THE UNITED REPUBLIC OF TANZANIA

NATIONAL EXAMINATIONS COUNCIL OF TANZANIA

ADVANCED CERTIFICATE OF SECONDARY EDUCATION EXAMINATION

131/2B **PHYSICS 2B**

(For Both School and Private Candidates)

Time: 2:30 Hours **ANSWERS** **Year: 1998**

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.

1. (a) (i) Define simple harmonic motion

Simple harmonic motion is a type of periodic motion in which the restoring force is directly proportional to the displacement from the mean position and acts in the opposite direction. It is given by the equation:

$F = -kx$

where k is the force constant and x is the displacement.

(ii) Prove that the velocity v of a particle moving in simple harmonic motion is given by

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

where A is the amplitude of oscillation, v the angular frequency, and y the displacement from the mean position.

In simple harmonic motion, displacement is given by:

$y = A \cos(\omega t)$

Differentiating with respect to time to obtain velocity:

$v = dy/dt = -A\omega \sin(\omega t)$

Using the identity $\sin^2(\omega t) = 1 - \cos^2(\omega t)$, we get:

$v^2 = A^2\omega^2(1 - \cos^2(\omega t))$

Since $y = A \cos(\omega t)$,

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

(b) A simple pendulum has a period of 2.8 seconds. When its length is shortened by 1.0 meter, the period becomes 2.0 seconds. From this information, determine the acceleration g of gravity and the original length of the pendulum.

The period of a pendulum is given by:

$T = 2\pi\sqrt{(L/g)}$

For the first case:

$2.8 = 2\pi\sqrt{(L/g)}$

Squaring both sides:
$(2.8)^2 = 4\pi^2 L/g$

For the second case:
$2.0 = 2\pi\sqrt{((L - 1)/g)}$

Squaring both sides:
$(2.0)^2 = 4\pi^2(L - 1)/g$

Dividing the first equation by the second and solving for L and g:

$L \approx 1.96$ m
$g \approx 9.81$ m/s²

(c) A particle rests on a horizontal platform which is moving vertically in simple harmonic motion with an amplitude of 50 mm. Above a certain frequency, the particle ceases to remain in contact with the platform throughout the motion.

(i) Find the lowest frequency at which this situation occurs

At the maximum acceleration, the condition for losing contact is:

$a = \omega^2 A = g$

Solving for ω:

$\omega = \sqrt{(g/A)}$

Using A = 50 mm = 0.05 m and g = 9.81 m/s²:

$\omega = \sqrt{(9.81 / 0.05)}$
$\omega \approx 14$ rad/s

Frequency $f = \omega / (2\pi)$

$f \approx 2.23$ Hz

(ii) Find the position at which contact ceases

Contact ceases when acceleration equals gravity, which occurs at $y = A/2$.

2. (a) (i) What is terminal velocity?

Terminal velocity is the constant velocity reached by an object falling through a fluid when the downward gravitational force is balanced by the upward drag and buoyant forces.

(ii) Briefly explain an experiment designed to measure terminal velocity

A ball is dropped into a fluid, and its motion is tracked using a high-speed camera. The velocity is measured at different time intervals until it becomes constant, indicating terminal velocity.

(b) A small sphere of radius r and density σ is released from the bottom of a column of liquid of density ρ which is slightly higher than σ.

(i) Deduce expressions for the initial acceleration of the sphere

Using Newton's second law:

m a = (Buoyant Force + Upthrust) - Weight

Using the volume of the sphere,

$m = (4/3)\pi r^3\sigma$

Initial acceleration:

$a = (4/3)\pi r^3(\rho - \sigma)g / ((4/3)\pi r^3\sigma)$
$a = (\rho - \sigma)g / \sigma$

(ii) Find the terminal velocity of the sphere

At terminal velocity:

Drag Force + Buoyant Force = Weight

Using Stokes' law for drag force:

$6\pi\eta rv = (4/3)\pi r^3 g(\sigma - \rho)$

Solving for v:

$v = (2r^2 g(\sigma - \rho)) / (9\eta)$

(c) Two equal drops of water are falling through air with a steady velocity of 0.15 m/s. If the drops coalesce, find their new terminal velocity.

Using Stoke's law:

$v \propto r^2$

Since volume is conserved:

$r_{new} = 2^{(1/3)} r$

$v_{new} = 2^{(2/3)} v$

$v_{new} = 2^{(2/3)} \times 0.15$
$v_{new} \approx 0.24$ m/s

3. (a) (i) State Newton's laws of motion

1. A body remains at rest or in uniform motion unless acted upon by an external force.
2. Force is equal to mass times acceleration ($F = ma$).
3. Every action has an equal and opposite reaction.

(ii) Explain why a length of horse pipe which is lying in a curve on a smooth horizontal surface straightens out when a fast flowing stream of water passes through it

The water flow exerts an outward force due to centrifugal force, causing the pipe to straighten.

(b) A ball of mass 0.4 kg is dropped vertically from a height of 2.5 m onto a horizontal table and bounces to a height of 1.5 m.

(i) Find the kinetic energy of the ball just before striking the table

$KE = mgh$

$KE = 0.4 \times 9.81 \times 2.5$
$KE = 9.81$ J

(ii) Find the kinetic energy just after impact

$KE' = mgh'$

$KE' = 0.4 \times 9.81 \times 1.5$
$KE' = 5.89$ J

(iii) Suggest reasons for the difference between these two values of kinetic energy

- Energy loss due to air resistance
- Energy converted into sound and heat upon impact

(iv) What height would you expect the ball to reach after its next bounce from the table?

$h'' = (h'/h)\, h'$

$h'' = (1.5/2.5) \times 1.5$
$h'' \approx 0.9$ m

(c) A jet of water flowing with a velocity of 20 m/s from a pipe of cross-sectional area 5.0×10^{-3} m² strikes a wall at right angles and loses all its velocity.

(i) Find the mass of water striking the wall per second

$m = \rho A v$

$m = 1000 \times (5.0 \times 10^{-3}) \times 20$
$m = 100$ kg/s

(ii) Find the change in momentum per second of the water hitting the wall

$\Delta p = m \Delta v$

$\Delta p = 100 \times (20 - 0)$
$\Delta p = 2000$ kg m/s²

(iii) Find the force exerted on the wall
$F = \Delta p / \Delta t$

$F = 2000$ N

4. (a) What is a diffraction grating?

A diffraction grating is an optical device consisting of a series of parallel lines or slits that diffract light into multiple beams. It is used to disperse light into its component wavelengths based on the principle of diffraction and interference.

(b) A diffraction grating has 5000 lines per centimeter. At what angles will bright diffraction images be observed if it is used with monochromatic light of wavelength 6.0×10^{-7} m at normal incidence?

The diffraction equation is given by:

$d \sin \theta = n\lambda$

where
$d = 1$ / number of lines per meter
number of lines per meter $= 5000 \times 10^2 = 5 \times 10^5$ lines/m
$d = 1 / (5 \times 10^5) = 2 \times 10^{-6}$ m
$\lambda = 6.0 \times 10^{-7}$ m

For first-order ($n = 1$):

$\sin \theta_1 = (1 \times 6.0 \times 10^{-7}) / (2 \times 10^{-6})$
$\theta_1 = \sin^{-1}(0.3)$
$\theta_1 \approx 17.46°$

For second-order ($n = 2$):

$\sin \theta_2 = (2 \times 6.0 \times 10^{-7}) / (2 \times 10^{-6})$
$\theta_2 = \sin^{-1}(0.6)$
$\theta_2 \approx 36.87°$

For third-order ($n = 3$):

$\sin \theta_3 = (3 \times 6.0 \times 10^{-7}) / (2 \times 10^{-6})$
$\theta_3 = \sin^{-1}(0.9)$
$\theta_3 \approx 64.16°$

Bright diffraction images will be observed at angles 17.46°, 36.87°, and 64.16° for first, second, and third-order diffraction, respectively.

(c) A lamp emits two wavelengths, 4.2×10^{-7} m and 6.0×10^{-7} m. Find the angular separation of these two waves in the third-order diffraction pattern produced by a diffraction grating having 4000 lines per centimeter, when light is at normal incidence on the grating.

The diffraction equation is given by:
$d \sin \theta = n\lambda$

where
number of lines per meter $= 4000 \times 10^2 = 4 \times 10^5$ lines/m
$d = 1 / (4 \times 10^5) = 2.5 \times 10^{-6}$ m
$n = 3$

For wavelength $\lambda_1 = 4.2 \times 10^{-7}$ m:

$\sin \theta_1 = (3 \times 4.2 \times 10^{-7}) / (2.5 \times 10^{-6})$
$\theta_1 = \sin^{-1}(0.504)$
$\theta_1 \approx 30.23°$

For wavelength $\lambda_2 = 6.0 \times 10^{-7}$ m:

$\sin \theta_2 = (3 \times 6.0 \times 10^{-7}) / (2.5 \times 10^{-6})$
$\theta_2 = \sin^{-1}(0.72)$
$\theta_2 \approx 46.17°$

The angular separation is:

$\Delta\theta = \theta_2 - \theta_1$
$\Delta\theta = 46.17° - 30.23°$
$\Delta\theta = 15.94°$

The angular separation of the two wavelengths in the third-order diffraction pattern is 15.94°.

5. (a) (i) A girl is holding a metal rod in her hand and rubs its surface with fur. Explain what happens to the rod.

When the girl rubs the metal rod with fur, the fur tends to transfer electrons to the metal if the metal is capable of holding a charge. However, since metals are conductors, any charge that accumulates on the rod will quickly dissipate through her hand to the ground, preventing significant charge buildup.

(ii) Can charge be conserved? Give at least two examples to support your answer.

Yes, charge is always conserved in an isolated system. Examples include:

- In a chemical reaction, the total charge of reactants and products remains the same.
- In nuclear reactions, though new particles may form, the total charge before and after the reaction remains conserved.

(b) The distance between the electron and proton in the hydrogen atom is about 5.3×10^{-11} m. Calculate the electrical and gravitational forces between these particles. How do they compare?

The electrical force is given by Coulomb's Law:

$F_e = k (q_1 q_2) / r^2$

where
$k = 8.99 \times 10^9$ N·m²/C²

$q_1 = q_2 = 1.6 \times 10^{-19}$ C
$r = 5.3 \times 10^{-11}$ m

$F\_e = (8.99 \times 10^9 \times (1.6 \times 10^{-19})^2) / (5.3 \times 10^{-11})^2$
$F\_e \approx 8.19 \times 10^{-8}$ N

The gravitational force is given by Newton's Law of Gravitation:

$F\_g = G (m_1 m_2) / r^2$

where
$G = 6.674 \times 10^{-11}$ N·m²/kg²
$m_1 = m_2 = 9.11 \times 10^{-31}$ kg (electron mass)

$F\_g = (6.674 \times 10^{-11} \times (9.11 \times 10^{-31}) \times (1.67 \times 10^{-27})) / (5.3 \times 10^{-11})^2$
$F\_g \approx 3.63 \times 10^{-47}$ N

Comparing F_e and F_g:

$F\_e / F\_g \approx 2.26 \times 10^{39}$

The electrical force between the electron and proton is about 10^{39} times stronger than the gravitational force.

(c) A capacitor of capacitance 3 μF is charged until a potential difference of 200 V is developed across its plates. Another capacitor of capacitance 2 μF developed a potential difference of 100 V across its plates on being charged.

(i) What is the energy stored in each capacitor?

Energy stored in a capacitor is given by:

$U = ½ C V^2$

For the first capacitor:

$U_1 = ½ \times (3 \times 10^{-6}) \times (200)^2$
$U_1 = 0.06$ J

For the second capacitor:

$U_2 = ½ \times (2 \times 10^{-6}) \times (100)^2$
$U_2 = 0.01$ J

(ii) The capacitors are then connected by wires of negligible resistance so that the plates carrying like charges are connected together. What is the total energy stored in the combined capacitors?

Total charge before connection:

$Q_1 = C_1V_1 = (3 \times 10^{-6}) \times 200$
$Q_1 = 6 \times 10^{-4}$ C

$Q_2 = C_2V_2 = (2 \times 10^{-6}) \times 100$
$Q_2 = 2 \times 10^{-4}$ C

Total charge:

$Q_{total} = Q_1 + Q_2$
$Q_{total} = (6 \times 10^{-4}) + (2 \times 10^{-4})$
$Q_{total} = 8 \times 10^{-4}$ C

Equivalent capacitance (parallel connection):

$C_{total} = C_1 + C_2$
$C_{total} = (3 + 2) \times 10^{-6}$
$C_{total} = 5 \times 10^{-6}$ F

Final voltage:

$V_f = Q_{total} / C_{total}$
$V_f = (8 \times 10^{-4}) / (5 \times 10^{-6})$
$V_f = 160$ V

Final energy stored:

$U_f = \frac{1}{2} C_{total} V_f^2$
$U_f = \frac{1}{2} \times (5 \times 10^{-6}) \times (160)^2$
$U_f = 0.064$ J

Energy loss due to redistribution of charge:

$\Delta U = (U_1 + U_2) - U_f$
$\Delta U = (0.06 + 0.01) - 0.064$
$\Delta U = 0.006$ J

The energy lost (0.006 J) is dissipated as heat due to redistribution of charge.

6. (a) (i) Define the term self-inductance for a coil

Self-inductance is the property of a coil by which it opposes the change in current flowing through it by inducing an electromotive force (emf) in itself.

(ii) Give the SI unit of self-inductance

The SI unit of self-inductance is the henry (H).

(b) Derive an expression for the coefficient of self-induction of a uniformly wound solenoid of length l, cross-sectional area A, and having N turns in air

The magnetic flux through a solenoid is given by:

$\Phi = B A N$

where B is the magnetic field inside the solenoid, given by:

$B = \mu_0 N I / l$

Substituting for B:

$\Phi = (\mu_0 N I A) / l$

The self-inductance is given by:

$L = N \Phi / I$

$L = (N (\mu_0 N I A) / l) / I$

$L = \mu_0 N^2 A / l$

Thus, the coefficient of self-induction of a solenoid is:

$L = \mu_0 N^2 A / l$

(c) Two coils A and B have 200 and 800 turns respectively. A current of 2 amperes in A produces a magnetic flux of 1.8×10^{-4} Wb in each turn of B. Compute:

(i) The mutual inductance

The mutual inductance is given by:

$M = N_2 \Phi_2 / I_1$

$M = (800 \times 1.8 \times 10^{-4}) / 2$
$M = 0.072$ H

(ii) The magnetic flux through A when there is a current of 4.0 amperes in B

Using the relation:
$\Phi_A = M I_2 / N_1$

$\Phi_A = (0.072 \times 4) / 200$

$\Phi_A = 1.44 \times 10^{-3}$ Wb

(iii) The emf induced in B when the current in A changes from 3 amperes to 1 ampere in 0.2 seconds

Using Faraday's law:

$e = -M (dI / dt)$

$e = - (0.072 \times (1 - 3)) / 0.2$

$e = 0.72$ V

7. (a) Describe and explain briefly a method for measuring the specific charge. Mention the errors expected in this method

The specific charge (e/m) of an electron can be determined using Thomson's method. An electron beam is passed through an electric and magnetic field perpendicular to each other. By adjusting the fields such that the electron beam remains undeflected, the specific charge can be determined using:

$e/m = (E^2) / (2B^2V)$

where E is the electric field, B is the magnetic field, and V is the accelerating potential.

Errors in this method include:
- Inaccuracies in measuring the deflection
- Non-uniformity of the magnetic or electric field
- Residual air molecules affecting electron motion

(b) An electron is projected horizontally with a velocity of 2.0×10^6 m/s into a large evacuated enclosure. A magnetic field which has a flux density of 15×10^{-4} T is directed vertically downwards throughout the enclosure.

(i) Find the radius of curvature of the electron's path

The radius of curvature is given by:

$r = (m v) / (e B)$

where
$m = 9.11 \times 10^{-31}$ kg
$e = 1.6 \times 10^{-19}$ C
$v = 2.0 \times 10^{6}$ m/s
$B = 15 \times 10^{-4}$ T

$r = (9.11 \times 10^{-31} \times 2.0 \times 10^{6}) / (1.6 \times 10^{-19} \times 15 \times 10^{-4})$

$r \approx 0.076$ m

(ii) Find how many complete loops must the electron describe before it falls by 1.0 cm under the influence of gravity

Using vertical displacement formula:

$y = \frac{1}{2} g t^2$

Solving for time t:

$t = \sqrt{(2y / g)}$

$t = \sqrt{(2 \times 0.01 / 9.81)}$

$t \approx 0.045$ s

Number of loops = t / T, where $T = 2\pi r / v$

$T = (2\pi \times 0.076) / (2.0 \times 10^{6})$
$T \approx 2.39 \times 10^{-7}$ s

Number of loops = $0.045 / (2.39 \times 10^{-7})$

$\approx 1.88 \times 10^{5}$ loops

(iii) What would be the effect of changing the direction of the magnetic field to upwards?

The electron would move in a circular path in the opposite direction due to the reversal of the Lorentz force.

8. (a) What is thermionic emission?

Thermionic emission is the release of electrons from a heated metal surface due to thermal energy overcoming the work function of the metal.

(b) Describe the function of each of the following:

(i) The electron gun

The electron gun generates and accelerates a focused beam of electrons using a cathode, a grid, and an anode.

(ii) The deflection system

The deflection system consists of electric or magnetic fields that control the path of the electron beam for display or measurement purposes.

(iii) The display system of the Cathode Ray Oscilloscope

The display system consists of a fluorescent screen that glows when struck by the electron beam, producing a visible trace.

(c) The figure shows a waveform displayed on the screen of a Cathode Ray Oscilloscope. The grid has squares of 1.0 cm. If the Y amplification is 2 V/cm and the time base is 30 ms/cm, find

(i) The peak voltage

Peak voltage = peak height × Y gain

$V_{peak} = 1.0 \text{ cm} \times 2 \text{ V/cm}$

$V_{peak} = 2 \text{ V}$

(ii) The frequency

Period T = total horizontal divisions × time base

$T = (4 \times 30) \text{ ms}$

$T = 120 \text{ ms}$

$f = 1 / T$

$f = 1 / (120 \times 10^{-3})$

$f \approx 8.33$ Hz

(d) Sketch the traces seen on the screen of a cathode ray oscilloscope when two sinusoidal potential differences of the same frequency and amplitude are applied simultaneously to X and Y plates of a cathode ray oscilloscope, when the phase difference between them is:

(i) 0° – A straight line
(ii) 45° – An elliptical shape
(iii) 90° – A circle

9. (a) Explain the terms atomic mass unit, mass defect, packing fraction, and binding energy

Atomic mass unit: A unit of mass equal to one-twelfth of the mass of a carbon-12 atom.
Mass defect: The difference between the sum of individual nucleon masses and the actual mass of the nucleus.
Packing fraction: The ratio of mass defect to the total mass of the nucleus.
Binding energy: The energy required to completely separate a nucleus into its individual nucleons.

(b) Discuss carbon dating

Carbon dating is a technique used to determine the age of ancient biological materials by measuring the ratio of carbon-14 to carbon-12 in a sample. Since carbon-14 decays over time, the remaining amount gives an estimate of the sample's age.

(c) Find the age at death of an organism, if the ratio of the amount of C^{14} at death to that at the present time is 10^8 and the half-life of C^{14} is 5600 years

Using the half-life formula:
$N/N_0 = (1/2)^\wedge(t/T)$
$10^8 = (1/2)^\wedge(t/5600)$
Taking logarithms:
$t = 5600 \times \log(10^8) / \log(2)$
$t \approx 1.87 \times 10^5$ years

10. (a) Explain the following terms: Earthquake, Earthquake focus, Epicentre, and Body waves
Earthquake: A sudden shaking of the Earth's crust due to seismic activity.
Earthquake focus: The point inside the Earth where the earthquake originates.
Epicentre: The point on the Earth's surface directly above the focus.
Body waves: Seismic waves that travel through the interior of the Earth.

(b) List down three sources of earthquakes

- Tectonic plate movement
- Volcanic eruptions
- Human activities such as mining or nuclear testing

(c) (i) Define ionosphere

The ionosphere is the part of Earth's upper atmosphere that contains ionized particles, affecting radio wave propagation.

(ii) Mention the ionospheric layers that exist during the daytime

The D, E, and F layers exist during the daytime.

(iii) Give the reason for better reception of radio waves for High Frequency signals at night than during the daytime

At night, the D layer disappears, reducing absorption and allowing better signal propagation.

(d) Explain briefly three different types of radio waves traveling from a transmitting station to a receiving antenna

i. Ground waves – These waves travel along the surface of the Earth and are used for low-frequency communication such as AM radio transmission. They are affected by terrain and conductivity of the ground.

ii. Sky waves – These waves are reflected or refracted back to Earth by the ionosphere. They are used for long-distance communication, especially in shortwave radio and HF (high-frequency) transmissions. The ionosphere's conditions influence their propagation.

iii. Space waves – These waves travel directly from the transmitter to the receiver without being affected by the Earth's surface. They are used for satellite communication, television, and mobile signals. They require line-of-sight between the transmitter and receiver.