

(c) With the aid of a labelled diagram, describe the action of an ionization chamber. (05marks)

(d) What is meant by unified atomic unit and electron volt. (02marks)

(e) (i) The nucleus ${}_{83}^{212}\text{Bi}$ decays by alpha emission as follows



Calculate the energy released by 2g of ${}_{83}^{212}\text{Bi}$. (05marks)

(ii) Explain two uses of radioactive isotopes. (04marks)

4. (a) Define the following

- (i) Binding energy (01marks)
- (ii) Unified Atomic Energy (01marks)

(b) Explain how energy is released in a nuclear fusion process. (03marks)

(c) Explain what is observed in a discharge tube when the pressure is gradually reduced to low values? (05marks)

(d) With the aid of a diagram, describe the operation of Bainbridge mass spectrometer in the determination of charge to mass ratio. (07marks)

(e) An ion of mass 2.6×10^{-26} kg moving at a speed of $4 \times 10^4 \text{ms}^{-1}$ enter a region of uniform magnetic field of flux density 0.05T. Calculate the radius of the circle described by the ion.

5. (a)(i) State three differences between X-rays and cathode rays. (03marks)

(ii) Describe using a labelled diagram, the mode of operation of an X-ray tube (06marks)

(iii) What is the difference between soft and hard X-rays (01mark)

(b) (i) What is the main distinction between work function and ionization energy? (02marks)

(ii) An electron of charge, e , enters at right angles into a uniform magnetic field of flux density B and rotates at frequency, f , in a circle of radius, r .

Show that the frequency, f , is given by; $f = \frac{Be}{2\pi m}$. (03marks)

(c) An X-ray beam is produced when electrons are accelerated through 50kV are stopped by the target of an X-ray tube. When the beam falls on a set of parallel atomic plates of a certain metal at glancing angle of 16° , a first order diffraction maximum occurs. Calculate the atomic spacing of the planes. (05marks)

6. (a) State two differences between alpha and beta particles

- (b) Describe with the aid of a diagram, the structure and mode of operation of an ionization chamber. (06marks)
- (c)(i) Explain the application of carbon-14 in carbon dating. (03marks)
- (ii) A sample of dead wood was found to have activity of 20 units due to carbon-14 isotope whose half-life is 5600 years. If activity of wood just cut is 47.8 units, estimate the age of the sample. (03marks)
- (d) The photoelectric work function of potassium is 2.25 eV. Light having a wavelength of 360 nm falls on a potassium metal.
- (i) Calculate the stopping potential (04marks)
- (ii) Calculate the speed of the most energetic electron emitted by the metal (02marks)
7. (a) What is meant by the following
- (i) Radioactivity (01mark)
- (ii) Isotopes (01marks)
- (b) (i) Define mass defect (01mark)
- (ii) State the conditions for a heavy nucleus to be unstable (01mark)
- (iii) Explain your answer in (b)(ii) (02marks)
- (c) A sample of $^{226}_{88}\text{Ra}$ emits both α -particles and γ -rays. A mass defect of 0.0053 u occurs in the decay.
- (i) Calculate the energy released in joules. (03 marks)
- (ii) If the sample decays by emission of α -particle, each of energy 4.60 MeV and γ -rays, find the frequency of the γ -rays emitted. (04marks)
- (d) (i) Sketch a graph showing the variation of binding energy per nucleon with mass number, clearly showing the fusion and fissions. (02marks)
- (ii) Use the sketch in (d)(i) to explain how energy is released in each of the process of fusion and fission. (03marks)
- (e) State two
- (i) applications of radioisotopes (01marks)
- (ii) health hazards of radioisotopes (01mark)
8. (a) What are X-rays? (01marks)
- (b) (i) With the aid of a diagram explain how X-rays are produced in an X-ray tube (05marks)
- (ii) State the energy changes that take place in the production of X-rays in an X-ray tube. (02marks)
- (c) In an X-ray tube, the electrons strike the target with a velocity of $3.75 \times 10^7 \text{ ms}^{-1}$ after travelling a distance of 5.0 cm from the cathode. If a current of 10 mA flows through the tube, find the
- (i) tube voltage (02marks)
- (ii) number of electrons striking the target per second. (02marks)

- (ii) Number of electrons within the space of 1cm length between the anode and the cathode. (05marks)
- (d) Briefly explain one medical application of x-rays (03marks)
9. (a) state Bohr's postulates of an atom (03marks)
- (b) Explain the occurrence of the emission and absorption line spectra. (06marks)
- (c) Explain the main observations in Rutherford's α -particles scattering experiment. (06marks)
- (d) A beam of alpha particles of energy 3.5MeV is incident normal to the gold foil.
- (i) Calculate the least distance of approach to the nucleus of the gold atom given its atomic number is 79, (04marks)
- (ii) State the significance of the value of the least distance of approach. (01mark)
10. (a) (i) Distinguish between mass defect and binding of an atomic nucleus (01mark)
- (ii) Sketch a graph of nuclear binding energy per nucleon versus mass number for naturally occurring isotopes and use it to distinguish between nuclear fission and fusion. (04marks)
- (b) Describe with the aid of a labelled diagram, Millikan's oil drop experiment to determine the charge on an oil drop. (07marks)
- (c) (i) Explain briefly diffraction of X-rays by crystals and derive Bragg's law. (06marks)
- (ii) A second order diffraction image is obtained by reflection of X-ray at atomic planes of a crystal for a glancing angle of $11^{\circ}24'$. Calculate the atomic spacing of the planes if the wavelength of X-rays is $4.0 \times 10^{-11}\text{m}$ (02marks)
11. (a) State Bohr's model of an atom. (02marks)
- (b) An electron of mass m and charge $-e$, is considered to move in circular orbit about a proton.
- (i) Write down the expression for the electric force on the electron. (02marks)
- (ii) Derive an expression for total energy given that the angular momentum for the electron is equal to $\frac{nh}{2\pi}$ where n is an integer and h is Plank's constant. (06marks)
- (c) With the aid of a labelled diagram, describe the operation of a diffusion type cloud chamber. (06marks)
- (d) The energy levels of an atom have values
- $E_1 = -21.4\text{eV}$
- $E_2 = -4.87\text{ eV}$
- $E_3 = -2.77\text{ eV}$
- $E_4 = -0.81\text{eV}$

$$E_{\infty} = 0.00\text{eV}$$

- (i) Calculate the wavelength of radiation emitted when an electron makes a transition from E_3 to E_2 (03marks)
 - (ii) State the region of the electromagnetic spectrum where the radiation lies (01mark)
12. (a) Describe how positive rays are produced. (03marks)
- (b) Describe how a Bainbridge spectrometer can be used to detect isotopes. (05marks)
- (c) (i) What is time base as applied to a Cathode Ray Oscilloscope? (01mark)
- (ii) Draw a sketch graph showing the variation of time base voltage with time (01mark)
- (d) An alternating p.d applied to the Y-plate of an oscilloscope produces five complete waves on a 10cm length of the screen when the time base setting is 10mscm^{-1} . Find the frequency of the alternating voltage. (03marks)
- (e) (i) Explain the motion of an electron projected perpendicularly into a uniform magnetic field. (03marks)
- (ii) An electron accelerated from rest by a p.d of 100V, enters perpendicularly into a uniform electric field intensity 105Vm^{-1} . Find the magnetic field density, B, which must be applied perpendicularly to the electric field so that the electron passes undeflected through the fields. (04marks)
13. (a) (i) Define Avogadro's constant and Faraday's constant. (02marks)
- (ii) Show that the charge carried by a monovalent ion is $1.6 \times 10^{-19}\text{C}$. (02marks)
- (b) With the use of a labelled diagram, describe Millikan's oil drop experiment for the determination of the charge of an electron. (07marks)
- (c) A beam of positive ions moving with velocity v enters a region of a uniform magnetic field density B with the velocity at right angles to the field B. By use of a diagram, describe the motion of ions. (03marks)
- (d) A charged oil drop of density 880kgm^{-3} is held stationary between two parallel plates 6.0mm apart held at a potential difference of 103V. When the electric field is switched off, the drop is observed to fall a distance of 2.0mm in 35.7s. (Viscosity of air = $1.8 \times 10^{-5}\text{Nsm}^{-2}$, Density of air = 1.29kgm^{-3}).
- (i) Calculate the radius of the drop. (03marks)
- (ii) Estimate the number of excess electrons on the drop. (03marks)
14. (a) (i) State the laws of photoelectric emission (04marks)
- (ii) Explain briefly one application of photoelectric effect. (04marks)
- (b) In a photoelectric set up. A point source of light of power $3.2 \times 10^{-3}\text{W}$ emits mono-energetic photons of energy 5.0eV. The source is located at a distance of 0.8m from the center of a stationary metallic sphere of work function 3.0eV and radius $8.0 \times 10^{-3}\text{m}$. The efficiency of photoelectron emission is one in every 10^6 incident photons.

Calculate

- (i) Number of photoelectrons emitted per second. (04marks)
- (ii) Maximum kinetic energy in joules, the photo electrons. (02marks)

(c) (i) State Bragg's law of X-ray diffraction (01marks)

(ii) Show that density, ρ , of a crystal can be given by

$$\rho = \frac{M \sin^3 \theta}{125 N_A (n\lambda)^3}$$

where θ is the glancing angle, n , is the order of diffraction, λ is the X-ray wavelength and M is the molecular weight of the crystal. (05marks)

15. (a) With reference to a Geiger-Muller tube, define the following

- (i) quenching agent (01mark)
- (ii) back ground count rate (01mark)

(b) (i) With the aid of a labelled diagram, describe the operation of a Geiger-Muller (GM) tube (06marks)

(ii) Explain how the half-life of a short lived radioactive source can be obtained by use of a Geiger-Muller tube. (04marks)

(c) A radioactive isotope $^{32}_{15}\text{P}$ which has a half-life of 14.3days, disintegrates to form a stable product. A sample of the isotope is prepared with initial activity of $2.0 \times 10^6 \text{s}^{-1}$. Calculate the

- (i) the number of ^{32}P atoms present (03marks)
 - (ii) activity after 30days (03marks)
 - (iii) number of ^{32}P atoms after 30 days (02marks)
- (Assume $N = N_0 e^{-\lambda t}$)

16. (a) State Rutherford's model of the atom. (02marks)

(b) Explain how Bohr's model of the atom addresses the two main failures of Rutherford's model. (07marks)

(c) With the aid of a labelled diagram, describe how cathode rays are produced. (05marks)

(d) (i) What is binding energy of a nucleus? (01mark)

(ii) Calculate the energy in MeV released by fusing four protons to form an alpha particle and two beta particles.

Mass of beta particle = 0.000549u

Mass of hydrogen atom = 1.007825u

Mass of helium atom = 4.002664u

[1u = 931MeV] (05marks)

17. (a) What is photo electric emission? (01mark)

(b)(i) Describe an experiment to demonstrate photo electric effect. (04marks)

(ii) When a clean surface of a metal in a vacuum is irradiated with light of wave length $5.5 \times 10^{-7}\text{m}$, electrons just emerge from the surface. However when light of wavelength $5 \times 10^{-7}\text{m}$ is incident on the metal surface, electrons are emitted each with energy $3.62 \times 10^{-20}\text{J}$. Find Plank's constant. (04marks)

(c) (i) With the aid of a labelled diagram, describe an X-ray tube and how X-rays are produced. (05marks)

(ii) Describe how the intensity and quality of X-rays is controlled in an X-ray tube. (02marks)

(d) An X-ray tube operates at $1.5 \times 10^{-3}\text{V}$ and the current through it is $1.0 \times 10^{-3}\text{A}$.

Find the

- (i) number of electrons crossing the tube per second. (02marks)
- (ii) kinetic energy gained by electron traversing the tube (02marks)

18. (a)(i) What is specific charge? (01mark)

(ii) State the **unit** of specific charge (01mark)

(iii) Describe with the aid of a diagram how the specific charge of positive ions can be determined using a mass spectrometer. (06marks)

(b) A beam of strongly ionized carbon atoms passes undeflected through a region of crossed magnetic and electric field of 0.10T and $1.0 \times 10^4\text{NC}^{-1}$ respectively. When it enters a region of uniform magnetic field, it is deflected through an arc of radius 0.75m . Calculate the magnetic flux density of this magnetic field. (Mass of carbon atom = $2.0 \times 10^{-26}\text{kg}$) (05marks)

(c) (i) Draw a graph to illustrate the variation of ionization current and p.d across an ionization chamber and explain its features. (03marks)

(ii) Explain how ionization chamber can be used to detect ionization radiation (04marks)

19. (a) Explain briefly how positive rays are produced (03marks)

(b) An electron of charge, e , and mass, m , is emitted from a hot cathode and then accelerated by an electric field towards the anode. If the potential difference between the cathode and the anode is V , show that the speed of the electron, u , is given by

$$u = \sqrt{\left(\frac{2eV}{m}\right)} \quad (03\text{marks})$$

(c) An electron starts from rest and moves in an electric field intensity of $2.4 \times 10^3\text{Vm}^{-1}$.

Find the

- (i) force on the electron (02 marks)
- (ii) acceleration of the electron. (02marks)
- (iii) velocity acquired in moving through a p.d of 90V (02marks)

(d) A beam of electrons each of mass, m , and charge, e , is directed horizontally with speed, u , into an electric field between two horizontal metal plates separated by a distance, d .

(i) If the p.d between the plates is V , show that the deflection y of the beam is given by

$$y = \frac{1}{2m} \left(\frac{eV}{du^2} \right) x^2$$

where, x , is the horizontal distance travelled. (06marks)

(ii) Explain the path of the electron beam as it emerges out of the electric field. (02marks)

20. (a) The table below shows the energy levels of a hydrogen atom.

Principal quantum number, n	Energy, eV
6	-0.38
5	-0.54
4	-0.85
3	-1.51
2	-3.39
1	-13.60

- (i) Why are the energies for the different levels negative? (01mark)
- (ii) Calculate the wavelength of the line arising from a transition from the third to the second level. (03marks)
- (iii) Calculate the ionization energy in joules of hydrogen atom. (02marks)

(b) Explain the physical processes in an X-ray tube that account for

- (i) cut off wavelength (03marks)
- (ii) characteristic lines (04marks)

(c) Calculate the maximum frequency of radiation emitted by an X-ray tube using an accelerating voltage of 33.0kV (03marks)

(d) Derive Bragg's law of X-ray diffraction in crystals. (04marks)

21. (a) A beam of α -particles is directed normally to a thin metal foil

Explain why

- (i) Most of the α -particles passed straight through the foil (02marks)

- (ii) Few α -particles are deflected through angles more than 90° . (02marks)
- (b) Calculate the least distance of approach of a 3.5MeV α -particles to the nucleus of a gold atom. (Atomic number of gold= 79) (04marks)
- (c) (i) Define space charge as applied to thermionic diodes. (01mark)
- (ii) Draw anode current-diode voltage curves of a thermionic diode for two different filament currents and explain their main features. (06marks)
- (d) (i) What is a decay constant?
- (ii) A sample from fresh wood of a certain species of tree has activity of 16.0 counts per minute per gram. However, the activity of 5g of dead wood of the same species of tree is 10 counts per minute. Calculate the age of the deadwood. (Assume half-life of 5730years) (04marks)
22. (a) (i) What are cathode rays?
- (ii) With the aid of a diagram, describe an experiment to show that cathode rays travel in straight line (04marks)
- (b) A beam of electrons is accelerated through a potential difference of 500V. The beam enters midway between two similar parallel plates of length 10cm and are 3cm apart. If the potential difference across the plates is 600V, find the velocity of an electron as it leaves the region between the plates. (08marks)
- (c) State the laws of photoelectric emission (04marks)
- (d) Explain how line emission spectra are produced. (03marks)
23. (a) (i) what is meant by terms: radioactive decay, half-life and decay constant? (03marks)
- (ii) show that the half-life, $t_{1/2}$ of a radioactive isotope is given by $t_{1/2} = \frac{0.693}{\lambda}$ where λ is the decay constant
- (Assume the decay law $N = N_0 e^{-\lambda t}$)
- (b) With the aid of a labelled diagram, describe the structure and action of a cloud chamber (05marks)
- (c) A radioactive isotope ${}^{99}_{43}\text{X}$ decays by emission of a gamma ray. The half-life of the isotope is 360minutes. What is the activity of 1mg of the isotope? (06marks)
- (d) Explain the term avalanche as applied to an ionization chamber. (03marks)
24. (a) Define the terms below as applied to a triode
- (i) space charge (01mark)
- (ii) Amplification factor (01mark)
- (iii) Mutual conductance (01mark)

- (b) With the aid of a labelled diagram explain full wave rectification. (07marks)
- (c) Derive an expression for the amplification factor, μ , in terms of anode resistance, R_a and mutual conductance, g_m , for a triode valve. (03marks)
- (d) A triode with mutual conductance 3mA V^{-1} and anode resistance of $10\text{k}\Omega$ is connected to a load resistance of $20\text{k}\Omega$. Calculate the amplitude of output signal, if the input signal is 25mV . (04marks)
- (e) (i) Sketch the output characteristics of a transistor. (02marks)
- (ii) Identify on the sketch in (e)(i), the region over which the transistor can be used as amplifier. (01).

25. (a) (i) Describe with the aid of a well labelled diagram, the structure and mode of operation of a C.R.O (06marks)

(ii) State the advantages of C.R.O over a moving coil voltmeter. (02marks)

(b) In the determination of the electron charge by Millikan's method, a potential difference of 1.5kV is applied between horizontal metal plates, 12mm apart. With the field switched off, a drop of oil of mass $1.0 \times 10^{-14}\text{ kg}$ is observed to fall with constant velocity, $4 \times 10^{-4}\text{ms}^{-1}$ between two metal plates. When a potential difference of 1.5kV is applied across the plates, the drop rises with constant velocity of $8.0 \times 10^{-5}\text{ms}^{-1}$.

How many electron charges are there on the drop? (Assume air resistance is proportional to the velocity of the drop and neglect air buoyancy.)

(c) Explain why

(i) the apparatus in Millikan's experiment is surrounded with a constant temperature enclosure, (03marks)

(ii) low vapor-pressure oil is used. (02marks)

(d) In Millikan's experiment, the radius, r , of the drop is calculated from

$$r = \sqrt{\frac{9\eta v}{2\rho g}}$$

where η is the viscosity of air and ρ is the density of oil.

Identify the symbol v and describe briefly how it is measured. (02mark)

26. (a) (i) Explain how X-rays are produced in an X-ray tube (04 marks)

(ii) Explain the emission of X-ray characteristic spectra. (03 marks)

(iii) Derive the Bragg X-ray diffraction equation (04marks)

(iv) Under what conditions does X-ray diffraction occurs? (02marks)

(b) With the aid of a labelled diagram, describe how a Bainbridge mass spectrometer is used to measure specific charge. (07marks)

27. (a) What is meant by unified atomic mass unit? (01mark)

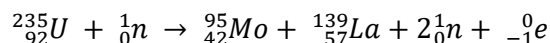
(b) (i) Distinguish between nuclear fusion and nuclear fission (02marks)

(ii) State the conditions necessary for each of the nuclear reaction in (b) (i) to occur. (02marks)

(c) (i) With the aid of a labelled diagram, describe the operation of an ionization chamber. (06marks)

(ii) Sketch the curve of ionization current against applied p.d and explain its main features. (04marks)

(d) A typical nuclear reaction is given by:



Calculate the total energy released by 1g of uranium. (05marks)

$$\text{Mass of } {}^1_0\text{n} = 1.009\mu$$

$${}^0_{-1}\text{e} = 0.00055\mu$$

$${}^{95}_{42}\text{Mo} = 94.906\mu$$

$${}^{139}_{57}\text{La} = 138.906\mu$$

$${}^{235}_{92}\text{U} = 235.044\mu$$

$$1\mu = 1.66 \times 10^{-27}\text{kg}$$

28. (a) (i) With the aid of a labelled diagram, describe what is observed when a high tension voltage is applied across a gas tube in which pressure is gradually reduced to very low value. (05marks)

(ii) Give two applications of discharge tubes. (01mark)

(b) Describe Thomson's experiment to determine the specific charge of an electron. (06marks)

(c) In a Millikan's experiment, a charged oil drop of radius $9.2 \times 10^{-7}\text{m}$ and density 800kgm^{-3} is held stationary in an electric field of intensity $4.0 \times 10^4\text{Vm}^{-1}$.

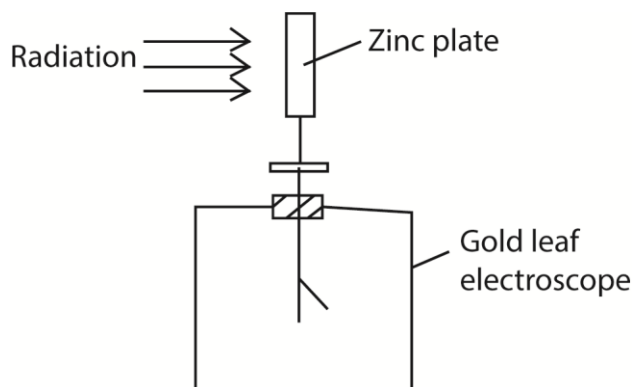
(i) How many electron charges are on the drop? (04marks)

(ii) Find the electric field intensity that can be applied vertically to move the drop with velocity 0.005ms^{-1} upwards.

[Density of air = 1.29kgm^{-3} , coefficient of viscosity of air = $1.8 \times 10^{-5}\text{Nsm}^{-1}$]

29. (a) Explain what is meant by photoelectric effect. (02marks)

(b)



Ultraviolet and infrared radiations are directed in turns on to a zinc plate which is attached to a gold leaf electroscope as shown in the figure above

Explain that happens when

- (i) Ultraviolet radiation falls on the zinc plate (02marks)
 - (ii) Infrared falls on the zinc plate. (01mark)
 - (iii) The intensity of each radiation is increased. (02marks)
- (c) An X-ray of wavelength 10^{-10}m is required for the study of its diffraction in a crystal. Find the least accelerating voltage to be applied on an X-ray tube in order to produce these X-rays. (04marks)
- (d) Sodium has a work function of 2.0eV and is illuminated by radiation of wavelength 150nm. Calculate the maximum speed of the emitted electrons. (04marks)
- (e) With the aid of a well labelled diagram, describe how stopping potential of a metal can be measured. (05marks)

30. (a) (i) What is meant by mass defect? (01marks)

(ii) Sketch a graph showing how binding energy per nucleon varies with mass number and explain its features. (03marks)

(iii) Find the binding energy per nucleon of ${}^{56}_{26}\text{Fe}$ given that

Mass of 1 proton = 1.007825u

Mass of 1neutron = 1.008665u

[1u = 931MeV) (03marks)

(b) With the aid of a diagram, explain how an ionization chamber works (06marks)

(c) (i) Show that an alpha particle collides head on with an atom of atomic number, Z, the closest distance of approach to the nucleus X_0 is given by

$$X_0 = \frac{ze^2}{\pi\epsilon_0 mv^2}$$

Where

e is electronic charge

ϵ_0 is permittivity of free space

m is mass of alpha particle

v is initial speed of alpha particle (04marks)

- (ii) In a head on collision between an alpha particle and a gold nucleus, the minimum distance of approach is $5 \times 10^{-14}\text{m}$. Calculate the energy of alpha particle (in MeV)

[atomic number of gold= 79]

31. (a) State four differences between cathode rays and positive rays (02marks)

- (b) An electron having energy of $4.5 \times 10^3\text{eV}$ moves at right angles to a uniform magnetic field of flux density $1.5 \times 10^{-3}\text{T}$. Find the

(i) radius of the path followed by the electron. (04marks)

(ii) period of the motion. (03marks)

- (c) (i) Define the term Avogadro constant and Faraday constant (02marks)

(ii) Use the Avogadro constant and Faraday constants to calculate the charge on anion of monatomic element. (03marks)

- (d) Explain the meaning of the following terms as applied to a Geiger-Muller tube.

(i) threshold potential difference (02marks)

(ii) Dead time (02marks)

(iii) A quenching agent (02marks)

32. (a) State the laws of photoelectric effect (04marks)

- (b) Describe an experiment to determine the stopping potential of a metal surface. (05 marks)

- (c) A 100mW beam of light of wavelength $4.0 \times 10^{-7}\text{m}$ falls on caesium surface of a photocell.

(i) How many photons strike the caesium surface per second? (03marks)

(ii) If 65% of the photons emit photoelectrons, find the resulting photocurrent. (03marks)

(iii) Calculate the kinetic energy of each photon if the work function of caesium is 2.20eV . (03marks)

- (d) Distinguish between continuous and line spectra in an X-ray tube. (02marks)

33. (a) (i) Explain the observation made in the Rutherford α -particle scattering experiment. (06marks)

(b) Distinguish between excitation and ionization energies of an atom. (02marks)

- (c) Draw a labelled diagram showing the main components of an X-ray tube (03marks)
- (d) An X-ray tube is operated at 50kV and 20mA. If 1% of the total energy supplied is emitted as X-radiation, calculate the
- maximum frequency of emitted radiation (03marks)
 - rate at which heat must be removed from the target in order to keep it at a steady temperature. (03marks)
- (e) A beam of X-ray of wavelength 0.2nm is incident on a crystal at glancing angle 30° . If the interplanar separation is 0.20nm, find the order of diffraction. (02marks)
34. (a) What is meant by a line spectrum? (02marks)
- (b) Explain how line spectrum accounts for existence of discrete energy levels in an atom. (04marks)
- (c) The energy levels in mercury atom are -10.4eV, -5.5eV, -3.7eV and -1.6eV.
- Find the ionization energy of mercury in joules (02marks)
 - What is likely to happen if mercury atom in unexcited state is bombarded with an electron of energy 4.0eV, 6.7eV or 11.0eV? (03marks)
- (d) Describe with the aid of a diagram, the action of an X-ray tube. (05marks)
- (e) An X-ray tube is operated at 20kV with electron current 16mA in the tube. Estimate the:
- the number of electrons hitting the target per second. (02marks)
 - rate of production of heat, assuming 99.5% of the kinetic energy of electron is converted to heat. ($e = 1.6 \times 10^{-19}\text{C}$)
35. (a) (i) Define the term binding energy (01marks)
- (ii) Sketch a graph showing the variation of binding energy per nucleon with mass number (02marks)
- (iii) Use the sketch graph you have drawn in (a)(ii) to explain how energy is released during fission and fusion. (03marks)
- (b) Explain why a high temperature is required during fusion of nuclides. (01mark)
- (c) The isotope $^{238}_{92}\text{U}$ emits an alpha particle and forms an isotope of thorium (Th), while the isotope $^{235}_{92}\text{U}$ when bombarded by a neutron, forms $^{144}_{56}\text{Ba}$, $^{90}_{36}\text{Kr}$ and neutrons.
- Write the nuclear equation for the reaction of $^{238}_{92}\text{U}$ and $^{235}_{92}\text{U}$. (02marks)
 - How does the reaction of $^{235}_{92}\text{U}$ differ from that of $^{238}_{92}\text{U}$ (03marks)
- (d) A steel piston ring contains 15g of radioactive iron, $^{54}_{26}\text{Fe}$. The activity of $^{54}_{26}\text{Fe}$ is 3.7×10^5 disintegration per second.

After 100 days of continuous use, the crankcase oil was found to have a total activity of 1.23×10^3 disintegrations per second. Find the

- (i) Half-life of ${}^{54}_{26}\text{Fe}$ (05marks)
- (ii) Average mass of iron worn off the ring per day, assuming that all the metal from the ring accumulates in the oil. (03marks)

36. (a) Describe the mechanism of thermionic emission (03marks)

(b) Explain the following terms as applied to a vacuum diode

- (i) space charge limitation (03marks)
- (ii) Saturation (01 mark)
- (iii) Rectification (02marks)

(c) Sketch the current potential difference characteristics of a thermionic diode for two different operating temperatures and explain their main features (05marks)

(d) (i) A triode valve with an anode resistance of $3.0 \times 10^3 \Omega$ is used as an amplifier. A sinusoidal alternating signal of amplitude 0.5V is applied to the grid of the valve. Find the r.m.s value of the output voltage if the amplification factor is 15 and anode load is $50\text{k}\Omega$.

(ii) Draw an equivalent circuit of a triode as a single-stage amplifier. (01marks)

37. (a) Describe briefly the mechanism of thermionic emission (03marks)

(b) (i) Draw a labelled circuit to show a triode being used as a single-stage voltage amplifier. (03marks)

(ii) With the aid of an equivalent circuit of a triode as an amplifier, obtain an expression for voltage gain (04marks)

(iii) A triode with mutual conductance of $3.0 \times 10^{-3} \text{ A V}^{-1}$ and anode resistance of $1 \times 10^4 \Omega$, is used as a single-stage amplifier. If the load resistance is $3 \times 10^4 \Omega$, calculate the voltage gain of the amplifier. (05marks)

(c) (i) Describe the structure of a junction transistor. (02marks)

(ii) sketch and describe the collector-current against collector-emitter voltage characteristic of a junction transistor. (03marks)

38. (a) What are isotopes? (01mark)

(b) With the aid of a diagram, describe the operation of Bainbridge spectrometer in determining the specific charge of ions. (06marks)

(c) Explain the purpose of each of the following in a Geiger-Muller tube

- (i) a thin mica window
- (ii) Argon gas at low pressure
- (iii) Halogen gas mixed with argon gas
- (iv) An anode in the form of a wire (04marks)

- (d) (i) What is meant by binding energy per nucleon of a nucleus? (01mark)
- (ii) Sketch a graph of binding energy per nucleon against mass number for naturally occurring nuclides (01marks)
- (iii) State one similarity between nuclear fusion and nuclear fission. (01mark)
- (e) (i) At a certain time, an α -particle detector registers a count rate of 32s^{-1} . Exactly 10days later, the count rate dropped to 8s^{-1} . Find the decay constant. (04marks)
- (ii) State two industrial uses and two health hazards of radioactivity. (04marks)
39. (a) (i) Describe, with aid of a diagram, the production of cathode rays
- (ii) state and justify two properties of cathode rays (02marks)y
- (b) Explain each of the following terms as applied to photoelectric emission:
- (i) stopping potential (01marks)
- (ii) threshold frequency (01mark)
- (c) Explain X- ray diffraction by crystals and derive Bragg's law (06marks)
- (d) The potential difference between the cathode and anode of an X-ray tube is $5.0 \times 10^{-4}\text{V}$. If only 0.4% of the kinetic energy of the electrons is converted into X-rays and the rest is dissipated as heat in the target at a rate of 600W, find the
- (i) current that flows (03marks)
- (ii) speed of the electrons striking the target. (03marks)
40. (a) (i) What is a photon? (01mark)
- (ii) Explain, using quantum theory, the experimental observation on the photoelectric effect. (06marks)
- (iii) when light of wavelength 150nm falls on a certain metal, electrons of maximum kinetic energy 0.76eV are emitted. Find the threshold frequency for the metal. (04marks)
- (b) Explain, using suitable sketch graph, how X-ray spectrum in an X-ray tube are formed. (06marks)
- (c) A beam of X-rays of wavelength $8.42 \times 10^{-11}\text{m}$ is incident on a sodium chloride crystal of interplanar separation $2.82 \times 10^{-10}\text{m}$. Calculate the first order of diffraction angle. (03marks)
41. (a) (i) A beam of electrons, having a common velocity, enters a uniform magnetic field in a direction normal to the field. Describe and explain the subsequent path of the electrons (04marks)
- (ii) Explain whether a similar path would be followed if a uniform electric field were substituted for magnetic field (01mark)
- (b) Describe an experiment to measure the ratio of the charge to mass of an electron (07marks)

- (c) Electrodes are mounted at opposite ends of low pressure discharge tube and a potential difference of 1.20kV applied between them. Assuming the electrons are accelerated from rest, calculate the maximum velocity which they could acquire. [Specific electron charge = $-1.76 \times 10^{11} \text{ C kg}^{-1}$] (02marks)
- (d) (i) Give an account of the stages observed when an electric discharge passes through a gas at pressure varying from atmospheric to about 0.01mmHg as air is pumped out when the p.d across the tube is maintained at extra high tension. (05marks)
- (ii) State two disadvantages of discharge tubes when used to study cathode rays. (01mark)
42. (a) (i) What is meant by half-life of a radioactive material? (01mark)
- (ii) Given the radioactive law, $N_t = N_0 e^{-\lambda t}$, obtain the relationship between λ and half-life $T_{\frac{1}{2}}$ (02marks)
- (iii) What are radioisotopes? (01mark)
- (iv) The radioisotope $^{90}_{38}\text{Sr}$ decays by emission of β -particles. The half-life of the radioisotope is 28.8years. Determine the activity of 1g of the isotope (05marks)
- (b) (i) With aid of a diagram describe the structure and action of Geiger-Muller tube. (06marks)
- (ii) Sketch the current –voltage characteristic of the Geiger- Muller tube and explain its main features. (03marks)
- (iii) Identify, giving reasons, the suitable range in (b) (ii) of operation of the tube (02marks)
43. (a)(i) Draw a labelled diagram of an X-ray tube. (02marks)
- (ii) Use the diagram in (a)(i) to describe how X-rays are produced. (03marks)
- (iii) State one industrial and one biological use of X-rays. (01marks)
- (b)(i) Sketch a graph of intensity versus wavelength of X-rays from an X-ray tube and describe its main features. (04marks)
- (ii) Calculate the maximum frequency of X-rays emitted by an X-ray tube operating on voltage of 34.0kV. (03marks)
- (c) In the measurement of electron charge by Millikan's apparatus, a potential difference of 1.6kV is applied between two horizontal plates 14mm apart. With the potential difference switched off, an oil drop is observed to fall with constant velocity $4.0 \times 10^{-4} \text{ ms}^{-1}$. When the potential difference is switched on, the drop rises with constant velocity $8.0 \times 10^{-5} \text{ ms}^{-1}$. If the mass of the oil drop is $1.0 \times 10^{-14} \text{ kg}$, find the number of electron charges on the drop. [assume air resistance is proportional to velocity of the oil drop and neglect the up thrust due to air] (07marks)
44. (a) (i) State the laws of photo-electric emission. (04marks)
- (ii) Write down Einstein's equation for photo electric emission. (02marks)
- (iii) Ultra –violet light of wavelength $3.3 \times 10^{-8} \text{ m}$ is incident on a metal. Given the work function of the metal is 3.5eV, calculate the maximum velocity of the liberated electron. (03marks)
- (b) Describe, with aid of a diagram, the structure and mode of operation of a cathode ray oscilloscope (C.R.O) (06marks)

A C.R.O has its y-sensitivity set to 10Vm^{-1} . A sinusoidal input voltage is suitably applied to give a steady trace with time base switched on so that the electron beam takes 0.01s to traverse the screen. If the trace seen has a peak-to-peak height of 4.0cm and contains two complete cycles, find the

(i) r.m.s value of the input voltage. (03marks)

(ii) frequency of the input signal. (02marks)

45. (a) define binding energy of nuclide (01mark)

(b) (i) Sketch a graph showing how binding energy per nucleon varies with mas number (01mark)

(ii) Describe the main features of the graph in (b)(i). (03marks)

(c) Distinguish between nuclear fission and nuclear fusion and account for the energy released. (03mark)

(d) (i) with the aid of a labelled diagram describe the working of the Geiger-Muller tube. (05marks)

(ii) How would you use a Geiger-Muller tube to determine the half-life of a radioactive sample? (04marks)

(e) A radioactive source produces alpha particles each of energy 60eV. If 20% of the alpha particles enter an ionization chamber a current of $0.2\mu\text{A}$ flows. Find the activity of the alpha source, if the energy needed to make an ion pair in the chamber is 32MeV. (03marks)

46. (a) (i) Describe with the aid of a labelled diagram the main features of a cathode ray oscilloscope (C.R.O) (08marks)

(ii) State two uses of C.R.O (01mark)

(iii) The gain control of a C.R.O is set on 0.5Vcm^{-1} and an alternating voltage produces a vertical trace of 2.0cm long with the time base off. Find the root mean value of the applied voltage. (02marks)

(b) a beam of electrons is accelerated through a potential difference of 2000V and is directed mid-way between two horizontal plates of length 5.0cm and separation of 2.0cm. The potential difference across the plates is 80V.

(i) Calculate the speed of the electron as they enter the region between the plates. (03marks)

(ii) Explain the motion of the electrons between the plates. (02marks)

(iii) find the speed of electrons as they emerge from the region between the plates. (04marks)

47. (a) Explain the term stopping potential as applied to photo electric effect. (02marks)

(b) Explain how intensity and penetrating power of X-rays from X-ray tube would be affected by changing:

(i) the filament current (02marks)

(ii) the high tension potential difference across the tube (02marks)

(c) When a p.d of 60kV is applied across an X-ray tube, a current of 30mA flows. If 99% of the power supplied is converted into heat at the anode, calculate the rate at which the temperature of the water rises. [Specific heat capacity of water = $4.2 \times 10^3\text{Jkg}^{-1}\text{K}^{-1}$] (05marks)

(d) (i) Derive Bragg's law of X-ray diffraction. (05marks)

(ii) Calculate the atomic spacing of sodium chloride if the relative atomic mass of sodium is 23.0 and that of chlorine is 35.5.

[Density of sodium chloride = $2.18 \times 10^3\text{kgm}^{-3}$] (04marks)

48. (a) (i) Explain briefly the mechanism of thermionic emission. (02marks)
 (ii) Draw a labelled diagram of the circuit used to determine the anode current and anode voltage characteristics of a thermionic diode. (02marks)
 (iii) Sketch the characteristic expected in (a) (ii) at constant filament current, and account for its special features. (04marks)
- (b) Describe, with the aid of a labelled diagram, the structure and action of a diffraction cloud chamber (06marks)
- (c) (i) Define radioactivity and half-life of a radioactive substance (02marks)
 (ii) A radioactive isotope of strontium of mass $5.0\mu\text{g}$ has a half-life of 28years. Find the mass of the isotope left after 14 years.
 [Assume the decay law $N = N_0 e^{-\lambda t}$]
49. (a) (i) State Rutherford's model of the atom. (02marks)
 (ii) Explain two main features of Rutherford's model of the atom. (03marks)
- (b) (i) Explain how Millikan's experiment for measuring the charge of an electron proves that charge is quantized. (04marks)
 (ii) Oil droplets are introduced into the space between two flat horizontal plates, set 5.0mm apart. The plate voltage is then adjusted to exactly 780V so that one of the droplets is held stationary. Then the plate voltage is switched off and the selected droplet is observed to fall a measured distance of 1.5mm in 11.2s. Given the density of oil used is 900kgm^{-3} and the viscosity of air is $1.8 \times 10^{-5}\text{Nsm}^{-2}$, calculate the charge on the droplet. (06marks)
- (c) A beam of positive ions is accelerated through a potential difference of $1 \times 10^3\text{V}$ into a region of uniform magnetic field of flux density 0.2T. While in magnetic field it moves in a circle of radius 2.3cm. Derive an expression for the charge to mass ratio of the ions, and calculate the value. (05marks)
50. (a) (i) What is meant by thermionic emission? (01mark)
 (ii) Sketch the current-potential difference characteristics of a thermionic diode for two different operating temperature and explain their main features. (05marks)
 (iii) Describe one application of a diode. (02marks)
- (b) (i) What features of an x-ray tube make it suitable for continuous production of X-rays. (03marks)
 (ii) Sketch a graph of intensity versus frequency of a radiation produced in an X-ray tube and explain its main feature. (05marks)
 (iii) A mono chromatic X-ray beam of wavelength $1.0 \times 10^{-10}\text{m}$ is incident on a set of planes in a crystal of spacing $2.8 \times 10^{-10}\text{m}$. What is the maximum order possible with these X-rays? (04marks)
51. (a) What is meant by the following terms:
 (i) nuclear number (01mark)
 (ii) binding energy (01marks)

(b) Calculate the energy released during the decay of ${}^{220}_{86}\text{Rn}$ nucleus into ${}^{216}_{84}\text{Po}$ and α -particle

$$\left\{ \begin{array}{l} \text{Mass of } {}^{220}_{86}\text{Rn} = 219.964176\text{u} \\ \text{Mass of } {}^{216}_{84}\text{Po} = 215.955794\text{u} \\ \text{Mass of } {}^4_2\text{He} = 4.001566\text{u} \\ (1\text{u} = 931\text{eV}) \end{array} \right\} \quad (04\text{marks})$$

(c) Describe the Bainbridge mass spectrometer and explain how it can be used to distinguish between isotopes (07marks)

(d) (i) Explain how you would use a decay curve for a radioactive material to determine its half-life. (02marks)

(ii) A radioactive source contain $1.0\mu\text{g}$ of plutonium of mass number 239. If the source emits 2300 α -particles per second, calculate the half-life of plutonium.

[Assume the decay law $N = N_0 e^{-\lambda t}$] (05mark)

52. (a) What is meant by

(i) Bohr atom (01mark)

(ii) binding energy of a nucleus (02marks)

(b) The total energy, E , of an electron in an atom may be expressed as

$$E = \frac{-mq^4}{8\epsilon_0^2 n^2 h^2}$$

(i) Identify the quantities, m , q , n and h in this expression (02marks)

(ii) Explain the physical implication of the fact that E is always negative (02marks)

(iii) Draw an energy level diagram for hydrogen to indicate emission of ultraviolet, visible and infrared spectral lines. (03marks)

(c)(i) Explain briefly the sources and absorption of infrared radiation. (04 marks)

(ii) Describe briefly, the method of detecting infrared radiation (03marks)

(d) The atomic nucleus may be considered to be a sphere of positive charge with a diameter very much less than that of an atom. Discuss the experimental evidence which supports this view. (03marks)

53. (a) (i) What are cathode rays? (01mark)

(ii) An electron gun operating at $3 \times 10^3\text{V}$ is used to project electrons into the space between two oppositely charged parallel plates of length 10cm and separation 5cm .

Calculate the deflection of the electrons as they emerge from the region between the charged plates when the potential difference is $1 \times 10^3 \text{V}$. (03marks)

- (b) (i) Describe a simple experiment to demonstrate photoelectric emission. (04marks)
- (ii) Explain why the wave theory of light fails to account for the photoelectric effect. (06marks)
- (iii) Describe an experiment to verify Einstein's equation for the photoelectric effect and explain how Planck's constant may be obtained from the experiment. (06marks)

54. (a) What is meant by

- (i) half-life of radioactive element (01mark)
- (ii) nuclear fission (01mark)
- (iii) Nuclear fusion

(b) An atom of ^{222}Ra emits an α -particle of energy 5.3eV. Given that the half-life of ^{222}Ra is 3.8days. Use the decay law, $N = N_0 e^{-\lambda t}$ to calculate the:

- (i) decay constant (03marks)
- (ii) amount of energy released by $3.0 \times 10^{-9} \text{kg}$ of ^{222}Ra after 3.8days (05marks)

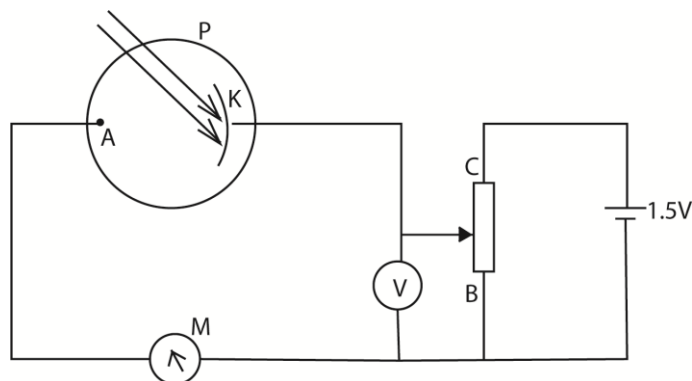
(c) Describe a simple form of a mass spectrometer and explain how it is used to distinguish between isotopes (07marks)

(d) the nucleus of $^{37}_{17}\text{Cl}$ emits an α -particle followed by two β -particles. Show that the final nucleus is an isotope of chlorine (02mark)

55. (a) (i) Write down the Einstein photo-electric equation (01mark)

(ii) Explain how the equation in (a)(i) above accounts for the emission of electrons from metal surfaces illuminated by radiation. (04marks)

(b)



P is a vacuum photocell with anode, A, and cathode, K, made from the same metal of work function 2.0eV. The cathode is illuminated by monochromatic light of constant intensity and wavelength $4.4 \times 10^{-7} \text{m}$

- (i) Describe and explain how the current shown by the micro ammeter, M will vary as the slider of potential divider is moved from B to C. (03marks)
- (ii) What will the reading of the high-resistance voltmeter, V, be when photo-electric emission just ceases? (03marks)
- (c) With the slider set mid-way between B and C, describe and explain how the reading of M would change if
- (i) the intensity of the light was increased, (03marks)
- (ii) the wavelength of the light was changed to $5.5 \times 10^{-7}\text{m}$
56. (a) What is meant by the following
- (i) an alpha particle, (01mark)
- (ii) radioactivity (01mark)
- (b) Show that when an alpha particle collides head –on with an atom of atomic number Z, the closest distance of approach to the nucleus b_o , is given by
- $$b_o = \frac{Ze^2}{\pi\epsilon_0mv^2}$$
- where e is the electronic charge, ϵ_0 is the permittivity of free space, m, mass of the alpha particle and v is the initial velocity of the particle. (06marks)
- (c) Describe the structure and action of a cloud chamber. (06marks)
- (d) State four uses of radioactive isotopes (02marks)
- (e) one kilogram of wood from a ship wreck has activity of 1.2×10^2 counts per second due to ^{14}C , whereas the same amount of wood had an activity of 2.0×10^2 counts per second. Find the age of the ship wreck. [Half-life of ^{14}C = 5.7×10^3 years] (04 marks)
57. (a) what is meant by emission line spectra?

E_∞	0eV
E_4	-0.81eV
E_3	-2.77eV
E_2	-4.87eV
E_1	-27.47eV

- (ii) The figure above shows some energy levels of neon. Determine the wavelength of the radiation emitted in an electron transition from E_4 to E_3 . In what region of the electromagnetic spectrum does the radiation lie? (04marks)
- (b) Outline the principles of generation of continuous line spectra of X-rays in X-ray tube. (05marks)

(c) State Bragg's law of X-ray diffraction. (01mark)

(d) A beam of X-rays of wavelength $1.0 \times 10^{-10}\text{m}$ is incident on a set of cubic planes in a sodium chloride crystals. The first order diffraction m is obtained for a grazing angle of 10.2° .

Find

(i) The spacing between consecutive planes (03marks)

(ii) The density of the sodium chloride (04marks)

58. (a) state the laws of photo electric emission. (04marks)

(b) (i) Describe an experiment to find Planck's constant. (05marks)

(ii) Violet light wavelength $0.4\mu\text{m}$ is incident on a metal surface of threshold wavelength $0.65\mu\text{m}$. Find the maximum speed of emitted electrons

(iii) Explain why light whose frequency is less than the threshold frequency cannot cause photo emission. (02marks)

(c) (i) What are X-rays? (01marks)

(ii) Explain how the intensity and penetrating power of X-rays produced by an X-ray tube can be varied. (04marks)

59. (a)(i) Define the terms half-life and decay constant as applied to radioactivity. (02marks)

(ii) State relationship between half-life and decay constant. (01mark)

(b) The radioisotope ^{60}Co decays by emission of a β -particle and γ -rays. Its half-life is 5.3years.

(i) find the activity of a source containing 0.10g of ^{60}Co . (04marks)

(ii) In which ways do γ -rays differ from β -particles (03marks)

(c) (i) What is meant by mass defect in nuclear physics? (01mark)

(ii) Calculate the mass defect for $^{59}_{26}\text{Fe}$, given the following information

Mass of $^{59}_{26}\text{Fe}$ nucleus = 58.93488u

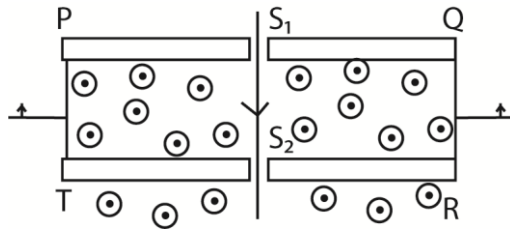
Mass of a proton = 1.00728u

Mass of neutron = 1.00867u (04marks)

(d) Describe the structure and action of ionization chamber. (05marks)

60. (a) what is meant by specific charge of an ion? (01mark)

(b)



Positive ions of the same charge are directed through slit S_1 into a region PQRT as shown in the figure above. There is a uniform electric field of intensity 300NC^{-1} between the plate PT and QR. A uniform magnetic field of flux density 0.6T is directed perpendicularly out of the paper as shown above.

- (i) Calculate the velocity of the ions which go through slit S_2 . (03marks)
 - (ii) Describe the motion of ions in the region TR. (3marks)
- (c) When fast moving electrons strike a metal target in X-ray tube, two type of X-ray spectra are produced
- (i) Draw a sketch graph of intensity against wavelength of the X-rays (02marks)
 - (ii) Account for the occurrence of the two types of spectra (05marks)
- (d) Outline the experimental evidences for the quantum theory of matter. (06marks)



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Based on, best for sciences

1. (a) (i) What are cathode rays? (01marks)

Cathode rays are streams of fast moving electrons

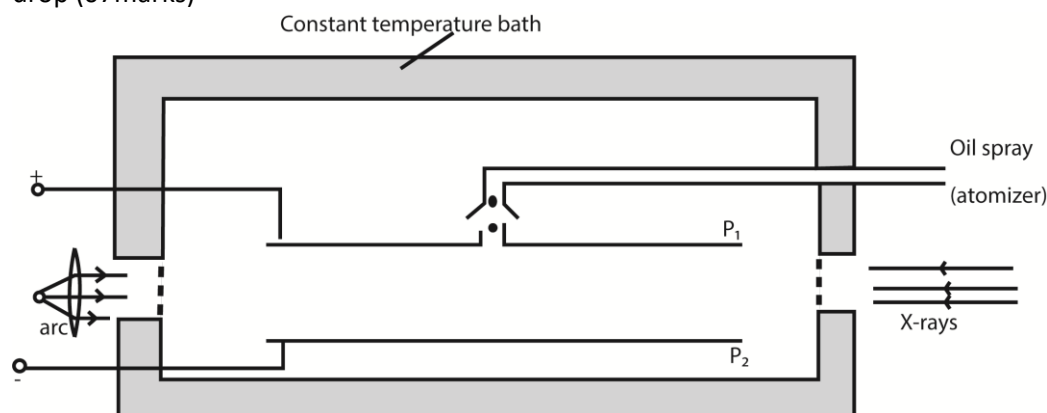
- (ii) State two properties of cathode rays (01mark)

- They are negatively charged
- Travel in straight lines
- Travel with the same speed
- Affect photographic plates

- (iii) Explain two disadvantages of using the discharge tube in producing cathode rays. (02marks)

- a discharge tube is operated at very high voltage which is not safe to handle
- gas required at very low pressure which may not be achieved practically

- (b) With the aid of a diagram, describe Millikan's experiment to determine the charge on an oil drop (07marks)



- Separation between the plates P_1 and P_2 is measured
- Oil is sprayed through the hole in plate P_1 .
- Oil drops are ionized by friction and /or X-rays
- With no p.d applied a drop is selected and its terminal velocity v_1 is calculated
- For known density ρ of oil, density σ of air and coefficient of viscosity, η of air, radius of the drop is calculated from

$$\frac{4}{3}\pi r^3 \rho g = \frac{4}{3}\pi r^3 \sigma g + 6\pi \eta r v_1$$

- The p.d is now applied between the plates and varied until the selected drop remain stationary
- The p.d V is read and recorded.
- The charge Q carried by the drop is determined from

$$Q = \frac{6\pi r v_1 d}{V}$$

(c) A beam of electrons is accelerated through a potential difference of 1.98kV and directed midway between two horizontal plates of length 4.8cm and separated by a distance of 2.0cm. The potential difference applied across the plates is 80.0V.

(i) Calculate the speed of the electrons as they enter the region between the plates (03marks)

$$\text{From } \frac{1}{2} m u^2 = eV$$

$$\frac{1}{2} \times 9.11 \times 10^{-31} \times u^2 = 1.6 \times 10^{-19} \times 1.98 \times 10^3$$

$$u = 2.64 \times 10^7 \text{ms}^{-1}$$

(ii) Explain the motion of the electrons between the plates (02marks)

- The horizontal velocity is unaffected because the net force is zero
- The vertical component of velocity changes with time due to electric force. Thus electron beam describes a parabolic path.

(iii) Find the speed of electrons as they emerge from the region between the plates (04marks)

$$v_x = 2.64 \times 10^7 \text{ms}^{-1}$$

$$\text{From } v = u + at; t = \frac{L}{u}$$

$$v_y = \frac{Ee}{m} \cdot \frac{L}{u} = \frac{80 \times 1.6 \times 10^{-19} \times 4.8 \times 10^{-2}}{2 \times 10^{-2} \times 9.11 \times 10^{-31} \times 2.6 \times 10^7} = 1.277 \times 10^6 \text{ms}^{-1}$$

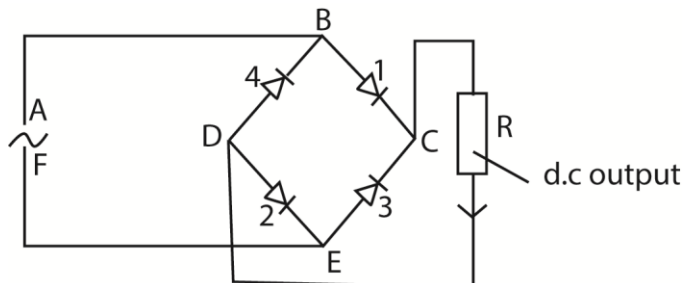
Speed of the electron

$$v = \sqrt{(v_x^2 + v_y^2)} = \sqrt{(2.64 \times 10^7)^2 + (1.277 \times 10^6)^2} = 2.643 \times 10^7 \text{ms}^{-1}$$

2. (a)(i) What is meant by thermionic emission? (01marks)

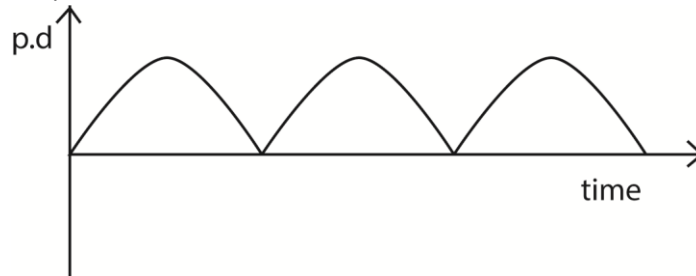
Thermionic emission is the ejection of electrons from metal surface when heated

(ii) Describe how full-wave rectification of a.c can be achieved using four semiconductor diodes. (04marks)



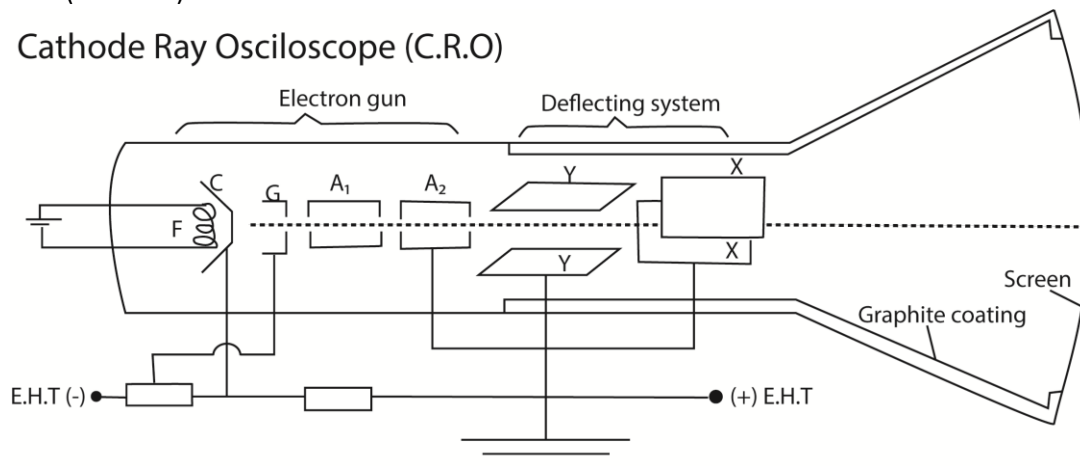
- Four diodes are arranged in a bridge network as shown above.
- If A is positive during the first half cycle, diode 1 and 2 conduct and current takes the path ABCRDEF

- In the next half cycle when F is positive, diode 3 and 4 conduct and current flows through the path FECRDBA
- Once again current flows through R in the same direction during both cycle of input and d.c output is obtained.



- (b) (i) Draw a labelled diagram to show the main parts of a cathode ray oscilloscope (C.R.O) (03marks)

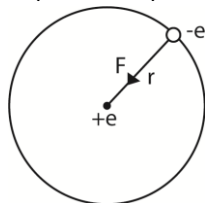
Cathode Ray Oscilloscope (C.R.O)



- (ii) Describe how a C.R.O can be used as an a.c voltmeter. (02marks)

- Unknown a.c voltage V is connected to the Y-plates.
- The Y-sensitivity gain setting is adjusted to a suitable value V_0 volts per centimeter
- When the time base is off, the vertical line on the screen is centered and its length L measured
- The unknown a.c voltage, $V = V_0 L$

- (c) (i) an electron of charge $-e$ and mass m moves in circular orbit round a central hydrogen nucleus of charge $+e$. Derive an expression for total energy of electron in an orbit of radius r . (05 marks)



$$\text{Kinetic energy of electron} = \frac{1}{2} m v^2$$

From circular motion,

Centripetal force = electrostatic force

$$\frac{1}{2}mv^2 = \frac{e^2}{4\pi\epsilon_0 r^2}$$

$$mv^2 = \frac{e^2}{4\pi\epsilon_0 r}$$

Multiplying by $\frac{1}{2}$ both sides

$$\text{Kinetic energy} = \frac{1}{2}mv^2 = \frac{e^2}{8\pi\epsilon_0 r}$$

$$\text{Electrical energy} = \int_{\infty}^r F dx = \int_{\infty}^r \frac{e^2}{4\pi\epsilon_0 x^2} dx = \frac{-e^2}{4\pi\epsilon_0 r}$$

Total energy $E = \text{K.E} + \text{P.E}$

$$= \frac{e^2}{8\pi\epsilon_0 r} + \frac{-e^2}{4\pi\epsilon_0 r}$$

$$= \frac{-e^2}{8\pi\epsilon_0 r}$$

(ii) Why is this energy always negative (01marks)

The energy is always negative because the electron is bound to the nucleus by electrostatic force.

(d) (i) what is meant by excitation potential of an atom? (01marks)

Excitation potential of an atom is the potential required to raise atom from its ground state to excited state.

(ii) Some of the energy levels in mercury spectrum are shown in the figure below.

A ————— 0

B ————— 5.5eV

C ————— 10.4eV

Calculate the wavelength of the radiation emitted when electron makes a transition from level A to level C. (03marks)

$$E_A - E_C = hf = \frac{hc}{\lambda}$$

$$\lambda = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{(0-10.4) \times 1.6 \times 10^{-19}} = 1.19 \times 10^{-7} \text{m}$$

3. (a) What is meant by the following as applied to radioactivity?

(i) Activity (01marks)

Activity is the number of atoms disintegrating per second

(ii) Half-life of a radioactive material (01marks)

Half-life is the time taken by the number of atoms to decay to half original value.

(b) Using the radioactive decay law $N = N_0 e^{-\lambda t}$, show that the half-life $T_{\frac{1}{2}} = \frac{1}{\lambda}$ (02marks)

From $N = N_0 e^{-\lambda t}$

$$t = T_{\frac{1}{2}}, N = \frac{N_0}{2}$$

$$\frac{N_0}{2} = N_0 e^{-\lambda T_{\frac{1}{2}}}$$

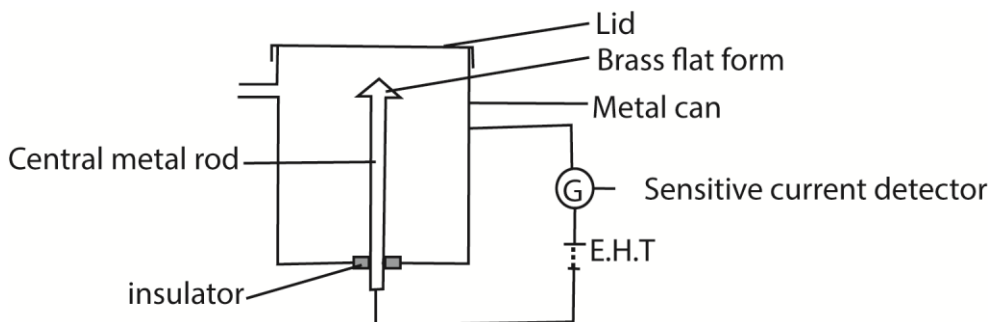
$$\frac{1}{2} = e^{-\lambda T_{\frac{1}{2}}}$$

$$\ln \frac{1}{2} = -\lambda T_{\frac{1}{2}} \ln e$$

$$\ln 2 = \lambda T_{\frac{1}{2}}$$

$$T_{\frac{1}{2}} = \frac{0.693}{\lambda}$$

(c) With the aid of a labelled diagram, describe the action of an ionization chamber. (05marks)



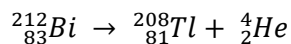
- A radiation source on the brass flat form causes ionization of air in the chamber producing electrons and positive ions.
- The electrons move to the metal can and positive ions drift to the central metal rod.
- Movement of the ions to the electrodes causes discharge and current pulse flows in external circuit.
- The current sensitive detector detects current.
- The magnitude of current detected shows the extent to which ionization takes place.

(d) What is meant by unified atomic unit and electron volt? (02marks)

Unified atomic mass unit is $\frac{1}{12}$ of the mass of 1 atom of carbon – 12 isotope

Electron volt is the kinetic energy gained by electron which has been accelerated through a p.d of 1volt.

(e) (i) The nucleus ${}^{212}_{83}\text{Bi}$ decays by alpha emission as follows



Calculate the energy released by 2g of ${}^{212}_{83}\text{Bi}$. (05marks)

Mass defect= Δm (cannot be obtained since unified atomic mass units of the products are not given.

$$\text{Energy released} = \Delta mc^2$$

(ii) Explain two uses of radioactive isotopes. (04marks)

- Carbon dating: activity of fresh and dead material samples are obtained and the age of the dead material obtained.
- Treatment of cancer, A dose of the radioactive isotope is administered to a patient. The isotope emits radiation which destroy cancer cells
- Detection of leakage in underground sewage and water pipes.

4. (a) Define the following

(i) Binding energy (01marks)

Binding energy is the energy required to split the nucleus into protons and neutrons.

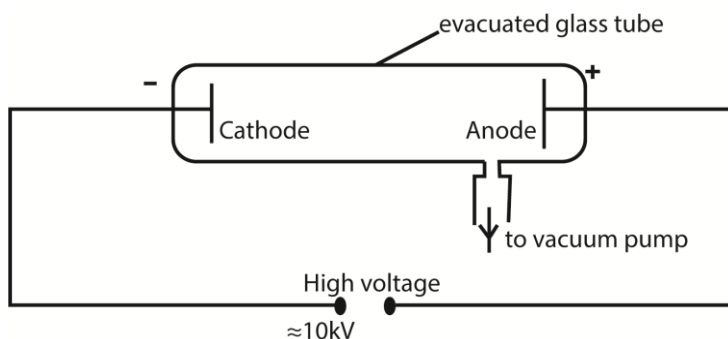
(ii) Unified Atomic Energy (01marks)

Unified atomic mass unit is a twelfth of the mass of one atom of carbon-12 isotope.

(b) Explain how energy is released in a nuclear fusion process. (03marks)

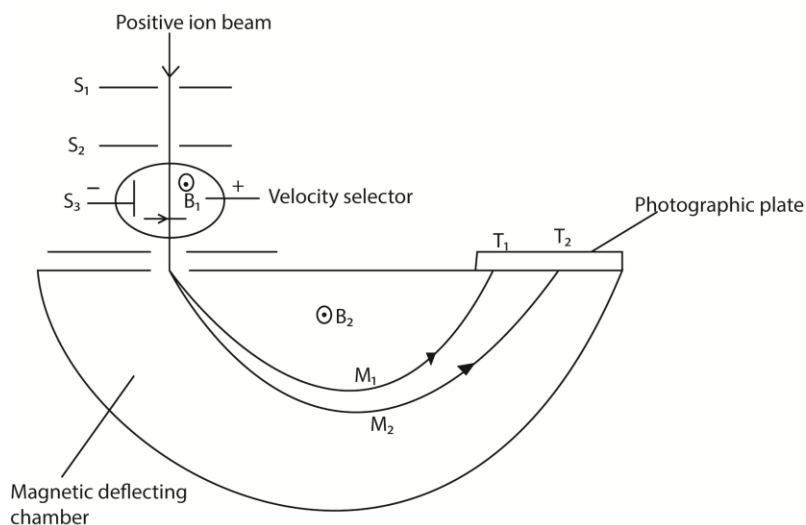
When two small nuclei combine, the total mass of the two nuclei is greater than the mass of the resulting heavy nucleus. The difference in the mass accounts for the energy released.

(c) Explain what is observed in a discharge tube when the pressure is gradually reduced to low values? (05marks)



- At 100mmHg, thin streamer of luminous gas appear between the electrodes.
- Between 10mmHg and 0.1mmHg, the discharge becomes a steady glow spreading throughout the tube. Four regions appear

(d) With the aid of a diagram, describe the operation of Bainbridge mass spectrometer in the determination of charge to mass ratio. (07marks)



T_1 and T_2 are tracers on photographic plate, S_1 , S_2 and S_3 are slits

Mode of action

- Positive ions are produced in a discharge tube and admitted as a beam through slits S_1 and S_2 .
- The beam then passes between insulated plates P, Q, connected to a battery, which create an electric field of intensity E .
- A uniform magnetic field B_1 , perpendicular to E is applied over the region of the plates and all ions, charge e with the same velocity, v given by $B_1 ev = Ee$ will then pass undeflected through the plates and through a slit S_3 .
- The selected ions are deflected in a circular path of radius r by a uniform perpendicular magnetic field B_2 and an image is produced on a photographic plate as shown.

In this case

$$\frac{mv^2}{r} = B_2 ev$$

$$\therefore \frac{m}{e} = \frac{rB_2}{v}$$

But for the ions selected $v = \frac{E}{B_1}$ from above

$$\therefore \frac{m}{e} = \frac{rB_2B_1}{E}$$

(e) An ion of mass 2.6×10^{-26} kg moving at a speed of $4 \times 10^4 \text{ ms}^{-1}$ enter a region of uniform magnetic field of flux density 0.05T. Calculate the radius of the circle described by the ion.

$$\frac{mv^2}{r} = Bev$$

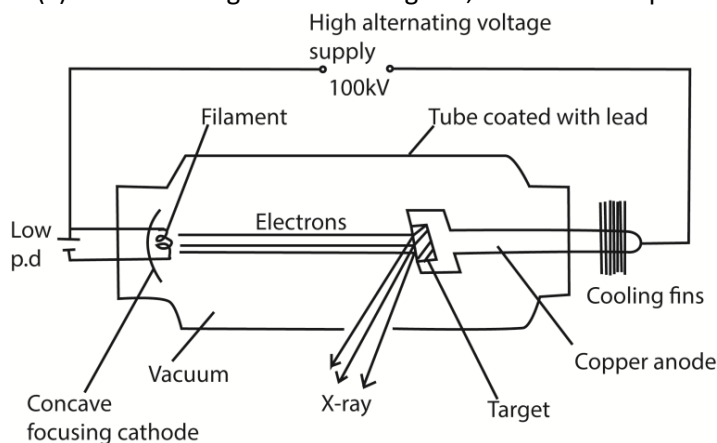
$$r = \frac{mv}{Be} = \frac{2.6 \times 10^{-26} \times 4 \times 10^4}{0.05 \times 1.6 \times 10^{-19}} = 0.13 \text{ m}$$

5. (a)(i) State three differences between X-rays and cathode rays. (03marks)

X-rays	Cathode rays
Electrical magnetic wave of very short wavelength	Streams of fast moving electrons

Have no charge	Are negatively charged
Are not deflected by electric and magnetic field	Are deflected by both magnetic and electric field
Move with high speed	Move with low speed
Affect photographic plates	Have no effect on photographic plates

(ii) Describe using a labelled diagram, the mode of operation of an X-ray tube (06marks)



Mode of operation

- The filament is heated by a low voltage supply and the electrons are emitted by thermionic emission.
- The concave focusing cathode focuses the electrons from the filament onto the target.
- These electrons are accelerated towards the anode by the high voltage between the filament and the Anode.
- When the electrons (cathode rays) strike the metal target, about only 1% their kinetic energy is converted to X-rays and the 99% of their kinetic energy is converted to heat, which is conducted away by the cooling fins.

(iii) What is the difference between soft and hard X-rays (01mark)

- Hard X-rays have higher penetrating power than soft X-rays
- Hard X-rays have shorter wavelength than soft X-ray.

(b) (i) What is the main distinction between work function and ionization energy? (02marks)

Ionization energy is the minimum energy required to remove its most loosely bound electron from the atom while work function is the minimum energy required to liberate an electron from a metal surface.

(ii) An electron of charge, e , enters at right angles into a uniform magnetic field of flux density B and rotates at frequency, f , in a circle of radius, r .

Show that the frequency, f , is given by; $f = \frac{Be}{2\pi m}$. (03marks)

$$Bev = \frac{mv^2}{r}$$

$$Be = \frac{mv}{r} = \frac{m}{r}(2\pi fr) \text{ since } v = 2\pi fr$$

$$f = \frac{Be}{2\pi m}$$

- (c) An X-ray beam is produced when electrons are accelerated through 50kV are stopped by the target of an X-ray tube. When the beam falls on a set of parallel atomic plates of a certain metal at glancing angle of 16° , a first order diffraction maximum occurs. Calculate the atomic spacing of the planes. (05marks)

$$\text{From } \frac{hc}{\lambda} = eV$$

$$\lambda = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-19} \times 50000} = 2.48 \times 10^{-11} \text{m}$$

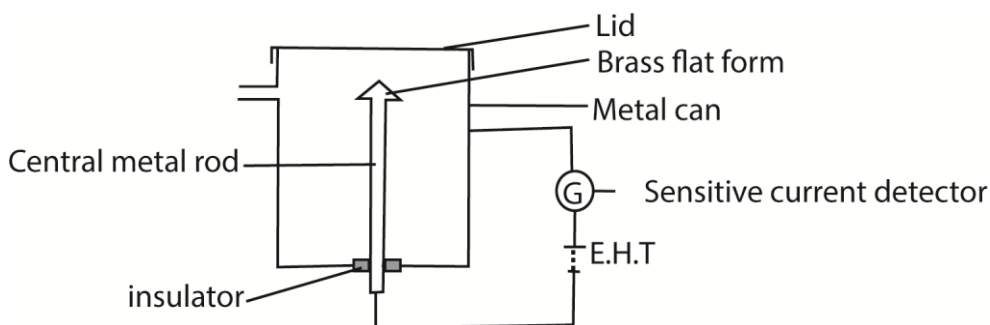
$$2d \sin \theta = n\lambda$$

$$d = \frac{1 \times 2.48 \times 10^{-11}}{2 \sin 16^\circ} = 4.5 \times 10^{-11} \text{m}$$

6. (a) State two differences between alpha and beta particles

Alpha particle	Beta particles
Positively charged	Negatively charged
Low penetrating power	High penetrating power
High ionizing power	Low ionizing power
Helium nucleus	An electron

- (b) Describe with the aid of a diagram, the structure and mode of operation of an ionization chamber. (06marks)



- A radiation source on the brass flat form causes ionization of air in the chamber producing electrons and positive ions.
- The electrons move to the metal can and positive ions drift to the central metal rod.
- Movement of the ions to the electrodes causes discharge and current pulse flows in external circuit.
- The current sensitive detector detects current.
- The magnitude of current detected shows the extent to which ionization takes place.

(c)(i) Explain the application of carbon-14 in carbon dating. (03marks)

- Carbon-14 isotope is radioactive with half-life $t_{1/2} = 5600$ years
- It is absorbed and maintained at constant concentration by plants during photosynthesis.
- When plants die carbon-14 decays and its concentration falls due to lack of renewal by photosynthesis.
- If N_0 is the activity of fresh plant and N is the activity of dead plant after time t , the age of the dead plant t is deduced from $N = N_0 e^{\frac{0.693}{5600}t}$

(ii) A sample of dead wood was found to have activity of 20 units due to carbon-14 isotope whose half-life is 5600 years. If activity of wood just cut is 47.8 units, estimate the age of the sample. (03marks)

$$\text{From } N = N_0 e^{\frac{0.693}{5600}t}$$

$$47.8 = 20 e^{\frac{0.693}{5600}t}$$

$$\ln \frac{47.8}{20} = \frac{0.693}{5600} t$$

$$t = 7040.8 \text{ years}$$

(d) The photoelectric work function of potassium is 2.25 eV. Light having a wavelength of 360 nm falls on a potassium metal.

(i) Calculate the stopping potential (04marks)

$$hf = w_0 + \frac{1}{2}mv^2$$

$$\text{but } \frac{1}{2}mv_{\max}^2 = eV_s$$

$$\begin{aligned} - \quad \frac{hc}{\lambda e} &= w_0 + V_s \\ \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{360 \times 10^{-3}} &= 2.25 \times 10^{-19} + eV_s \\ V_s &= -2.25V \end{aligned}$$

(ii) Calculate the speed of the most energetic electron emitted by the metal (02marks)

$$\frac{1}{2}mv_{\max}^2 = eV_s$$

$$v_{\max} = \sqrt{\frac{2 \times 2.25 \times 10^{-19}}{9.11 \times 10^{-31}}} = 8.89 \times 10^5 \text{ ms}^{-1}$$

7. (a) What is meant by the following

(i) Radioactivity (01mark)

Radioactivity is the spontaneous disintegration of radioactive nuclide or atoms accompanied by emission of radiation

(ii) Isotopes (01marks)

Isotopes are atoms of the same atomic number but difference atomic mass

(b) (i) Define mass defect (01mark)

Mass defect is the difference in mass of constituent nucleons and the nucleus of an atom

(ii) State the conditions for a heavy nucleus to be unstable (01mark)

A heavy nucleus is unstable if there are too many neutrons or too many protons.

(iii) Explain your answer in (b)(ii) (02marks)

- Large number of protons increase electrostatic repulsion between themselves in a nucleus
- Large number of neutrons lead to unbalanced nuclear forces

(c) A sample of $^{226}_{88}\text{Ra}$ emits both α -particles and γ -rays. A mass defect of 0.0053u occurs in the decay.

(i) Calculate the energy released in joules. (03 marks)

$$E = mc^2 = 0.0053 \times 1.66 \times 10^{-27} \times (3 \times 10^8)^2 = 7.92 \times 10^{-13} \text{J}$$

(ii) If the sample decays by emission of α -particle, each of energy 4.60MeV and γ -rays, find the frequency of the γ -rays emitted. (04marks)

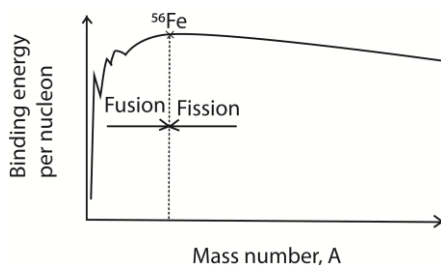
$$4.60 \text{MeV} = 4.60 \times 10^6 \times 1.6 \times 10^{-19} = 7.36 \times 10^{-13} \text{J}$$

$$\text{Energy of a photon of } \gamma \text{ - rays} = 7.9 \times 10^{-13} - 7.36 \times 10^{-13} = 0.56 \times 10^{-13}$$

From $E = hf$

$$f = \frac{0.56 \times 10^{-13}}{6.6 \times 10^{-34}} = 8.5 \times 10^{19} \text{Hz}$$

(d) (i) Sketch a graph showing the variation of binding energy per nucleon with mass number, clearly showing the fusion and fissions. (02marks)



(ii) Use the sketch in (d)(i) to explain how energy is released in each of the process of fusion and fission

- Two small nuclei with atomic mass less than 56 fuse to give a heavier nucleus with a higher binding energy per nucleon to increase nuclear stability
- A nucleus with atomic mass higher than 56 split to form two small nuclei each with higher binding energy per nucleon and thus with higher nuclear stability

(e) State two

(i) applications of radioisotopes (01marks)

- Treatment of cancer
- Production of energy in nuclear reaction
- Detection of leaks in pipes
- Carbon dating

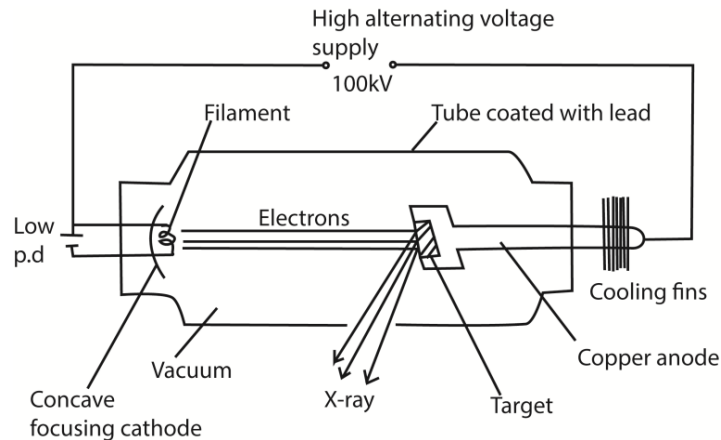
(ii) health hazards of radioisotopes (01mark)

- Cause genetic mutation
- Cause cancer
- Cause deep seated wounds in humans

8. (a) What are X-rays? (01marks)

X-rays are electromagnetic radiations of very high frequency (short wavelength) produced when cathode rays strike metal target.

(b) (i) With the aid of a diagram explain how X-rays are produced in an X-ray tube (05marks)



Mode of operation

- The filament is heated by a low voltage supply and the electrons are emitted by thermionic emission.
- The concave focusing cathode focuses the electrons from the filament onto the target.
- These electrons are accelerated towards the anode by the high voltage between the filament and the Anode.
- When the electrons (cathode rays) strike the metal target, about only 1% their kinetic energy is converted to X-rays and the 99% of their kinetic energy is converted to heat, which is conducted away by the cooling fins.

(ii) State the energy changes that take place in the production of X-rays in an X-ray tube. (02marks)

Electrical energy → kinetic energy → X-rays + heat

(c) In an X-ray tube, the electrons strike the target with a velocity of $3.75 \times 10^7 \text{ ms}^{-1}$ after travelling a distance of 5.0cm from the cathode. If a current of 10mA flows through the tube, find the

(i) tube voltage (02marks)

$$\text{From } eV = \frac{1}{2}mv^2$$

$$V = \frac{1}{2e}mv^2 = \frac{9.11 \times 10^{-31} \times (3.75 \times 10^7)^2}{2 \times 1.6 \times 10^{-19}} = 4003\text{V}$$

(ii) number of electrons striking the target per second. (02marks)

$$I = ne$$

$$n = \frac{10 \times 10^{-3}}{1.6 \times 10^{-19}} = 6.25 \times 10^{16} \text{ electrons}$$

- (iii) Number of electrons within the space of 1cm length between the anode and the cathode. (05marks)

$$\text{Number of electron in space of 1cm length} = 6.25 \times 10^{16} \times \frac{1}{100} = 6.25 \times 10^{14}$$

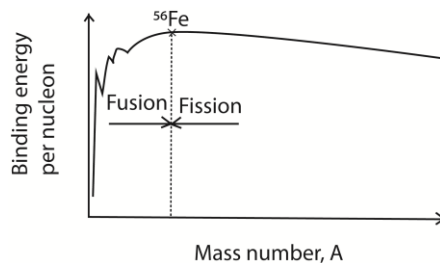
- (d) Briefly explain one medical application of x-rays (03marks)

X-rays are used to kill cancer cells

9. (a) (i) Distinguish between mass defect and binding energy of an atomic nucleus (01mark)
Mass defect is the difference between the mass of nucleons that make up a nucleus and the mass of a nucleus.

Binding energy of an atomic nucleus is the minimum energy to break up a nucleus into its constituent nucleons.

- (ii) Sketch a graph of nuclear binding energy per nucleon versus mass number for naturally occurring isotopes and use it to distinguish between nuclear fission and fusion. (04marks)

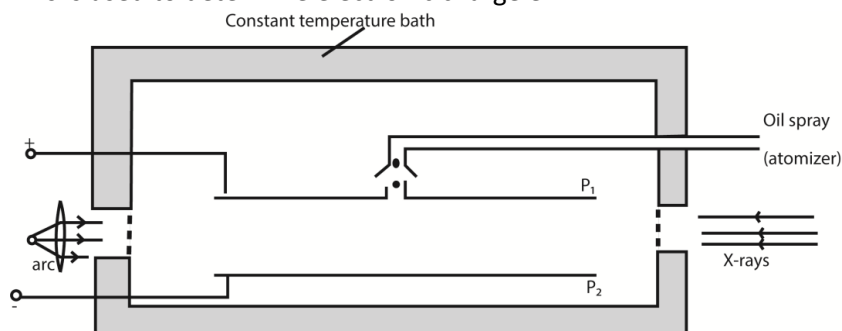


- Two Small nuclei with atomic mass less than 56 each fuse to give a heavier nuclei with smaller mass by higher binding energy to increase stability of nucleon
- A nucleus with atomic mass higher than 56 split to form lighter nuclei of higher binding energy per nucleon.

- (b) Describe with the aid of a diagram, Millikan's oil drop experiment to determine charge on oil drop. (07marks)

Millikan's Oil drop experiment

This is used to determine electronic charge e



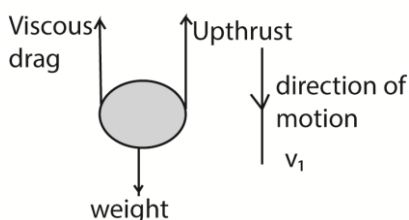
Procedure

- Set up of the apparatus is as shown above
- Oil drops are introduced between the plates P_1 and P_2 by spraying using the atomizer.
- These oil drops are charged in the process of spraying by friction but the charge may be increased further ionization due to X-rays.
- The oil drops are strongly illuminated by an intense light from the arc lamp so that they appear as bright spots when observed through a low power microscope.
- With no electric field between the plates, record the time t_1 taken for drop to fall from P_1 to P_2 .
- The electric field between the plates is turned on and adjusted so that the drop becomes stationary.

Case 1

With no electric field, the oil drop falls with a uniform velocity v_1 called terminal velocity

Forces of falling oil drop



$$\text{Weight} = \text{Upthrust} + \text{viscous drag} \dots\dots\dots (i)$$

$$= \text{volume of the oil drop} \times \text{density} \times \text{gravity}$$

$$= \frac{4}{3}\pi r^3 \rho g \quad (\rho = \text{density of oil, } r = \text{radius of oil drop})$$

$$\text{Upthrust} = \text{weight of air displaced by oil drop}$$

$$= \text{volume of the air displaced by oil drop} \times \text{density} \times \text{gravity}$$

$$= \frac{4}{3}\pi r^3 \sigma g \quad (\sigma = \text{density of air})$$

$$\text{Viscous drag} = 6\pi r \eta v_1 \quad (\text{From Stokes' law})$$

From 1

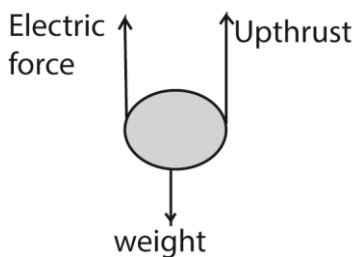
$$\frac{4}{3}\pi r^3 \rho g = \frac{4}{3}\pi r^3 \sigma g + 6\pi r \eta v_1 \dots\dots\dots (ii)$$

$$r = \left[\frac{9\eta v_1}{2g(\rho - \sigma)} \right]^{\frac{1}{2}}$$

Case 2

When the electric field is applied so that the drop is stationary, the drop has no velocity and no acceleration.

Forces of stationary oil drop



Weight = Upthrust + electric force

$$\frac{4}{3}\pi r^3 \rho g = \frac{4}{3}\pi r^3 \sigma g + qE \dots\dots\dots (iii)$$

From (ii) and (iii)

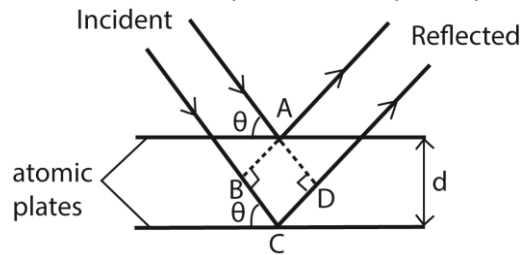
$$q = \frac{6\pi\eta v_1}{E} \text{ but } E = \frac{V}{d}$$

Substituting for r

$$q = \frac{6\pi\eta d v_1}{V} \left[\frac{9\eta v_1}{2g(\rho - \sigma)} \right]^{\frac{1}{2}}$$

(c) (i) Explain briefly diffraction of X-rays by crystals and derive Bragg's law. (06marks)

- A parallel beam of monochromatic X-rays incident on a crystal is reflected from successive atomic planes and super-imposed, forming an interference pattern.



For constructive interference to occur, the path difference is equal to the whole number of wavelength

Thus $BC + CD = n\lambda$

$$\Rightarrow d\sin\theta + d\sin\theta = n\lambda$$

$$\text{or } 2d\sin\theta = n\lambda \text{ where } n = 1, 2, 3, 4 \dots$$

(ii) A second order diffraction image by reflection of X-rays at atomic plates of crystal for glancing angle of $11^\circ 24'$. Calculate the atomic spacing of the plates if the wavelength of X-ray is $4.0 \times 10^{-11}\text{m}$. (02marks)

From $2d\sin\theta = n\lambda$

$$d = \frac{2 \times 4 \times 10^{-11}}{2 \times \sin 11^\circ 24'} = 2.02 \times 10^{-10}\text{m}$$

10. (a) state Bohr's postulates of an atom (03marks)

Bohr's model state that electrons move in allowed orbits round the nucleus and while in orbits, they do not radiate any energy

(b) An electron of mass m and charge $-e$, is considered to move in circular orbit about a proton.

(i) Write down the expression for the electric force on the electron. (02marks)

$$\text{Force} = \frac{e^2}{4\pi\epsilon_0 r^2} \text{ where } e = \text{electronic charge, } r = \text{orbit radius}$$

(ii) Derive an expression for total energy given that the angular momentum for the electron is equal to $\frac{nh}{2\pi}$ where n is an integer and h is Plank's constant. (06marks)

In the orbit, $\frac{mv^2}{r} = \frac{e^2}{4\pi\epsilon_0 r^2}$

$\Rightarrow$ Kinetic energy $= \frac{e^2}{8\pi\epsilon_0 r}$ (i)

Potential energy $= \int_{\infty}^r \frac{-e^2}{4\pi\epsilon_0 r^2} dr = -\frac{e^2}{4\pi\epsilon_0 r}$

Total energy, $E_t = P.E + K.e$

$$= -\frac{e^2}{4\pi\epsilon_0 r} + \frac{e^2}{8\pi\epsilon_0 r} = -\frac{e^2}{8\pi\epsilon_0 r} \text{ (ii)}$$

Angular momentum $= mvr$

$$mvr = \frac{nh}{2\pi}$$

$$\therefore m^2 v^2 r^2 = \frac{n^2 h^2}{4\pi^2}$$

$$\frac{1}{2} m v^2 = \frac{n^2 h^2}{8\pi^2 m r^2}$$

From (i) $\frac{e^2}{8\pi\epsilon_0 r} = \frac{n^2 h^2}{8\pi^2 m r^2}$

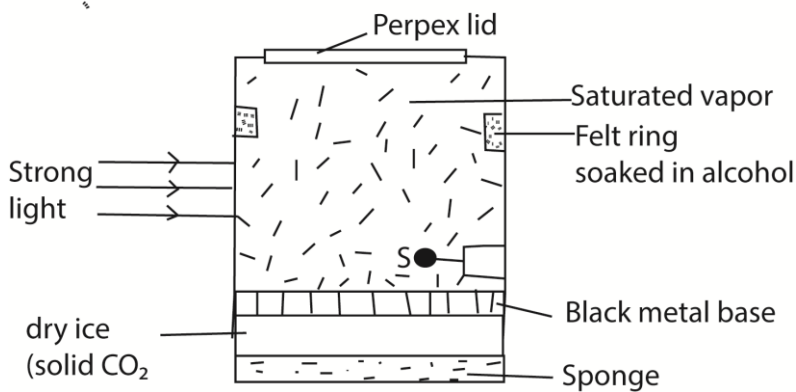
$$r = \frac{n^2 h^2 \epsilon_0}{\pi m e^2}$$

Substituting for r in equation (ii)

$$E_t = -\frac{e^2}{8\pi\epsilon_0} \times \frac{\pi m e^2}{n^2 h^2 \epsilon_0}$$

$$= \frac{-m e^4}{8 n^2 h^2 \epsilon_0^2}$$

(c) With the aid of a labelled diagram, describe the operation of a diffusion type cloud chamber. (06marks)



- The base of the chamber is maintained at low temperature, about -80°C by the solid carbon dioxide while the top of the chamber is at room temperature, and so there is a temperature gradient between the top and the bottom of the chamber.

- The air at the top of the chamber is saturated with alcohol vapor from the felt ring. This vapor continuously diffuses downwards into the cooler regions so that the air at the chamber is super saturated with alcohol vapor.
- Radiations from the radioactive source S cause the ionization of the vapor.
- The ionizations from the radioactive source S cause condensation of the vapor on the ions formed, hence the path of the ionizing radiations are traced by series of small droplets of condensation.
- The thickness and length of the path indicate the extent to which ionization has taken place.
- Alpha particles produce short, thick, continuous straight tracks
- Beta particles which are less massive produce longer, thin but straggly paths owing to collisions with gas molecules
- Gamma radiations are uncharged and for ionization to take place, it must collide with an atom and eject an electron which then ionizes the vapor.

(d) The energy levels of an atom have values

$$E_1 = -21.4\text{eV}$$

$$E_2 = -4.87\text{ eV}$$

$$E_3 = -2.77\text{ eV}$$

$$E_4 = -0.81\text{eV}$$

$$E_\infty = 0.00\text{eV}$$

(i) Calculate the wavelength of radiation emitted when an electron makes a transition from E_3 to E_2 (03marks)

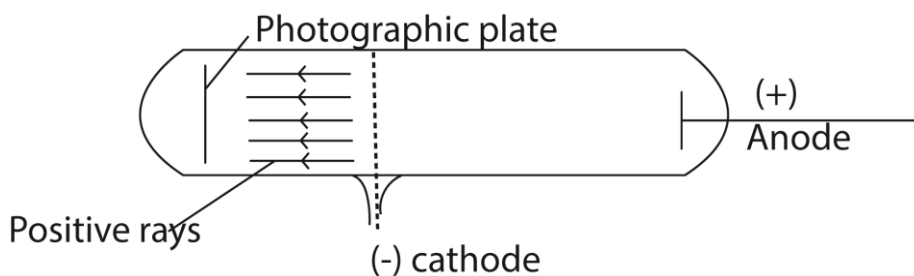
$$E_3 - E_2 = hf = \frac{hc}{\lambda}$$

$$\lambda = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{(-2.77 - (-4.87)) \times 10^{-19}} = 5.97 \times 10^{-7}\text{m}$$

(ii) State the region of the electromagnetic spectrum where the radiation lies (01mark)

Visible spectrum

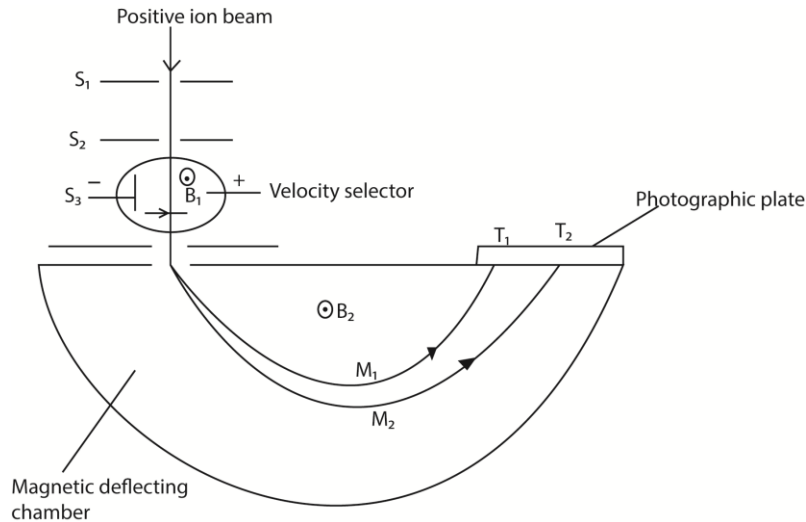
11. (a) Describe how positive rays are produced. (03marks)



Positive rays are produced when a stream of electrons is passed through a vapor (gas) in discharge tube. The electrons dislodge electrons from the atoms producing positively charged ions. The

positive ions are accelerated towards perforated cathode. The ions pass through the slits and are further accelerated. These ions constitute a stream of positive rays.

(b) Describe how a Bainbridge spectrometer can be used to detect isotopes. (05marks)

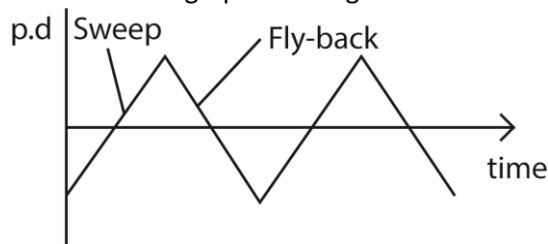


- Positive ions are directed through slits S_1 and S_2 .
- The ions enter a velocity selector carrying crossed electric and magnetic field.
- Selected ions enter a region of uniform magnetic field in circular paths and strike the photographic plate at different points

(c) (i) What is time base as applied to a Cathode Ray Oscilloscope? (01mark)

Is a circuit connected to the x-plate of cathode ray oscilloscope to sweep the electron beam across a screen of a C.R.O

(iii) Draw a sketch graph showing the variation of time base voltage with time (01mark)



(d) An alternating p.d applied to the Y-plate of an oscilloscope produces five complete waves on a 10cm length of the screen when the time base setting is 10mscm^{-1} . Find the frequency of the alternating voltage. (03marks)

$$\text{Period, } T = \frac{10 \times 10 \times 10^{-3}}{5} = 0.02\text{s}$$

$$\text{Frequency} = \frac{1}{T} = \frac{1}{0.02} = 50\text{Hz}$$

- (e) (i) Explain the motion of an electron projected perpendicularly into a uniform magnetic field. (03marks)

By Fleming's left hand rule, the electrons experience a force which is always at right angles to the magnetic field and the direction of motion. The speed of electrons remain unaltered but the electrons is deflected by from its original path by this force. The motion of electrons in a magnetic field is a circular path.

- (ii) An electron accelerated from rest by a p.d of 100V, enters perpendicularly into a uniform electric field intensity 105Vm⁻¹. Find the magnetic field density, B, which must be applied perpendicularly to the electric field so that the electron passes undeflected through the fields. (04marks)

$$\frac{1}{2}mu^2 = eV$$

$$u = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 100}{9.11 \times 10^{-31}}} = 5.93 \times 10^6 \text{ms}^{-1}$$

when the electron passes through crossed field undeflected

$$Beu = eE$$

$$B = \frac{E}{u} = \frac{105}{5.93 \times 10^6} = 0.0169\text{T}$$

12. (a) (i) Define Avogadro's constant and Faraday's constant. (02marks)

Avogadro's constant is the number of atoms in one mole of substance.

Faradays constant is the charge required to liberate one mole of monovalent ions during electrolysis.

- (ii) Show that the charge carried by a monovalent ion is $1.6 \times 10^{-19}\text{C}$. (02marks)

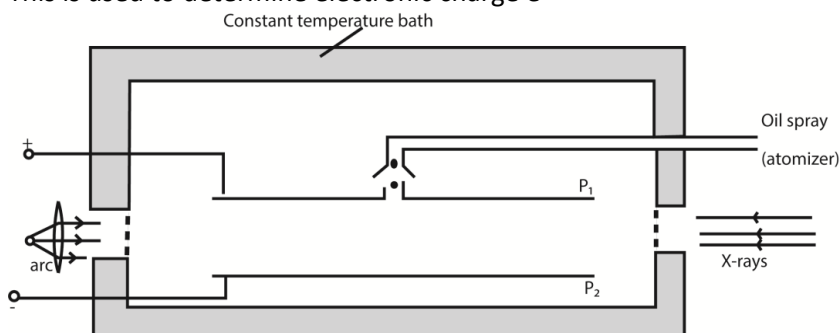
$$1F = nq \text{ (q = electronic charge)}$$

$$q = \frac{96500}{6.02 \times 10^{23}} = 1.6 \times 10^{-19}\text{C}$$

- (b) With the use of a labelled diagram, describe Millikan's oil drop experiment for the determination of the charge of an electron. (07marks)

Millikan's Oil drop experiment

This is used to determine electronic charge e



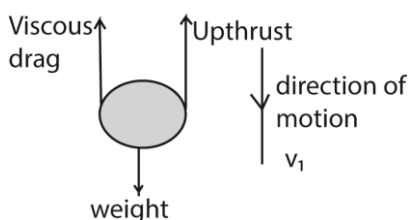
Procedure

- Set up of the apparatus is as shown above
- Oil drops are introduced between the plates P_1 and P_2 by spraying using the atomizer.
- These oil drops are charged in the process of spraying by friction but the charge may be increased further ionization due to X-rays.
- The oil drops are strongly illuminated by an intense light from the arc lamp so that they appear as bright spots when observed through a low power microscope.
- With no electric field between the plates, record the time t_1 taken for drop to fall from P_1 to P_2 .
- The electric field between the plates is turned on and adjusted so that the drop becomes stationary.

Case 1

With no electric field, the oil drop falls with a uniform velocity v_1 called terminal velocity

Forces of falling oil drop



$$\text{Weight} = \text{Upthrust} + \text{viscous drag} \dots\dots\dots (i)$$

$$= \text{volume of the oil drop} \times \text{density} \times \text{gravity}$$

$$= \frac{4}{3}\pi r^3 \rho g \quad (\rho = \text{density of oil, } r = \text{radius of oil drop})$$

$$\text{Upthrust} = \text{weight of air displaced by oil drop}$$

$$= \text{volume of the air displaced by oil drop} \times \text{density} \times \text{gravity}$$

$$= \frac{4}{3}\pi r^3 \sigma g \quad (\sigma = \text{density of air})$$

$$\text{Viscous drag} = 6\pi r \eta v_1 \quad (\text{From Stokes' law})$$

From 1

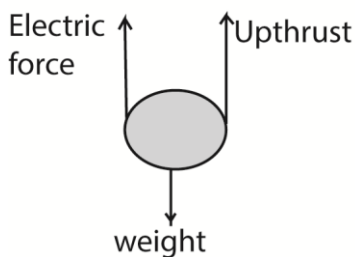
$$\frac{4}{3}\pi r^3 \rho g = \frac{4}{3}\pi r^3 \sigma g + 6\pi r \eta v_1 \dots\dots\dots (ii)$$

$$r = \left[\frac{9\eta v_1}{2g(\rho - \sigma)} \right]^{\frac{1}{2}}$$

Case 2

When the electric field is applied so that the drop is stationary, the drop has no velocity and no acceleration.

Forces of stationary oil drop



Weight = Upthrust + electric force

$$\frac{4}{3}\pi r^3 \rho g = \frac{4}{3}\pi r^3 \sigma g + qE \dots\dots\dots (iii)$$

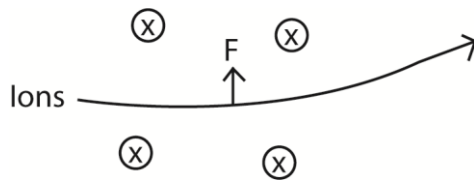
From (ii) and (iii)

$$q = \frac{6\pi r^3 \eta v_1}{E} \text{ but } E = \frac{V}{d}$$

Substituting for r

$$q = \frac{6\pi \eta d v_1}{V} \left[\frac{9\eta v_1}{2g(\rho - \sigma)} \right]^{\frac{1}{2}}$$

- (c) A beam of positive ions moving with velocity v enters a region of a uniform magnetic field density B with the velocity at right angles to the field B . By use of a diagram, describe the motion of ions. (03marks)



Magnetic force, $F = BQV$ acts on the ions. The force is perpendicular to both B and V according to Fleming's rule. The ion describe a circular path of radius, r , given by

$$BQV = \frac{mV^2}{r}$$

$$r = \frac{mV}{BQ} \text{ where } Q \text{ is the charge on the ions.}$$

- (d) A charged oil drop of density 880kgm^{-3} is held stationary between two parallel plates 6.0mm apart held at a potential difference of 10^3V . When the electric field is switched off, the drop is observed to fall a distance of 2.0mm in 35.7s . (Viscosity of air = $1.8 \times 10^{-5}\text{Nsm}^{-2}$, Density of air = 1.29kgm^{-3}).

- (i) Calculate the radius of the drop. (03marks)

$$V_0 = \frac{2 \times 10^{-3}}{35.7} = 5.6 \times 10^{-5}\text{ms}^{-1}$$

$$r = \left(\frac{9\eta V_0}{2g(\rho - \sigma)} \right)^{\frac{1}{2}} = \left(\frac{9 \times 1.8 \times 10^{-5} \times 5.6 \times 10^{-5}}{2 \times 9.81 (880 - 1.29)} \right)^{\frac{1}{2}} = 7.254 \times 10^{-7}\text{m}$$

- (ii) Estimate the number of excess electrons on the drop. (03marks)

$$\begin{aligned} Q &= \frac{4\pi r^3 g}{3E} (\rho - \sigma) = \frac{4\pi r^3 g d}{3V} \\ &= \frac{4\pi (7.254 \times 10^{-7})^3 \times 9.81 \times 6 \times 10^{-3}}{3 \times 10^3} (880 - 1.29) \\ &= 8.029 \times 10^{-19}\text{C} \end{aligned}$$

$$Q = ne$$

$$n = \frac{8.026 \times 10^{-19}}{1.6 \times 10^{-19}} = 5$$

13. (a) (i) State the laws of photoelectric emission (04marks)

- The time lag between irradiation of the metal surface and emission of the electrons by the metal surface is negligible.
- For a given metal, surface there is a minimum value of frequency of radiation called threshold frequency (f_0) below which no photo electrons are emitted from the metal however intense the incident radiation may be.
- The number of photoelectrons emitted from the surface per second is directly proportional to the intensity of incident radiation for a particular incident frequency
- The K.E of the photoelectrons emitted is independent of the intensity of the incident radiation but depends only on its frequency

(ii) Explain briefly one application of photoelectric effect. (04marks)

Use in a photocell in a burglar alarm: when an intruder intercepts infrared radiation incident on the photocell, the flow of current is interrupted. The alarm is set off

- (b) In a photoelectric set up. A point source of light of power $3.2 \times 10^{-3} \text{W}$ emits mono-energetic photons of energy 5.0eV. The source is located at a distance of 0.8m from the center of a stationary metallic sphere of work function 3.0eV and radius $8.0 \times 10^{-3} \text{m}$. The efficiency of photoelectron emission is one in every 10^6 incident photons.

Calculate

(i) Number of photoelectrons emitted per second. (04marks)

$$\text{The number of photons emitted per second by the lamp} = \frac{3.2 \times 10^{-3}}{5.0 \times 1.6 \times 10^{-19}} = 4.0 \times 10^{15}$$

$$\text{Photons incident on the sphere} = \frac{4.0 \times 10^{15} \times \pi \times (8.0 \times 10^{-3})^2}{4\pi \times 0.8^2} = 1.0 \times 10^{11} \text{ photons}$$

$$\text{Number of electrons emitted per second} = \frac{10^{11}}{10^6} = 10^5$$

(ii) Maximum kinetic energy in joules, the photo electrons. (02marks)

$$\text{Maximum kinetic energy} = 5 - 3 = 2\text{eV} = 2 \times 1.6 \times 10^{-19} = 3.2 \times 10^{-19} \text{J}$$

(c) (i) State Bragg's law of X-ray diffraction (01marks)

It states that for constructive interference of diffracted X-rays to occur, the path difference is an integral multiple of the wavelength of the X-ray.

Or

$$2d \sin \theta = n\lambda$$

Where d = interatomic spacing

θ = glancing angle

λ = wavelength of X-rays

n = integral number

(ii) Show that density, ρ , of a crystal can be given by

$$\rho = \frac{M \sin^3 \theta}{125 N_A (n\lambda)^3}$$

where θ is the glancing angle, n , is the order of diffraction, λ is the X-ray wavelength and M is the molecular weight of the crystal. (05marks)

$$\text{Density, } \rho = \frac{M}{V}$$

Volume of crystal molecule with interatomic spacing $d = d^3$

1mole weight M g

$$\therefore \text{1 molecule weigh } \frac{M \times 10^{-3}}{N_A}$$

$$\text{Density of a molecule, } \rho = \frac{M \times 10^{-3}}{N_A d^3}$$

$$\text{From Bragg's law, } d = \frac{n\lambda}{2 \sin \theta}$$

$$\rho = \frac{M \times 10^{-3}}{N_A \left(\frac{n\lambda}{2 \sin \theta} \right)^3} = \frac{M \sin^3 \theta}{125 N_A (n\lambda)^3}$$

14. (a) With reference to a Geiger-Muller tube, define the following

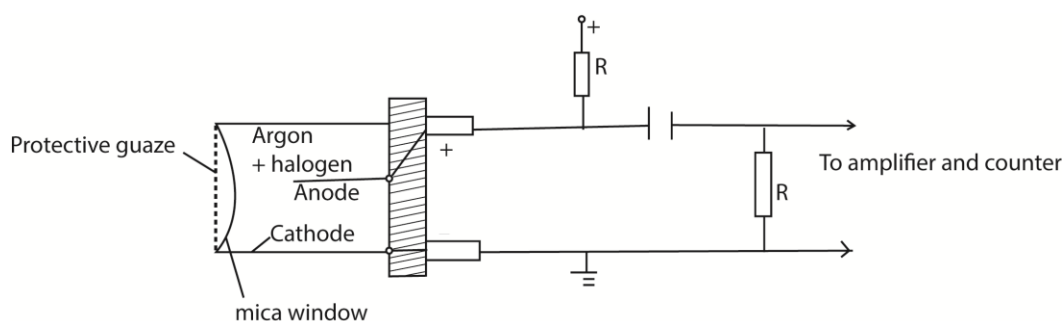
(i) quenching agent (01mark)

It is a halogen gas placed in a Geiger-Muller tube to prevent positive ions from causing the release of electrons from the cathode.

(ii) back ground count rate (01mark)

It is the activity detected by the GM tube in absence of the radioactive source.

(b) (i) With the aid of a labelled diagram, describe the operation of a Geiger-Muller (GM) tube (06marks)



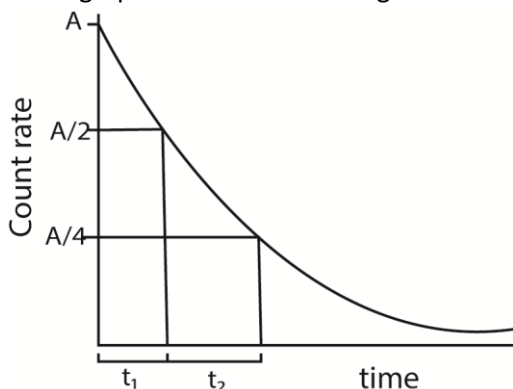
The thin mica window allows the passage and detection of the weak penetrating alpha particles. The GM tube is first evacuated then filled with Neon, Argon plus Halogen gas which is used as a quenching agent.

Mode of operation

- When an ionizing particle enters the tube through the window, argon atoms are ionized.
- The electrons move to the anode while the positive ions drift to the cathode.
- A discharge occurs and the current flows in the external circuit.
- A p.d is obtained across a large resistance, R which is amplified and passed to the scale.
- The magnitude of the pulse registered gives the extent to which ionization occurred.

(ii) Explain how the half-life of a short lived radioactive source can be obtained by use of a Geiger-Muller tube. (04marks)

- Switch on the GM-tube, note and record the background count rate, A.
- Place a source of ionizing radiation near the GM-window.
- Note and record the count rate recorded the count rate at equal intervals.
- For each count rate recorded subtract the background count rate to get the true rate.
- Plot a graph of the count rate against time.



Find time t_1 taken for the activity to reduce to $A/2$ and t_2 taken for activity to reduce to $A/4$ from $A/2$

$$\text{Half-life} = \frac{1}{2}(t_1 + t_2)$$

(c) A radioactive isotope $^{32}_{15}\text{P}$ which has a half-life of 14.3 days, disintegrates to form a stable product. A sample of the isotope is prepared with initial activity of $2.0 \times 10^6 \text{ s}^{-1}$. Calculate the

(Assume $N = N_0 e^{-\lambda t}$)

(i) the number of ^{32}P atoms present (03marks)

$$\text{Activity, } A_0 = \lambda N_0 \text{ but } \frac{0.693}{t_{\frac{1}{2}}}$$

$$2.0 \times 10^6 = \frac{0.693 \times N_0}{14.3 \times 24 \times 60 \times 60}$$

$$N_0 = 3.56 \times 10^{12} \text{ atoms}$$

(ii) activity after 30 days (03marks)

$$\text{From } \ln \frac{A_0}{A} = \lambda t \text{ where } \lambda = \frac{0.693}{t_{\frac{1}{2}}}$$

$$\ln \frac{2 \times 10^6}{A} = \frac{0.693 \times 30 \times 24 \times 60 \times 60}{14.2 \times 24 \times 60 \times 60}$$

$$A = 4.67 \times 10^5 \text{ s}^{-1}$$

(iii) number of ^{32}P atoms after 30 days (02marks)

$$\text{Activity, } A = \lambda N$$

$$4.67 \times 10^5 = \frac{0.693 \times N}{14.2 \times 24 \times 60 \times 60} = 3.49 \times 10^{12} \text{ atoms}$$

$$\text{Number of atoms } N = 8.3 \times 10^{11}$$

15. (a) State Rutherford's model of the atom. (02marks)

The positive charge of an atom and nearly all the mass is concentrated in a small volume at the center. Electrons are in motion in circular orbits around the nucleus and the volume of the atom is accounted for by the electron cloud.

(b) Explain how Bohr's model of the atom addresses the two main failures of Rutherford's model. (07marks)

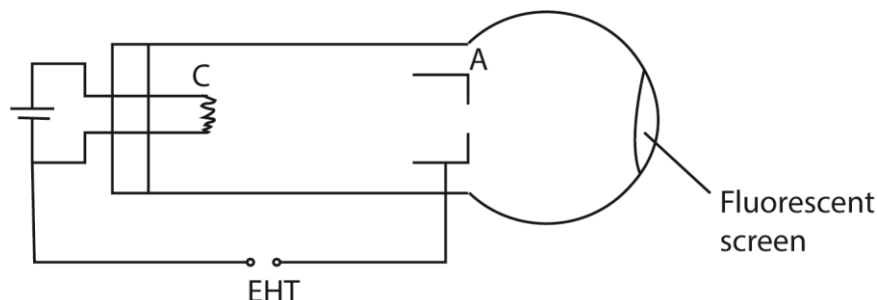
Orbiting electrons experience centripetal acceleration. Therefore they continuously emit electromagnetic radiation hence would lose energy. This therefore implies that the electrons would spiral towards the nucleus and the atom ceases to exist. Yet the atom is stable. Thus Rutherford model cannot explain the stability of the atom.

Since electron continuously accelerating around the nucleus, a continuous emission spectra should be emitted by the atom. However experimental observation reveals that it is atomic emission spectrum

From Bohr's model, electrons move around the nucleus in circular orbits. In these orbits the electron does not radiate energy. Electromagnetic radiation is emitted when the electron makes a transition between orbits

The electron can only move in allowed orbits in which their angular momentum is equal to $\frac{nh}{2\pi}$

(c) With the aid of a labelled diagram, describe how cathode rays are produced. (05marks)



Hot Cathode C produces electrons by thermionic emission. The electrons are accelerated by p.d between cathode C and anode A

(d) (i) What is binding energy of a nucleus? (01mark)

Binding energy is the energy released when a nucleus is formed from its components (protons and neutrons)

(ii) Calculate the energy in MeV released by fusing four protons to form an alpha particle and two beta particles.

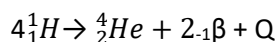
Mass of beta particle = 0.000549u

Mass of hydrogen atom = 1.007825u

Mass of helium atom = 4.002664u

[1u = 931MeV] (05marks)

Solution



Mass of the reactant = 4 x 1.00782 = 4.031300

Mass of the products = 4.002664 + 2 x 0.000549 = 4.003762

Decrease in mass = 4.031300 - 4.003762 = 0.027538u

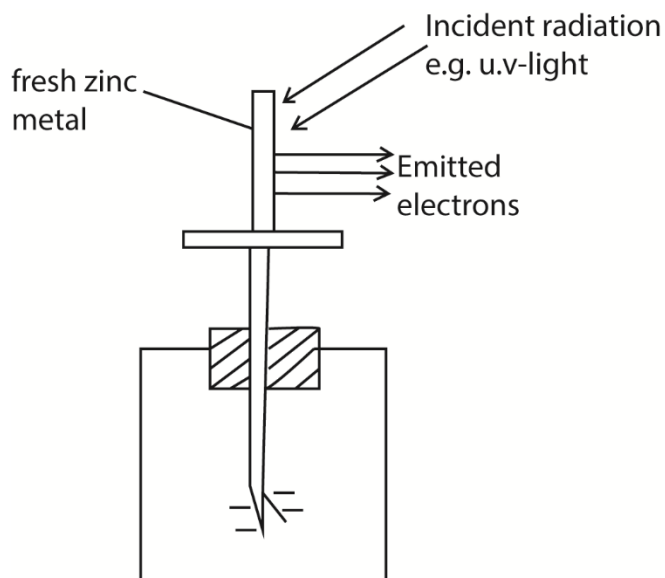
$$= 0.027538 \times 931$$

$$= 25.64\text{MeV}$$

16. (a) What is photo electric emission? (01mark)

Is the emission of electrons from a clean surface of a metal when irradiated by electromagnetic radiation of light

(b)(i) Describe an experiment to demonstrate photo electric effect. (04marks)



- Freshly cleaned zinc plate is placed on top of a negatively charged electroscope.
- Ultraviolet radiation is directed onto the zinc plate
- The leaf gradually falls indicating the electroscope has lost charge which are electrons.

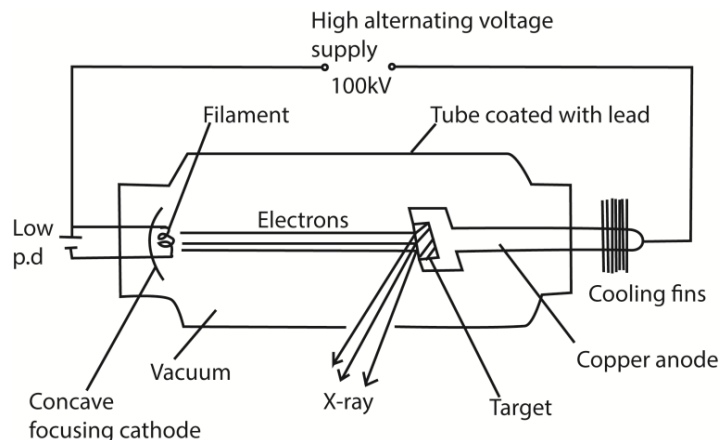
(ii) When a clean surface of a metal in a vacuum is irradiated with light of wave length $5.5 \times 10^{-7}\text{m}$, electrons just emerge from the surface. However when light of wavelength $5 \times 10^{-7}\text{m}$ is incident on the metal surface, electrons are emitted each with energy $3.62 \times 10^{-20}\text{J}$. Find Plank's constant. (04marks)

$$\text{K.E} = \frac{hc}{\lambda} - \frac{hc}{\lambda_0}$$

$$3.62 \times 10^{-20} = h \times 3 \times 10^8 \left(\frac{1}{5 \times 10^{-7}} - \frac{1}{5.5 \times 10^{-7}} \right)$$

$$\therefore h = 6.64 \times 10^{-34}\text{Js}$$

(c) (i) With the aid of a labelled diagram, describe an X-ray tube and how X-rays are produced. (05marks)



Mode of operation

- The filament is heated by a low voltage supply and the electrons are emitted by thermionic emission.
- The concave focusing cathode focuses the electrons from the filament onto the target.
- These electrons are accelerated towards the anode by the high voltage between the filament and the Anode.
- When the electrons (cathode rays) strike the metal target, about only 1% their kinetic energy is converted to X-rays and the 99% of their kinetic energy is converted to heat, which is conducted away by the cooling fins.

(ii) Describe how the intensity and quality of X-rays is controlled in an X-ray tube. (02marks)

- Intensity of X-rays is controlled by varying the filament current
- Quality of X-rays is controlled by the high voltage

(d) An X-ray tube operates at $1.5 \times 10^{-3}\text{V}$ and the current through it is $1.0 \times 10^{-3}\text{A}$.

Find the

(i) number of electrons crossing the tube per second. (02marks)

$$n = \frac{I}{e} = \frac{1.0 \times 10^{-3}}{1.6 \times 10^{-19}} = 6.15 \times 10^{15}$$

(ii) kinetic energy gained by electron traversing the tube (02marks)

$$\text{K.E} = eV = 1.6 \times 10^{-19} \times 1.5 \times 10^{-3} = 2.4 \times 10^{-16}\text{J}$$

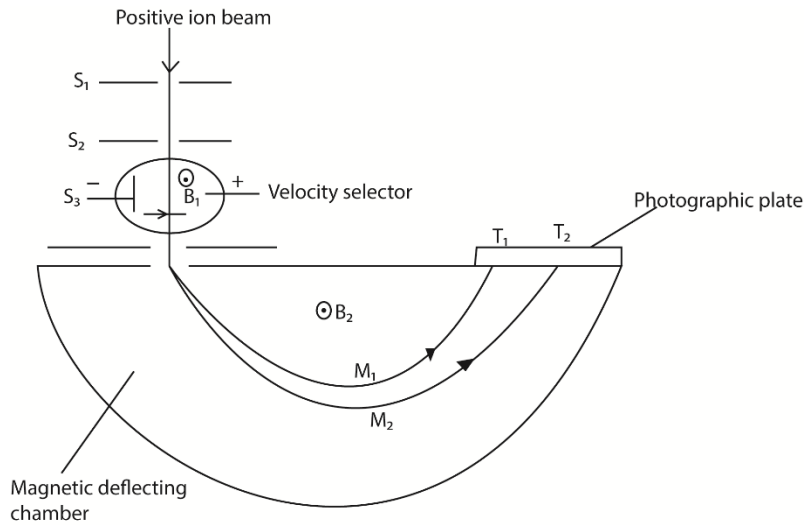
17. (a)(i) What is specific charge? (01mark)

Specific charge is the ratio of charge to mass of a particle

(ii) State the **unit** of specific charge (01mark)

$$\text{Unit} = \text{Ckg}^{-1}$$

(iii) Describe with the aid of a diagram how the specific charge of positive ions can be determined using a mass spectrometer. (06marks)



T_1 and T_2 are tracers on photographic plate, S_1 , S_2 and S_3 are slits

Mode of Action

- Positive ions are produced in a discharge tube and admitted as a beam through slits S_1 and S_2 .
- The beam then passes between insulated plates P, Q, connected to a battery, which create an electric field of intensity E .
- A uniform magnetic field B_1 , perpendicular to E is applied over the region of the plates and all ions, charge e with the same velocity, v given by $B_1 ev = Ee$ will then pass undeflected through the plates and through a slit S_3 .
- The selected ions are deflected in a circular path of radius r by a uniform perpendicular magnetic field B_2 and an image is produced on a photographic plate as shown.

In this case

$$\frac{mv^2}{r} = B_2 ev$$

$$\therefore \frac{m}{e} = \frac{rB_2}{v}$$

But for the ions selected $v = \frac{E}{B_1}$ from above

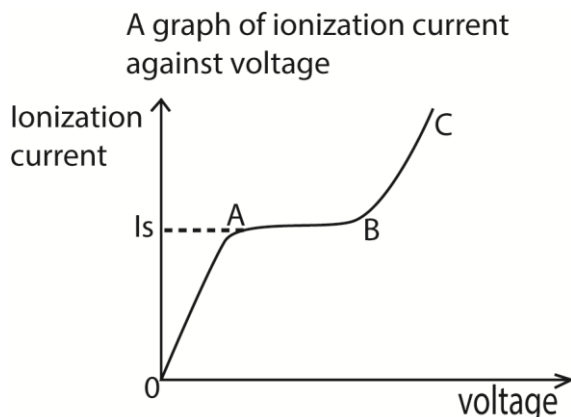
Specific charge, $\frac{e}{m} = \frac{E}{rB_2B_1}$,

- (b) A beam of strongly ionized carbon atoms passes undeflected through a region of crossed magnetic and electric field of 0.10T and $1.0 \times 10^4 \text{NC}^{-1}$ respectively. When it enters a region of uniform magnetic field, it is deflected through an arc of radius 0.75m . Calculate the magnetic flux density of this magnetic field. (Mass of carbon atom = $2.0 \times 10^{-26}\text{kg}$) (05marks)

$$B_1 qv = qE, v = \frac{E}{B_1} \text{ and } B_2 qv = \frac{mv^2}{R}$$

$$\therefore B_2 = \frac{mE}{qRB_1} = \frac{2.0 \times 10^{-26} \times 1.0 \times 10^4}{1.6 \times 10^{-19} \times 0.75 \times 0.1} = 0.0167\text{T}$$

- (c) (i) Draw a graph to illustrate the variation of ionization current and p.d across an ionization chamber and explain its features. (03marks)



Region OA:

Current detected increases gradually but p.d is not large enough to prevent recombination of the ions.

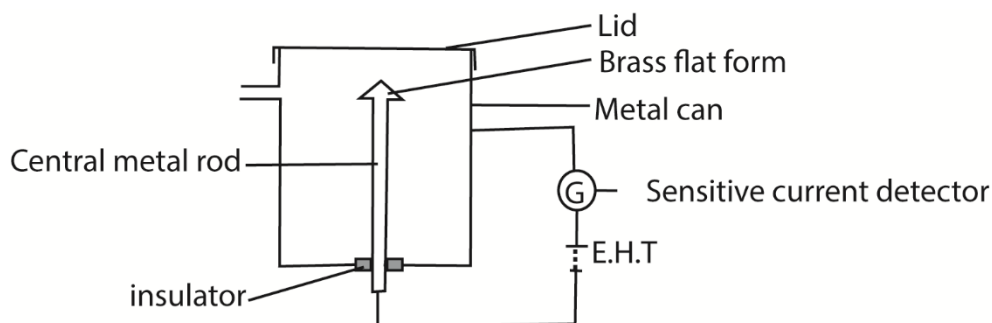
Region AB. (saturation region)

Current is almost constant, all ions reach the electrode before recombination but there is no secondary ionization.

Region BC (gas amplification)

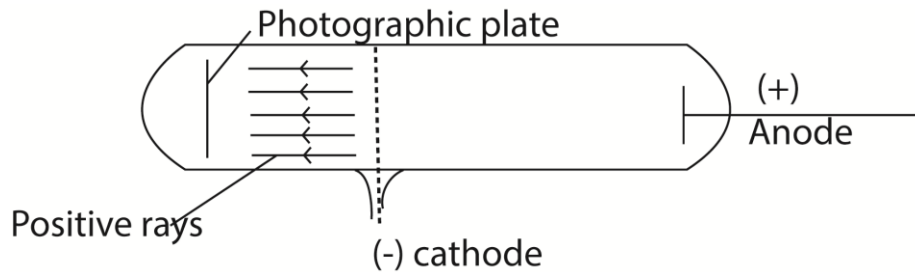
Current increases rapidly for small increase (change) in p.d. because secondary ionization takes place due to primary ions being produced. This implies many ion pairs, thus a larger current detected.

- (ii) Explain how ionization chamber can be used to detect ionization radiation (04marks)



- A radiation source on the brass flat form causes ionization of air in the chamber producing electrons and positive ions.
- The electrons move to the metal can and positive ions drift to the central metal rod.
- Movement of the ions to the electrodes causes discharge and current pulse flows in external circuit.
- The current sensitive detector detects current.
- The magnitude of current detected shows the extent to which ionization takes place.

18. (a) Explain briefly how positive rays are produced (03marks)



- Positive rays are produced when a stream of electrons is passed through a vapor (gas) in discharge tube.
- The electrons dislodge electrons from the atoms producing positively charged ions.
- The positive ions are accelerated towards perforated cathode.
- The ions pass through the slits and are further accelerated.
- These ions constitute a stream of positive rays.

(b) An electron of charge, e , and mass, m , is emitted from a hot cathode and then accelerated by an electric field towards the anode. If the potential difference between the cathode and the anode is V , show that the speed of the electron, u , is given by

$$u = \sqrt{\left(\frac{2eV}{m}\right)} \quad (03\text{marks})$$

Gain in K.E = work done on an electron by the accelerating p.d, V

$$\frac{1}{2}mu^2 = eV$$

$$\therefore u = \sqrt{\frac{2eV}{m}}$$

(c) An electron starts from rest and moves in an electric field intensity of $2.4 \times 10^3 \text{Vm}^{-1}$.

Find the

(i) force on the electron (02 marks)

Force, F , on electron

$$F = eE = 1.6 \times 10^{-19} \times 2.4 \times 10^3 = 3.84 \times 10^{-16} \text{N}$$

(ii) acceleration of the electron. (02marks)

From $F = ma$

$$a = \frac{F}{m} = \frac{3.84 \times 10^{-16}}{9.11 \times 10^{-31}} = 4.22 \times 10^{14} \text{ms}^{-1}$$

(iii) velocity acquired in moving through a p.d of 90V (02marks)

$$\text{From } u = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 90}{9.11 \times 10^{-31}}} = 5.62 \times 10^6 \text{ms}^{-1}$$

(d) A beam of electrons each of mass, m , and charge, e , is directed horizontally with speed, u , into an electric field between two horizontal metal plates separated by a distance, d .

(i) If the p.d between the plates is V, show that the deflection y of the beam is given by

$$y = \frac{1}{2m} \left(\frac{eV}{du^2} \right) x^2$$

where, x, is the horizontal distance travelled. (06marks)

Horizontal motion, $x = ut$

In the same time, t, vertical displacement

$$y = \frac{1}{2} at^2$$

from $F = ma = eE$

$$\therefore a = \frac{eE}{m}$$

$$y = \frac{eE}{2m} t^2 = \frac{eE}{2m} \left(\frac{x}{u} \right)^2 = \frac{eEx^2}{2mu^2}$$

$$\text{But } E = \frac{V}{d}$$

$$y = \frac{eEx^2}{2mu^2} = \frac{1}{2m} \left(\frac{eV}{du^2} \right) x^2$$

(ii) Explain the path of the electron beam as it emerges out of the electric field. (02marks)

The electron beam continues in a straight path with constant velocity since the electric force on it is zero.

19. (a) The table below shows the energy levels of a hydrogen atom.

Principal quantum number, n	Energy, eV
6	-0.38
5	-0.54
4	-0.85
3	-1.51
2	-3.39
1	-13.60

(i) Why are the energies for the different levels negative? (01mark)

Work is done in order to remove an electron to infinity.

(ii) Calculate the wavelength of the line arising from a transition from the third to the second level. (03marks)

$$E_3 - E_2 = hf = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E_3 - E_2} = \frac{6.6 \times 10^{-34} \times 3.0 \times 10^8}{(-1.51 + 3.39) \times 1.6 \times 10^{-19}} = 6.58 \times 10^{-7} \text{m}$$

(iii) Calculate the ionization energy in joules of hydrogen atom. (02marks)

$$\text{Ionization energy} = 13.6 \times 1.6 \times 10^{-19} = 2.18 \times 10^{-18} \text{J}$$

(b) Explain the physical processes in an X-ray tube that account for

(i) cut off wavelength (03marks)

Electrons from the cathode strike the target and lose all their kinetic energy in single encounter with the target atoms. This results in the production of the most energetic X-rays photon of maximum frequency and corresponding minimum wavelength ($\lambda_{\min}$) called the cut off wavelength.

(ii) characteristic lines (04marks)

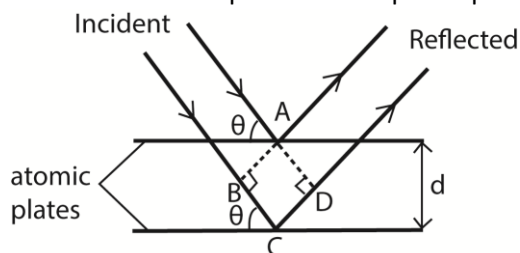
At high tube voltages, the bombarding electron penetrate deep into the atom and knock out the electron from inner shell. The knocked out electron can either be ejected completely out of the atom or it occupies any of the higher shell. This puts an atom in an excited state and the atom therefore becomes unstable. Electron transition from higher shell to a vacancy left in the lower shell results in emission of an X-ray photon of energy equal to the difference between the energy levels.

(c) Calculate the maximum frequency of radiation emitted by an X-ray tube using an accelerating voltage of 33.0kV (03marks)

$$f_{\max} = \frac{eV}{h} = \frac{1.6 \times 10^{-19} \times 33 \times 10^3}{6.6 \times 10^{-34}} = 8.0 \times 10^{18} \text{Hz}$$

(d) Derive Bragg's law of X-ray diffraction in crystals. (04marks)

- A parallel beam of monochromatic X-rays incident on a crystal is reflected from successive atomic planes and super-imposed, forming an interference pattern.



For constructive interference to occur, the path difference is equal to the whole number of wavelength

$$\text{Thus } BC + CD = n\lambda$$

$$\Rightarrow d\sin\theta + d\sin\theta = n\lambda$$

$$\text{or } 2d\sin\theta = n\lambda \text{ where } n = 1, 2, 3, 4 \dots$$

20. (a) A beam of α -particles is directed normally to a thin metal foil

Explain why

(i) Most of the α -particles passed straight through the foil (02marks)

The atoms of the foil contain concentrated mass in a very tiny nuclei surrounded by empty space containing electrons

(ii) Few α -particles are deflected through angles more than 90° . (02marks)

The nucleus a very small space of an atom. Therefore very few α -particles are incident close to it that are strongly repelled.

(b) Calculate the least distance of approach of a 3.5MeV α -particles to the nucleus of a gold atom. (Atomic number of gold= 79) (04marks)

Initial K.E = eV = P.E at the closest distance of approach; Z = 79

$$\begin{aligned} \text{eV} &= \frac{2e \times Ze}{4\pi\epsilon_0 d} \\ &= \frac{2e^2 Z}{4\pi\epsilon_0 d} \end{aligned}$$

$$3.5 \times 10^6 \times 1.6 \times 10^{-19} = \frac{2(1.6 \times 10^{-19})^2 \times 79}{4\pi\epsilon_0 \times d}$$

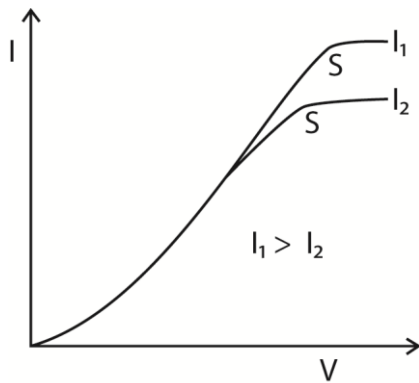
$$d = \frac{2 \times 1.6 \times 10^{-19} \times 79 \times 9 \times 10^9}{3.5 \times 10^6}$$

$$= 6.5 \times 10^{-14} \text{m}$$

(c) (i) Define space charge as applied to thermionic diodes. (01mark)

Space charge is cloud of negative charge around the cathode at low anode potential difference.

(ii) Draw anode current-diode voltage curves of a thermionic diode for two different filament currents and explain their main features. (06marks)



The current increases with the positive anode potential as far as the point S. Beyond this point the current does not increase, because the anode is collecting all the electrons emitted by the filament ; the current is said to be saturated.

(d) (i)What is a decay constant?

Decay constant is the fractional number of disintegrations per second.

- (ii) A sample from fresh wood of a certain species of tree has activity of 16.0 counts per minute per gram. However, the activity of 5g of dead wood of the same species of tree is 10 counts per minute. Calculate the age of the deadwood. (Assume half-life of 5730years) (04marks)

$$\text{From } N = N_0 e^{-\lambda t}$$

$$\lambda = \frac{0.693}{5730} = 1.21 \times 10^{-4} \text{ per year}$$

$$A = \frac{10}{5} = 2.0 \text{ min}^{-1} \text{ g}^{-1}$$

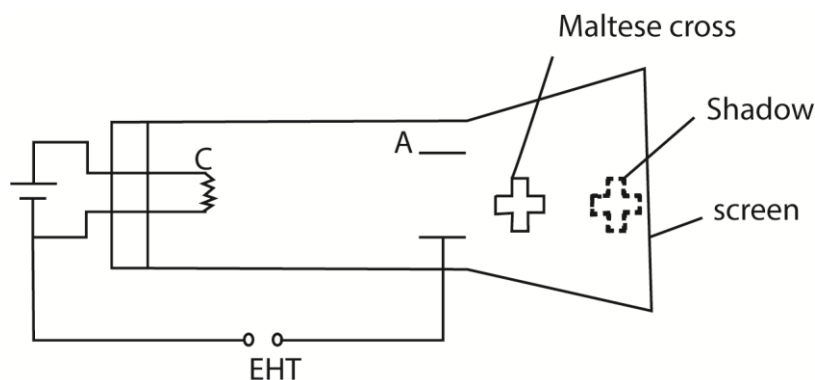
$$2 = 16e^{-1.21 \times 10^{-4} t}$$

$$t = 1.719 \times 10^4 \text{ years}$$

21. (a) (i) What are cathode rays?

Cathode rays are stream of fast moving electrons

- (ii) With the aid of a diagram, describe an experiment to show that cathode rays travel in straight line (04marks)



Electrons emitted from the cathode, C are accelerated by the anode A towards a Maltese cross placed in the center of the glass tube. A sharp shadow of the Maltese cross is cast on the screen at the end of the tube. This shows that cathode rays travel in a straight line.

- (b) A beam of electrons is accelerated through a potential difference of 500V. The beam enters midway between two similar parallel plates of length 10cm and are 3cm apart. If the potential difference across the plates is 600V, find the velocity of an electron as it leaves the region between the plates. (08marks)

$$eV = \frac{1}{2} mu^2$$

$$1.6 \times 10^{-19} \times 500 = \frac{1}{2} \times 9.11 \times 10^{-31} \times u^2$$

$$u = 1.33 \times 10^7 \text{ ms}^{-1}$$

$$\text{Horizontal component is constant} = u_x = 1.33 \times 10^7 \text{ ms}^{-1}$$

$$\text{Vertically, } F = eE = ma, \text{ but } E = \frac{V}{d}$$

$$a = \frac{eV}{md} = \frac{1.6 \times 10^{-19} \times 600}{9.11 \times 10^{-31} \times 3 \times 10^{-2}} = 3.5 \times 10^{15} \text{ms}^{-2}$$

$$v_y = u_y + at \text{ where } t = \frac{L}{u_x}$$

$$v_y = 3.5 \times 10^{15} \times \frac{0.1}{1.33 \times 10^7} = 2.6 \times 10^7 \text{ms}^{-1}$$

$$v = \sqrt{v_y^2 + u_x^2} = \sqrt{(2.6 \times 10^7)^2 + (1.33 \times 10^7)^2}$$

$$= 2.92 \times 10^7 \text{ms}^{-1}$$

Direction

$$\tan\theta = \frac{v_y}{v_x} = \frac{2.6 \times 10^7}{1.33 \times 10^7} = 1.7$$

$$\theta = 86.6^\circ \text{ to the horizontal}$$

(c) State the laws of photoelectric emission (04marks)

- The time lag between irradiation of the metal surface and emission of the electrons by the metal surface is negligible.
- For a given metal, surface there is a minimum value of frequency of radiation called threshold frequency (f_0) below which no photo electrons are emitted from the metal however intense the incident radiation may be.
- The number of photoelectrons emitted from the surface per second is directly proportional to the intensity of incident radiation for a particular incident frequency
- The K.E of the photoelectrons emitted is independent of the intensity of the incident radiation but depends only on its frequency

(d) Explain how line emission spectra are produced. (03marks)

When a gas is heated to high temperature, atoms are excited and electrons jump to high energy levels. When the electrons fall back to the lower energy levels, they emit radiations of definite wavelength.

Alternatively

When energetic electrons penetrate the atoms, electrons from innermost energy levels are displaced to high energy levels. When the electrons fall back to lower energy levels, they emit radiations of definite wavelength of frequency

22. (a) (i) what is meant by terms: radioactive decay, half-life and decay constant? (03marks)

Radioactive decay is the spontaneous disintegration of unstable radioactive nuclei into stable nuclei with emission of radiations.

Half-life is the time taken for half the number of nuclei present to disintegrate.

Decay constant is the fraction of number of nuclei disintegration per second.

(ii) Show that the half-life, $t_{1/2}$ of a radioactive isotope is given by $t_{1/2} = \frac{0.693}{\lambda}$ where λ is the decay constant

(Assume the decay law $N = N_0 e^{-\lambda t}$)

$$\text{At } t = t_{1/2}, N = \frac{N_0}{2}$$

$$\Rightarrow \frac{N_0}{2} = N_0 e^{-\lambda t_{1/2}}$$

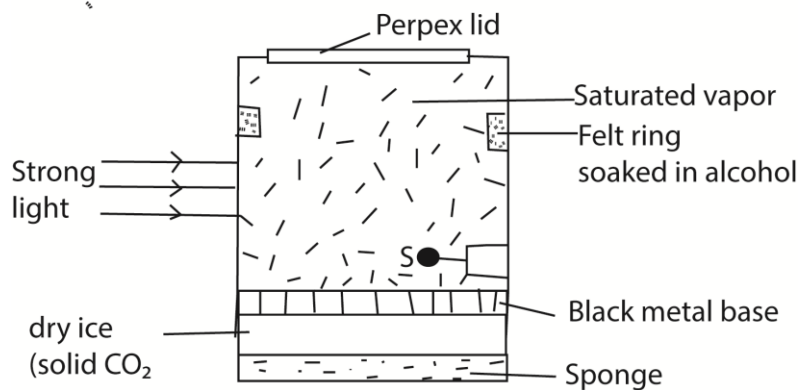
$$\frac{1}{2} = e^{-\lambda t_{1/2}}$$

$$\ln 2 = \lambda t_{1/2}$$

$$t_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$$

(b) With the aid of a labelled diagram, describe the structure and action of a cloud chamber
(05marks)

The diffusion cloud chamber

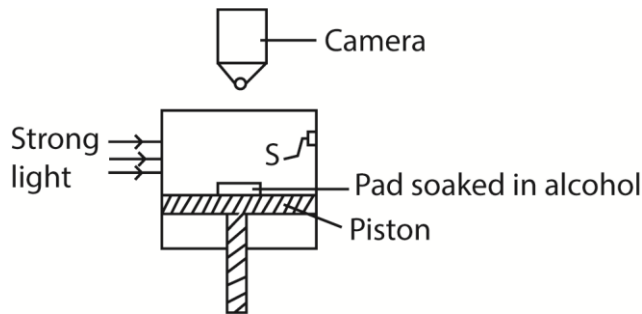


- The base of the chamber is maintained at low temperature, about -80°C by the solid carbon dioxide while the top of the chamber is at room temperature, and so there is a temperature gradient between the top and the bottom of the chamber.
- The air at the top of the chamber is saturated with alcohol vapor from the felt ring. This vapor continuously diffuses downwards into the cooler regions so that the air at the chamber is super saturated with alcohol vapor.
- Radiations from the radioactive source S cause the ionization of the vapor.
- The ionizations from the radioactive source S cause condensation of the vapor on the ions formed, hence the path of the ionizing radiations are traced by series of small droplets of condensation.
- The thickness and length of the path indicate the extent to which ionization has taken place.

- Alpha particles produce short, thick, continuous straight tracks
- Beta particles which are less massive produce longer, thin but straggly paths owing to collisions with gas molecules
- Gamma radiations are uncharged and for ionization to take place, it must collide with an atom and eject an electron which then ionizes the vapor.

Alternatively

The Wilson cloud chamber



Mode of action

When the piston is quickly moved, the air in the chamber is saturated with alcohol vapour undergoes an adiabatic expansion and it cools.

The dust particles are carried away leaving behind air which is dust free. This is then subjected to controlled expansion making it super saturated.

It is then simultaneously subjected to ionizing radiation from a source, S. the vapour condenses on the ions formed to form water droplets around the ions

These are then illuminated and photographed by the camera.

The nature of the path formed reveals the type of ionizing agent.

- (c) A radioactive isotope $^{99}_{43}\text{X}$ decays by emission of a gamma ray. The half-life of the isotope is 360 minutes. What is the activity of 1mg of the isotope? (06marks)

$$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$$

99g of X contain 6.02×10^{23} atoms

1mg of X contains $\frac{1 \times 10^{-3}}{99} \times 6.02 \times 10^{23} = 6.08 \times 10^{18}$ atoms

$$\text{Activity} = \lambda N = \frac{0.693}{360 \times 60} \times 6.08 \times 10^{18} = 1.95 \times 10^{14} \text{ s}^{-1}$$

- (d) Explain the term avalanche as applied to an ionization chamber. (03marks)

An avalanche is a large number of moving ionized particles created as a result of secondary ionization due to collision between ions and gaseous atoms when electrons are accelerated by high p.d. whereby each ion pair formed causes further ionization of the gas.

23. (a) Define the terms below as applied to a triode

(i) space charge (01mark)

Space charge is the cloud of electrons formed around the cathode when the p.d. across the tube is not enough to attract all emitted electrons.

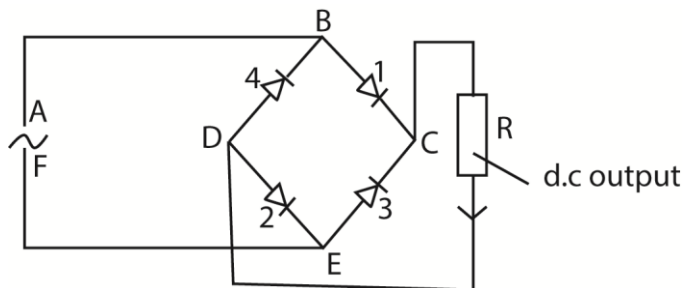
(ii) Amplification factor (01mark)

Amplification factor is the ratio of change in anode voltage to change in grid voltage at constant current

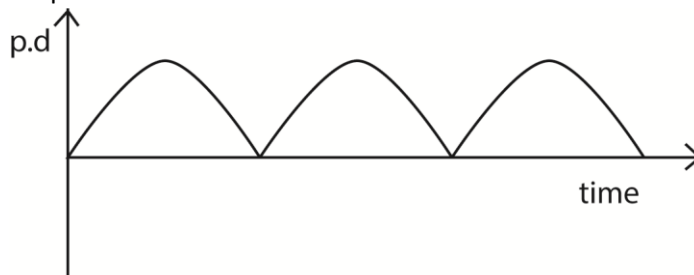
(iii) Mutual conductance (01mark)

Mutual conductance is the ratio of change in anode current to change in grid voltage at constant anode voltage

(b) With the aid of a labelled diagram explain full wave rectification. (07marks)



- Four diodes are arranged in a bridge network as shown above.
- If A is positive during the first half cycle, diode 1 and 2 conduct and current takes the path ABCRDEF
- In the next half cycle when F is positive, diode 3 and 4 conduct and current flows through the path FECRDBA
- Once again current flows through R in the same direction during both cycles of input and d.c output is obtained.



(c) Derive an expression for the amplification factor, μ , in terms of anode resistance, R_a and mutual conductance, g_m , for a triode valve. (03marks)

$$\text{Amplification factor, } \mu = \frac{\Delta V_a}{\Delta V_g} \times \frac{\Delta I_g}{\Delta I_a}$$

$$= \frac{\Delta V_a}{\Delta I_a} \times \frac{\Delta I_g}{\Delta V_g}$$

But $\frac{\Delta V_a}{\Delta I_a} = R_a$ and $\frac{\Delta I_g}{\Delta V_g} = g_m$

$$\therefore \mu = R_a \times g_m$$

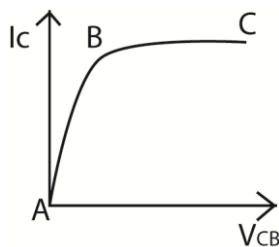
- (d) A triode with mutual conductance 3mA/V^{-1} and anode resistance of $10\text{k}\Omega$ is connected to a load resistance of $20\text{k}\Omega$, Calculate the amplitude of output signal, if the input signal is 25mV . (04marks)

$$g_m = 3.0 \times 10^{-3} \text{AV}^{-1}, R_a = 10 \times 10^3 \Omega, R_L = 20 \times 10^3 \Omega$$

$$\text{Voltage gain} = \frac{\mu R_L}{R_L + R_a} = \frac{R_a \times g_m \times R_L}{R_L + R_a} = \frac{10 \times 10^3 \times 3 \times 10^{-3} \times 20 \times 10^3}{20 \times 10^3 + 10 \times 10^3} = 20$$

$$\text{Magnitude of output signal} = 20 \times 25 \times 10^{-3} = 0.50\text{V}$$

- (e) (i) Sketch the output characteristics of a transistor. (02marks)

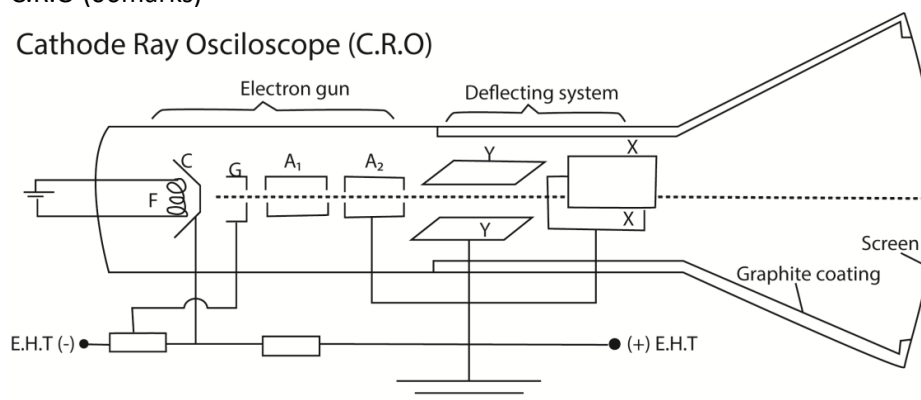


- (ii) Identify on the sketch in (e)(i), the region over which the transistor can be used as amplifier. (01).

Linear region BC

24. (a) (i) Describe with the aid of a well labelled diagram, the structure and mode of operation of a C.R.O (06marks)

Cathode Ray Oscilloscope (C.R.O)



A- Anodes

G- Grids

B- Cathode

C- Y and X- deflecting system

The cathode ray oscilloscope consists of

- (i) Electron gun produces electron by thermionic emission
- (ii) Anodes accelerate electrons
- (iii) Y and X- plates deflect electrons vertically and horizontally respectively
- (iv) The screen is coated with zinc sulphide to glow when hit by electron
- (v) Time base is connected to X- plates and provides a saw tooth p.d that sweep the electron spot from left to right of the screen at steady speed

(ii) State the advantages of C.R.O over a moving coil voltmeter. (02marks)

- draws very little current
- measures both alternating and direct voltages
- has no coil to burn out
- gives instantaneous response

(b) In the determination of the electron charge by Millikan's method, a potential difference of 1.5kV is applied between horizontal metal plates, 12mm apart. With the field switched off, a drop of oil of mass 1.0×10^{-14} kg is observed to fall with constant velocity, $4 \times 10^{-4} \text{ms}^{-1}$ between two metal plates. When a potential difference of 1.5kV is applied across the plates, the drop rises with constant velocity of $8.0 \times 10^{-5} \text{ms}^{-1}$.

How many electron charges are there on the drop? (Assume air resistance is proportional to the velocity of the drop and neglect air buoyancy).

$$mg = kv_1$$

$$k = \frac{9.81 \times 10^{-14}}{4 \times 10^{-4}}$$

$$Eq - mf = kv_2 \quad \text{But } E = \frac{V}{d} = \frac{1.5 \times 10^3}{12 \times 10^{-3}}$$

$$\Rightarrow \frac{1.5 \times 10^3}{12 \times 10^{-3}} Q - 9.81 \times 10^{-14} = \frac{9.81 \times 10^{-14}}{4 \times 10^{-4}} \times 8.0 \times 10^{-5}$$

$$Q = 9.4176 \times 10^{-19} \text{C}$$

$$\text{But } Q = ne$$

$$n = \frac{9.4176 \times 10^{-19}}{1.6 \times 10^{-19}} = 6$$

(c) Explain why

(i) the apparatus in Millikan's experiment is surrounded with a constant temperature enclosure, (03marks)

- to keep the density oil and air constant
- to eliminate conventional currents

(ii) low vapor-pressure oil is used. (02marks)

- to maintain the size of the drop by minimizing evaporation

(d) In Millikan's experiment, the radius, r , of the drop is calculated from

$$r = \sqrt{\frac{9\eta v}{2\rho g}}$$

where η is the viscosity of air and ρ is the density of oil.

Identify the symbol v and describe briefly how it is measured. (02mark)

v = terminal velocity; it is measure by measuring the time t taken by the drop to fall through a known distance S . then $v = \frac{S}{t}$.

25. (a) (i) Explain how X-rays are produced in an X-ray tube (04 marks)

- The cathode is heated and electrons emitted by thermionic emission.
- The electrons are accelerated by tube voltage towards the metal target.
- When the high energy electrons strike the metal target X-rays are produced with liberation of heat

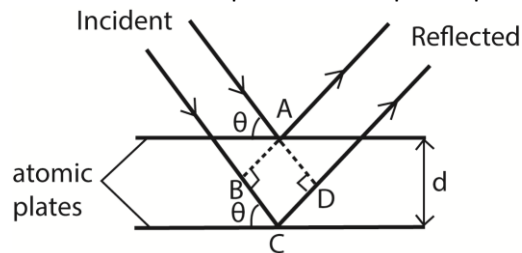
(ii) Explain the emission of X-ray characteristic spectra. (03 marks)

When an energetic electron strikes the metal target, it dislodges electrons from the innermost shell of the atom of the metal target. This creates vacancies in the inner shell making the atom unstable.

When electrons fall back to occupy the vacant orbits left, X-rays are produced of definite frequency characteristic of the atoms of target metal.

(iii) Derive the Bragg X-ray diffraction equation (04marks)

- A parallel beam of monochromatic X-rays incident on a crystal is reflected from successive atomic planes and super-imposed, forming an interference pattern.



For constructive interference to occur, the path difference is equal to the whole number of wavelength

Thus $BC + CD = n\lambda$

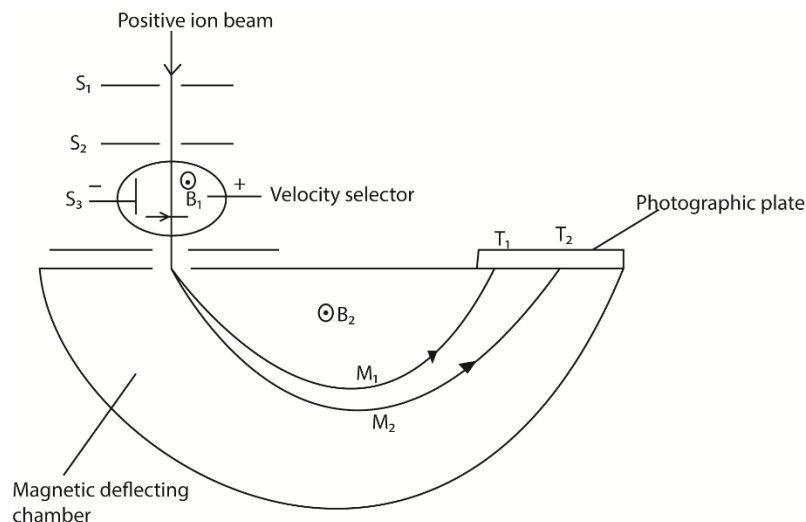
$$\Rightarrow d\sin\theta + d\sin\theta = n\lambda$$

$$\text{or } 2d\sin\theta = n\lambda \text{ where } n = 1, 2, 3, 4 \dots$$

(iv) Under what conditions does X-ray diffraction occurs? (02marks)

- Wavelength of X-ray must be of the same order as the interplanar spacing.
- Parallel beam of X-ray must be incident on the planes

(b) With the aid of a labelled diagram, describe how a Bainbridge mass spectrometer is used to measure specific charge. (07marks)



T₁ and T₂ are tracers on photographic plate, S₁, S₂ and S₃ are slits

Mode of Action

- Positive ions are produced in a discharge tube and admitted as a beam through slits S₁ and S₂.
- The beam then passes between insulated plates P, Q, connected to a battery, which create an electric field of intensity E.
- A uniform magnetic field B₁, perpendicular to E is applied over the region of the plates and all ions, charge e with the same velocity, v given by B₁ev = Ee will then pass undeflected through the plates and through a slit S₃.
- The selected ions are deflected in a circular path of radius r by a uniform perpendicular magnetic field B₂ and an image is produced on a photographic plate as shown.

In this case

$$\frac{mv^2}{r} = B_2 ev$$

$$\therefore \frac{m}{e} = \frac{rB_2}{v}$$

But for the ions selected $v = \frac{E}{B_1}$ from above

$$\text{Specific charge, } \frac{e}{m} = \frac{E}{rB_2B_1}$$

26. (a) What is meant by unified atomic mass unit? (01mark)

Unified atomic unit is one twelfth the mass of one atom of carbon-12

(b) (i) Distinguish between nuclear fusion and nuclear fission (02marks)

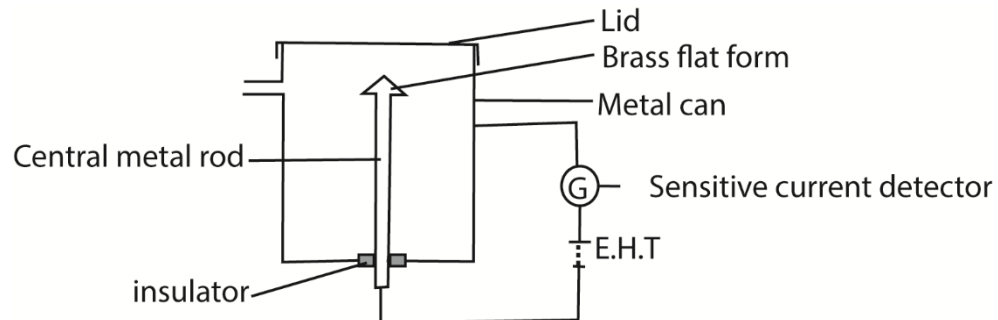
Nuclear fusion is the process where two light nuclei combine to form a heavier nuclei accompanied by release of energy

Nuclear fission is a process where a heavy nucleus splits into two lighter nuclei accompanied by release of energy.

(ii) State the conditions necessary for each of the nuclear reaction in (b) (i) to occur. (02marks)

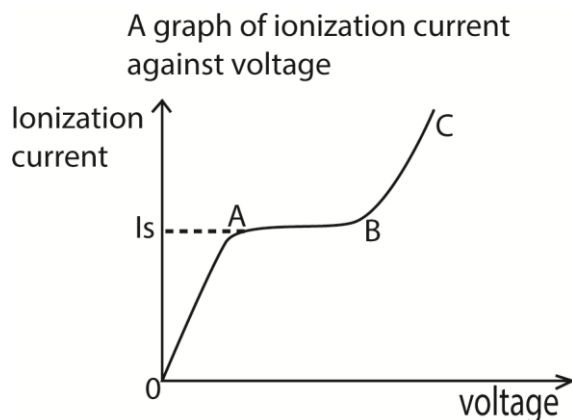
- Fusion requires very high temperature
- Fission requires energetic bombarding particles or heavy unstable nuclei.

(c) (i) With the aid of a labelled diagram, describe the operation of an ionization chamber. (06marks)



- A radiation source on the brass flat form causes ionization of air in the chamber producing electrons and positive ions.
- The electrons move to the metal can and positive ions drift to the central metal rod.
- Movement of the ions to the electrodes causes discharge and current pulse flows in external circuit.
- The current sensitive detector detects current.
- The magnitude of current detected shows the extent to which ionization takes place.

(ii) Sketch the curve of ionization current against applied p.d and explain its main features. (04marks)



Region OA:

Current detected increases gradually but p.d is not large enough to prevent recombination of the ions.

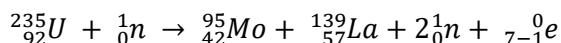
Region AB. (saturation region)

Current is almost constant, all ions reach the electrode before recombination but there is no secondary ionization.

Region BC (gas amplification)

Current increases rapidly for small increase (change) in p.d. because secondary ionization takes place due to primary ions being produced. This implies many ion pairs, thus a larger current detected.

(d) A typical nuclear reaction is given by:



Calculate the total energy released by 1g of uranium. (05marks)

$$\text{Mass of } {}_0^1\text{n} = 1.009\mu$$

$${}_{-1}^0\text{e} = 0.00055\mu$$

$${}_{42}^{95}\text{Mo} = 94.906\mu$$

$${}_{57}^{139}\text{La} = 138.906\mu$$

$${}_{92}^{235}\text{U} = 235.044\mu$$

$$1\mu = 1.66 \times 10^{-27} \text{ kg}$$

Solution

$$\text{Total mass on the left hand side} = 235.044 + 1.009 = 236.053\text{U}$$

$$\text{Total mass on the right hand side} = (94.906 + 138.906 + 2 \times 1.009 + 0.00055)\text{U} = 235.83385\text{U}$$

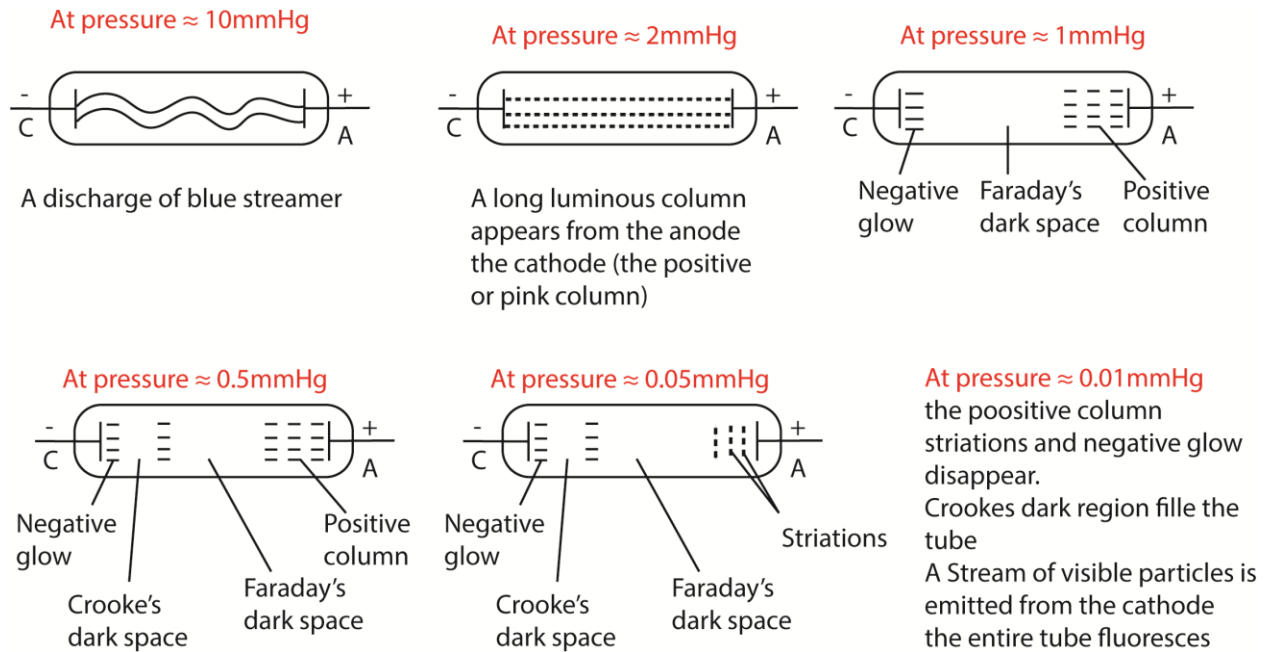
$$\text{Mass defect} = 236.053 - 235.83385 = 0.21915\text{U}$$

$$\text{Energy released} = mc^2 = 0.21915 \times 1.66 \times 10^{-27} \times (3 \times 10^8)^2 = 3.274 \times 10^{-11} \text{ J}$$

$$\text{Number of atoms in 1g of uranium} = \frac{1}{235} \times 6.02 \times 10^{23}$$

$$\text{Total energy released} = \frac{1}{235} \times 6.02 \times 10^{23} \times 3.274 \times 10^{-11} = 8.387 \times 10^{10} \text{ J}$$

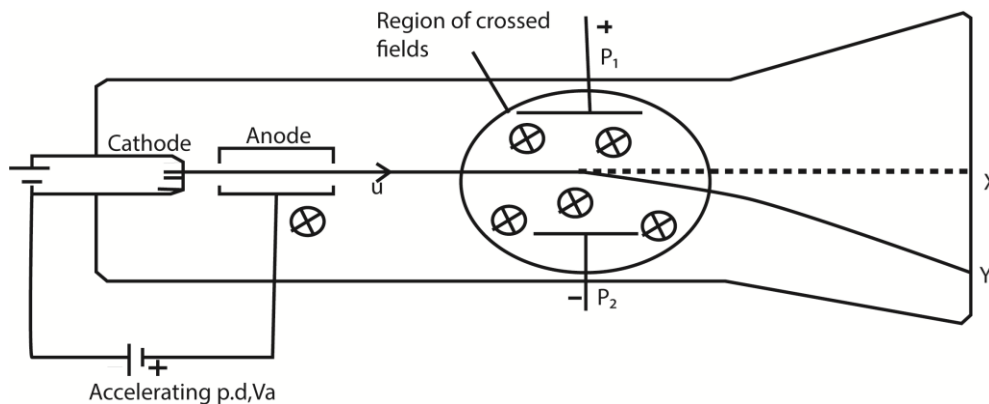
27. (a) (i) With the aid of a labelled diagram, describe what is observed when a high tension voltage is applied across a gas tube in which pressure is gradually reduced to vary low value. (05marks)



(ii) Give two applications of discharge tubes. (01mark)

- Making mercury lamps, sodium lamps
- Neon signs
- Florescent tubes

(b) Describe Thomson's experiment to determine the specific charge of an electron. (06marks)



- The electrons are produced thermionically by a hot filament cathode and are accelerated towards a cylindrical anode and pass through it.
- The small hole on the anode confines the electrons to a narrow beam.

- When both the electric field and the magnetic field are off, the electrons reach the screen at X and cause fluorescence.
- If the velocity of the electrons on emerging from the anode is u then

$$eVa = \frac{1}{2}mu^2$$

$$\Rightarrow \frac{e}{m} = \frac{u^2}{2Va} \dots\dots\dots (i)$$

Where Va is the accelerating voltage between the cathode and anode.

- The magnetic field is switched on and the beam is deflected to position Y.
- In order to bring the beam back to the original position X, the electric field is switched on and adjusted until the beam is at X again.
- This implies that The magnetic force = the electric force

$$Beu = eE$$

$$\therefore u = \frac{E}{B} \dots\dots\dots (ii)$$

Substituting eqn. (ii) in (i)

$$\frac{e}{m} = \frac{E^2}{2B^2Va} \quad \text{but } E = \frac{V}{d}$$

$$\therefore \frac{e}{m} = \frac{V^2}{2B^2d^2Va} \quad \text{where, } V \text{ is the p.d between the plates at separation of } d \text{ apart}$$

(c) In a Millikan's experiment, a charged oil drop of radius $9.2 \times 10^{-7}\text{m}$ and density 800kgm^{-3} is held stationary in an electric field of intensity $4.0 \times 10^4\text{Vm}^{-1}$.

[Density of air = 1.29kgm^{-3} , coefficient of viscosity of air = $1.8 \times 10^{-5}\text{Nsm}^{-1}$]

(i) How many electron charges are on the drop? (04marks)

$$mg = U + Eq$$

$$\frac{4}{3}\pi r^3 \rho g = \frac{4}{3}\pi r^3 \sigma g + Eq$$

$$q = \frac{\frac{4}{3}\pi r^3 (\rho - \sigma)g}{E} = \frac{\frac{4}{3}\pi \times (9.2 \times 10^{-7})^3 (800 - 1.29) \times 9.81}{4 \times 10^4} = 6.39 \times 10^{-19}$$

$$n = \frac{q}{e} = \frac{6.39 \times 10^{-19}}{1.6 \times 10^{-19}} = 4$$

(ii) Find the electric field intensity that can be applied vertically to move the drop with velocity 0.005ms^{-1} upwards.

$$Mg + Fv = U + Eq$$

$$E = \frac{mg - U + Fv}{q} = \frac{\frac{4}{3}\pi r^3 (\rho - \sigma)g + Fv}{q} = \frac{\frac{4}{3}\pi r^3 (\rho - \sigma)g + 6\pi \eta r v_0}{q}$$

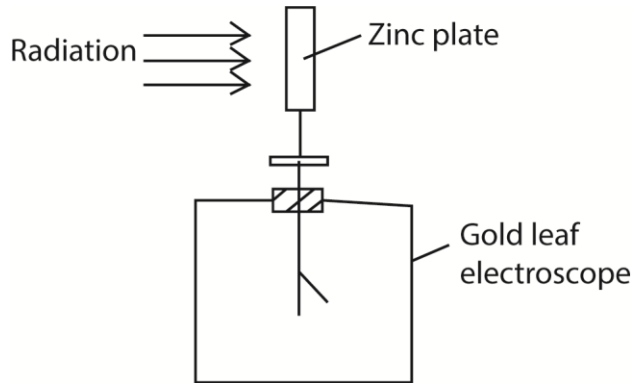
$$= \frac{\frac{4}{3}\pi \times (9.2 \times 10^{-7})^3 (800 - 1.29) \times 9.81 + 6\pi \times 1.8 \times 10^{-5} \times 9.2 \times 10^{-7} \times 0.005}{1.6 \times 10^{-19}}$$

$$= 2.48 \times 10^6 \text{Vm}^{-1}$$

28. (a) Explain what is meant by photoelectric effect. (02marks)

Emission of electrons from clean metal surface struck by electromagnetic radiations of high energy.

(b)



Ultraviolet and infrared radiations are directed in turns on to a zinc plate which is attached to a gold leaf electroscope as shown in the figure above

Explain that happens when

- (i) Ultraviolet radiation falls on the zinc plate (02marks)
Electrons will be emitted and a net positive charge will be left on the zinc plate. Both the plate and the leaf acquire a positive charge and the leaf diverge.
- (ii) Infrared falls on the zinc plate. (01mark)
Infrared has low frequency, therefore no electrons will be emitted from the zinc plate and the leaf will not diverge.
- (iii) The intensity of each radiation is increased. (02marks)
In case of ultraviolet, more electrons will be emitted per second and the leaf diverges rapidly
In case of infrared, the leaf does not diverge because the frequency is low

(c) An X-ray of wavelength 10^{-10}m is required for the study of its diffraction in a crystal. Find the least accelerating voltage to be applied on an X-ray tube in order to produce these X-rays. (04marks)

$$E = h\frac{c}{\lambda} = 6.6 \times 10^{-34} \times \frac{3 \times 10^8}{10^{-10}} = 1.98 \times 10^{-15}\text{J}$$

$$\text{Energy of electron} = eV = 1.98 \times 10^{-15}\text{J}$$

$$V = \frac{1.98 \times 10^{-15}}{1.6 \times 10^{-19}} = 1.24 \times 10^4\text{V}$$

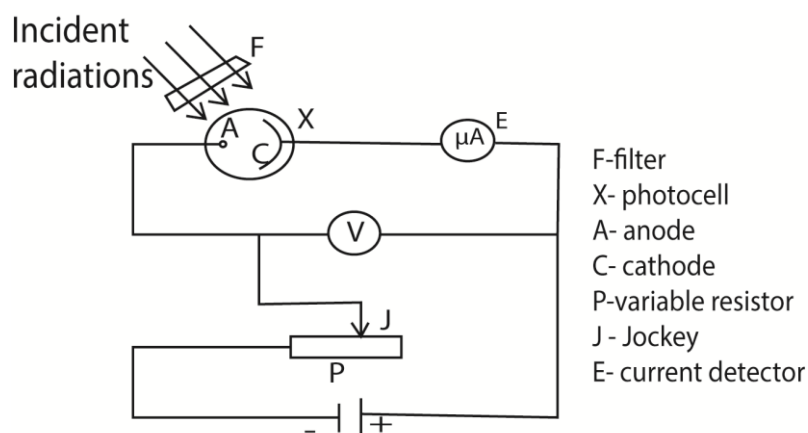
(d) Sodium has a work function of 2.0eV and is illuminated by radiation of wavelength 150nm. Calculate the maximum speed of the emitted electrons. (04marks)

$$\text{K.E} = h\frac{c}{\lambda e} - w_0$$

$$\frac{1}{2} \times 9.11 \times 10^{-31} v^2 = \left(\frac{6.6 \times 10^{-34}}{1.6 \times 10^{-19}} \times \frac{3 \times 10^8}{150 \times 10^{-9}} - 2.0 \right) \times 1.6 \times 10^{-19}$$

$$v = 1.48 \times 10^6 \text{ms}^{-1}$$

(e) With the aid of a well labelled diagram, describe how stopping potential of a metal can be measured. (05marks)

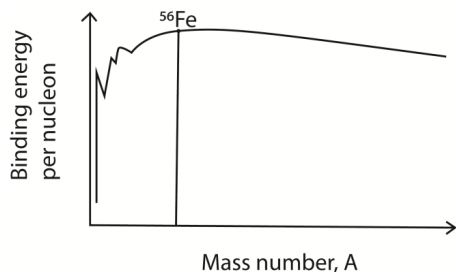


- An evacuated electric cell X that has inside it a photo-emissive metal cathode, C of large surface area and an anode A for collecting the electron produced
- A is made negative in potential relative to C.
- The photoelectrons emitted from C when illuminated with a suitable beam experience a retarding potential.
- The p.d V is increased negatively until the current become zero and the stopping potential V_s is noted from the voltmeter.

29. (a) (i) What is meant by mass defect? (01marks)

Mass defect is the difference in sum of mass of the components of the nucleus and the mass of the nucleus

(ii) Sketch a graph showing how binding energy per nucleon varies with mass number and explain its features. (03marks)



Binding energy increases rapidly from mass number=1 to a peak of mass number, A = 56 and then decreases gradually.

(iii) Find the binding energy per nucleon of ${}^{56}_{26}\text{Fe}$ given that

Mass of 1 proton = 1.007825u

Mass of 1neutron = 1.008665u

[1u = 931MeV) (03marks)

Solution

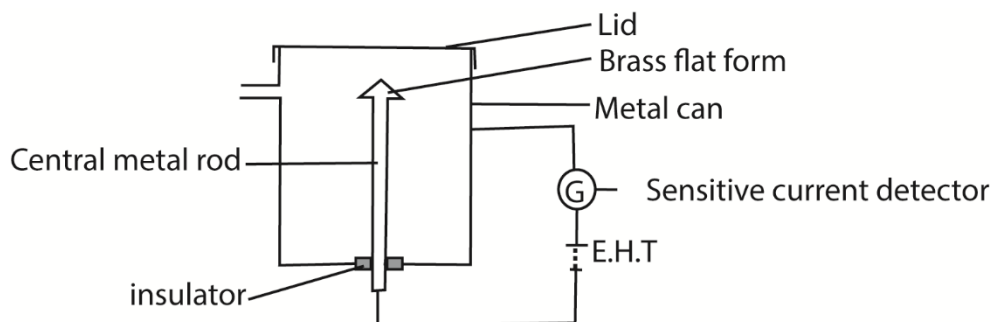
Binding energy = $(26 \times 1.007825 + 30 \times 1.008665 - m_f)U$

where m_f is the mass of the nucleus of Fe-56

Binding energy = $(56.4634 - m_f) \times 931\text{eV}$

Binding energy per nucleon = $\frac{(56.4634 - m_f) \times 931}{56}\text{eV}$

(b) With the aid of a diagram, explain how an ionization chamber works (06marks)



- A radiation source on the brass flat form causes ionization of air in the chamber producing electrons and positive ions.
- The electrons move to the metal can and positive ions drift to the central metal rod.
- Movement of the ions to the electrodes causes discharge and current pulse flows in external circuit.
- The current sensitive detector detects current.
- The magnitude of current detected shows the extent to which ionization takes place.

(c) (i) Show that an alpha particle collides head on with an atom of atomic number, Z , the closest distance of approach to the nucleus X_0 is given by

$$X_0 = \frac{ze^2}{\pi\epsilon_0 mv^2}$$

Where

e is electronic charge

ϵ_0 is permittivity of free space

m is mass of alpha particle

v is initial speed of alpha particle (04marks)

charge on ${}^4_2\text{He} = 2e$

charge on atomic nucleus = Ze

kinetic energy of ${}^4_2\text{He} = \frac{1}{2}mv^2$ where v= speed of collision

Electrostatic potential energy = $\frac{1}{4\pi\epsilon_0} \times \frac{(Ze)(2e)}{x_0}$

At closest distance x_0 of approach;

Kinetic energy = electrostatic potential energy

$$\frac{1}{2}mv^2 = \frac{2Ze^2}{4\pi\epsilon_0 x_0}$$

$$x_0 = \frac{Ze^2}{\pi\epsilon_0 v^2}$$

(ii) In a head on collision between an alpha particle and a gold nucleus, the minimum distance of approach is $5 \times 10^{-14}\text{m}$. Calculate the energy of alpha particle (in MeV)

[atomic number of gold= 79]

$$\text{Kinetic energy} = \frac{1}{2}mv^2 = \frac{2Ze^2}{4\pi\epsilon_0 x_0} = \frac{9 \times 10^9 \times 2 \times 79 \times (1.6 \times 10^{-19})^2}{5 \times 10^{-15}} = 7.28 \times 10^{-13}\text{J} = 4.55\text{MeV}$$

30. (a) State four differences between cathode rays and positive rays (02marks)

Cathode ray	Positive ray
Negatively charged	Positively charged
Produce X-rays on striking matter	Do not produce x-ray on striking matter
Deflected towards anode and north pole of the magnet	Deflected towards cathode and south pole of the magnet

(b) An electron having energy of $4.5 \times 10^2\text{eV}$ moves at right angles to a uniform magnetic field of flux density $1.5 \times 10^{-3}\text{T}$. Find the

(i) radius of the path followed by the electron. (04marks)

$$\frac{1}{2}m_e v^2 = eV$$

$$u = \sqrt{\frac{2eV}{m_e}}$$

$$Beu = \frac{m_e u^2}{r} \Rightarrow r = \frac{m_e u}{eB}$$

$$r = \frac{1}{B} \sqrt{\frac{2m_e V}{e}} \text{ but } \frac{e}{m_e} = 1.8 \times 10^{11}$$

$$\therefore r = \frac{1}{1.5 \times 10^{-3}} \sqrt{\frac{2 \times 450}{1.8 \times 10^{11}}} = 4.71 \times 10^{-2} \text{m}$$

(ii) period of the motion. (03marks)

$$T = \frac{2\pi r}{u} = 2\pi r \sqrt{\frac{m_e}{2eV}} = 2\pi \times 4.71 \times 10^{-2} \sqrt{\frac{1}{2} \times \frac{1}{1.8 \times 10^{11}} \times \frac{1}{450}} = 2.32 \times 10^{-8} \text{s}$$

(c) (i) Define the term Avogadro constant and Faraday constant (02marks)

Avogadro constant is the number of atoms or molecules in one mole of a substance.

Faraday's constant is the quantity of charge required to deposit one mole of a monovalent element.

(ii) Use the Avogadro constant and Faraday constants to calculate the charge on anion of monatomic element. (03marks)

$$\text{Charge} = \frac{F}{N_A} = \frac{96500}{6.02 \times 10^{23}} = 1.6 \times 10^{-19} \text{C}$$

(d) Explain the meaning of the following terms as applied to a Geiger-Muller tube.

(i) threshold potential difference (02marks)

Threshold p.d is the minimum p.d below which no pulse can be detected. This is because there is no sufficient gas amplification.

(ii) Dead time (02marks)

Dead time is the time ions take to travel towards the cathode before the electric field at the cathode returns to level large enough for an avalanche to start. Ionizing particles arriving within this time will not be detected.

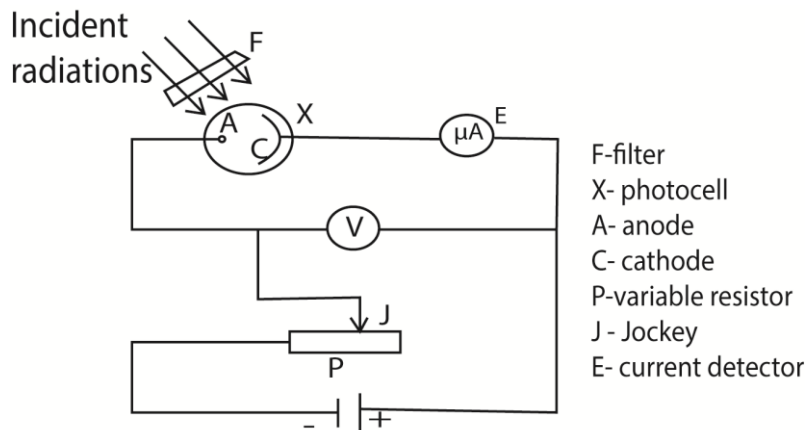
(iii) A quenching agent (02marks)

A quenching agent is a gas or vapour inside a Geiger-Muller tube to ensure that only one pulse is produced by each ionizing particle that enter the tube. It slows down the positive ions and prevent further ionization.

31. (a) State the laws of photoelectric effect (04marks)

- The time lag between irradiation of the metal surface and emission of the electrons by the metal surface is negligible.
- For a given metal, surface there is a minimum value of frequency of radiation called threshold frequency (f_0) below which no photo electrons are emitted from the metal however intense the incident radiation may be.
- The number of photoelectrons emitted from the surface per second is directly proportional to the intensity of incident radiation for a particular incident frequency
- The K.E of the photoelectrons emitted is independent of the intensity of the incident radiation but depends only on its frequency

(b) Describe an experiment to determine the stopping potential of a metal surface. (05 marks)



- An evacuated electric cell X that has inside it a photo-emissive metal cathode, C of large surface area and an anode A for collecting the electron produced
- A is made negative in potential relative to C.
- The photoelectrons emitted from C when illuminated with a suitable beam experience a retarding potential.
- The p.d V is increased negatively until the current become zero and the stopping potential V_s is noted from the voltmeter.

(c) A 100mW beam of light of wavelength $4.0 \times 10^{-7}\text{m}$ falls on caesium surface of a photocell.

(i) How many photons strike the caesium surface per second? (03marks)

$$P = \frac{nhc}{\lambda} \Rightarrow n = \frac{P\lambda}{hc} = \frac{100 \times 10^{-3} \times 4.0 \times 10^{-7}}{6.6 \times 10^{-34} \times 3.0 \times 10^8} = 2.02 \times 10^{17}$$

(ii) If 65% of the photons emit photoelectrons, find the resulting photocurrent. (03marks)

$$65\% \text{ of } n = \frac{65}{100} \times 2.02 \times 10^{17}$$

$$I = ne = \frac{65}{100} \times 2.02 \times 10^{17} \times 1.6 \times 10^{-19} = 2.1 \times 10^{-2}\text{A}$$

(iii) Calculate the kinetic energy of each photon if the work function of caesium is 2.20eV. (03marks)

$$hf = w_0 + \frac{1}{2}mv^2$$

$$K.E = \frac{6.6 \times 10^{-34} \times 3.0 \times 10^8}{4 \times 10^{-7}} - 2.2 \times 1.6 \times 10^{-19} = 1.43 \times 10^{-19}\text{J}$$

(d) Distinguish between continuous and line spectra in an X-ray tube. (02marks)

Continuous spectrum is produced by multiple collision of electrons with target atoms.

Line spectrum is a result of electron transition from higher to lower energy levels.

32. (a) (i) Explain the observation made in the Rutherford α -particle scattering experiment.

(06marks)

- Most alpha particle passed through metal foil undeflected. This is because most space in an atom is empty.
- A few alpha particles are deflected through small angles less than 90° . This is because the positive alpha particle are repelled by the positive nucleus of the gold atom.
- Very few particles are scattered through large angle greater than 90° . This is because the chances of head-on collision are very minimal. This implies the nucleus occupies a small portion of the available space.

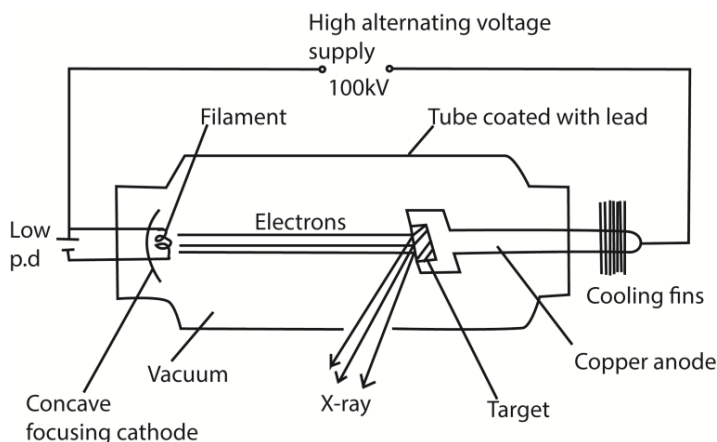
(ii) Why is a vacuum necessary in this experiment? (01mark)

- To enable the alpha particle to reach the detector.

(b) Distinguish between excitation and ionization energies of an atom. (02marks)

- **Excitation energy** is the energy required to remove an electron from an atom in its ground state to a higher energy level.
- **Ionization energy** is the energy required to remove an electron from an atom in its ground state that is completely lost

(c) Draw a labelled diagram showing the main components of an X-ray tube (03marks)



(d) An X-ray tube is operated at 50kV and 20mA. If 1% of the total energy supplied is emitted as X-radiation, calculate the

(i) maximum frequency of emitted radiation (03marks)

$$eV = hf_{\max}$$

$$1.6 \times 10^{-19} \times 50 \times 10^3 = 6.6 \times 10^{-34} \times f_{\max}$$

$$f_{\max} = 1.21 \times 10^{19} \text{Hz}$$

(ii) rate at which heat must be removed from the target in order to keep it at a steady temperature. (03marks)

$$\text{Power supplied} = IV = 20 \times 10^{-3} \times 50 \times 10^3 = 1000\text{W}$$

$$\text{Power converted to heat and removed} = \frac{99}{100} \times 1000 = 990W$$

- (e) A beam of X-ray of wavelength 0.2nm is incident on a crystal at glancing angle 30° . If the interplanar separation is 0.20nm, find the order of diffraction. (02marks)

$$2d\sin\theta = n\lambda$$

$$2 \times 2 \times 10^{-10} \sin 30 = n \times 10^{-10}$$

$$n = 1$$

33. (a) What is meant by a line spectrum? (02marks)

Line spectrum are discontinuous lines produced by electronic transitions within the atom as the electrons fall back to lower energy levels.

- (b) Explain how line spectrum accounts for existence of discrete energy levels in an atom. (04marks)

Atoms of a particular element emit radiation with definite frequencies or wavelengths. When an atom is in excited state, an electron may fall into a vacant position in lower energy level. This is accompanied by emission of electromagnetic radiation with the characteristic $E = hf$;

Where E is the difference in the energy of involved energy level and h is Plank's constant. Since the frequencies are definite for a particular element, it implies that the energy levels are discrete.

- (c) The energy levels in mercury atom are -10.4eV, -5.5eV, -3.7eV and -1.6eV.

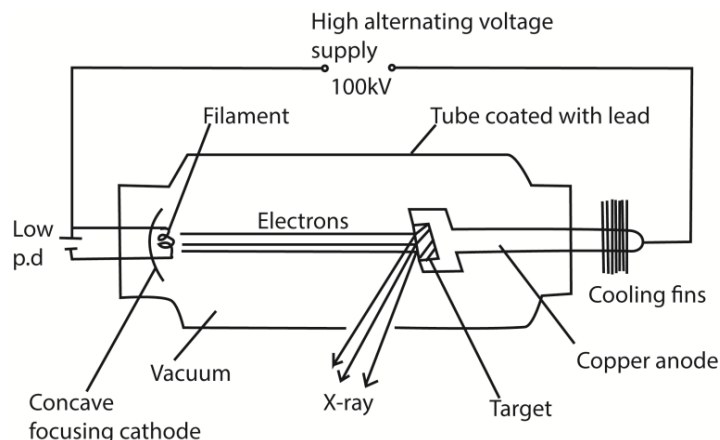
- (i) Find the ionization energy of mercury in joules (02marks)

$$10.4 \times 1.6 \times 10^{-19} = 1.664 \times 10^{-18}J$$

- (ii) What is likely to happen if mercury atom in unexcited state is bombarded with an electron of energy 4.0eV, 6.7eV or 11.0eV? (03marks)

- With 4.0eV and 11.0eV no observable change
- With 6.7eV electron transits from -3.7eV to -10.4eV energy level.

- (d) Describe with the aid of a diagram, the action of an X-ray tube. (05marks)



Mode of operation

- The filament is heated by a low voltage supply and the electrons are emitted by thermionic emission.
- The concave focusing cathode focuses the electrons from the filament onto the target.
- These electrons are accelerated towards the anode by the high voltage between the filament and the Anode.
- When the electrons (cathode rays) strike the metal target, about only 1% their kinetic energy is converted to X-rays and the 99% of their kinetic energy is converted to heat, which is conducted away by the cooling fins.

(e) An X-ray tube is operated at 20kV with electron current 16mA in the tube. Estimate the:

(i) the number of electrons hitting the target per second. (02marks)

$$n = \frac{I}{e} = \frac{16 \times 10^{-3}}{1.6 \times 10^{-19}} = 1.0 \times 10^{17} \text{ electrons per second}$$

(ii) rate of production of heat, assuming 99.5% of the kinetic energy of electron is converted to heat. ($e = 1.6 \times 10^{-19} \text{C}$)

For single electron, energy = eV

Energy per second = $1.0 \times 10^{17} \text{eV}$

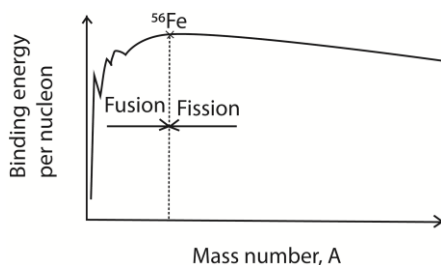
$$= 1.0 \times 10^{17} \times 1.6 \times 10^{-19} \times 20 \times 10^3 = 320 \text{W}$$

$$\text{The rate of heat production} = \frac{99.5}{100} \times 320 = 318.4 \text{W}$$

34. (a) (i) Define the term binding energy (01marks)

Binding energy of the nucleus is the energy required to split the nucleus into its constituent nucleons.

(ii) Sketch a graph showing the variation of binding energy per nucleon with mass number (02marks)



(ii) Use the sketch in (d)(i) to explain how energy is released in each of the process of fusion and fission. (03marks)

- Two Small nuclei with atomic mass less than 56 each fuse to give a heavier nuclei with smaller mass by higher binding energy to increase stability of nucleon

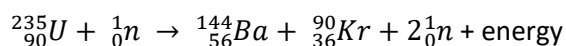
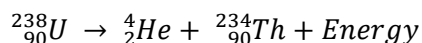
- A nucleus with atomic mass higher than 56 split to form lighter nuclei of higher binding energy per nucleon.

(b) Explain why a high temperature is required during fusion of nuclides. (01mark)

High temperature provides enough kinetic energy to fusing particles to overcome electrostatic repulsive forces

(c) The isotope $^{238}_{92}\text{U}$ emits an alpha particle and forms an isotope of thorium (Th), while the isotope $^{235}_{92}\text{U}$ when bombarded by a neutron, forms $^{144}_{56}\text{Ba}$, $^{90}_{36}\text{Kr}$ and neutrons.

(i) Write the nuclear equation for the reaction of $^{238}_{92}\text{U}$ and $^{235}_{92}\text{U}$. (02marks)



(ii) How does the reaction of $^{235}_{92}\text{U}$ differ from that of $^{238}_{92}\text{U}$ (03marks)

Uranium-235	Uranium-238
Non-radioactive	Radioactive since it emits alpha particles
It undergoes chain reaction (since it is initiated by a neutron and neutrons are part of the product.	It does not undergo chain reaction
It is artificial, so it is controllable	It is natural and cannot be controlled.

(d) A steel piston ring contains 15g of radioactive iron, $^{54}_{26}\text{Fe}$. The activity of $^{54}_{26}\text{Fe}$ is 3.7×10^5 disintegration per second.

After 100 days of continuous use, the crankcase oil was found to have a total activity of 1.23×10^3 disintegrations per second. Find the

(i) Half-life of $^{54}_{26}\text{Fe}$ (05marks)

$$\text{Activity, } A = \lambda N, \text{ but } \lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$$

$$A = \frac{\ln 2}{t_{\frac{1}{2}}} N$$

$$t_{\frac{1}{2}} = \frac{N}{A} \ln 2 \dots\dots\dots (i)$$

54g of Fe has 6.02×10^{23} atoms

15g contain $\frac{15}{54} \times 6.02 \times 10^{23} = 1.67 \times 10^{23}$ atoms

Thus, $N_0 = 1.67 \times 10^{23}$ atoms

$$t_{1/2} = \frac{1.67 \times 10^{23} \times \ln 2}{3.7 \times 10^5} = 3.13 \times 10^{17} \text{s}$$

- (ii) Average mass of iron worn off the ring per day, assuming that all the metal from the ring accumulates in the oil. (03marks)

$$\text{From } A = \frac{\ln 2}{t_{1/2}} N$$

$$1.23 \times 10^{23} = \frac{\ln 2}{3.13 \times 10^{17}} N$$

$$N = 5.55 \times 10^{20} \text{atoms}$$

$$6.02 \times 10^{23} \text{ atoms} \equiv 54 \text{g}$$

$$5.55 \times 10^{20} \text{ atoms} \equiv \frac{5.55 \times 10^{20}}{6.02 \times 10^{23}} \times 54 = 4.9 \times 10^{-2} \text{g}$$

$$\text{Mass worn off in 100 days} = 4.9 \times 10^{-2} \text{g}$$

$$\text{For 1 day, mass worn off} = \frac{4.9 \times 10^{-2}}{100} = 4.9 \times 10^{-4} \text{g}$$

35. (a) Describe briefly the mechanism of thermionic emission (03marks)

- (b)(i) Draw a labelled circuit to show a triode being used as a single gate voltage a single-stage voltage amplifier. (03marks)

- (ii) With the aid of an equivalent circuit of the triode as an amplifier, obtain an expression for the voltage gain. (04marks)

- (iii) A triode with mutual conductance of $3.0 \times 10^{-3} \text{AV}^{-1}$ and anode resistance of $1 \times 10^4 \Omega$ is used as a single-stage amplifier. If the load resistance is $3 \times 10^4 \Omega$. Calculate the voltage gain of amplifier. (05marks)

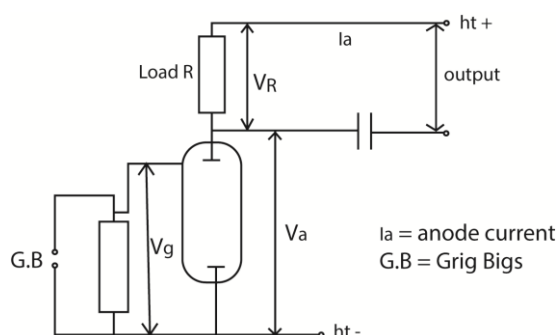
- (c) (i) Describe the structure of a junction transistor. (02marks)

- (ii) Sketch and describe the collector-current against collector emitter voltage characteristic of a junction transistor.

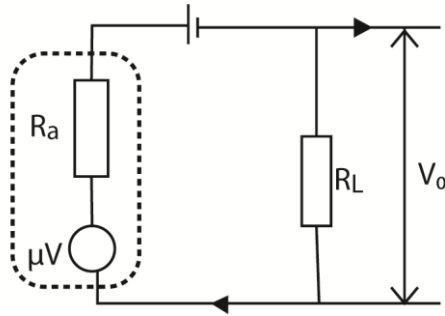
36. (a) Describe briefly the mechanism of thermionic emission (03marks)

High temperature raises the kinetic energy of free electrons in metallic lattice and make electrons to escape from the surface of the metal against the attraction of positive ions

- (b) (i) Draw a labelled circuit to show a triode being used as a single-stage voltage amplifier. (03marks)



- (ii) With the aid of an equivalent circuit of a triode as an amplifier, obtain an expression for voltage gain (04marks)



If V_i is input voltage, μ amplification factor,

$$\Rightarrow \text{e.m.f} = \mu V_i$$

Output voltage = $I_a R_L$

$$I_a = \frac{\mu V_i}{R_a + R_L}$$

$$\text{Thus } V_0 = \frac{\mu V_i R_L}{R_a + R_L}$$

$$\text{Voltage gain} = \frac{V_0}{V_i} = \frac{\mu V_i}{R_a + R_L}$$

- (iii) A triode with mutual conductance of $3.0 \times 10^{-3} \text{ A V}^{-1}$ and anode resistance of $1 \times 10^4 \Omega$, is used as a single-stage amplifier. If the load resistance is $3 \times 10^4 \Omega$, calculate the voltage gain of the amplifier. (05marks)

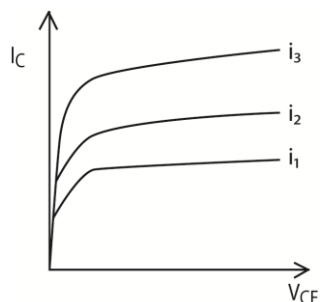
$$\text{From } \mu = R_a g_m = 3.0 \times 10^{-2} \times 1 \times 10^4 = 30$$

$$\begin{aligned} \text{From } A &= \frac{V_0}{V_i} = \frac{\mu V_i}{R_a + R_L} \\ &= \frac{30 \times 3 \times 10^4}{1 \times 10^4 + 3 \times 10^4} \\ &= 22.5 \end{aligned}$$

- (c) (i) Describe the structure of a junction transistor. (02marks)

A transistor consists of 3 layers of P- and n- semiconductors called respectively emitter, base and collector. The base is thinner. It can be PnP type or nPn transistor.

- (ii) Sketch and describe the collector-current against collector-emitter voltage characteristic of a junction transistor. (03marks)

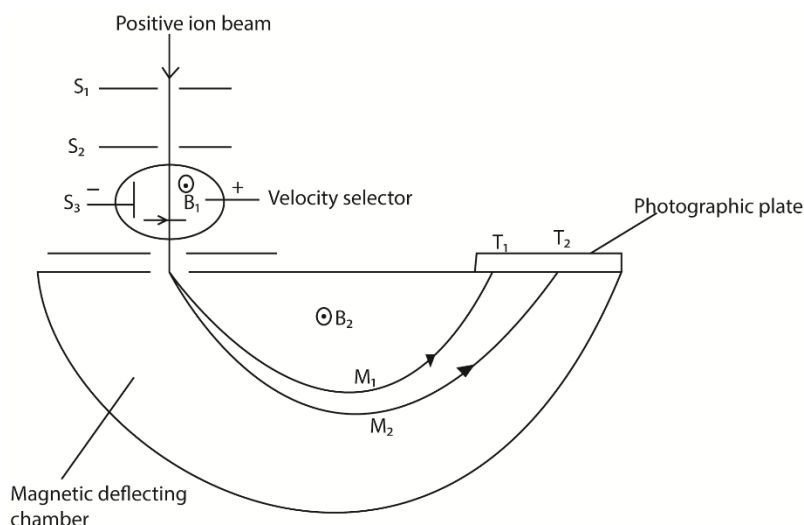


For small values of V , I_C increases linearly with V but strongly dependent on i .

37. (a) What are isotopes? (01mark)

Isotopes are atoms of the same element with the same atomic number but different atomic mass.

(b) With the aid of a diagram, describe the operation of Bainbridge spectrometer in determining the specific charge of ions. (06marks)



T_1 and T_2 are tracers on photographic plate, S_1 , S_2 and S_3 are slits

Mode of Action

- Positive ions are produced in a discharge tube and admitted as a beam through slits S_1 and S_2 .
- The beam then passes between insulated plates P , Q , connected to a battery, which create an electric field of intensity E .
- A uniform magnetic field B_1 , perpendicular to E is applied over the region of the plates and all ions, charge e with the same velocity, v given by $B_1 ev = Ee$ will then pass undeflected through the plates and through a slit S_3 .
- The selected ions are deflected in a circular path of radius r by a uniform perpendicular magnetic field B_2 and an image is produced on a photographic plate as shown.

In this case

$$\frac{mv^2}{r} = B_2 ev$$

$$\therefore \frac{m}{e} = \frac{rB_2}{v}$$

But for the ions selected $v = \frac{E}{B_1}$ from above

Specific charge, $\frac{e}{m} = \frac{E}{rB_2B_1}$

(c) Explain the purpose of each of the following in a Geiger-Muller tube

(i) a thin mica window

To allow easy entry of ionizing particles in the GMT

(ii) Argon gas at low pressure

Argon form ions when it is struck by ionizing particle.

Low pressured reduces resistance to ion movement to respective electrodes.

(iii) Halogen gas mixed with argon gas

Form quenching agent to prevent secondary ionization.

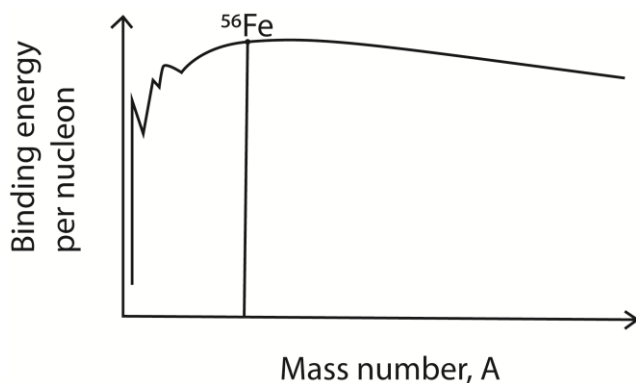
(iv) An anode in the form of a wire (04marks)

Anode in form of a wire increases strength of electric field intensity

(d) (i) What is meant by binding energy per nucleon of a nucleus? (01mark)

Binding energy per nucleon is the ratio of the energy required to split a nucleus into the individual nucleons to the number of nucleon in the nucleus.

(ii) Sketch a graph of binding energy per nucleon against mass number for naturally occurring nuclides (01marks)



(iii) State one similarity between nuclear fusion and nuclear fission. (01mark)

Both release energy

(e) (i) At a certain time, an α -particle detector registers a count rate of $32s^{-1}$. Exactly 10days later, the count rate dropped to $8s^{-1}$. Find the decay constant. (04marks)

$$A = A_0 e^{-\lambda t}$$

$$8 = 32 e^{-10\lambda}$$

$$\lambda = 0.1386 \text{ per day}$$

(ii) State two industrial uses and two health hazards of radioactivity. (04marks)

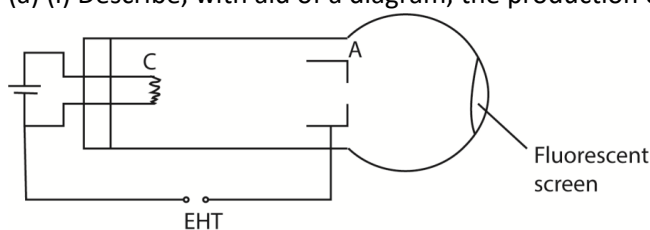
Industrial uses

- Estimate the rate of wear in machinery
- Automatic control of thickness of paper, plastic or metal sheeting
- Investigating the flow of liquids in chemical plants or underground water and sewage pipeline.

Hazards

- May cause skin burn
- Cancers
- Gene mutation

38. (a) (i) Describe, with aid of a diagram, the production of cathode rays



- Cathode C produces electrons by thermionic emission.
- Electrons are accelerated by p.d between cathode and anode

(ii) State and justify two properties of cathode rays (02marks)

- carry negative charge because they are attracted towards a positive potential
- move in straight line because they cast a shadow when intercepted by Maltese cross

(b) Explain each of the following terms as applied to photoelectric emission:

(i) stopping potential (01marks)

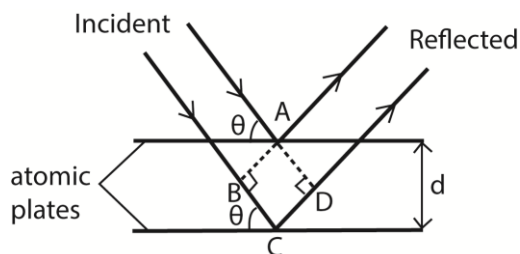
Stopping potential is a minimum potential that reduces photocurrent to zero.

(ii) threshold frequency (01mark)

It is the frequency of radiation below which no electron emission takes place.

(c) Explain X-ray diffraction by crystals and derive Bragg's law (06marks)

- A parallel beam of monochromatic X-rays incident on a crystal is reflected from successive atomic planes and super-imposed, forming an interference pattern.



For constructive interference to occur, the path difference is equal to the whole number of wavelength

$$\text{Thus } BC + CD = n\lambda$$

$$\Rightarrow d\sin\theta + d\sin\theta = n\lambda$$

$$\text{or } 2d\sin\theta = n\lambda \text{ where } n = 1, 2, 3, 4 \dots$$

(d) The potential difference between the cathode and anode of an X-ray tube is $5.0 \times 10^{-4}\text{V}$. If only 0.4% of the kinetic energy of the electrons is converted into X-rays and the rest is dissipated as heat in the target at a rate of 600W, find the

(i) current that flows (03marks)

99% of energy is converted to heat.

$$\text{Power converted to heat} = 0.99IV = 600\text{W}$$

$$\Rightarrow 0.99 \times I \times 5.0 \times 10^{-4} = 600$$

$$I = 1.21 \times 10^6\text{A}$$

(ii) speed of the electrons striking the target. (03marks)

$$\frac{1}{2}mv^2 = eV$$

$$u = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 5 \times 10^{-4}}{9.11 \times 10^{-31}}} = 1.33 \times 10^4\text{ms}^{-1}$$

39. (a) (i) What is a photon? (01mark)

A photon is a packet of energy that is carried by electromagnetic radiation equal to hf where h is Planck's constant and f is the frequency of the radiation

(ii) Explain, using quantum theory, the experimental observation on the photoelectric effect. (06marks)

Observations:

- Photoelectric effect starts at the instant metal surface receives radiation
- The photocurrent is proportional to the intensity of radiation
- The maximum kinetic energy of photoelectrons is proportional to the frequency of the incident radiation and is independent of the intensity of the radiation.
- For a given metal surface, there exist a minimum frequency below which photoelectric emission occurs regardless of the intensity of the radiation

Explanation

- According to the quantum theory, radiation is emitted and absorbed in quanta.
- When a single quantum (photon) interacts with an electron on a metal surface, it gives it all or none of its energy implying that only one electron absorbs the energy of a photon. Therefore the number of photo-electrons is proportional to the number of incident photons (intensity of radiation) of energy.
- Part of this energy is used to overcome attraction of the electron by the metal surface and the rest is kinetic energy of the emitted electrons.
- Minimum energy is required to emit an electron, and thus there is minimum frequency of a radiation that emit electrons since the energy of a radiation is proportional to frequency.

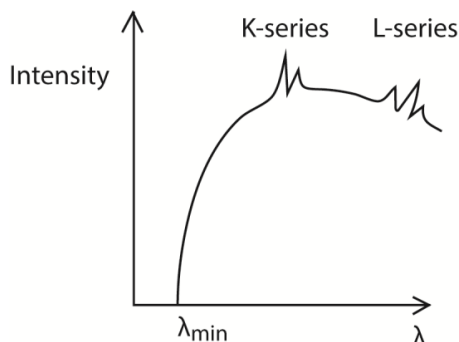
(iii) When light of wavelength 450nm falls on a certain metal, electrons of maximum kinetic energy 0.76eV are emitted. Find the threshold frequency for the metal. (04marks)

$$hf_0 = \frac{hc}{\lambda} - \text{kinetic energy}$$

$$6.6 \times 10^{-34} \times hf_0 = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{450 \times 10^{-9}} - 0.76 \times 1.6 \times 10^{-19}$$

$$f_0 = 4.83 \times 10^{14} \text{Hz}$$

(b) Explain, using suitable sketch graph, how X-ray spectrum in an X-ray tube are formed. (06marks)



The spectrum consists of two major components, i.e. the continuous (background) spectrum and the very sharp line spectrum superimposed onto the background spectrum.

The continuous spectrum is produced when electrons make multiple collisions with the target atoms in which they are decelerated. At each deceleration, X-rays of differing wavelength are produced.

The shortest Wavelength X-rays are produced when electrons lose all their energy as X-ray photon in a single encounter with the target atoms. The wavelength of the X-rays at this point is known as the cut off wavelength. At cut off wavelength, energy in an X-ray photon equals kinetic energy of the electron;

i.e. $hf = eV$ or $\frac{hc}{\lambda_{max}} = eV$ where $V = p.d$

The line spectrum

At high tube voltages, the bombarding electrons penetrate deep into the target atoms and knock out electrons from inner shell. The knocked out electrons occupy vacant spaces in higher unfilled shells putting the atom in excited state and making them unstable.

Transition of an electron from higher to lower energy levels results in an emission of X-ray photon of energy equal to energy difference between the energy levels.

If the transition ends in the K-shell, it produces K-series and if the transition ends in L-shell. It produces L-series.

- (c) A beam of X-rays of wavelength $8.42 \times 10^{-11} \text{m}$ is incident on a sodium chloride crystal of interplanar separation $2.82 \times 10^{-10} \text{m}$. Calculate the first order of diffraction angle. (03marks)

From $2d \sin \theta = n\lambda$

$$\theta = \sin^{-1} \left(\frac{1 \times 8.42 \times 10^{-11}}{2 \times 2.82 \times 10^{-10}} \right) = 8.58^\circ$$

40. (a) (i) A beam of electrons, having a common velocity, enters a uniform magnetic field in a direction normal to the field. Describe and explain the subsequent path of the electrons (04marks)

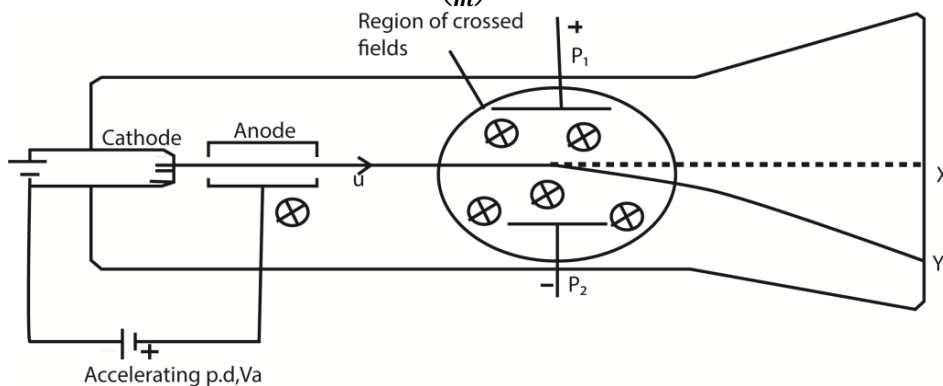
The electrons will describe a circular path, since they experience a magnetic force ($F = Bev$) at right angle to their direction of motion and to the field. This provides a centripetal force.

- (ii) Explain whether a similar path would be followed if a uniform electric field were substituted for magnetic field (01mark)

The electrons experience an electric force ($F = eE$) in direction opposite that of magnetic field. Thus causes them to describe a parabolic force

- (b) Describe an experiment to measure the ratio of the charge to mass of an electron (07marks)

Determination of Specific Charge $\left(\frac{e}{m}\right)$ of an electron: (J.J Thomson's Method)



- The electrons are produced thermionically by a hot filament cathode and are accelerated towards a cylindrical anode and pass through it.
- The small hole on the anode confines the electrons to a narrow beam.
- When both the electric field and the magnetic field are off, the electrons reach the screen at X and cause fluorescence.
- If the velocity of the electrons on emerging from the anode is u then

$$eVa = \frac{1}{2}mu^2$$

$$\Rightarrow \frac{e}{m} = \frac{u^2}{2Va} \dots\dots\dots (i)$$

Where Va is the accelerating voltage between the cathode and anode.

- The magnetic field is switched on and the beam is deflected to position Y.
- In order to bring the beam back to the original position X, the electric field is switched on and adjusted until the beam is at X again.
- This implies that The magnetic force = the electric force

$$Beu = eE$$

$$\therefore u = \frac{E}{B} \dots\dots\dots (ii)$$

Substituting eqn. (ii) in (i)

$$\frac{e}{m} = \frac{E^2}{2B^2Va} \text{ but } E = \frac{V}{d}$$

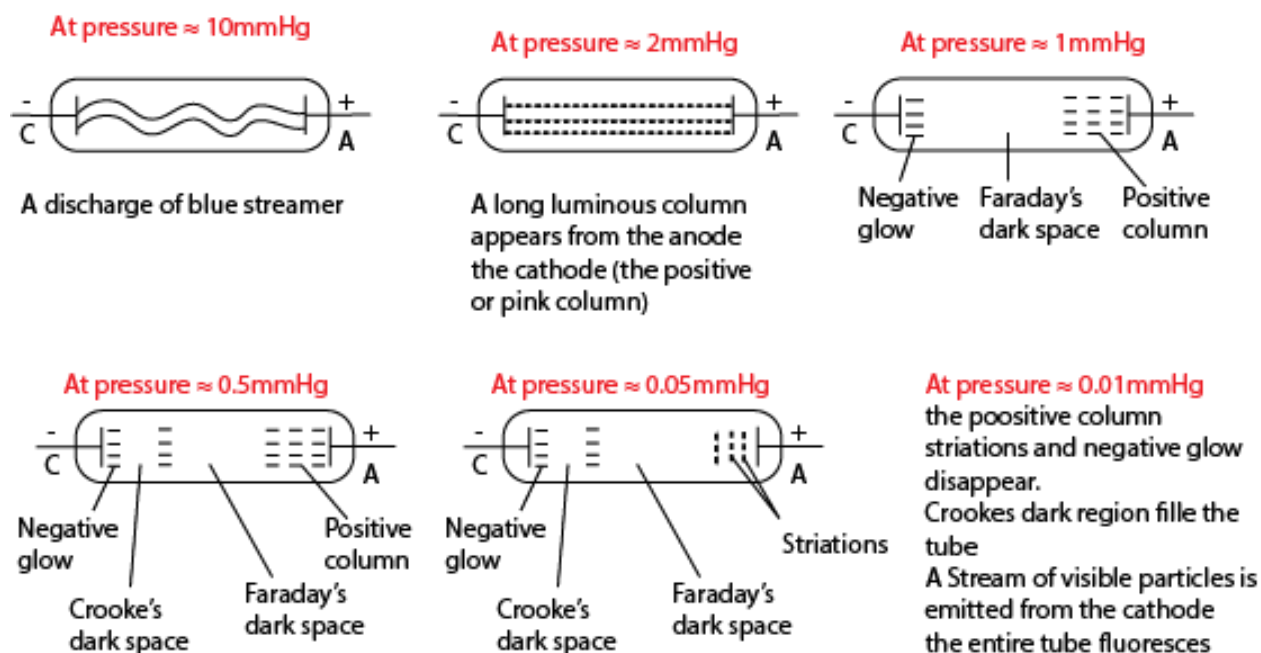
$$\therefore \frac{e}{m} = \frac{V^2}{2B^2d^2Va} \text{ where, } V \text{ is the p.d between the plates at separation of } d \text{ apart}$$

- (c) Electrodes are mounted at opposite ends of low pressure discharge tube and a potential difference of 1.20kV applied between them. Assuming the electrons are accelerated from rest, calculate the maximum velocity which they could acquire. [Specific electron charge = $-1.76 \times 10^{11} \text{ Ckg}^{-1}$] (02marks)

$$\text{From } \frac{1}{2}mv^2 = eV$$

$$v = \sqrt{\frac{2eV}{m}} = \sqrt{2 \times 1.7 \times 10^{11} \times 1.2 \times 10^3} = 2.06 \times 10^7 \text{ms}^{-1}$$

- (d) (i) Give an account of the stages observed when an electric discharge passes through a gas at pressure varying from atmospheric to about 0.01mmHg as air is pumped out when the p.d across the tube is maintained at extra high tension. (05marks)



(ii) State two disadvantages of discharge tubes when used to study cathode rays. (01mark)

- A gas is needed at very low pressure which may not be easy to achieve practically.
- A very high p.d is needed across tube which may not be safe to handle
- X-rays may be produced and these are unsafe.

41. (a) (i) What is meant by half-life of a radioactive material? (01mark)

- Half-life is the time taken for the activity of a material to decrease to half its original value.

(ii) Given the radioactive law, $N_t = N_0 e^{-\lambda t}$, obtain the relationship between λ and half-life $T_{\frac{1}{2}}$ (02marks)

$$\ln \frac{N_0}{N} = \lambda t \text{ at } t = T_{\frac{1}{2}}, N = \frac{N_0}{2}$$

$$\Rightarrow \ln \frac{N_0}{\frac{N_0}{2}} = \lambda T_{\frac{1}{2}}$$

$$\lambda = \frac{\ln 2}{T_{\frac{1}{2}}}$$

(iii) What are radioisotopes? (01mark)

Radioisotope are radioactive atoms of the same element having the same atomic number but different atomic mass

(iv) The radioisotope $^{90}_{38}\text{Sr}$ decays by emission of β -particles. The half-life of the radioisotope is 28.8 years. Determine the activity of 1g of the isotope (05marks)

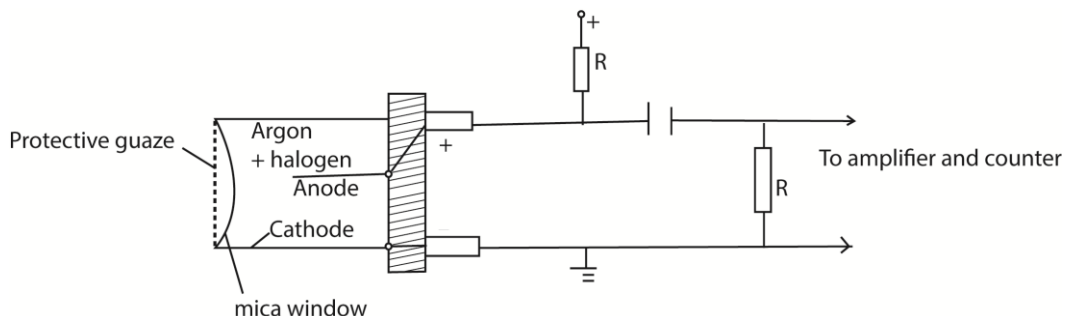
$$\text{Activity, } A = \lambda N, \text{ where } N = \frac{N_{AM}}{M} \text{ and } \lambda = \frac{\ln 2}{T_{\frac{1}{2}}}$$

$$\text{Activity, } A = \frac{\ln 2}{28.8 \times 365 \times 24 \times 3600 \times 1} = 7.63 \times 10^{-10} \text{ s}^{-1}$$

(b) (i) With aid of a diagram describe the structure and action of Geiger-Muller tube. (06marks)

The GMT is used to detect the presence of X- rays, Gamma rays, beta particles and if the window of the tube used is very thin, it detects even alpha particles.

Structure



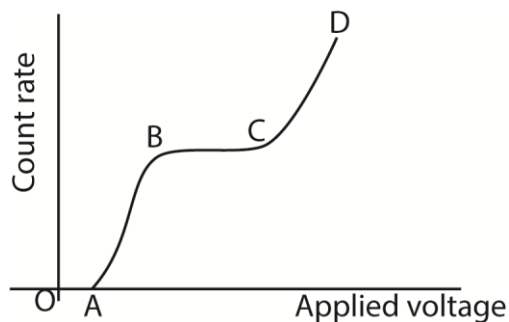
The thin mica window allows the passage and detection of the weak penetrating alpha particles. The GM tube is first evacuated then filled with Neon, Argon plus Halogen gas which is used as a quenching agent.

Mode of operation

Mode of operation

- When an ionizing particle enters the tube through the window, argon atoms are ionized.
- The electrons move to the anode while the positive ions drift to the cathode.
- A discharge occurs and the current flows in the external circuit.
- A p.d is obtained across a large resistance, R which is amplified and passed to the scale.
- The magnitude of the pulse registered gives the extent to which ionization occurred.

(ii) Sketch the current –voltage characteristic of the Geiger- Muller tube and explain its main features. (03marks)



OA – the operating voltage is not enough to attract the ions to the respective electrodes and hence the counter registers no reading. This voltage (i.e. at A) is called the threshold voltage.

AB – the applied p.d not enough to attract all electrons; hence increasing the p.d increases the number of electrons being attracted and hence increase in counter rate.

BC – here the count rate is constant. This is called the plateau region.

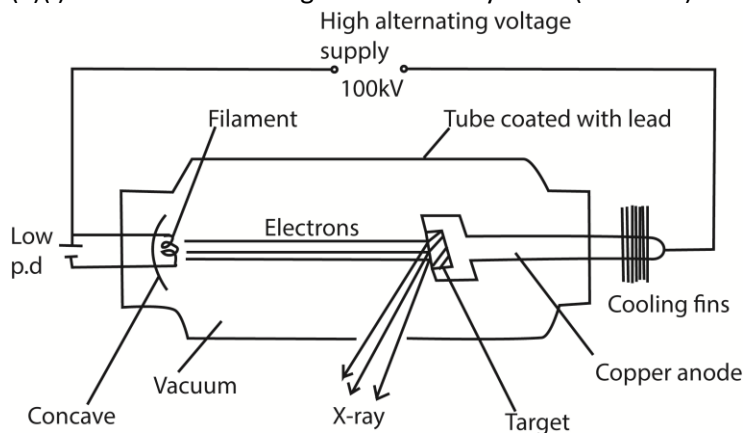
- Between BC, all the negative ions are able to reach the anode because the operating voltage is large enough to attract them.
- Full avalanche is obtained along the entire length of the anode.
- Here the tube is said to be operating normally.

CD: - The count rate increases rapidly because the quenching process becomes ineffective and eventually a continuous discharge occurs which might damage the tube.

(iii) Identify, giving reasons, the suitable range in (b) (ii) of operation of the tube (02marks)

The suitable region is BC, in this range, every particle which produces ionization is detected.

42. (a)(i) Draw a labelled diagram of an X-ray tube. (02marks)



(ii) Use the diagram in (a)(i) to describe how X-rays are produced. (03marks)

- The filament is heated by a low voltage supply and the electrons are emitted by thermionic emission.
- The concave focusing cathode focuses the electrons from the filament onto the target.
- These electrons are accelerated towards the anode by the high voltage between the filament and the Anode.
- When the electrons (cathode rays) strike the metal target, about only 1% their kinetic energy is converted to X-rays and the 99% of their kinetic energy is converted to heat, which is conducted away by the cooling fins.

(iii) State one industrial and one biological use of X-rays. (01marks)

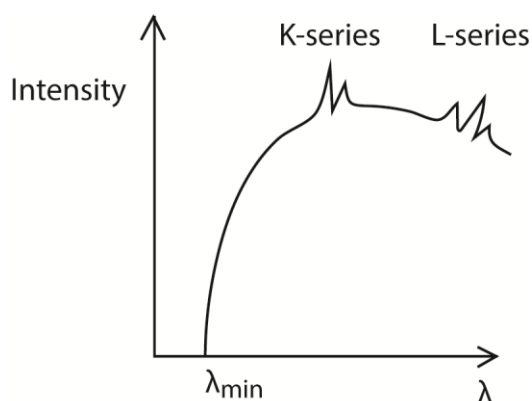
Industrial use

1. Inspecting metal casting and welding joints for perfection
2. Structural analysis, stresses, fractures in solids, castings and welded joints can be analyzed by examining X-ray photograph.
3. Crystallography; Orientation and identification of minerals by analysis of diffraction patterns using Bragg's law.

Biological use

- Identifying fractures
- Treatment of cancer

(b)(i) Sketch a graph of intensity versus wavelength of X-rays from an X-ray tube and describe its main features. (04marks)



The spectrum consists of two major components, i.e. the continuous (background) spectrum and the very sharp line spectrum superimposed onto the background spectrum.

The continuous spectrum is produced when electrons make multiple collisions with the target atoms in which they are decelerated. At each deceleration, X-rays of differing wavelength are produced.

The shortest Wavelength X-rays are produced when electrons lose all their energy as X-ray photon in a single encounter with the target atoms. The wavelength of the X-rays at this point is known as the cut off wavelength. At cut off wavelength, energy in an X-ray photon equals kinetic energy of the electron; i.e. $hf = eV$ or $\frac{hc}{\lambda_{max}} = eV$ where $V = p.d$

The line spectrum

At high tube voltages, the bombarding electrons penetrate deep into the target atoms and knock out electrons from inner shell. The knocked out electrons occupy vacant spaces in higher unfilled shells putting the atom in excited state and making them unstable.

Transition of an electron from higher to lower energy levels results in an emission of X-ray photon of energy equal to energy difference between the energy levels.

If the transition ends in the K-shell, it produces K-series and if the transition ends in L-shell. It produces L-series.

- (ii) Calculate the maximum frequency of X-rays emitted by an X-ray tube operating on voltage of 34.0kV. (03marks)

$$\text{From } hf_{\max} = eV$$

$$f_{\max} = \frac{1.6 \times 10^{-19} \times 34 \times 10^3}{6.63 \times 10^{-34}} = 8.205 \times 10^{18} \text{ Hz}$$

- (c) In the measurement of electron charge by Millikan's apparatus, a potential difference of 1.6kV is applied between two horizontal plates 14mm apart. With the potential difference switched off, an oil drop is observed to fall with constant velocity $4.0 \times 10^{-4} \text{ ms}^{-1}$. When the potential difference is switched on, the drop rises with constant velocity $8.0 \times 10^{-5} \text{ ms}^{-1}$. If the mass of the oil drop is $1.0 \times 10^{-14} \text{ kg}$, find the number of electron charges on the drop. [assume air resistance is proportional to velocity of the oil drop and neglect the up thrust due to air] (07marks)

Neglecting up thrust due to air resistance

$$mg = 6\pi\eta av_0$$

$$\eta a = \frac{mg}{6\pi v_0} = \frac{1.0 \times 10^{-14} \times 9.81}{6\pi \times 4 \times 10^{-4}} = 1.3 \times 10^{-11} \text{ Nsm}^{-1}.$$

When p.d of $1.6 \times 10^3 \text{ V}$ is applied, $v = 8 \times 10^{-5} \text{ ms}^{-1}$

$$mg = F + F_E$$

$$mg = 6\pi\eta av + qE$$

$$q = \frac{mg - 6\pi\eta av}{E} = \frac{mg - 6\pi\eta av}{V/d} = \frac{(1.0 \times 10^{-14} \times 9.81 - (6\pi \times 1.3 \times 10^{-11} \times 8.5 \times 10^{-5})) \times 14 \times 10^{-3}}{1.6 \times 10^3} \\ = 6.76 \times 10^{-19} \text{ C}$$

But $q = ne$

$$n = \frac{q}{e} = \frac{6.76 \times 10^{-19}}{1.6 \times 10^{-19}} = 4$$

43. (a) (i) State the laws of photo-electric emission. (04marks)

- The time lag between irradiation of the metal surface and emission of the electrons by the metal surface is negligible.
- For a given metal, surface there is a minimum value of frequency of radiation called threshold frequency (f_0) below which no photo electrons are emitted from the metal however intense the incident radiation may be.
- The number of photoelectrons emitted from the surface per second is directly proportional to the intensity of incident radiation for a particular incident frequency
- The K.E of the photoelectrons emitted is independent of the intensity of the incident radiation but depends only on its frequency

- (ii) Write down Einstein's equation for photo electric emission. (02marks)

$$hf = w_0 + \frac{1}{2} mv^2 ;$$

where h = Planck's constant, f = frequency of radiation, w_0 = work function, m = mass of electron, v = velocity of electron

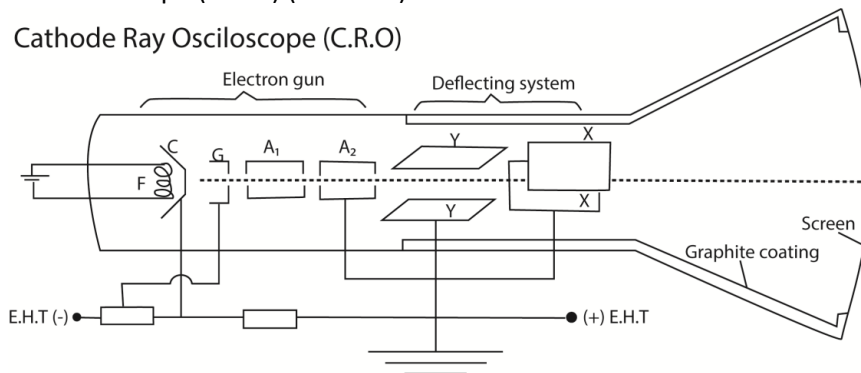
- (iii) Ultra –violet light of wavelength $3.3 \times 10^{-8}\text{m}$ is incident on a metal. Given the work function of the metal is 3.5eV, calculate the maximum velocity of the liberated electron. (03marks)

$$\text{From } hf = w_0 + \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2\left(\frac{hc}{e\lambda} - w_0\right)e}{m}} = \sqrt{\frac{2\left(\frac{6.6 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-19} \times 3.3 \times 10^{-8}} - 3.5\right) \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}}} = 3.47 \times 10^6 \text{ms}^{-1}$$

- (b) Describe, with aid of a diagram, the structure and mode of operation of a cathode ray oscilloscope (C.R.O) (06marks)

Cathode Ray Oscilloscope (C.R.O)



The following are the main features of CRO

- a hot filament emits electrons
- The grid G has a negative potential with respect to the filament and controls the number of electrons entering and reaching anode A_1
- Anodes A_1 and A_2 accelerate the electron beam at a high speed the screen
- Deflecting system consist of Y- and X-plates; Y-plated deflect the beam vertically while X-plates deflect the beam horizontally.
- The screen is coated with zinc sulphide to display the arrival of the beam by emitting light when struck by the beam
- Carbon coating prevents the electron beam from the influence of any external electric field.

- (c) A C.R.O has its y-sensitivity set to 10Vm^{-1} . A sinusoidal input voltage is suitably applied to give a steady trace with time base switched on so that the electron beam takes 0.01s to traverse the screen. If the trace seen has a peak-to-peak height of 4.0cm and contains two complete cycles, find the

- (i) r.m.s value of the input voltage. (03marks)

$$\begin{aligned} \text{Peak to peak voltage} &= \text{y-sensitivity} \times \text{height} \\ &= 10 \times 4 \\ &= 40\text{V} \end{aligned}$$

$$V_{r.m.s} = \frac{V_{max}}{\sqrt{2}} = \frac{20}{\sqrt{2}} = 14\text{V}$$

- (ii) frequency of the input signal. (02marks)

Period T = time for one oscillation

$$= \frac{0.01}{2} = 0.005\text{s}$$

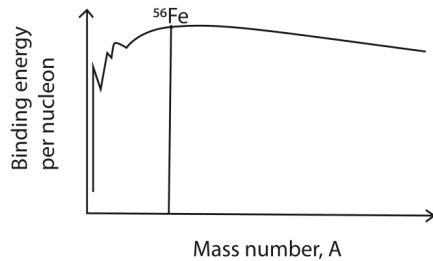
$$\text{Frequency, } f = \frac{1}{T} = \frac{1}{0.005} = 200\text{Hz}$$

44. (a) Define binding energy of nuclide (01mark)

Binding energy is the energy required to split the nucleus into its individual nucleons, i.e. protons and neutrons.

(b) (i) Sketch a graph showing how binding energy per nucleon varies with mass number

(01mark)



(ii) Describe the main features of the graph in (b)(i). (03marks)

Binding energy per nucleon increases with a few peaks up to the maximum mass number = 56 and then decreases gradually.

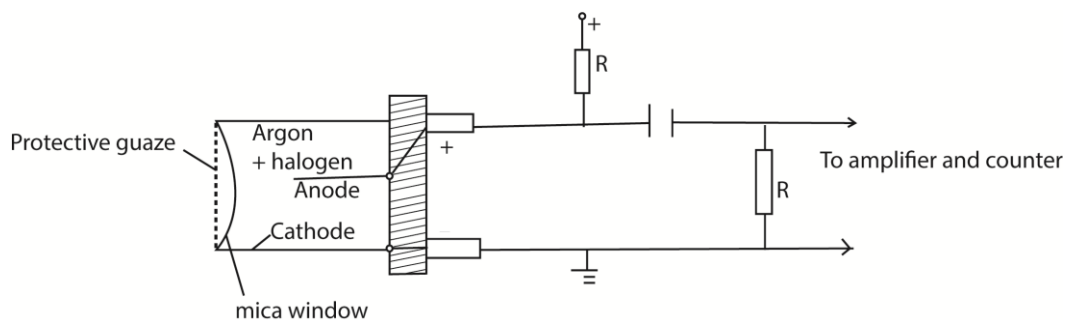
(c) Distinguish between nuclear fission and nuclear fusion and account for the energy released.

(03mark)

- Nuclear fusion is the combination of two light nuclei to form heavier nucleus accompanied with release of energy.
- Nuclear fission is the splitting of a heavy unstable nucleus into small stable nuclei accompanied by release of energy.

(d) (i) with the aid of a labelled diagram describe the working of the Geiger-Muller tube.

(05marks)



The thin mica window allows the passage and detection of the weak penetrating alpha particles. The GM tube is first evacuated then filled with Neon, Argon plus Halogen gas which is used as a quenching agent.

Mode of operation

Mode of operation

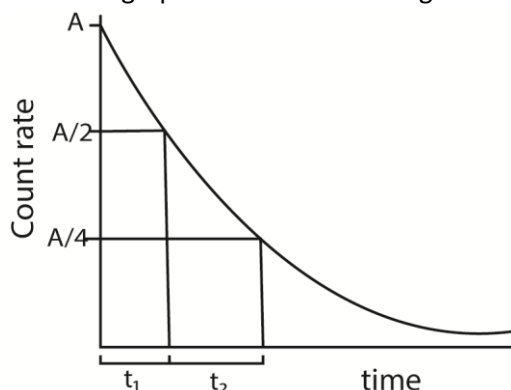
- When an ionizing particle enters the tube through the window, argon atoms are ionized.
- The electrons move to the anode while the positive ions drift to the cathode.
- A discharge occurs and the current flows in the external circuit.

- A p.d is obtained across a large resistance, R which is amplified and passed to the scale.
- The magnitude of the pulse registered gives the extent to which ionization occurred.

(ii) How would you use a Geiger-Muller tube to determine the half-life of a radioactive sample? (04marks)

Experiment to determine a half-life of radioactive substance using GM- tube

- Switch on the GM-tube, note and record the background count rate, A.
- Place a source of ionizing radiation near the GM-window.
- Note and record the count rate recorded the count rate at equal intervals.
- For each count rate recorded subtract the background count rate to get the true rate.
- Plot a graph of the count rate against time.



Find time t_1 taken for the activity to reduce to $A/2$ and t_2 taken for activity to reduce to $A/4$ from $A/2$

$$\text{Half-life} = \frac{1}{2}(t_1 + t_2)$$

(e) A radioactive source produces alpha particles each of energy 60eV. If 20% of the alpha particles enter an ionization chamber a current of $0.2\mu\text{A}$ flows. Find the activity of the alpha source, if the energy needed to make an ion pair in the chamber is 32MeV. (03marks)

The charge of $1e = 1.6 \times 10^{-19}$ per second is produced by an energy of 32eV

1e amperes is produced by 32MeV

$$0.2\mu\text{A} \text{ is produced by } \frac{32\text{MeV}}{e} \times 0.2\mu\text{A} = y$$

$$\therefore 20\% \text{ of } x = y$$

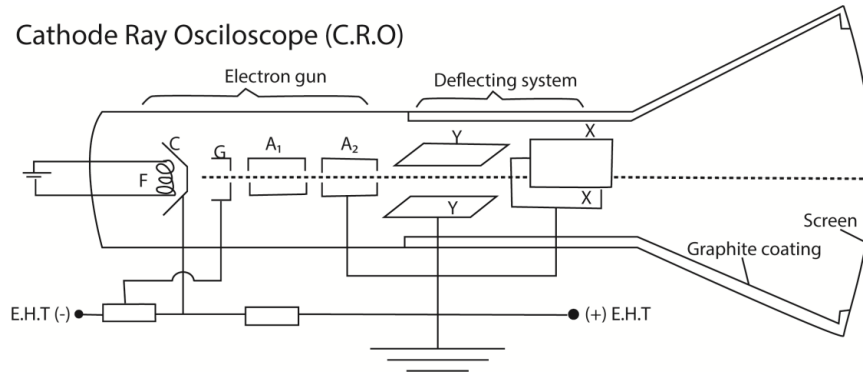
Where x is the energy that would be required to ionize all alpha particles

$$\Rightarrow X = 5y$$

$$\text{Number of alpha particles} = \frac{x}{60\text{MeV}} = \frac{5 \times 32\text{MeV} \times 0.2 \times 10^{-6}}{e \times 60\text{MeV}} = 3.3 \times 10^{12} \text{Bq}$$

45. (a) (i) Describe with the aid of a labelled diagram the main features of a cathode ray oscilloscope (C.R.O) (08marks)

Cathode Ray Oscilloscope (C.R.O)



The following are the main features of CRO

- a hot filament emits electrons
- The grid G has a negative potential with respect to the filament and controls the number of electrons entering and reaching anode A₁
- Anodes A₁ and A₂ accelerate the electron beam at a high speed the screen
- Deflecting system consist of Y- and X-plates; Y-plated deflect the beam vertically while X-plates deflect the beam horizontally.
- The screen is coated with zinc sulphide to display the arrival of the beam by emitting light when struck by the beam
- Carbon coating prevents the electron beam from the influence of any external electric field.

(ii) State two uses of C.R.O (01mark)

- Display waveforms
- Measuring both a.c and d.c voltage
- Measuring phase differences

(iii) The gain control of a C.R.O is set on 0.5Vcm^{-1} and an alternating voltage produces a vertical trace of 2.0cm long with the time base off. Find the root mean value of the applied voltage. (02marks)

Peak to peak voltage, $V = 2 \times 0.5\text{V} = 1\text{V}$

Peak voltage $V_0 = \frac{V}{2} = \frac{1}{2} = 0.5\text{V}$

$$V_{r.m.s} = \frac{V_0}{\sqrt{2}} = \frac{0.5}{\sqrt{2}} = 0.354\text{V}$$

(b) A beam of electrons is accelerated through a potential difference of 2000V and is directed mid-way between two horizontal plates of length 5.0cm and separation of 2.0cm. The potential difference across the plates is 80V.

(i) Calculate the speed of the electron as they enter the region between the plates. (03marks)

$$\frac{1}{2}mu^2 = eV$$

$$u = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 2000}{9.11 \times 10^{-31}}} = 2.65 \times 10^7 \text{ms}^{-1}$$

(ii) Explain the motion of the electrons between the plates. (02marks)

It is parabolic

- (iii) find the speed of electrons as they emerge from the region between the plates. (04marks)

$$v_x = 2.65 \times 10^7 \text{ms}^{-1}$$

$$v_y = at$$

$$a = \frac{Ee}{m} = \frac{Ve}{dm}$$

$$t = \frac{L}{u} = \frac{5 \times 10^{-2}}{2.65 \times 10^7} = 1.89 \times 10^{-9} \text{s}$$

$$\begin{aligned} \Rightarrow v_y &= \frac{Ve}{dm} \times 1.89 \times 10^{-9} \\ &= \frac{80 \times 1.6 \times 10^{-19}}{2 \times 10^{-2} \times 9.11 \times 10^{-31}} \times 1.89 \times 10^{-9} \\ &= 1.33 \times 10^6 \text{ms}^{-1} \end{aligned}$$

$$v = \sqrt{v_x^2 + v_y^2} = \sqrt{(2.65 \times 10^7)^2 + (1.33 \times 10^6)^2} = 2.65 \times 10^7 \text{ms}^{-1}$$

46. (a) Explain the term stopping potential as applied to photo electric effect. (02marks)

It is the minimum potential difference between the anode and the cathode that reduces the photocurrent to zero.

- (b) Explain how intensity and penetrating power of X-rays from X-ray tube would be affected by changing:

- (i) the filament current (02marks)

When the filament current is increased, the intensity of the X-rays increases since the number of electrons hitting the target increases but the penetrating power remains constant since the kinetic energy of the electrons is not changed.

- (ii) the high tension potential difference across the tube (02marks)

Penetrating power increases with potential difference.

- (c) When a p.d of 60kV is applied across an X-ray tube, a current of 30mA flows. The anode is cooled by water flowing at a rate of 0.060kg s^{-1} . If 99% of the power supplied is converted into heat at the anode, calculate the rate at which the temperature of the water rises.

{Specific heat capacity of water = $4.2 \times 10^3 \text{J kg}^{-1} \text{K}^{-1}$ } (05marks)

$$\text{Electrical energy supplied per second} = IV = 30 \times 10^{-3} \times 60 \times 10^3 = 1.8 \times 10^3 \text{W}$$

Since 99% of this energy is converted to heat

$$\Rightarrow \text{the rate of heat production} = 0.99 \times 1800 = 1.782 \times 10^3 \text{W}$$

$$\text{Rate of heat gain by water} = \frac{dm}{dt} \times c \times \Delta\theta \text{ where } \Delta\theta \text{ is temperature change}$$

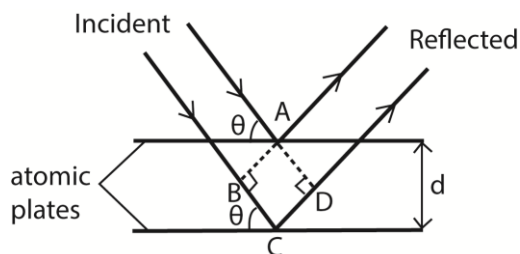
All the heat produced is removed by water.

$$\text{Then } \frac{dm}{dt} \times c \times \Delta\theta = 1.782 \times 10^3 \text{W}$$

$$\Delta\theta = \frac{1.782 \times 10^3}{0.060 \times 4.2 \times 10^3} = 7.07^\circ$$

- (d) (i) Derive Bragg's law of X-ray diffraction. (05marks)

- A parallel beam of monochromatic X-rays incident on a crystal is reflected from successive atomic planes and super-imposed, forming an interference pattern.



For constructive interference to occur, the path difference is equal to the whole number of wavelength

Thus $BC + CD = n\lambda$

$$\Rightarrow d\sin\theta + d\sin\theta = n\lambda$$

$$\text{or } 2d\sin\theta = n\lambda \text{ where } n = 1, 2, 3, 4 \dots$$

(ii) Calculate the atomic spacing of sodium chloride if the relative atomic mass of sodium is 23.0 and that of chlorine is 35.5.

[Density of sodium chloride = $2.18 \times 10^3 \text{ kg m}^{-3}$] (04marks)

$$\text{From volume} = \frac{\text{mass}}{\rho}$$

$$\text{Volume of 1 mole} = \frac{(23+35.5) \times 10^{-3}}{2.18 \times 10^3} \text{ m}^3$$

1 mole of NaCl contains 6.02×10^{23} molecules

$$\text{Volume of 1 molecule} = \frac{(23+35.5) \times 10^{-3}}{2.18 \times 10^3 \times 6.02 \times 10^{23}}$$

$$\text{Volume of 1 atom} = \frac{(23+35.5) \times 10^{-3}}{2.18 \times 10^3 \times 6.02 \times 10^{23}} \times \frac{1}{2} = 2.23 \times 10^{-29} \text{ m}^3$$

It the interatomic spacing is d ,

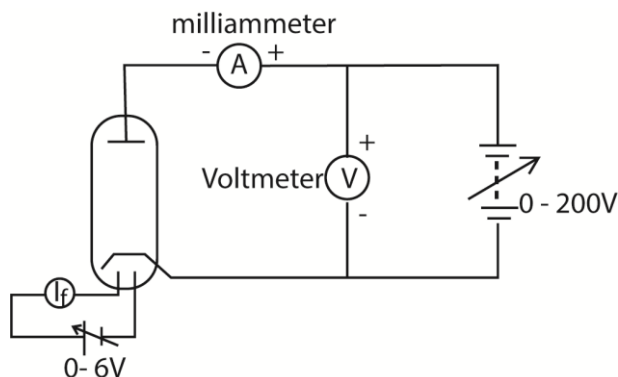
$$d^3 = 2.23 \times 10^{-29} \text{ m}^3$$

$$d = 2.81 \times 10^{-10} \text{ m}$$

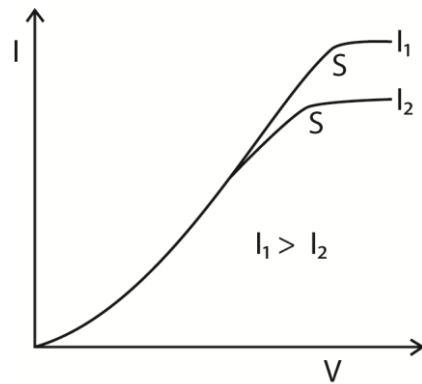
47. (a) (i) Explain briefly the mechanism of thermionic emission. (02marks)

When a metal is heat electron surface electrons acquire enough kinetic energy to overcome the nuclear attraction and escape from the surface. The escape of electrons from hot metal surface is termed thermionic emission.

(ii) Draw a labelled diagram of the circuit used to determine the anode current and anode voltage characteristics of a thermionic diode. (02marks)

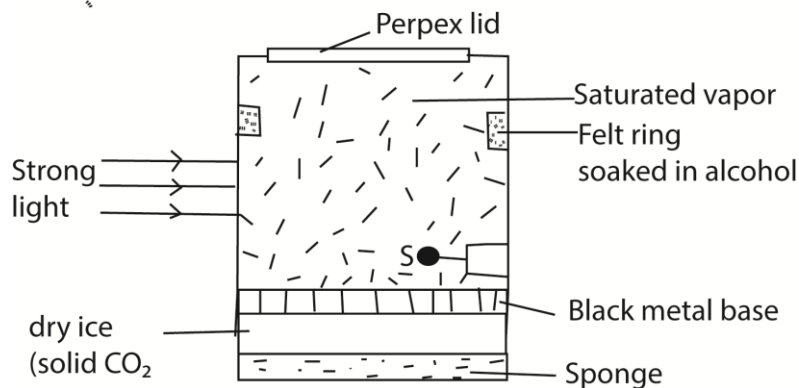


- (iv) Sketch the characteristic expected in (a) (ii) at constant filament current, and account for its special features. (04marks)



The current increases with the positive anode potential as far as the point S. Beyond this point the current does not increase, because the anode is collecting all the electrons emitted by the filament ; the current is said to be saturated.

- (b) Describe, with the aid of a labelled diagram, the structure and action of a diffusion cloud chamber (06marks)



- The base of the chamber is maintained at low temperature, about -80°C by the solid carbon dioxide while the top of the chamber is at room temperature, and so there is a temperature gradient between the top and the bottom of the chamber.
- The air at the top of the chamber is saturated with alcohol vapor from the felt ring. This vapor continuously diffuses downwards into the cooler regions so that the air at the bottom of the chamber is super saturated with alcohol vapor.
- Radiations from the radioactive source S cause the ionization of the vapor.

- The ionizations from the radioactive source S cause condensation of the vapor on the ions formed, hence the path of the ionizing radiations are traced by series of small droplets of condensation.
- The thickness and length of the path indicate the extent to which ionization has taken place.
- Alpha particles produce short, thick, continuous straight tracks
- Beta particles which are less massive produce longer, thin but straggly paths owing to collisions with gas molecules
- Gamma radiations are uncharged and for ionization to take place, it must collide with an atom and eject an electron which then ionizes the vapor.

(c) (i) Define radioactivity and half-life of a radioactive substance (02marks)

Radioactivity is the spontaneous disintegration of unstable nucleus acquire a more stable state by emission of α , β or γ –rays.

Half-life of a radioactive substance is the time taken for half the number of radioactive nuclei to disintegrate.

(ii) A radioactive isotope of strontium of mass $5.0\mu\text{g}$ has a half-life of 28years. Find the mass of the isotope left after 14 years.

[Assume the decay law $N = N_0 e^{-\lambda t}$]

$$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$$

$$N = 5 \times 10^{-6} e^{-\frac{\ln 2}{28} \times 14} = 3.54 \times 10^{-6} \text{g} = 3.54\mu\text{g}$$

48. (a) (i) State Rutherford's model of the atom. (02marks)

- The atom consists of positive charges confined to the center where most mass is concentrated
- Electrons orbit around the nucleus just like planets around the sun
- It is the electron cloud that accounts for the volume of an atom

(ii) Explain two main failures of Rutherford's model of the atom. (03marks)

- Much as electrons revolve around the nucleus, they do so only in certain allowed orbit. While in these orbits, they do not emit energy. Rutherford failed to explain this.
- Electrons can jump from one orbit to another of lower energy and energy emitted equal to energy difference between the energy levels equal hf , where f is the frequency of radiation emitted and h = Planck's constant. Rutherford failed to explain this.

(b) (i) Explain how Millikan's experiment for measuring the charge of an electron proves that charge is quantized. (04marks)

Millikan found out that the charge on every other droplet was always a multiple of basic unit $1.6 \times 10^{-19}\text{C}$ and a whole number. Thus the charge carried by an electron is $-1.6 \times 10^{-19}\text{C}$. A drop carrying charge of $N \times 10^{-19}\text{C}$ has either N electrons too many or too few. Thus Millikan concluded that charge is quantized.

(ii) Oil droplets are introduced into the space between two flat horizontal plates, set 5.0mm apart. The plate voltage is then adjusted to exactly 780V so that one of the droplets is held stationary. Then the plate voltage is switched off and the selected droplet is observed to fall a measured distance of 1.5mm in 11.2s. Given the density of oil used is

900kgm^{-3} and the viscosity of air is $1.8 \times 10^{-5}\text{Nsm}^{-2}$, calculate the charge on the droplet. (06marks)

When the uncharged drop is falling steadily under gravity with terminal velocity. v_0 .

$$\frac{4}{3}\pi r^3 \rho g = \frac{4}{3}\pi r^3 \sigma g + 6\pi \eta v_1$$

Where σ is density of air, ρ is density of oil and η is viscosity of air

$$\Rightarrow r = \left[\frac{9\eta v_1}{2g(\rho - \sigma)} \right]^{\frac{1}{2}}$$

$$\text{But } v_1 = \frac{\text{distance moved by oil drop}}{\text{time}} = \frac{1.5 \times 10^{-3}}{11.2} = 1.339 \times 10^{-4} \text{ms}^{-1}$$

Neglecting density of air, i.e. $\sigma = 0$

$$r = \frac{9 \times 1.8 \times 10^{-5} \times 1.339 \times 10^{-4}}{2 \times 9.81 \times 900} = 1.09 \times 10^{-16} \text{m}$$

When an electric field is applied across the plates,

$$\frac{4}{3}\pi r^3 \rho g = \frac{4}{3}\pi r^3 \sigma g + 6\pi \eta v_2 - Eq \text{ where } v_2 \text{ is the new speed}$$

$$Eq = \frac{4}{3}\pi r^3 (\rho - \sigma) - 6\pi \eta v_2$$

$$= 6\pi \eta v_1 - 6\pi \eta v_2$$

$$\text{Also } E = \frac{V}{d} = \frac{780}{50 \times 10^{-3}} = 1.56 \times 10^5 \text{Vm}^{-1}$$

Since the charged drop is held stationary by the field $v_2 = 0$

$$\begin{aligned} \text{Hence } q &= \frac{6\pi \eta v_1}{E} \\ &= \frac{6\pi \times 1.8 \times 10^{-5} \times 1.1 \times 10^{-6} \times 1.339 \times 10^{-4}}{1.56 \times 10^5} \\ &= 3.204 \times 10^{-19} \text{C} \\ &= 2e \end{aligned}$$

- (c) A beam of positive ions is accelerated through a potential difference of $1 \times 10^3 \text{V}$ into a region of uniform magnetic field of flux density 0.2T . While in magnetic field it moves in a circle of radius 2.3cm . Derive an expression for the charge to mass ratio of the ions, and calculate the value. (05marks)

When positive ions are accelerated through a p.d they acquire kinetic energy equal to $\frac{1}{2} mv^2$.

The force, F , on an electron moving normal to magnetic field is given by $F = Bqv$. This force provides the required centripetal force, F_c .

Thus $F_c = F_B$

$$\text{Now } \frac{mv^2}{r} = Bqv$$

$$u = \frac{Bqr}{m}$$

The kinetic energy should balance the energy due to the electric field

$$\text{K.E} = \frac{1}{2} mv^2 = qV$$

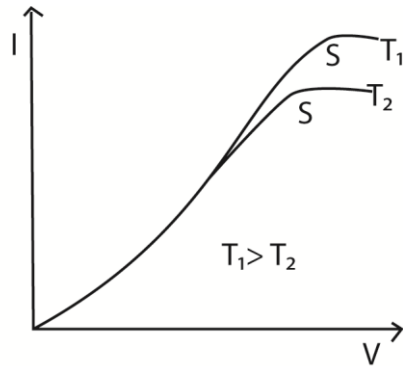
$$\frac{B^2 q^2 r^2}{2m} = qV$$

$$\frac{q}{m} = \frac{2V}{r^2 B^2} = \frac{2 \times 1 \times 10^3}{(2.3 \times 10^{-2})^2 \times 0.2^2} = 9.5 \times 10^7 \text{Ckg}^{-1}$$

49. (a) (i) What is meant by thermionic emission? (01mark)

It emission of electrons from a metal surface when heated.

- (ii) Sketch the current-potential difference characteristics of a thermionic diode for two different operating temperature and explain their main features. (05marks)



The current increases with the positive anode potential as far as the point S. Beyond this point the current does not increase, because the anode is collecting all the electrons emitted by the filament ; the current is said to be saturated. More electrons are emitted at a higher temperature T_1 than T_2 .

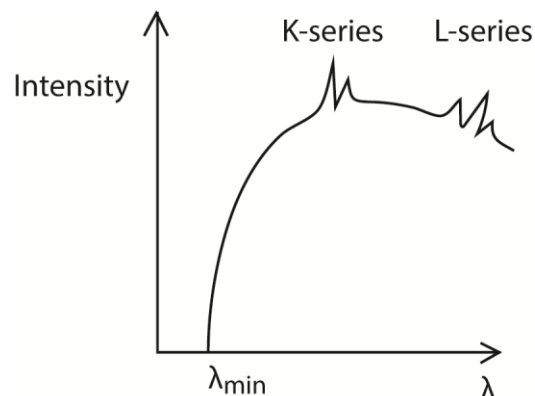
- (v) Describe one application of a diode. (02marks)

Diodes are used in rectification of a.c into d.c since they conduct in one direction only.

- (b) (i) What features of an x-ray tube make it suitable for continuous production of X-rays. (03marks)

- low voltage source for heating the cathode an electron source by thermionic emission
- accelerating p.d
- high melting point target
- highly conducting copper anode and cooling fins to dissipate heat by radiation and convection to prevent damage to apparatus due to overheating.

- (ii) Sketch a graph of intensity versus frequency of a radiation produced in an X-ray tube and explain its main feature. (05marks)



The spectrum consists of two major components, i.e. the continuous (background) spectrum and the very sharp line spectrum superimposed onto the background spectrum.

The continuous spectrum is produced when electrons make multiple collisions with the target atoms in which they are decelerated. At each deceleration, X-rays of differing wavelength are produced.

The shortest Wavelength X-rays are produced when electrons lose all their energy as X-ray photon in a single encounter with the target atoms. The wavelength of the X-rays at this point is known as the cut off wavelength. At cut off wavelength, energy in an X-ray photon equals kinetic energy of the electron; i.e. $hf = eV$ or $\frac{hc}{\lambda_{max}} = eV$ where $V = p.d$

The line spectrum

At high tube voltages, the bombarding electrons penetrate deep into the target atoms and knock out electrons from inner shell. The knocked out electrons occupy vacant spaces in higher unfilled shells putting the atom in excited state and making them unstable.

Transition of an electron from higher to lower energy levels results in an emission of X-ray photon of energy equal to energy difference between the energy levels.

If the transition ends in the K-shell, it produces K-series and if the transition ends in L-shell. It produces L-series.

- (iii) A mono chromatic X-ray beam of wavelength $1.0 \times 10^{-10} \text{cm}$ is incident on a set of planes in a crystal of spacing $2.8 \times 10^{-10} \text{m}$. What is the maximum order possible with these X-rays? (04marks)

$$\text{From } 2d \sin \theta = n\lambda$$

$$\text{For } n \text{ maximum } \sin \theta = 1$$

$$n = \frac{2 \times 2.8 \times 10^{-10}}{1 \times 10^{-10}} = 5$$

50. (a) What is meant by the following terms:

- (i) nuclear number (01mark)

Nuclear number is the number of nucleons in the nucleus of an atom

- (ii) binding energy (01marks)

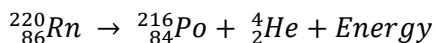
This is the energy require to split the nucleus into its constituent nucleons

(b) Calculate the energy released during the decay of $^{220}_{86}\text{Rn}$ nucleus into $^{216}_{84}\text{Po}$ and α -particle

$$\left\{ \begin{array}{l} \text{Mass of } ^{220}_{86}\text{Rn} = 219.964176\text{u} \\ \text{Mass of } ^{216}_{84}\text{Po} = 215.955794\text{u} \\ \text{Mass of } ^4_2\text{He} = 4.001566\text{u} \end{array} \right\}$$

$$(1u = 931\text{eV})$$

(04marks)



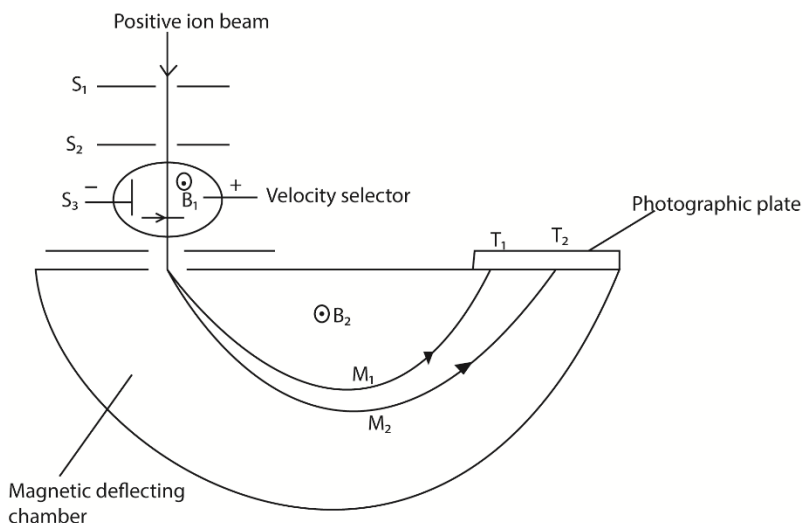
$$219.964U = 215.955U + 4.0015U + E$$

$$E = 6.816 \times 10^{-3}U$$

$$= 6.816 \times 10^{-3} \times 931\text{MeV}$$

$$= 6.35\text{MeV}$$

(c) Describe the Bainbridge mass spectrometer and explain how it can be used to distinguish between isotopes (07marks)



T_1 and T_2 are tracers on photographic plate, S_1 , S_2 and S_3 are slits

Mode of Action

- Positive ions are produced in a discharge tube and admitted as a beam through slits S_1 and S_2 .
- The beam then passes between insulated plates P, Q, connected to a battery, which create an electric field of intensity E .
- A uniform magnetic field B_1 , perpendicular to E is applied over the region of the plates and all ions, charge e with the same velocity, v given by $B_1ev = Ee$ will then pass undeflected through the plates and through a slit S_3 .
- The selected ions are deflected in a circular path of radius r by a uniform perpendicular magnetic field B_2 and an image is produced on a photographic plate as shown.

In this case

$$\frac{mv^2}{r} = B_2ev$$

But for the ions selected $v = \frac{E}{B_1}$ from above

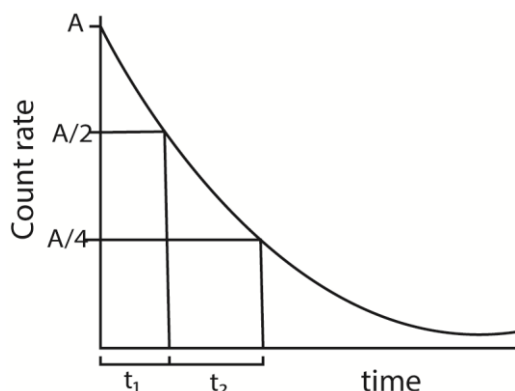
$$\therefore \frac{m}{e} = \frac{rB_2B_1}{E}$$

$$r = \left(\frac{E}{B_1B_2Q} \right) m$$

thus different isotopes strike the photographic plate at different points.

- (d) (i) Explain how you would use a decay curve for a radioactive material to determine its half-life. (02marks)

The curve is defined by $N = N_0 e^{-\lambda t}$



Find time t_1 taken for the activity to reduce to $A/2$ and t_2 taken for activity to reduce to $A/4$ from $A/2$, where A is the initial count rate.

$$\text{Half-life} = \frac{1}{2} (t_1 + t_2),$$

- (ii) A radioactive source contain $1.0\mu\text{g}$ of plutonium of mass number 239. If the source emits 2300 α -particles per second, calculate the half-life of plutonium.

[Assume the decay law $N = N_0 e^{-\lambda t}$] (05mark)

$$\text{Activity } A = \lambda N$$

$$\Rightarrow 2300 = \lambda N \dots\dots\dots (i)$$

$$239\text{g of Plutonium} \equiv 6.02 \times 10^{23} \text{ atoms}$$

$$1\mu\text{g Of Plutonium} = \frac{6.02 \times 10^{23}}{239} \times 10^{-6} = 2.52 \times 10^{15} \text{ atoms}$$

$$\therefore \text{number of atoms } N = 2.52 \times 10^{15}$$

From eqn. (i)

$$\lambda = \frac{2300}{2.52 \times 10^{15}} = 9.126 \times 10^{-13} \text{ s}^{-1}$$

$$t_{1/2} = \frac{\ln 2}{\lambda} = \frac{\ln 2}{9.126 \times 10^{-13}} = 7.50 \times 10^{11} \text{ seconds}$$

51. (a) What is meant by

- (i) Bohr atom (01mark)

A Bohr atom is an atom with small central positive nucleus with electrons revolving round it only in certain allowed orbits; while in orbits they do not emit radiations.

- (ii) binding energy of a nucleus (02marks)

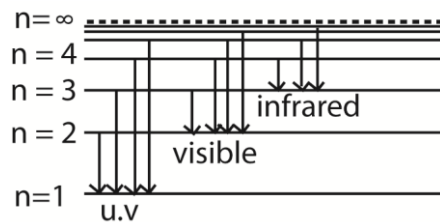
Binding energy is the energy required to split the nucleus into constituent nucleons

(b) The total energy, E, of an electron in an atom may be expressed as

$$E = \frac{-mq^4}{8\epsilon_0^2 n^2 h^2}$$

- (i) Identify the quantities, m, q, n and h in this expression (02marks)
 - m- mass of electron
 - q- charge on electron
 - n – principle quantum number
 - h – Planck's constant
- (ii) Explain the physical implication of the fact that E is always negative (02marks)

Electrons are bound to the nucleus. Work must be done to remove an electron from the atom. This work is done against nuclear attraction binding electrons in the atom.
- (iii) Draw an energy level diagram for hydrogen to indicate emission of ultraviolet, visible and infrared spectral lines. (03marks)



(c)(i) Explain briefly the sources and absorption of infrared radiation. (04 marks)

Source: Surfaces of all bodies emit infrared radiations in continuous range of wavelengths with relative amount of each wavelength depending mainly on temperature and nature of the surface.

Absorption: Infrared radiations is absorbed by matter. Like all other types of electromagnetic radiations, it causes increase of internal energy which leads to temperature rise. They thus produce a sensation of warmth when they fall on the skin.

Except red wavelength near to that of red light, infrared is absorbed by glass but transmitted by rock salt. Water vapour and carbon dioxide in the lower layers of the atmosphere collectively absorb infrared emitted by the earth.

(ii) Describe briefly, the method of detecting infrared radiation (03marks)

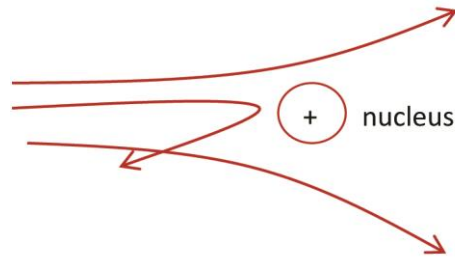
By thermopiles radiation falling on a hot junction produces e.m.f. the e.m.f is detected by the galvanometer connected across thermopile

(d) The atomic nucleus may be considered to be a sphere of positive charge with a diameter very much less than that of an atom. Discuss the experimental evidence which supports this view. (03marks)

In alpha particle experiment by Rutherford, most α - alpha particles passed through with negligible deflection. Some suffered various deviations. Very few were deflected back through angles greater than 90° due to head on collision with nucleus.

Majority of α -particles went through undeflected implying that most part of the atom is empty space.

About 1 in 8000 suffered deflection greater than 90° implying that the nucleus has a very small diameter compared to that of an atom



52. (a) (i) What are cathode rays? (01mark)

Cathode rays are a beam of fast moving electrons

(ii) An electron gun operating at $3 \times 10^3 \text{V}$ is used to project electrons into the space between two oppositely charged parallel plates of length 10cm and separation 5cm.

Calculate the deflection of the electrons as they emerge from the region between the charged plates when the potential difference is $1 \times 10^3 \text{V}$. (03marks)

$$\frac{1}{2}mv^2 = eV$$

$$v = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 3 \times 10^3}{9.11 \times 10^{-31}}} = 3.25 \times 10^7 \text{ms}^{-1}$$

$$v_x = 3.25 \times 10^7 \text{ms}^{-1}$$

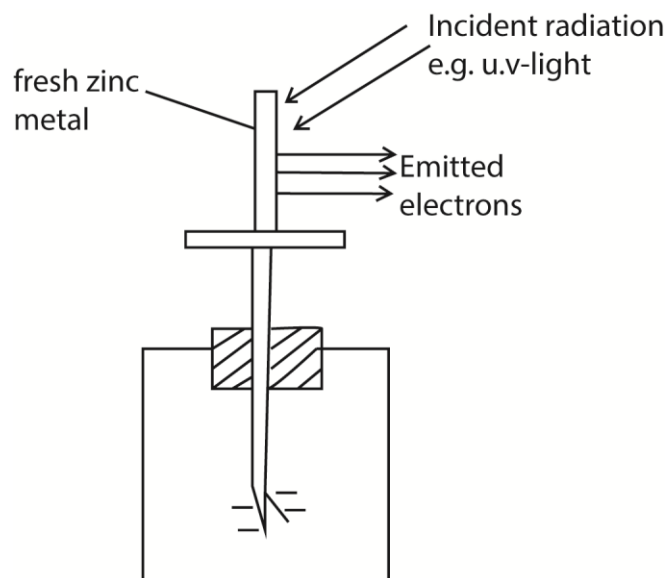
$$\text{Deflection, } y = \frac{1}{2}at^2 \text{ where } t = \frac{L}{u}, a = \frac{eE}{m}, E = \frac{V}{d}$$

$$= \frac{1.6 \times 10^{-19} \times 1 \times 10^3 \times (10 \times 10^{-2})^2}{2 \times 9 \times 10^{-31} \times 5 \times 10^{-2} \times (3.25 \times 10^7)^2}$$

$$= 1.67 \times 10^{-2} \text{m}$$

(b) (i) Describe a simple experiment to demonstrate photoelectric emission. (04marks)

- A freshly cleaned Zinc plate is connected to the cap of a negatively charged gold leaf electroscope.
- Ultra violet radiations are allowed to fall on the zinc plate



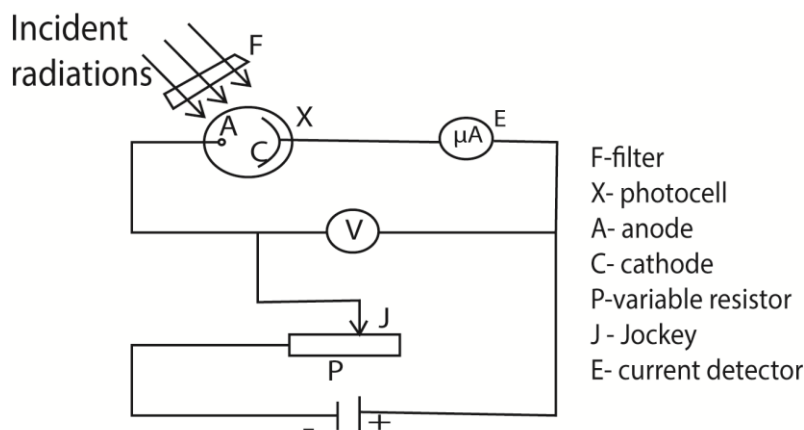
Observations

- The leaf of the electroscope gradually falls
- This shows that both the zinc plate and the electroscope have lost charges.
- The lost charges are found to be electrons, hence photoelectric effect has occurred.

(ii) Explain why the wave theory of light fails to account for the photoelectric effect. (06marks)

- Instantaneous emission: according to the wave theory radiation energy is uniformly spread over the whole wave front. Since the amount of energy incident on any electron would be extremely small, sometime would elapse before an electron escapes from the metal surface. On the contrary, no such a time lag between the start of radiation and start of emission is observed even when the radiation is weak.
- Variation of kinetic energy: by the wave theory, increasing intensity would mean more energy and hence greater value of maximum kinetic energy. But maximum kinetic energy depends on frequency of incident radiation and not intensity.
- Existence of threshold frequency: the wave theory predicts continuous absorption and accumulation of energy. Radiation of high enough intensity should cause emission even when the frequency is below minimum value. Hence the theory cannot account for threshold frequency.

(iii) Describe an experiment to verify Einstein's equation for the photoelectric effect and explain how Plank's constant may be obtained from the experiment. (06marks)



- A radiation of known frequency, f , is made incident on the photocathode
- Emitted electrons travel to the anode and cause a current to flow, detected at E.
- The p.d V is adjusted until the reading of E is zero (i.e. no current flows).
- The value of this p.d is the stopping potential (V_s) and is recorded from the voltmeter V.
- The procedure is repeated with light of different frequencies, f .
- A graph of stopping potential (V_s) against frequency (f) is plotted
- A straight line graph is obtained which verifies Einstein's equation; $V_s = \frac{h}{e}f - \frac{h}{e}f_0$
- The slope of the graph is $\frac{h}{e}$ from which Plank's constant, h , can be obtained.

53. (a) What is meant by

(i) half-life of radioactive element (01mark)

This is the time taken for the number of active nuclei present in the source at a given time to fall to half its value

(ii) nuclear fission (01mark)

Nuclear fission is the splitting of heavy unstable nucleus into two nuclei accompanied by release of energy.

(iii) Nuclear fusion

Nuclear fusion is the combination of light nuclei to form a heavier nucleus accompanied by release of energy.

(b) An atom of ^{222}Ra emits an α -particle of energy 5.3eV. Given that the half-life of ^{222}Ra is 3.8days. Use the decay law, $N = N_0 e^{-\lambda t}$ to calculate the:

(i) decay constant (03marks)

$$\text{Decay constant, } \lambda = \frac{\ln 2}{t_{\frac{1}{2}}} = \frac{0.693}{3.8 \times 24 \times 60 \times 60} = 2.11 \times 10^{-6} \text{ s}^{-1}$$

(ii) amount of energy released by $3.0 \times 10^{-9} \text{ kg}$ of ^{222}Ra after 3.8days (05marks)

1mole of Radium weighs 222g = 0.222kg $\equiv 6.02 \times 10^{23}$ atoms

$$3.0 \times 10^{-9} \text{ kg} \equiv \frac{6.02 \times 10^{23} \times 3 \times 10^{-9}}{0.222} = 8.135 \times 10^{15} \text{ atoms}$$

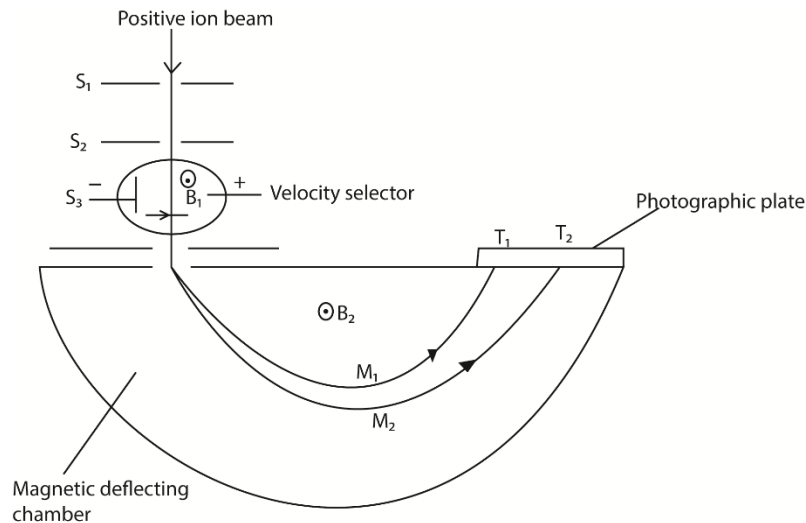
After 3.8 days, the number decays to half its original value

$$\Rightarrow \text{number of decayed atoms} = \frac{N_0}{2} = \frac{8.135 \times 10^{15}}{2} = 4.068 \times 10^{15}$$

$$\text{One atom releases } 5.3\text{MeV} = 5.3 \times 10^6 \times 1.6 \times 10^{-19} = 8.48 \times 10^{-13}\text{J}$$

$$\therefore 4.068 \times 10^{15} \text{ atoms release } 4.068 \times 10^{15} \times 8.48 \times 10^{-13} = 3449\text{J}$$

(c) Describe a simple form of a mass spectrometer and explain how it is used to distinguish between isotopes (07marks)



T₁ and T₂ are tracers on photographic plate, S₁, S₂ and S₃ are slits

Mode of Action

- Positive ions are produced in a discharge tube and admitted as a beam through slits S₁ and S₂.
- The beam then passes between insulated plates P, Q, connected to a battery, which create an electric field of intensity E.
- A uniform magnetic field B₁, perpendicular to E is applied over the region of the plates and all ions, charge e with the same velocity, v given by B₁ev = Ee will then pass undeflected through the plates and through a slit S₃.
- The selected ions are deflected in a circular path of radius r by a uniform perpendicular magnetic field B₂ and an image is produced on a photographic plate as shown.

In this case

$$\frac{mv^2}{r} = B_2 ev$$

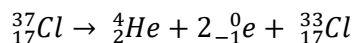
But for the ions selected $v = \frac{E}{B_1}$ from above

$$\therefore \frac{m}{e} = \frac{r B_2 B_1}{E}$$

$$r = \left(\frac{E}{B_1 B_2 Q} \right) m$$

thus different isotopes strike the photographic plate at different points.

- (d) the nucleus of ${}^{37}_{17}\text{Cl}$ emits an α -particle followed by two β -particles. Show that the final nucleus is an isotope of chlorine (02mark)



54. (a) (i) Write down the Einstein photo-electric equation (01mark)

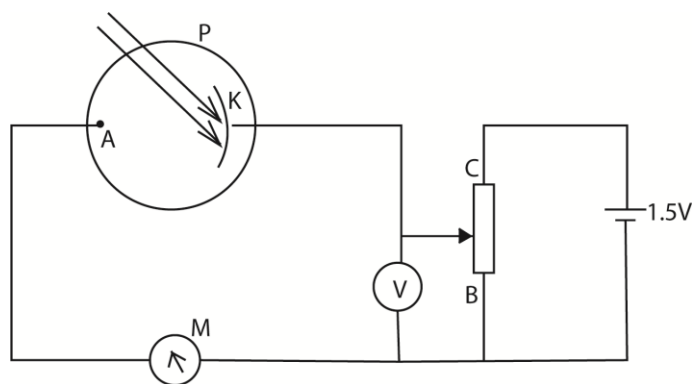
$hf = hf_0 + \frac{1}{2}mv_{\text{max}}^2$ where h = Planck's constant, f = frequency of incident radiation, f_0 = threshold frequency and v_{max} is the maximum velocity of a photoelectron

- (ii) Explain how the equation in (a)(i) above accounts for the emission of electrons from metal surfaces illuminated by radiation. (04marks)

Radiation consists of discrete packets of energy called photons, each of energy, hf , where f is the frequency. A free electrons absorb the whole amount of energy of a single photon or none.

If the energy is sufficient, part of it, hf_0 , goes into overcoming nuclear attraction and the rest become kinetic energy of photoelectron. Thus the electron can escape from the metal.

(b)



P is a vacuum photocell with anode, A, and cathode, K, made from the same metal of work function 2.0eV. The cathode is illuminated by monochromatic light of constant intensity and wavelength $4.4 \times 10^{-7}\text{m}$

- (i) Describe and explain how the current shown by the micro ammeter, M will vary as the slider of potential divider is moved from B to C. (03marks)

As the slider moves towards C, the cathode becomes more positive. This reduces the number of photoelectrons, photoelectric current decreases.

- (ii) What will the reading of the high-resistance voltmeter, V, be when photo-electric emission just ceases? (03marks)

$$V = \frac{1}{e} \left(\frac{hc}{\lambda} - w_0 \right) = \frac{1}{1.6 \times 10^{-19}} \left(\frac{6.6 \times 10^{-34} \times 3 \times 10^8}{4.4 \times 10^{-7}} - 2 \times 1.6 \times 10^{-19} \right) = 0.8125\text{V}$$

- (c) With the slider set mid-way between B and C, describe and explain how the reading of M would change if

- (i) the intensity of the light was increased, (03marks)

Increasing intensity increases the number of photons reaching the cathode per unit time. This in turn increases the number of electron emitted per second. At this point, the p.d across the photo cell is $\frac{1.5}{2} = 0.75V$. this is below the stopping potential (0.825V) reading. Therefore M also increases.

(ii) the wavelength of the light was changed to $5.5 \times 10^{-7}m$

$$w_0 = \frac{hc}{\lambda_0}$$

$$\lambda_0 = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{2 \times 1.6 \times 10^{-19}} = 6.1875 \times 10^{-7}m$$

Since the new frequency is greater than the previous one, but greater than threshold, electrons will be emitted but with lower kinetic energy. The number of electrons emitted per second remain the same if the intensity remains constant. Hence reading of M remains the same.

55. (a) What is meant by the following

(i) an alpha particle, (01mark)

An alpha particle is helium nucleus

(ii) radioactivity (01mark)

Radioactivity is spontaneous disintegration of the nucleus with emission of radiation.

(b) Show that when an alpha particle collides head –on with an atom of atomic number Z, the closest distance of approach to the nucleus b_0 , is given by

$$b_0 = \frac{Ze^2}{\pi\epsilon_0 mv^2}$$

where e is the electronic charge, ϵ_0 is the permittivity of free space, m, mass of the alpha particle and v is the initial velocity of the particle. (06marks)

Initial K.E of alpha particle = $\frac{1}{2} mv^2$

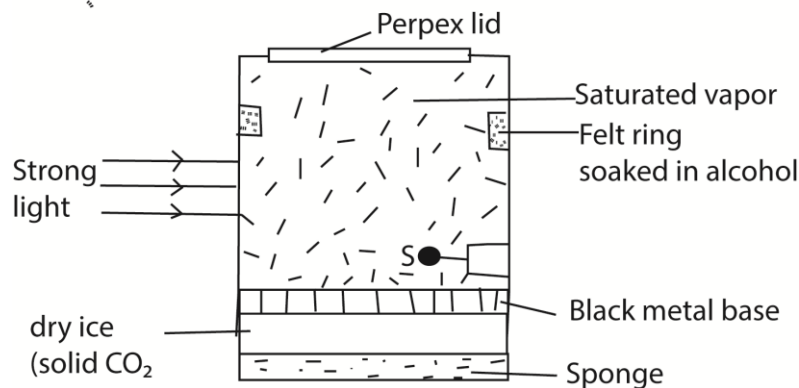
Electrostatic P.E of alpha particle and the nucleus at closet distance of approach = $\frac{Ze(2e)}{4\pi\epsilon_0 b_0}$

At closest distance of approach, the α -particle is instantaneously at rest and its initial kinetic energy = electrostatic potential energy

$$\text{Therefore } \frac{1}{2}mv^2 = \frac{Ze(2e)}{4\pi\epsilon_0 b_0}$$

$$b_0 = \frac{Ze^2}{\pi\epsilon_0 mv^2}$$

(c) Describe the structure and action of a cloud chamber. (06marks)



- The base of the chamber is maintained at low temperature, about -80°C by the solid carbon dioxide while the top of the chamber is at room temperature, and so there is a temperature gradient between the top and the bottom of the chamber.
- The air at the top of the chamber is saturated with alcohol vapor from the felt ring. This vapor continuously diffuses downwards into the cooler regions so that the air at the chamber is super saturated with alcohol vapor.
- Radiations from the radioactive source S cause the ionization of the vapor.
- The ionizations from the radioactive source S cause condensation of the vapor on the ions formed, hence the path of the ionizing radiations are traced by series of small droplets of condensation.
- The thickness and length of the path indicate the extent to which ionization has taken place.
- Alpha particles produce short, thick, continuous straight tracks
- Beta particles which are less massive produce longer, thin but straggly paths owing to collisions with gas molecules
- Gamma radiations are uncharged and for ionization to take place, it must collide with an atom and eject an electron which then ionizes the vapor.

(d) State four uses of radioactive isotopes (02marks)

- Detecting leakage in underground pipes
- Measuring rate of flow of liquids
- Tracing fertilizers using phosphorus-32
- Treatment of cancer

(e) one kilogram of wood from a ship wreck has activity of 1.2×10^2 counts per second due to ^{14}C , whereas the same amount of wood had an activity of 2.0×10^2 counts per second. Find the age of the ship wreck. [Half-life of ^{14}C = 5.7×10^3 years] (04 marks)

$$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}} = \frac{0.693}{5.7 \times 10^3} = 1.22 \times 10^{-4} \text{ year}^{-1}$$

$$\text{Using } A = A_0 e^{-\lambda t}$$

$$\ln \left(\frac{2 \times 10^2}{1.2 \times 10^2} \right) = 1.22 \times 10^{-4} t$$

$$t = 4187 \text{ years}$$

56. (a) What is meant by emission line spectra?

When a gas is heated to high temperatures, electronic transition occur from low to high energy levels. As electrons return to lower energy levels radiation of wavelength λ are emitted such that $\frac{hc}{\lambda}$ = energy difference between the initial and final levels is given off. The radiation consists of a series of lines when viewed through grating.

E_{∞}	0eV
E_4	-0.81eV
E_3	-2.77eV
E_2	-4.87eV
E_1	-27.47eV

(ii) The figure above shows some energy levels of neon. Determine the wavelength of the radiation emitted in an electron transition from E_4 to E_3 . In what region of the electromagnetic spectrum does the radiation lie? (04marks)

$$\frac{hc}{\lambda} = E_4 - E_3$$

$$\lambda = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{(2.77 - 0.81) \times 1.6 \times 10^{-19}} = 6.31 \times 10^{-7} \text{ m}$$

(b) Outline the principles of generation of continuous line spectra of X-rays in X-ray tube. (05marks)

Electrons make multiple collisions with the target atoms. During the collision, X-rays of different wavelength are produced. This gives a continuous X-ray spectrum.

When energetic electrons strike a target atom, an electron from innermost energy levels is displaced to higher energy levels leaving a vacancy and making an atom unstable. When the electron returns to the lower energy level, X-rays characteristic to target atoms are given off leading to X-ray line spectra

(c) State Bragg's law of X-ray diffraction. (01mark)

For two neighboring crystal planes separated by a distance, d , for diffraction, $2d \sin \theta = n\lambda$; where λ = wavelength of incident radiation, θ = glancing angle, and n = order of diffraction.

(d) A beam of X-rays of wavelength $1.0 \times 10^{-10} \text{ m}$ is incident on a set of cubic planes in a sodium chloride crystals. The first order diffraction m is obtained for a grazing angle of 10.2° .

Find

- (i) The spacing between consecutive planes (03marks)
From $2d \sin \theta = n\lambda$

$$d = \frac{1 \times 1 \times 10^{-10}}{2 \sin 10.2} = 2.82 \times 10^{-10} \text{m} = 2.82 \times 10^{-8} \text{cm}$$

(ii) The density of the sodium chloride (04marks)

Molecular mass of NaCl = 58.5g

1mole contain 6.02×10^{23} molecules

6.02×10^{23} molecules weigh 58.5g

$$1 \text{ molecule weighs} = \frac{58.5}{6.02 \times 10^{23}} \text{ g}$$

$$\text{Volume occupied by 1 molecule (2atoms- Na and Cl)} = \frac{\text{mass}}{\text{density}} = \frac{58.5}{6.02 \times 10^{23} \times \text{density of NaCl}}$$

$$\text{Volume associated with each atom} = \frac{1}{2} \times \frac{58.5}{6.02 \times 10^{23} \times \text{density of NaCl}} \text{ for cubic lattice}$$

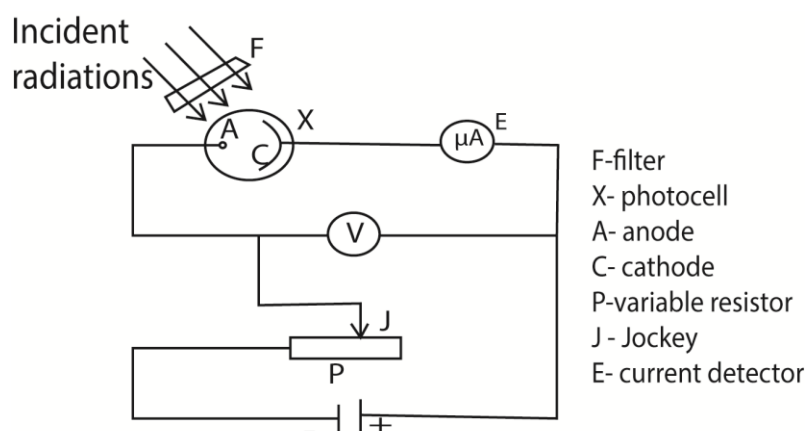
$$d^3 = \frac{1}{2} \times \frac{58.5}{6.02 \times 10^{23} \times \text{density of NaCl}}$$

$$\text{density of NaCl} = \frac{58.5}{6.02 \times 10^{23} \times (2.82 \times 10^{-8})^3} = 2.165 \text{gcm}^{-3}$$

57. (a) State the laws of photo electric emission. (04marks)

- The time lag between irradiation of the metal surface and emission of the electrons by the metal surface is negligible.
- For a given metal, surface there is a minimum value of frequency of radiation called threshold frequency (f_0) below which no photo electrons are emitted from the metal however intense the incident radiation may be.
- The number of photoelectrons emitted from the surface per second is directly proportional to the intensity of incident radiation for a particular incident frequency
- The K.E of the photoelectrons emitted is independent of the intensity of the incident radiation but depends only on its frequency

(b) (i) Describe an experiment Plank's constant. (05marks)



- A radiation of known frequency, f , is made incident on the photocathode
- Emitted electrons travel to the anode and cause a current to flow, detected at E.
- The p.d V is adjusted until the reading of E is zero (i.e. no current flows).
- The value of this p.d is the stopping potential (V_s) and is recorded from the voltmeter V.
- The procedure is repeated with light of different frequencies, f .

- A graph of stopping potential (V_s) against frequency (f) is plotted
- A straight line graph is obtained which verifies Einstein's equation; $V_s = \frac{h}{e}f - \frac{h}{e}f_0$
- The slope of the graph is $\frac{h}{e}$ from which Plank's constant, h , can be obtained.

(ii) Violet light wavelength $0.4\mu\text{m}$ is incident on a metal surface of threshold wavelength $0.65\mu\text{m}$. Find the maximum speed of emitted electrons

$$\text{From } hf = hf_0 + \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2hc}{m} \left(\frac{\lambda_0 - \lambda}{\lambda_0 \lambda} \right)} = \sqrt{\frac{2 \times 6.6 \times 10^{-34} \times 3 \times 10^8}{9.11 \times 10^{-31}} \left(\frac{0.65 - 0.4}{0.4 \times 0.65} \right)} \times 10^{-6} = 6.48 \times 10^6 \text{ms}^{-1}$$

(iii) Explain why light whose frequency is less than the threshold frequency cannot cause photoemission. (02marks)

According to the quantum theory, radiation is absorbed or emitted in discrete packets of energy called quanta with energy hf . Therefore light of frequency less than threshold would not be absorbed.

(c) (i) What are X-rays? (01marks)

X-ray are electromagnetic radiation of very short wavelength produced when fast moving electrons are stopped by metal target.

(ii) Explain how the intensity and penetrating power of X-rays produced by an X-ray tube can be varied. (04marks)

Intensity is the power transmitted per unit area. It is controlled by the filament current which determines the number of electrons striking the anode per second. The greater the filament current, the greater the number of electrons striking the anode per second and the greater the intensity.

Penetrating power is controlled by p.d between the filament and the anode which determines the kinetic energy with which electrons strike the anode.

58. (a)(i) Define the terms half-life and decay constant as applied to radioactivity. (02marks)

Half-life is the time taken for the number of active nuclei in a source at a given time to fall to half its value.

Decay constant is the number of nuclei decaying per unit time.

(ii) State relationship between half-life and decay constant. (01mark)

$$\text{Half-life, } t_{1/2} = \frac{\ln 2}{\text{decay constant, } \lambda}$$

(b) The radioisotope ^{60}Co decays by emission of a β -particle and γ -rays. Its half-life is 5.3years.

(i) find the activity of a source containing 0.10g of ^{60}Co . (04marks)

60g of cobalt contains 6.02×10^{23} atoms

0.1g of cobalt contain $\frac{6.02 \times 10^{23} \times 0.1}{60} = 1 \times 10^{21}$ atoms

From activity $= \lambda N = \frac{\ln 2N}{\text{decay constant, } \lambda} = \frac{0.693 \times 1 \times 10^{21}}{5.3 \times 365 \times 24 \times 60 \times 60} = 4.15 \times 10^{12} \text{s}^{-1}$

(ii) In which ways do γ -rays differ from β -particles (03marks)

Beta particle	Gamma rays
Negatively charges	No charge
Deflected by electric and magnetic field	Not affected by magnetic and electric field

(c) (i) What is meant by mass defect in nuclear physics? (01mark)

Mass defect is the difference in the mass of the constituents of a nucleus and mass of the nucleus

(ii) Calculate the mass defect for ${}^{59}_{26}\text{Fe}$, given the following information

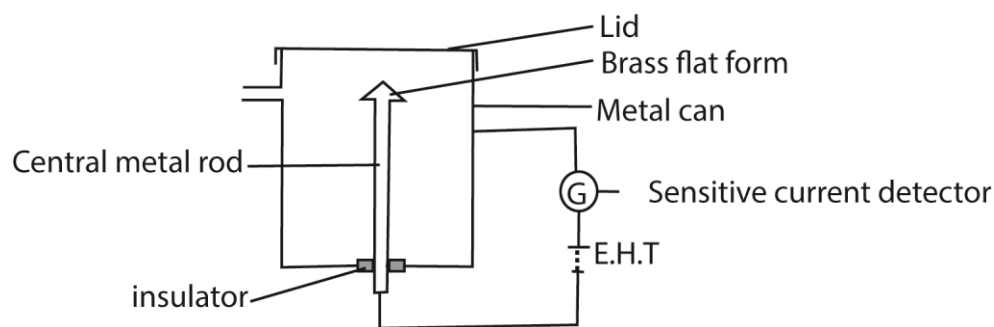
Mass of ${}^{59}_{26}\text{Fe}$ nucleus = 58.93488u

Mass of a proton = 1.00728u

Mass of neutron = 1.00867u (04marks)

Mass defect = $(26 \times 1.0072 + 33 \times 1.00867) - 58.93488 = 0.53733\text{U}$

(d) Describe the structure and action of ionization chamber. (05marks)

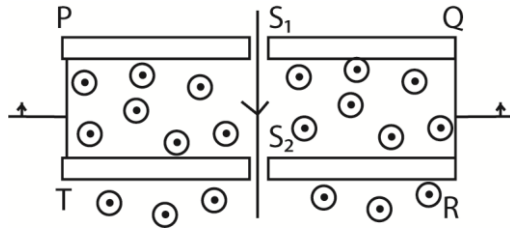


- A radiation source on the brass flat form causes ionization of air in the chamber producing electrons and positive ions.
- The electrons move to the metal can and positive ions drift to the central metal rod.
- Movement of the ions to the electrodes causes discharge and current pulse flows in external circuit.
- The current sensitive detector detects current.
- The magnitude of current detected shows the extent to which ionization takes place.

59. (a) What is meant by specific charge of an ion? (01mark)

It is the ratio of the charge to the mass of an ion.

(b)



Positive ions of the same charge are directed through slit S_1 into a region PQRT as shown in the figure above. There is a uniform electric field of intensity 300NC^{-1} between the plate PT and QR. A uniform magnetic field of flux density 0.6T is directed perpendicularly out of the paper as shown above.

- (i) Calculate the velocity of the ions which go through slit S_2 . (03marks)
Since the ions follow a straight line it implies that electrostatic force = magnetic force

$$qE = Bqv$$

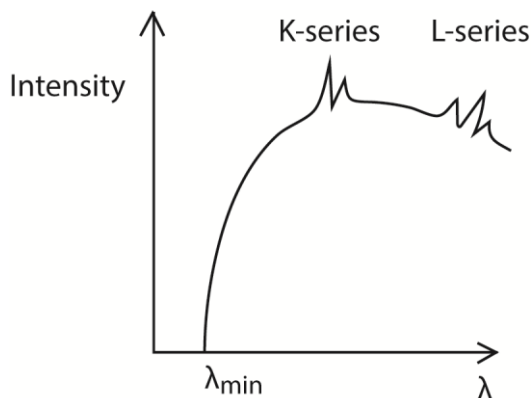
$$v = \frac{E}{B} = \frac{300}{0.6} = 500\text{ms}^{-1}$$

- (ii) Describe the motion of ions in the region TR. (3marks)

The path of ions in magnetic field is circular and the path is perpendicular to magnetic field due to the magnetic force producing a centripetal force.

(c) When fast moving electrons strike a metal target in X-ray tube, two type of X-ray spectra are produced

- (i) Draw a sketch graph of intensity against wavelength of the X-rays (02marks)



- (ii) Account for the occurrence of the two types of spectra (05marks)

The spectrum consists of two major components, i.e. the continuous (background) spectrum and the very sharp line spectrum superimposed onto the background spectrum.

The continuous spectrum is produced when electrons make multiple collisions with the target atoms in which they are decelerated. At each deceleration, X-rays of differing wavelength are produced.

The shortest Wavelength X-rays are produced when electrons lose all their energy as X-ray photon in a single encounter with the target atoms. The wavelength of the X-rays at this point is known as the cut off wavelength. At cut off wavelength, energy in an X-ray photon equals kinetic energy of the electron; i.e. $hf = eV$ or $\frac{hc}{\lambda_{max}} = eV$ where $V = p.d$

The line spectrum

At high tube voltages, the bombarding electrons penetrate deep into the target atoms and knock out electrons from inner shell. The knocked out electrons occupy vacant spaces in higher unfilled shells putting the atom in excited state and making them unstable.

Transition of an electron from higher to lower energy levels results in an emission of X-ray photon of energy equal to energy difference between the energy levels.

If the transition ends in the K-shell, it produces K-series and if the transition ends in L-shell. It produces L-series.

(d) Outline the experimental evidences for the quantum theory of matter. (06marks)

The quantum theory of matter states that energy of a radiation exists in discrete packets of magnitude hf where h is Plank's constant and f is the frequency. Some evidences are

- Photoelectric effect: to liberate an electron from a metal surface, a quantum (or packet) of energy called work function which is characteristic of the metal has to be supplied.
- Optical spectra: a line in optical emission spectrum indicates presence of a particular frequency, f , of light considered to arise from loss of energy which occurs in an excited atom when electron jumps directly or in steps from a higher energy level E_2 to lower energy level (s), E_1 . The frequency of a photon = $hf = E_1 - E_2$.
- X-ray line spectra: electron transition from one shell to another leads to liberation of energy in packets which are characteristic of the target atom