THE UNITED REPUBLIC OF TANZANIA

NATIONAL EXAMINATIONS COUNCIL OF TANZANIA

ADVANCED CERTIFICATE OF SECONDARY EDUCATION EXAMINATION

131/1 **PHYSICS 1**

(For Both School and Private Candidates)

Time: 2:30 Hours **ANSWERS** **Year: 1999**

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) Mention two applications and two limitations of dimensional analysis.

Applications:
1. Checking the correctness of equations by ensuring both sides have the same dimensions.
2. Deriving relationships between physical quantities when the exact formula is unknown.

Limitations:
1. It cannot determine dimensionless constants such as π, e, or proportionality constants.
2. It does not apply to equations involving trigonometric, exponential, or logarithmic functions.

(b) The frequency f of a note produced by a taut wire stretched between two supports depends on the distance ℓ between the supports, the mass per unit length of the wire, μ, and the tension T. Use dimensional analysis to find how f is related to ℓ, μ, and T.

Let f be related as:

$f = k\, \ell^a \mu^b T^c$

Expressing dimensions:

$[f] = T^{-1}$
$[\ell] = L$
$[\mu] = M L^{-1}$
$[T] = M L T^{-2}$

Equating dimensions:

$T^{-1} = (L^a) (M^b L^{-b}) (M^c L^c T^{-2c})$

Grouping terms:

$M^{b+c} L^{a-b+c} T^{-2c} = T^{-1}$

Equating powers:

$b + c = 0$
$a - b + c = 0$
$-2c = -1$

Solving for c:

$c = 1/2$

Substituting into $b + c = 0$:

$b + 1/2 = 0$
$b = -1/2$

Substituting into $a - b + c = 0$:

$a - (-1/2) + 1/2 = 0$
$a + 1/2 - 1/2 = 0$
$a = -1$

Thus, $f = k (\ell^{-1}) (\mu^{(-1/2)}) (T^{(1/2)})$, or

$f = k \sqrt{(T / \mu)} / \ell$

2. (a) Define the following terms: (i) momentum (ii) impulse of a force

(i) Momentum is the product of mass and velocity of an object, given by $p = mv$. It is a vector quantity.
(ii) Impulse of a force is the product of force and the time duration over which it acts, given by Impulse = $F\Delta t$. It equals the change in momentum.

(b) A jet of water emerges from a hose pipe of a cross-sectional area 5.0×10^{-3} m² with a velocity of 3.0 m/s and strikes a wall at a right angle. Assuming the water to be brought to rest by the wall and does not rebound, calculate the force on the wall.

The mass flow rate is:

$\dot{m} = \rho A v$

Given:
$\rho = 1000$ kg/m³ (density of water)
$A = 5.0 \times 10^{-3}$ m²
$v = 3.0$ m/s

$\dot{m} = (1000 \times 5.0 \times 10^{-3} \times 3.0)$
$\dot{m} = 15$ kg/s

Force exerted by water:

$F = \dot{m} v$

$F = 15 \times 3$
$F = 45$ N

3. (a) What do you understand by the term escape velocity?

Escape velocity is the minimum velocity an object must have to overcome a planet's gravitational pull without further propulsion. It is given by

$v_e = \sqrt{(2GM / R)}$

where G is the gravitational constant, M is the mass of the planet, and R is its radius.

(b) Calculate the escape velocity from the moon's surface given that a man on the moon has ⅙ his weight on earth. The mean radius of the moon is 1.75×10^6 m.

Escape velocity is given by:

$v_e = \sqrt{(2gR)}$

Since g on the moon is ⅙ that of earth ($g = 9.81$ m/s²),

$g_m = (9.81 / 6) = 1.635$ m/s²

$v_e = \sqrt{(2 \times 1.635 \times 1.75 \times 10^6)}$
$v_e = \sqrt{(5.72 \times 10^6)}$
$v_e \approx 2.39 \times 10^3$ m/s

4. (a) Give two similarities between simple harmonic motion and circular motion.

- Both involve periodic motion where displacement varies sinusoidally with time.
- Both involve a restoring force directed toward an equilibrium position.

(b) On the same set of axes, sketch how energy exchange (kinetic to potential) takes place in an oscillator placed in a damping medium.

A damped oscillator loses energy over time due to resistive forces. The graph shows oscillations decreasing exponentially, with kinetic and potential energy gradually reducing.

5. (a) State the parallel axis theorem.

The parallel axis theorem states that the moment of inertia I of a body about any axis parallel to its center of mass is given by:

$I = I_{cm} + Md^2$

where I_{cm} is the moment of inertia about the center of mass, M is the mass of the object, and d is the distance between the two axes.

(b) Show that the kinetic energy (K.E.) of rotation of a rigid body about an axis with a constant angular velocity ω is given by $KE = \frac{1}{2} I\omega^2$ where I is the moment of inertia.

Kinetic energy is given by:

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

For rotational motion, $v = r\omega$, and substituting:

$KE = \frac{1}{2} m (r\omega)^2$
$KE = \frac{1}{2} m r^2 \omega^2$

Summing over all particles in the rigid body:

$KE = \frac{1}{2} \Sigma (m r^2) \omega^2$
$KE = \frac{1}{2} I\omega^2$

where $I = \Sigma (m r^2)$ is the moment of inertia.

6. (a) Distinguish between static and dynamic friction.

Static friction acts between two surfaces at rest, preventing motion.
Dynamic (kinetic) friction acts when surfaces slide past each other and is usually lower than static friction.

(b) With the help of a well-labeled diagram, briefly explain how you will determine the coefficient of viscosity of a liquid by a constant pressure head apparatus in the laboratory.

The constant pressure head method involves measuring the time taken for a liquid to flow through a capillary tube under steady pressure. Using Poiseuille's law:

$\eta = (\pi r^4 \Delta P) / (8 L Q)$

where r is tube radius, ΔP is pressure difference, L is tube length, and Q is flow rate.

7. (a) Explain in terms of surface energy, what is meant by the surface tension, γ of a liquid.

Surface tension is the force per unit length acting along the surface of a liquid due to cohesive forces. It arises because molecules at the surface experience an unbalanced inward attraction, minimizing surface area.

(b) What energy is required to form a soap bubble of radius 1.00 mm if the surface tension of the soap solution is 2.5×10^{-4} N/m²?

The energy required is given by:
$E = 4\pi r^2 \gamma$

$E = 4\pi (1.00 \times 10^{-3})^2 (2.5 \times 10^{-4})$
$E = 4\pi (10^{-6}) (2.5 \times 10^{-4})$
$E \approx 3.14 \times 10^{-9}$ J

The energy required is approximately 3.14 nJ.
8. (a) Write down the equation of continuity of a fluid defining all your symbols.

The equation of continuity states that for an incompressible fluid, the mass flow rate remains constant along a streamline:

$A_1 v_1 = A_2 v_2$

where:
A_1, A_2 = cross-sectional areas of the fluid at different points
v_1, v_2 = fluid velocities at those points

(b) The velocity at a certain point in a flow pipe is 1.0 m/s and the gauge pressure there is 3×10^5 Nm⁻². The cross-sectional area at a point 10 m above the first is half that at the first point. If the flowing fluid is pure water, calculate the gauge pressure at the second point.

Using Bernoulli's equation:

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

Given:
$v_1 = 1.0$ m/s, $P_1 = 3 \times 10^5$ Nm⁻², $h_1 = 0$, $h_2 = 10$ m
$A_2 = A_1 / 2$, so $v_2 = 2 v_1 = 2 \times 1.0 = 2.0$ m/s
$\rho = 1000$ kg/m³, $g = 9.81$ m/s²

$P_2 = P_1 + \frac{1}{2} \rho (v_1^2 - v_2^2) - \rho g (h_2 - h_1)$
$P_2 = (3 \times 10^5) + \frac{1}{2} (1000) (1^2 - 2^2) - (1000 \times 9.81 \times 10)$
$P_2 = (3 \times 10^5) + \frac{1}{2} (1000) (1 - 4) - (98100)$
$P_2 = (3 \times 10^5) - (1500) - (98100)$
$P_2 = 2.02 \times 10^5$ Nm⁻²

The gauge pressure at the second point is 2.02×10^5 Nm⁻².

12. (a) What is the difference between refraction and diffraction as applied to waves?

Refraction: The bending of a wave as it passes from one medium to another due to a change in speed.
Diffraction: The spreading of waves when they encounter an obstacle or pass through a narrow opening.

(b) A parallel beam containing two wavelengths 600 nm and 602 nm is incident on a diffraction grating with 400 lines per mm. Calculate the angular separation of the first-order spectrum of the two wavelengths.

Using the diffraction grating equation:

$n\lambda = d \sin \theta$

where $d = 1 / (400 \times 10^3)$ m $= 2.5 \times 10^{-6}$ m

For first order (n = 1):

$\sin \theta_1 = (1 \times 600 \times 10^{-9}) / (2.5 \times 10^{-6})$
$\sin \theta_1 = 0.24$

$\theta_1 = \sin^{-1}(0.24)$
$\theta_1 \approx 13.9°$

$\sin \theta_2 = (1 \times 602 \times 10^{-9}) / (2.5 \times 10^{-6})$
$\sin \theta_2 = 0.2408$

$\theta_2 = \sin^{-1}(0.2408)$
$\theta_2 \approx 13.96°$

Angular separation $\Delta\theta = \theta_2 - \theta_1$
$\Delta\theta = 13.96° - 13.9°$
$\Delta\theta \approx 0.06°$

The angular separation of the first-order spectrum is approximately 0.06°.

13. (a) What is a "Doppler Effect"?

The Doppler Effect is the change in frequency or wavelength of a wave due to the relative motion between the source and the observer. When the source moves towards the observer, the frequency appears higher, and when it moves away, the frequency appears lower.

(b) A whistle sound of frequency 1200 Hz was directed to an approaching train moving at 48 km/h. The whistleman then listened to the beats between the emitted sound and that reflected from the train. What is the beat frequency detected by the whistleman?

Using the Doppler Effect formula for sound:

$f' = f (v + v_0) / (v - v_s)$

where:
$f = 1200$ Hz (source frequency)
$v = 343$ m/s (speed of sound in air)
$v_s = 48$ km/h = $(48 \times 1000) / 3600 = 13.33$ m/s
$v_0 = 0$ (observer is stationary)

$f' = 1200 \times (343 + 0) / (343 - 13.33)$
$f' = 1200 \times (343 / 329.67)$
$f' \approx 1248$ Hz

Beat frequency:

$f\_beat = |f' - f|$
$f\_beat = |1248 - 1200|$
$f\_beat = 48$ Hz

The beat frequency detected by the whistleman is 48 Hz.

14. (a) Explain why an uncharged metal is attracted by a charged one.

An uncharged metal is attracted to a charged object due to electrostatic induction. When a charged object is brought near, opposite charges in the metal are attracted towards the charged object, while like charges are repelled. This causes a net attractive force between the charged object and the uncharged metal.

(b) Charges $Q_1 = 1.2 \times 10^{-12}$ C and $Q_2 = -4 \times 10^{-12}$ C are placed 5.0 m apart in air. A third charge $Q_3 = 1 \times 10^{-14}$ C is introduced midway between them. Find the resultant force on the third charge.

Using Coulomb's law:

$F = k |Q_1 Q_2| / r^2$

Given:
$k = 9 \times 10^9$ Nm²/C²
$Q_1 = 1.2 \times 10^{-12}$ C
$Q_2 = -4 \times 10^{-12}$ C
$Q_3 = 1 \times 10^{-14}$ C
$r = 2.5$ m (since Q_3 is midway)

Force due to Q_1 on Q_3:

$F_1 = (9 \times 10^9 \times 1.2 \times 10^{-12} \times 1 \times 10^{-14}) / (2.5)^2$
$F_1 = (1.08 \times 10^{-16}) / 6.25$
$F_1 \approx 1.73 \times 10^{-17}$ N (towards Q_1)

Force due to Q_2 on Q_3:

$F_2 = (9 \times 10^9 \times 4 \times 10^{-12} \times 1 \times 10^{-14}) / (2.5)^2$
$F_2 = (3.6 \times 10^{-16}) / 6.25$
$F_2 \approx 5.76 \times 10^{-17}$ N (towards Q_2)

Since Q_1 is positive and Q_2 is negative, both forces act in the same direction.

Resultant force:

$F\_net = F_2 - F_1$
$F\_net = 5.76 \times 10^{-17} - 1.73 \times 10^{-17}$
$F\_net = 4.03 \times 10^{-17}$ N towards Q_2.

15. (a) State Kirchhoff's laws of circuit analysis.

- Kirchhoff's Current Law (KCL): The total current entering a junction equals the total current leaving the junction.
- Kirchhoff's Voltage Law (KVL): The sum of all voltage drops around a closed loop equals the total supplied voltage.

(b) Determine the magnitudes of I_1 and I_3 from the given circuit.

Using Kirchhoff's laws, apply KVL to the loops and solve for I_1 and I_3 using simultaneous equations. The exact solution requires solving the system using Ohm's law.

16. (a) Write down an expression for the forces on an electron when moving perpendicular to:

(i) an electric field
F = eE

(ii) a magnetic field
F = e v B

(b) An electron is moving in a uniform electric field of intensity 1.2×10^5 V/m. Find the acceleration of the electron.

Using Newton's second law:

$F = m a$

Since $F = eE$,

$eE = m a$

$a = eE / m$

Given:
$e = 1.6 \times 10^{-19}$ C
$E = 1.2 \times 10^5$ V/m
$m = 9.11 \times 10^{-31}$ kg

$a = (1.6 \times 10^{-19} \times 1.2 \times 10^5) / (9.11 \times 10^{-31})$
$a = (1.92 \times 10^{-14}) / (9.11 \times 10^{-31})$
$a \approx 2.11 \times 10^{16}$ m/s²

17. (a) What is a resonant frequency of an oscillator?

The resonant frequency is the frequency at which a system naturally oscillates with maximum amplitude when subjected to an external periodic force.
17. (b) Consider the LRC series circuit. The r.m.s. voltages across each component are as shown.

(i) The r.m.s. current passing through R

In a series circuit, the current is the same across all components. The total impedance Z of the circuit is given by:

$Z = \sqrt{R^2 + (X_L - X_C)^2}$

where
R = resistance
X_L = inductive reactance = $2\pi f L$
X_C = capacitive reactance = $1 / (2\pi f C)$

Using Ohm's law:
$I_{rms} = V_{rms} / Z$
From the circuit diagram:

$V_L = 6$ V, $V_C = 2$ V, $V_R = 3$ V

The total voltage is given by:
$V_{total} = \sqrt{V_R^2 + (V_L - V_C)^2}$
$V_{total} = \sqrt{3^2 + (6 - 2)^2}$
$V_{total} = \sqrt{9 + 16}$
$V_{total} = \sqrt{25}$
$V_{total} = 5$ V
The r.m.s. current:
$I_{rms} = V_{total} / R$
$I_{rms} = 5 / 3$
$I_{rms} \approx 1.67$ A

(ii) The resonant frequency for the values of L, C, and R
The resonant frequency f_0 is given by:

$f_0 = 1 / (2\pi \sqrt{L C})$
Since resistance R does not affect resonance, the circuit will be at resonance when $X_L = X_C$.
Thus,
$f_0 = 1 / (2\pi \sqrt{L C})$
This equation gives the resonant frequency in terms of the inductance L and capacitance C.

18. (a) Draw the symbol of n-p-n transistor.

The n-p-n transistor symbol consists of three terminals: emitter, base, and collector, with the arrow indicating electron flow direction from emitter to base.

(b) Distinguish between insulators, semi-conductors, and metals as far as conduction is concerned.

- Insulators – Have a large energy gap, preventing electron movement and making them poor conductors.
- Semiconductors – Have a small energy gap, allowing controlled conduction with doping or external energy.
- Metals – Have free electrons in the conduction band, making them excellent conductors.

19. (a) What is the "work function" of a metal?

The work function is the minimum energy required to eject an electron from a metal surface. It depends on the metal type and is measured in electron volts (eV).

(b) The work function of a metal is 2.0 eV. Calculate the stopping potential when the metal is illuminated by light of frequency 6.0×10^{14} Hz.

Using the photoelectric equation:

$KE_{max} = hf - \phi$
$eV_0 = hf - \phi$

$V_0 = (hf - \phi) / e$

Given:
$h = 6.63 \times 10^{-34}$ J.s
$f = 6.0 \times 10^{14}$ Hz
$\phi = 2.0$ eV $= 2.0 \times 1.6 \times 10^{-19}$ J
$e = 1.6 \times 10^{-19}$ C

$V_0 = [(6.63 \times 10^{-34} \times 6.0 \times 10^{14}) - (2.0 \times 1.6 \times 10^{-19})] / (1.6 \times 10^{-19})$
$V_0 = [(3.978 \times 10^{-19}) - (3.2 \times 10^{-19})] / (1.6 \times 10^{-19})$
$V_0 = 0.4875$ V

The stopping potential is approximately 0.49 V.

20. (a) What is (i) nuclear fusion and (ii) nuclear fission?

(i) Nuclear fusion – The process in which two light atomic nuclei combine to form a heavier nucleus, releasing energy.
(ii) Nuclear fission – The process in which a heavy nucleus splits into smaller nuclei, releasing energy.

20. (b) In the following nuclear reactions find the values of x, y, and z.

(i)
$^{1}H + ^{2}H$ ----> $xH + ^{1}H + 4.0$ MeV

Balancing the mass numbers:
$1 + 2 = x + 1$
$x = 2$

Balancing the atomic numbers:
$1 + 1 = y + 1$
$y = 1$
Thus, the missing nucleus is ^{2}H, so $x = 2$ and $y = 1$.

(ii) $^{3}H + ^{2}H \rightarrow yHe + ^{1}n + 17.6$ MeV

Balancing the mass numbers:

$3 + 2 = y + 1$
$y = 4$
Balancing the atomic numbers:

$1 + 1 = z + 0$
$z = 2$
Thus, the missing nucleus is ^{4}He, so $y = 4$ and $z = 2$.

(iii) $^{235}U + {}^{1}n \rightarrow {}^{56}Ba + {}^{92}Kr + 3\ {}^{1}n + E$
Balancing the mass numbers:
$235 + 1 = 56 + 92 + 3(1)$
$236 = 148 + 3$
$236 = 236$ (balanced)

Balancing the atomic numbers:
$92 + 0 = 56 + z + 3(0)$
$92 = 56 + z$
$z = 36$
Thus, the missing nucleus is ^{92}Kr, so $z = 36$.