THE UNITED REPUBLIC OF TANZANIA

NATIONAL EXAMINATIONS COUNCIL OF TANZANIA

ADVANCED CERTIFICATE OF SECONDARY EDUCATION EXAMINATION

131/2 **PHYSICS 2**

(For Both School and Private Candidates)

Time: 2:30 Hours **ANSWERS** **Year: 2018**

Instructions

1. This paper consists of section A, B and C with total of nine questions.

2. Answer five questions, choosing at least one question from each section.

3. Each question carries twenty marks.

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1.(a) Given the Bernoulli's equation: $p + \rho gh + \frac{1}{2} \rho v^2$ = constant where all the symbols carry their usual meaning.

(i) What quantity does each expression on the left-hand side of the equation represent?

p represents the pressure energy per unit volume
ρgh represents the gravitational potential energy per unit volume
$\frac{1}{2} \rho v^2$ represents the kinetic energy per unit volume

(ii) Mention any three conditions which make the equation to be valid.

- The fluid must be incompressible.
- The flow must be steady (no sudden changes in velocity or pressure).
- The flow must be non-viscous (no significant internal friction).

(b) Water is supplied to a house at ground level through a pipe of inner diameter 1.5 cm at an absolute pressure of 6.5×10^5 Pa and velocity of 5 m/s. The pipe leading to the second floor bathroom 8 m above has an inner diameter of 0.75 cm. Find the flow velocity and pressure at the pipe outlet in the second floor bathroom.

Given:
$d_1 = 1.5$ cm $= 0.015$ m
$d_2 = 0.75$ cm $= 0.0075$ m
$P_1 = 6.5 \times 10^5$ Pa
$v_1 = 5$ m/s
$h_1 = 0$ m
$h_2 = 8$ m

Using continuity equation:
$A_1v_1 = A_2v_2$

$\pi(d_1/2)^2 v_1 = \pi(d_2/2)^2 v_2$

$(0.015/2)^2 \times 5 = (0.0075/2)^2 \times v_2$

$(2.25 \times 10^{-4}) \times 5 = (5.625 \times 10^{-5}) \times v_2$

$v_2 = (1.125 \times 10^{-3}) / (5.625 \times 10^{-5})$

$v_2 \approx 20$ m/s

Using Bernoulli's equation:

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$P_1 + \rho g h_1 + \frac{1}{2} \rho v_1^2 = P_2 + \rho g h_2 + \frac{1}{2} \rho v_2^2$

Solving for P_2:

$P_2 = P_1 + \rho g(h_1 - h_2) + \frac{1}{2} \rho(v_1^2 - v_2^2)$

$P_2 = (6.5 \times 10^5) + (1000 \times 9.81 \times (0 - 8)) + \frac{1}{2} (1000 \times (5^2 - 20^2))$

$P_2 = (6.5 \times 10^5) - (78480) + \frac{1}{2} (1000 \times (-375))$

$P_2 = (6.5 \times 10^5) - (78480) - (187500)$

$P_2 = 2.74 \times 10^5$ Pa

(c) Define the following terms when applied to fluid flow:

(i) Non-viscous fluid
A fluid with negligible internal friction between its layers, meaning it has zero viscosity.

(ii) Steady flow
A type of flow where the velocity, pressure, and density of the fluid at a given point remain constant over time.

(iii) Line of flow
A path followed by fluid particles such that a tangent to it at any point represents the instantaneous velocity of the fluid at that point.

(iv) Turbulent flow
A flow in which the velocity of the fluid varies unpredictably at different points due to chaotic mixing and eddies.

(d) A horizontal pipeline increases uniformly from 0.080 m diameter to 0.160 m diameter in the direction of flow of water. When 96 liters of water is flowing per second, a pressure gauge at the 0.080 m diameter section reads 3.5×10^5 Pa. What should be the reading of the gauge at the 0.160 m diameter section neglecting any loss?

Given:
$d_1 = 0.080$ m
$d_2 = 0.160$ m
$Q = 96$ L/s $= 0.096$ m^3/s
$P_1 = 3.5 \times 10^5$ Pa

Using continuity equation:

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$A_1v_1 = A_2v_2$

$\pi(0.080/2)^2 \, v_1 = \pi(0.160/2)^2 \, v_2$

$(0.004) \, v_1 = (0.016) \, v_2$

Using $Q = A_1v_1$:
$0.096 = (0.004) \, v_1$

$v_1 = 24$ m/s

Solving for v_2:
$(0.004)(24) = (0.016) \, v_2$

$v_2 = (0.096) / (0.016)$
$v_2 = 6$ m/s

Using Bernoulli's equation:

$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$

Solving for P_2:

$P_2 = P_1 + \frac{1}{2}\rho (v_1^2 - v_2^2)$

$P_2 = (3.5 \times 10^5) + \frac{1}{2}(1000)((24^2 - 6^2))$

$P_2 = (3.5 \times 10^5) + \frac{1}{2}(1000)(576 - 36)$

$P_2 = (3.5 \times 10^5) + (270000)$

$P_2 = 6.2 \times 10^5$ Pa

2.(a)What do you understand by the terms:

(i) Progressive wave
A wave that moves through a medium, transferring energy from one point to another without the particles of the medium moving permanently with the wave.

(ii) Refraction of waves
The bending of waves as they pass from one medium to another due to a change in speed.

(iii) Diffraction of waves
The spreading of waves as they pass through a gap or around an obstacle, causing interference patterns.

(iv) Standing wave
A wave that remains stationary in a medium due to the interference of two waves traveling in opposite directions with the same frequency and amplitude.

(b)Two progressive waves traveling in the opposite direction in the medium are represented by $Y_1 = 5 \sin(\omega t + \pi/3)$ and $Y_2 = 5 \sin(\omega t - \pi/3)$. If the two progressive waves form a standing wave, determine the resultant amplitude and the phase angle formed.

Given:
$Y_1 = 5 \sin(\omega t + \pi/3)$
$Y_2 = 5 \sin(\omega t - \pi/3)$

Using the principle of superposition:

$Y = 2A \cos(\theta/2) \sin(\omega t + \varphi/2)$

Comparing with the given wave equations:
$A = 5$
$\theta = (\pi/3 - (-\pi/3)) = 2\pi/3$

Resultant amplitude:
$A_r = 2A \cos(\theta/2)$

$A_r = 2(5) \cos(\pi/3)$

$A_r = 10 \times 0.5$

$A_r = 5$

Phase angle:
$\varphi = (\pi/3 + (-\pi/3)) / 2$

$\varphi = 0$

Thus, the resultant amplitude is 5 and the phase angle is 0.

(c)The shortest length of the resonance tube closed at one end which resounds to a fork of frequency 256 Hz is 31.6 cm. The corresponding length for a fork of frequency 384 Hz is 20.5 cm. Determine the end correction for the tube and the velocity of sound in air.

Given:
$L_1 = 31.6$ cm = 0.316 m
$f_1 = 256$ Hz
$L_2 = 20.5$ cm = 0.205 m
$f_2 = 384$ Hz

For a tube closed at one end:
$L_1 = (1/4)\lambda_1 + e$
$L_2 = (1/4)\lambda_2 + e$

Since $v = f\lambda$, we write:

$\lambda_1 = v / f_1$
$\lambda_2 = v / f_2$

Substituting in length equations:

$0.316 = (1/4) (v/256) + e$
$0.205 = (1/4) (v/384) + e$

Solving for v and e:

$v = 4 (0.316 - e) \times 256$
$v = 4 (0.205 - e) \times 384$

$1024 (0.316 - e) = 1536 (0.205 - e)$

Expanding:

$323.584 - 1024e = 314.88 - 1536e$

Rearranging:

$323.584 - 314.88 = 1024e - 1536e$

$8.704 = -512e$

$e = -8.704 / -512$

$e = 0.017$ m (1.7 cm)

Now, solving for v:

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$v = 4 (0.316 - 0.017) \times 256$
$v = 4 \times 0.299 \times 256$
$v \approx 306$ m/s

Thus, the end correction is 1.7 cm, and the velocity of sound in air is approximately 306 m/s.

3.(a)Define the term coherent sources of light.

Coherent sources are two or more sources that emit light waves with a constant phase difference and the same frequency, producing stable interference patterns.

(b)(i)Interference patterns are formed when using Young's double-slit experiment. Mention three other methods that can be used to form interference patterns.

1. Lloyd's mirror experiment
2. Fresnel's biprism experiment
3. Newton's rings experiment

(ii)Giving reasons, explain whether either transverse or longitudinal waves could exist if the vibrating motion causing them were not simple harmonic motion.

If the vibrating motion is not simple harmonic, the wave would be irregular and non-periodic, meaning it would not maintain a fixed frequency. This would prevent the formation of structured transverse or longitudinal waves, as their defining characteristic is periodicity.

(c)A beam of monochromatic light of wavelength 680 nm in air passes into glass. Calculate:

(i)The speed of light in glass

Given:
Wavelength in air, $\lambda_{air} = 680$ nm $= 680 \times 10^{-9}$ m
Refractive index of glass, $n = 1.5$
Speed of light in vacuum, $c = 3 \times 10^8$ m/s

Using:
$v_{glass} = c / n$

$v_{glass} = (3 \times 10^8) / 1.5$
$v_{glass} = 2 \times 10^8$ m/s

(ii)The frequency of light

Using:

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$f = v_{air} / \lambda_{air}$

$f = (3 \times 10^8) / (680 \times 10^{-9})$

$f = 4.41 \times 10^{14}$ Hz

(iii)The wavelength of light in glass

Using:
$\lambda_{glass} = \lambda_{air} / n$

$\lambda_{glass} = (680 \times 10^{-9}) / 1.5$

$\lambda_{glass} = 453 \times 10^{-9}$ m

$\lambda_{glass} = 453$ nm

(d)A light of wavelength 644 nm is incident on a grating with a spacing of 2.00×10^{-6} m.

(i)What is the angle to the normal of a second-order maximum?
Using diffraction grating equation:

$n\lambda = d \sin\theta$

For second order (n = 2):

$2(644 \times 10^{-9}) = (2.00 \times 10^{-6}) \sin\theta$

$1.288 \times 10^{-6} = 2.00 \times 10^{-6} \sin\theta$

$\sin\theta = 1.288 / 2.00$

$\theta = \sin^{-1}(0.644)$
$\theta \approx 40.1°$

(ii)What is the largest number of orders that can be visible?

Using:
$n_{max} = d / \lambda$
$n_{max} = (2.00 \times 10^{-6}) / (644 \times 10^{-9})$
$n_{max} \approx 3.1$

Thus, the largest number of orders visible is 3.

(iii)Find the angular separation between the third and fourth order image.

Since n_max = 3, the fourth order is not visible, meaning there is no angular separation between the third and fourth order.

4.(a)Mention any two factors which affect the surface tension of the liquid and in each case explain two typical examples.

1. Temperature – Surface tension decreases with an increase in temperature because the kinetic energy of the molecules increases, reducing cohesive forces.
   - Example: Hot water spreads more easily than cold water on a surface due to lower surface tension.
   - Example: Bubbles in hot liquids form and burst more quickly than in cold liquids due to reduced surface tension.

2. Impurities– The presence of impurities can either increase or decrease surface tension depending on their nature.
   - Example: Adding detergent to water reduces surface tension, making water spread and penetrate surfaces better for cleaning.
   - Example: Salt dissolved in water increases surface tension by strengthening intermolecular forces.

(b)Why molecules on the surface of a liquid have more potential energy than those within the liquid? Briefly explain.

Molecules on the surface of a liquid experience an imbalance of forces because they are only pulled inward by neighboring molecules, while molecules inside the liquid are surrounded on all sides. This results in higher potential energy for surface molecules since they require additional energy to maintain their position without being pulled into the bulk of the liquid.

(c)(i)Derive an expression for excess pressure inside a soap bubble of radius R and surface tension σ when the pressures inside and outside the bubble are P_1 and P_2 respectively.

For a soap bubble, there are two interfaces contributing to surface tension. The excess pressure ΔP is given by:

$\Delta P = P_1 - P_2$

Using the general surface tension formula:

Tension force = Excess pressure × Area

Since a soap bubble has two surfaces, the force balance gives:

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$2\sigma \times (2\pi R) = \Delta P \times (\pi R^2)$

Simplifying:

$\Delta P = 4\sigma / R$

Thus, the excess pressure inside a soap bubble is given by:

$P_1 - P_2 = 4\sigma / R$

(ii)A soap bubble has a diameter of 5 mm. Calculate the pressure inside it if the atmospheric pressure is 10^5 Pa and the surface tension of a soap solution is 2.8×10^{-2} Nm^{-1}.

Given:
Diameter = 5 mm = 0.005 m
Radius, R = 0.0025 m
Atmospheric pressure, $P_2 = 10^5$ Pa
Surface tension, $\sigma = 2.8 \times 10^{-2}$ N/m

Using:

$P_1 - P_2 = 4\sigma / R$

$P_1 = P_2 + (4\sigma / R)$

$P_1 = 10^5 + (4 \times 2.8 \times 10^{-2}) / (0.0025)$

$P_1 = 10^5 + (0.112 / 0.0025)$

$P_1 = 10^5 + 44.8$

$P_1 \approx 100044.8$ Pa

$P_1 \approx 1.00045 \times 10^5$ Pa

(d)Water rises up in a glass capillary tube up to a height of 9.0 cm while mercury falls down by 3.4 cm in the same capillary. Assume angles of contact for water-glass and mercury-glass as 0° and 135° respectively. Determine the ratio of surface tensions of mercury and water.

Using Jurin's law:

$h = (2\sigma \cos\theta) / (\rho g r)$

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For water:

$h_1 = (2\sigma_w \cos 0°) / (\rho_w g r)$

For mercury:

$h_2 = (2\sigma_m \cos 135°) / (\rho_m g r)$

Taking the ratio:

$h_1 / h_2 = [(2\sigma_w \cos 0°) / (\rho_w g r)] \div [(2\sigma_m \cos 135°) / (\rho_m g r)]$

Since cos0° = 1 and cos135° = -0.707:

$(9.0 / 3.4) = [(2\sigma_w \times 1) / (\rho_w g r)] \div [(2\sigma_m \times -0.707) / (\rho_m g r)]$

$9.0 / 3.4 = (2\sigma_w) / (-1.414\sigma_m)$

$\sigma_m / \sigma_w = (-1.414 \times 3.4) / 9.0$

$\sigma_m / \sigma_w \approx 0.534$

Thus, the ratio of surface tensions of mercury to water is approximately 0.534.

5.(a)Briefly explain the following observations as applied to strengths of materials:

(i)Bridges are declared unsafe after long use.

Bridges experience continuous stress due to vehicles and environmental factors, leading to fatigue. Over time, microscopic cracks form and grow, reducing the structural integrity, which can lead to failure if not maintained.

(ii)Iron is more elastic than rubber.

Elasticity is the ability of a material to return to its original shape after deformation. Iron has a much higher Young's modulus compared to rubber, meaning it deforms less under stress and recovers more efficiently, making it more elastic in engineering terms.

(b)A composite wire of diameter 1 cm consists of copper and steel wires of lengths 2.2 m and 2 m respectively. Total extension of the wire when stretched by a force is 1.2 mm. Calculate the force, given that Young's modulus for copper is 1.1×10^{11} Pa and for steel is 2×10^{11} Pa.

Given:
$L_1 = 2.2$ m, $L_2 = 2$ m
$Y_1 = 1.1 \times 10^{11}$ Pa, $Y_2 = 2 \times 10^{11}$ Pa
$A = \pi(0.01/2)^2 = 7.85 \times 10^{-6}$ m²
$\Delta L = 1.2$ mm $= 1.2 \times 10^{-3}$ m

Using the total extension formula:

$$\Delta L = (FL_1 / Y_1A) + (FL_2 / Y_2A)$$

Substituting values:

$$1.2 \times 10^{-3} = [(F \times 2.2) / (1.1 \times 10^{11} \times 7.85 \times 10^{-6})] + [(F \times 2.0) / (2 \times 10^{11} \times 7.85 \times 10^{-6})]$$

Solving for F:

$$F \approx 4576 \text{ N}$$

(c)What do you understand by the following terms?

(i)A perfectly plastic material
A material that, once it reaches its yield point, undergoes permanent deformation without any increase in stress.

(ii)The ultimate tensile strength
The maximum stress that a material can withstand before failure.

(iii)An elastic limit
The maximum stress that a material can sustain without undergoing permanent deformation.

(iv)Poisson's ratio
The ratio of lateral strain to axial strain in a material subjected to stress.

(d)Two rods of different materials but of equal cross-sections and lengths 1.0 m each are joined to make a rod of length 2.0 m. The metal of one rod has a coefficient of linear thermal expansion of 10^{-5}/°C and Young's modulus 3×10^{10} N/m². The other rod has values 2×10^{-5}/°C and 10^{10} N/m² respectively. How much pressure must be applied to the ends of the composite rod to prevent its expansion when the temperature is raised by 100°C?

Using:

$$P = (Y_1\alpha_1 + Y_2\alpha_2)\,\Delta T / (Y_1 + Y_2)$$

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$P = [(3 \times 10^{10} \times 10^{-5}) + (10^{10} \times 2 \times 10^{-5})] \times 100 / (3 \times 10^{10} + 10^{10})$

$P = [(3 \times 10^5) + (2 \times 10^5)] \times 100 / (4 \times 10^{10})$

$P = 5 \times 10^7 / 4 \times 10^{10}$

$P = 1.25 \times 10^6$ Pa

6.(a)Briefly explain the effect of the dielectric material on the capacitance of a capacitor when the capacitor is:

(i)Isolated.

When a dielectric is inserted in an isolated capacitor, the capacitance increases as the dielectric reduces the effective electric field, allowing the capacitor to store more charge at the same voltage.

(ii)Connected to the battery.

When connected to a battery, the voltage remains constant. Inserting a dielectric increases capacitance, leading to an increase in stored charge while the potential difference remains unchanged.

(b)Two point charges of equal mass m and charge Q are suspended at a common point by two threads of negligible mass and length L. If the two point charges are at equilibrium, show that:

(i)The distance of separation $x = (Q^2L / (2\pi\varepsilon_0 mg))^{(1/3)}$.

For equilibrium, the horizontal component of the tension balances the electrostatic force:

$T \sin\theta = F_e$

$T \cos\theta = mg$

Dividing:

$\tan\theta = (1 / 4\pi\varepsilon_0) \times (Q^2 / x^2) \times (1 / mg)$

Approximating small angles:

$x = (Q^2L / (2\pi\varepsilon_0 mg))^{(1/3)}$

(ii)The angle of inclination $\beta = (Q^2 / (16\pi\varepsilon_0 mgL^2))^{(1/2)}$.

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Using equilibrium conditions and substituting for $\tan\theta$:

$\beta = (Q^2 / (16\pi\varepsilon_0 mgL^2))^{(1/2)}$.

(c)Two point charges, $q_a = +3\ \mu C$ and $q_\beta = -3\ \mu C$, are located 0.2 m apart in vacuum. Find:

(i)The electric field at the midpoint of the line joining two charges.

$E_{total} = E_{q_a} + E_{q_\beta}$

$E = (1 / 4\pi\varepsilon_0) \times [q / r^2]$

For each charge:

$E = (9 \times 10^9) \times (3 \times 10^{-6}) / (0.1)^2$

$E = 2.7 \times 10^6$ N/C

Since the fields due to both charges add up,

$E_{total} = 5.4 \times 10^6$ N/C

(ii)The force experienced by the negative test charge of magnitude 1.5×10^{-9} C placed at this point.

$F = qE$

$F = (1.5 \times 10^{-9}) \times (5.4 \times 10^6)$

$F = 8.1 \times 10^{-3}$ N

7.(a)(i)What is meant by the term ballistic galvanometer?

A ballistic galvanometer is a sensitive measuring instrument used to detect and measure small amounts of charge or transient currents by observing the deflection of a moving coil suspended in a magnetic field.

(ii)State two conditions to be fulfilled for a galvanometer to be used as a ballistic galvanometer.

- The restoring torque of the coil should be small so that the coil takes longer to return to its initial position.
- The moment of inertia of the moving coil should be large so that it moves slowly and records the total charge passing through it.

(iii)Consider a small flat coil which has N turns of area A and whose plane is perpendicular to a magnetic field of flux density B. If the search coil is connected to the ballistic galvanometer and the total resistance of the circuit is R, use the laws of electromagnetic induction to show that the charge delivered to the galvanometer does not depend on how long it takes to remove the search coil from the field.

Using Faraday's law of electromagnetic induction:

Induced e.m.f,

$E = - d\Phi/dt$

where Φ is the magnetic flux given by:

$\Phi = B A N$

Total charge delivered to the galvanometer is given by:

$Q = \int I \, dt$

From Ohm's law,

$I = E / R$

Substituting E:

$Q = \int (- d\Phi/dt) / R \, dt$

$Q = - (1/R) \int d\Phi$

$Q = - (1/R) (\Phi_{final} - \Phi_{initial})$

Since the coil is initially in the magnetic field and is completely removed,

$\Phi_{initial} = B A N$
$\Phi_{final} = 0$

$Q = (BAN) / R$

Since the charge delivered depends only on B, A, N, and R, but not on time, it confirms that the charge delivered to the galvanometer does not depend on how quickly the coil is removed.

(b)A circular coil of 300 turns has a radius of 10 cm and carries a current of 7.5 A. Calculate the magnetic field at:

(i)The center of the coil

Magnetic field at the center of a circular coil is given by:

$B = (\mu_0 N I) / (2 R)$

Given:
$N = 300$ turns
$I = 7.5$ A
$R = 10$ cm $= 0.1$ m
$\mu_0 = 4\pi \times 10^{-7}$ Tm/A

Substituting values:

$B = (4\pi \times 10^{-7} \times 300 \times 7.5) / (2 \times 0.1)$

$B = (9 \times 10^{-4}) / 0.2$

$B = 4.5 \times 10^{-3}$ T

(ii)A point which is at a distance of 5 cm from the center of the coil.

Using the formula for a point along the axis of the coil:

$B = (\mu_0 N I R^2) / (2 (R^2 + x^2)^{(3/2)})$

where $x = 5$ cm $= 0.05$ m

Substituting values:

$B = (4\pi \times 10^{-7} \times 300 \times 7.5 \times 0.1^2) / (2 \times (0.1^2 + 0.05^2)^{(3/2)})$

$B = (9 \times 10^{-4} \times 0.01) / (2 \times (0.01 + 0.0025)^{(3/2)})$

$B = (9 \times 10^{-6}) / (2 \times (0.0125)^{(3/2)})$

$B = (9 \times 10^{-6}) / (2 \times 0.00442)$

$B = (9 \times 10^{-6}) / 0.00884$

$B \approx 1.02 \times 10^{-3}$ T

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(c)(i)Mention three magnetic materials and briefly explain each one.

- Ferromagnetic materials - Materials that exhibit strong magnetization when placed in a magnetic field, such as iron and nickel.
- Paramagnetic materials - Materials that are weakly attracted to a magnetic field but do not retain magnetization, such as aluminum and platinum.
- Diamagnetic materials - Materials that create an induced magnetic field in the opposite direction when placed in an external magnetic field, causing weak repulsion, such as copper and bismuth.

(ii)Give the differences between the magnetic materials mentioned in (c)(i) in terms of their magnetic susceptibility.

- Ferromagnetic materials have very high positive susceptibility ($\chi >> 1$).
- Paramagnetic materials have small positive susceptibility ($\chi > 0$ but much less than 1).
- Diamagnetic materials have negative susceptibility ($\chi < 0$).

(d)Define the following terms:

(i)Ampere
Ampere is the SI unit of electric current, defined as the amount of charge flowing per second. One ampere is equal to one coulomb per second.

(ii)Hysteresis
Hysteresis is the lagging of magnetization behind the applied magnetic field in a ferromagnetic material. It represents the energy loss when the material undergoes cyclic magnetization.

(e)Two parallel conductors A and B are situated 0.16 m apart. Conductor A carries a current of 4 A and conductor B, carries a current of 8 A. The directions of the currents are shown in Figure 1. Find the distance from A to a point where the magnetic fields due to A and B cancel each other (Ignore the effects of earth's magnetic field).

Magnetic field due to a long straight conductor is given by:

$B = (\mu_0 I) / (2\pi r)$

Let x be the distance from conductor A to the point where fields cancel.

At the cancellation point, the magnetic field due to A must be equal in magnitude but opposite in direction to the magnetic field due to B.

$(\mu_0 \times 4) / (2\pi x) = (\mu_0 \times 8) / (2\pi (0.16 - x))$

Canceling $\mu_0 / 2\pi$ from both sides:

$4 / x = 8 / (0.16 - x)$

Cross-multiplying:

$4(0.16 - x) = 8x$

$0.64 - 4x = 8x$

$0.64 = 12x$

$x = 0.64 / 12$

$x \approx 0.0533$ m or 5.33 cm

Thus, the distance from conductor A to the point where the magnetic fields cancel is approximately 5.33 cm.

8.(a)(i)What do you understand by the term photon?

A photon is a quantum of electromagnetic radiation that carries energy proportional to its frequency and has zero rest mass.

(ii)List down any three properties of a photon.

- A photon has no rest mass but has momentum.
- A photon travels at the speed of light in a vacuum.
- A photon carries energy given by $E = hf$, where h is Planck's constant and f is frequency.

(iii)State any four laws of photoelectric emission.

- Photoelectric emission occurs only if the incident light has a frequency above a certain threshold frequency.
- The number of emitted electrons is directly proportional to the intensity of the incident light.
- The maximum kinetic energy of emitted electrons depends on the frequency of the incident light, not its intensity.
- The emission of electrons is instantaneous when the threshold frequency is met.

(b)(i)Briefly explain what led de Broglie to think that material particles may also show wave nature and why the wave nature of matter is not noticeable in our daily observations.

De Broglie hypothesized that particles of matter also exhibit wave properties similar to light. He proposed that the wavelength associated with a moving particle is inversely proportional to its momentum, given by $\lambda = h/p$. However, for macroscopic objects, the mass is very large, making the wavelength extremely small and unobservable in daily life.

(ii)Prove that de Broglie wavelength λ of electrons of kinetic energy E is given by

$\lambda = h / \sqrt{2meV}$, where m is the mass of the electron, e is the charge of the electron, h is Planck's constant, and V is the accelerating potential difference.

Using the kinetic energy equation:

$E = \frac{1}{2} mv^2$

Solving for velocity:

$v = \sqrt{2E / m}$

Since momentum p = mv,

$p = m \sqrt{2E / m}$

$p = \sqrt{2mE}$

From de Broglie's equation:

$\lambda = h / p$

Substituting for p:

$\lambda = h / \sqrt{2mE}$

Since E = eV for an electron accelerated through a potential difference V:

$\lambda = h / \sqrt{2meV}$

(iii)Light of wavelength 488 nm is produced by an argon laser which is used in the photoelectric effect. When light from this spectral line is incident on the emitter, the stopping (cut-off) potential of photoelectrons is 0.38 V. Find the work function of the material from which the emitter is made.

Given:
$\lambda = 488 \text{ nm} = 488 \times 10^{-9}$ m
Stopping potential $V_0 = 0.38$ V

Planck's constant $h = 6.63 \times 10^{-34}$ Js
Charge of electron $e = 1.6 \times 10^{-19}$ C
Speed of light $c = 3 \times 10^{8}$ m/s

Using the photoelectric equation:

$hf = \phi + eV_0$

First, calculate f:

$f = c / \lambda$
$= (3 \times 10^{8}) / (488 \times 10^{-9})$
$= 6.15 \times 10^{14}$ Hz

Now, calculate hf:

$hf = (6.63 \times 10^{-34}) \times (6.15 \times 10^{14})$
$= 4.08 \times 10^{-19}$ J

Solving for ϕ:

$\phi = hf - eV_0$

$\phi = (4.08 \times 10^{-19}) - (1.6 \times 10^{-19} \times 0.38)$

$\phi = 4.08 \times 10^{-19} - 0.608 \times 10^{-19}$

$\phi = 3.47 \times 10^{-19}$ J

Converting to eV:

$\phi = (3.47 \times 10^{-19}) / (1.6 \times 10^{-19})$

$\phi = 2.17$ eV

(c)Use the concept of radioactive decay and nuclear reactions to define the following terms:

(i)Alpha decay
A nuclear reaction in which an unstable nucleus emits an alpha particle ($^{4}_{2}He$), decreasing its atomic number by 2 and mass number by 4.
Example:
$^{238}U_{92} \rightarrow {}^{234}Th_{90} + {}^{4}He_{2}$

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(ii)Beta decay

A nuclear reaction in which a neutron transforms into a proton, emitting an electron (β^-) and an antineutrino, or a proton transforms into a neutron, emitting a positron (β^+).

Example:

$^{14}C_6 \rightarrow {}^{14}N_7 + e^- + \bar{\nu}$

(iii)Gamma decay

A nuclear process in which an excited nucleus releases excess energy in the form of gamma radiation (γ-rays) without changing the atomic number or mass.

Example:

$^{234}Pa \rightarrow {}^{234}Pa^* + \gamma$

(iv)Fission

A reaction in which a heavy nucleus splits into two lighter nuclei, releasing energy and neutrons.

Example:

$^{235}U_{92} + {}^{1}n_0 \rightarrow {}^{141}Ba_{56} + {}^{92}Kr_{36} + 3\ {}^{1}n_0$

(v)Fusion

A reaction in which two light nuclei combine to form a heavier nucleus, releasing energy.

Example:

$^{2}H_1 + {}^{3}H_1 \rightarrow {}^{4}He_2 + {}^{1}n_0 + \text{energy}$

(d)A freshly prepared sample of a radioactive isotope Y contains 10^{12} atoms. The half-life of the isotope is 15 hours. Calculate:

(i)The initial activity.

Activity is given by:

$A = \lambda N$

where $\lambda = \ln 2 / T_{1/2}$

$\lambda = 0.693 / 15$

$\lambda = 0.0462\ h^{-1}$

$A = (0.0462) \times (10^{12})$

$A = 4.62 \times 10^{10}$ decays per hour

(ii)The number of radioactive atoms of Y remaining after 2 hours.

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$N = N_0 e^{(-\lambda t)}$

$N = (10^{12}) e^{(-0.0462 \times 2)}$

$N = (10^{12}) e^{(-0.0924)}$

$N = (10^{12}) \times (0.9117)$

$N \approx 9.12 \times 10^{11}$ atoms

9.(a)(i)Mention any four important features in the design of a nuclear reactor.

1. A moderator to slow down neutrons (e.g., graphite or heavy water).
2. Control rods to regulate the rate of the reaction (e.g., made of boron or cadmium).
3. A coolant to remove heat and generate steam for turbines (e.g., water or liquid sodium).
4. A containment shield to prevent radiation leakage.

(ii)Differentiate binding energy from mass defect.

Mass defect is the difference between the sum of the masses of protons and neutrons in a nucleus and the actual measured nuclear mass.

Binding energy is the energy required to separate all nucleons in a nucleus and is related to mass defect by $E = mc^2$.

(iii)Calculate the binding energy per nucleon, in MeV and the packing fraction of an alpha particle.

Given:
Mass of proton = 1.0080 u
Mass of neutron = 1.0087 u
Mass of alpha particle = 4.0026 u

Total mass of nucleons:
$= (2 \times 1.0080) + (2 \times 1.0087)$
$= 2.0160 + 2.0174$
$= 4.0334$ u

Mass defect:
$\Delta m = 4.0334 - 4.0026$
$= 0.0308$ u

Binding energy:
$E = \Delta m \times 931.5$ MeV/u

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= 0.0308 × 931.5
= 28.7 MeV

Binding energy per nucleon:
= 28.7 / 4
= 7.175 MeV

9.(b)(i)State any three limitations of Bohr's model of the hydrogen atom.

1. Bohr's model does not explain the spectra of atoms with more than one electron, as it only works well for hydrogen.
2. It does not account for the fine structure and splitting of spectral lines due to electron spin and relativistic effects.
3. It fails to explain why electrons do not radiate energy continuously while orbiting, as predicted by classical electrodynamics.

(ii)In a hydrogen atom model, an electron of mass m and charge e revolves around the nucleus in a circular orbit of radius r. Develop an expression for the radius r of the orbit in terms of m, e, π, the quantum number n, Planck's constant h, and the permittivity of free space ε_0, and hence use their values to find the Bohr's radius.

From the centripetal force and Coulomb force equilibrium:

$m v^2 / r = (1 / 4\pi\varepsilon_0) \times (e^2 / r^2)$

Rearrange for v^2:

$v^2 = (1 / 4\pi\varepsilon_0) \times (e^2 / mr)$

Using Bohr's quantization condition:

$mvr = n (h / 2\pi)$

Solving for v:

$v = n (h / 2\pi mr)$

Substituting in v^2 equation:

$(n^2 h^2) / (4\pi^2 m^2 r^2) = (1 / 4\pi\varepsilon_0) \times (e^2 / mr)$

Rearrange for r:

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$r = (4\pi\varepsilon_0 n^2 h^2) / (4\pi^2 m e^2)$

Canceling out terms:

$r = (\varepsilon_0 n^2 h^2) / (\pi m e^2)$

For the first Bohr orbit (n = 1):

$r_1 = (\varepsilon_0 h^2) / (\pi m e^2)$

Using values:
$\varepsilon_0 = 8.85 \times 10^{-12}$ F/m
$h = 6.63 \times 10^{-34}$ Js
$m = 9.11 \times 10^{-31}$ kg
$e = 1.6 \times 10^{-19}$ C

$r_1 = [(8.85 \times 10^{-12}) \times (6.63 \times 10^{-34})^2] / [\pi \times (9.11 \times 10^{-31}) \times (1.6 \times 10^{-19})^2]$

$r_1 \approx 5.29 \times 10^{-11}$ m

This is the Bohr radius.

(c)(i)Distinguish between ionization energy and excitation energy.

Ionization energy is the minimum energy required to completely remove an electron from an atom, leaving it ionized.

Excitation energy is the energy required to move an electron from a lower to a higher energy level within an atom without completely removing it.

(ii)Why does the hydrogen spectrum contain a larger number of spectral lines although its atom has only one electron?

Each electron transition between energy levels produces a different wavelength of light. Since the electron can transition between multiple levels, many spectral lines are observed in emission and absorption spectra, even though there is only one electron per atom.

(d)Figure 2 shows the energy level diagram of the hydrogen atom.

(i)Calculate the frequency and wavelength of the radiation emitted as a result of an electron transition from n = 4 to when an electron is in its ground state.

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Energy of levels:
$E_4 = -0.85$ eV
$E_1 = -13.6$ eV

Energy difference:

$\Delta E = E_1 - E_4$
$\Delta E = (-0.85) - (-13.6)$
$\Delta E = 12.75$ eV

Convert to joules:

$\Delta E = 12.75 \times (1.6 \times 10^{-19})$
$\Delta E = 2.04 \times 10^{-18}$ J

Using Planck's equation:

$f = \Delta E / h$

$f = (2.04 \times 10^{-18}) / (6.63 \times 10^{-34})$

$f = 3.08 \times 10^{15}$ Hz

Using speed of light equation:

$\lambda = c / f$

$\lambda = (3 \times 10^{8}) / (3.08 \times 10^{15})$

$\lambda \approx 97.4$ nm

(ii)What is the energy at the level where n = 5?

Using the energy level formula:

$E_n = -13.6 / n^2$

$E_5 = -13.6 / 5^2$

$E_5 = -13.6 / 25$

$E_5 = -0.544$ eV

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