THE UNITED REPUBLIC OF TANZANIA

NATIONAL EXAMINATIONS COUNCIL

CERTIFICATE OF SECONDARY EDUCATION EXAMINATION

031/1 **PHYSICS 1**

(For Both School and Private Candidates)

Time : 2 ½ Hours **ANSWERS** **Year : 2006**

Instructions

1. This paper consists of sections A, B and C.
2. Non-programmable calculators may be used.
3. Communication devices and any unauthorised materials are **not** allowed in the examination room.
4. Write your **Examination Number** on every page of your answer booklet(s).

1. (a) The viscosity η of a liquid, flowing through a capillary tube of length L and radius r, is given by the equation:

$V/t = (\pi(P_1 - P_2) r^4) / (8\eta L)$

where P_1 and P_2 are pressures at the ends of the tube, and t is time for liquid of volume V to pass.

(i) Find an expression for the fractional error in η.

$\eta = (\pi(P_1 - P_2) r^4 t) / (8 L V)$

Taking logarithm:
$\ln \eta = \ln \pi + \ln(P_1 - P_2) + 4 \ln r + \ln t - \ln(8) - \ln L - \ln V$

Differentiating:
$\Delta\eta/\eta = \Delta(P_1 - P_2)/(P_1 - P_2) + 4\Delta r/r + \Delta t/t + \Delta L/L + \Delta V/V$

So, fractional error in $\eta = \Delta(P_1 - P_2)/(P_1 - P_2) + 4\Delta r/r + \Delta t/t + \Delta L/L + \Delta V/V$.

(ii) Calculate the percentage error in η using:
$L = 26.00 \pm 0.10$ cm, $r = (0.65 \pm 0.01) \times 10^{-3}$ m,
$P_1 = (8.10 \pm 0.05) \times 10^3$ Nm^{-2}, $P_2 = (5.40 \pm 0.05) \times 10^3$ Nm^{-2},
$V = 3.23 \pm 0.02$ cm^3, $t = 60.00 \pm 0.20$ s.

$(P_1 - P_2) = (8.10 - 5.40) \times 10^3 = 2.70 \times 10^3$.
Error in pressure difference = $\sqrt{((0.05)^2 + (0.05)^2)} \times 10^3 = 0.071 \times 10^3$.
Fractional error = 0.071/2.70 = 0.026 = 2.6%.

$\Delta L/L = 0.10/26.00 = 0.0038 = 0.38\%$
$\Delta r/r = 0.01/0.65 = 0.015 = 1.5\% \rightarrow$ multiplied by 4 = 6.0%
$\Delta t/t = 0.20/60.00 = 0.0033 = 0.33\%$
$\Delta V/V = 0.02/3.23 = 0.0062 = 0.62\%$

Total error = $2.6 + 0.38 + 6.0 + 0.33 + 0.62 \approx 9.9\%$

So percentage error $\approx$ 10%.

(iii) Write the experimental value of η (including order of accuracy).

Substituting values:

$\eta = (\pi \times 2.70\times10^3 \times (0.65\times10^{-3})^4 \times 60.00) / (8 \times 0.26 \times 3.23\times10^{-6})$.

$(0.65\times10^{-3})^4 = (0.65^4 \times 10^{-12}) = 0.1785 \times 10^{-12} = 1.785\times10^{-13}$.

Numerator $= \pi \times 2700 \times 1.785\times10^{-13} \times 60$.

$= 3.1416 \times 2700 \times 1.071\times10^{-11}$.

$= 9.05\times10^{-8}$.

Denominator $= 8 \times 0.26 \times 3.23\times10^{-6} = 6.73\times10^{-6}$.

$\eta = 9.05\times10^{-8} / 6.73\times10^{-6} \approx 1.34\times10^{-2}$ Nsm^{-2}.

With error ~10%, $\eta = (1.34 \pm 0.13) \times 10^{-2}$ Nsm^{-2}.

(b) (i) Distinguish between fundamental physical quantities and derived physical quantities giving one example for each.

Fundamental quantities are independent physical quantities that cannot be expressed in terms of others, such as mass, length, and time.

Derived quantities are obtained by combining fundamental quantities using physical laws, such as velocity (length/time) or force (mass × acceleration).

(ii) An equation showing a body accelerating vertically upwards is $S = at^2 - bt^2$, where S and t are measured in metres and seconds respectively. Determine the dimensions and units of a and b.

$S = at^2 - bt^2$.

So a and b both must have dimensions of length/time^2.

That is $[L][T^{-2}]$.

SI unit = m/s^2.

2. (a) (i) Discuss the meaning of the statement "during rocket propulsion both the rocket and the hot gases emitted gain kinetic energy and momentum".

When fuel burns, gases are expelled backward at high speed. The gases gain momentum in one direction, and by Newton's third law the rocket gains equal momentum in the opposite direction. Both rocket and gases have mass and velocity, so both gain kinetic energy as well. The rocket's propulsion is therefore explained by conservation of momentum.

(ii) The mass per second of gas emitted from a toy rocket is 0.1 kg/s. If the speed of the gas relative to the rocket is 50 m/s and the mass of the rocket is 2 kg, what is the initial acceleration of the rocket?

Thrust = rate of change of momentum = $\dot{m}v = 0.1 \times 50 = 5$ N.

Acceleration = Force / mass = 5 / 2 = 2.5 m/s^2.

(b) Two blocks connected to a string over a small frictionless pulley rest on frictionless planes as shown in figure: $M_1 = 100$ kg on 30°, $M_2 = 50$ kg on 60°.

(i) Calculate the acceleration of the block system.

Force pulling $M_1 = M_1 g \sin 30° = 100 \times 9.8 \times 0.5 = 490$ N.

Force pulling $M_2 = M_2 g \sin 60° = 50 \times 9.8 \times 0.866 = 424$ N.

Net force = 490 – 424 = 66 N.

Total mass = 150 kg.

Acceleration = F/m = 66 / 150 = 0.44 m/s^2.

(ii) Calculate the tension of the string.

For M_1: $T = M_1 g \sin 30° - M_1 a = 490 - (100 \times 0.44) = 490 - 44 = 446$ N.

So, tension ≈ 446 N.

3. (a) (i) Explain what is meant by angular velocity and centripetal acceleration.

Angular velocity is the rate at which a body rotates about a fixed point or axis, measured in radians per second.

Centripetal acceleration is the acceleration directed toward the center of a circle, required to keep a body moving in circular motion.

(ii) Why does a motorbike rider bend while going around a corner?

When a motorbike turns, the rider bends inward to balance the centripetal force with a component of the normal reaction. If the rider remains upright, the unbalanced outward force could topple the bike. Bending ensures stability by aligning the resultant force through the center of gravity.

(b) (i) What is the maximum speed at which a car can safely go round a circular curve of radius 48 m on a horizontal road if the coefficient of static friction between tyres and road is 0.82?

Maximum friction force = $\mu mg = 0.82mg$.
Centripetal force = mv^2/r.
So, $v = \sqrt{(\mu gr)} = \sqrt{(0.82 \times 9.8 \times 48)}$.
$= \sqrt{386} \approx 19.7$ m/s.

(ii) Will the car overturn or skid if it just exceeds the speed stated above? Assume wheel width = 1.5 m, center of gravity = 0.6 m above road.

For overturning: condition is $v^2/(rg) \geq b/2h = 0.75/0.6 = 1.25$.
$v^2/(rg) = (19.7^2)/(48 \times 9.8) = 388/470 = 0.83$.
Since $0.83 < 1.25$, the car will skid, not overturn.

4. (a) (i) What is the criterion for an object to execute simple harmonic motion?

The restoring force or acceleration must be directly proportional to displacement from equilibrium and directed toward equilibrium.

(ii) A body executing SHM is associated with the accelerating force acting on it, its velocity and its acceleration. Which of the three are in phase?

The acceleration and the restoring force are in phase. Velocity is 90° out of phase with them.

(b) (i) Suppose a tunnel is dug through the earth from one side to the other along a diameter. Show that the motion of a particle dropped into the tunnel is SHM.

Inside the earth, gravitational force varies linearly with distance from the center (since only the mass within that radius acts). So $F \propto x$, directed toward center. That is the condition for SHM. Therefore, the particle would oscillate back and forth through the tunnel.

(ii) A simple pendulum has a period of 1 second in city A, where $g = 9.66\ m/s^2$. It is taken to city B where it loses 20 seconds per day. Calculate the value of g in city B.

Period T = 1 s in A.
$T = 2\pi\sqrt{(L/g)}$.
So $L = gT^2/(4\pi^2) = 9.66/(39.48) = 0.245$ m.

In city B, pendulum loses 20 s per 86400 s.
Fractional change in period = $20/86400 = 2.31 \times 10^{-4}$.
So $\Delta T/T = 2.31 \times 10^{-4}$.
Since $T \propto 1/\sqrt{g}$, $\Delta T/T = -\frac{1}{2}\ \Delta g/g$.
So $\Delta g/g = -2(2.31 \times 10^{-4}) = -4.62 \times 10^{-4}$.
So $g_B = g_A(1 - 4.62 \times 10^{-4}) = 9.66 \times (0.99954)$.
$\approx 9.655\ m/s^2$.

5. (a) (i) Describe how mercury in glass thermometer could be made sensitive.

A mercury thermometer can be made more sensitive by using a narrow bore capillary tube so that a small expansion of mercury produces a larger movement of the mercury thread. Sensitivity can also be increased by using a bulb with a larger volume so that more mercury expands for the same temperature rise.

(ii) A sensitive thermometer can be used to investigate the difference in temperature between the top and bottom of the waterfall. Calculate the temperature difference of the waterfall 50 m high.

When water falls, potential energy converts into heat energy.
Heat per unit mass = mgh / m = gh.

Rise in temperature $\Delta T = gh / c$, where c is specific heat capacity of water (4200 J/kgK).

$\Delta T = (9.8 \times 50) / 4200 = 490 / 4200 = 0.117$ °C.

So the temperature difference is about 0.12 °C.

(b) (i) Platinum resistance thermometer and constant volume gas thermometer are based on different thermometric properties but are calibrated using the same fixed points. To what extent are the thermometers likely to agree when used to measure temperature near the ice point and near the steam point?

Since both are calibrated at ice point and steam point, they will agree exactly at these two points. But between the fixed points, their readings may differ slightly because resistance of platinum and pressure of a gas do not vary linearly with temperature in exactly the same way.

(ii) The resistance of the element of a platinum resistance thermometer is 2.0 Ω at ice point and 2.73 Ω at steam point. What temperature on the platinum resistance scale would correspond to a resistance value of 8.34 Ω and when measured on the gas scale the same temperature will correspond to a value of 1020 °C? Explain the discrepancy.

On platinum scale:
$\theta = (R - Ri) / (Rs - Ri) \times 100$.
$= (8.34 - 2.0) / (2.73 - 2.0) \times 100$.
$= 6.34 / 0.73 \times 100 = 868$ °C.

Gas scale gives 1020 °C.

Discrepancy occurs because resistance of platinum does not vary linearly with temperature over a wide range, whereas the gas thermometer is closer to true thermodynamic behavior.

6. (a) (i) Why is heat needed to change liquid water into vapour? What amount of energy is needed?

Heat is needed to overcome intermolecular forces holding water molecules together in the liquid state. This energy, called latent heat of vaporization, allows molecules to escape into vapour without raising the temperature.

The amount of energy needed = mL, where m is mass and L is specific latent heat.

(ii) The molar heat capacity of hydrogen at constant volume is 20.2 J mol^{-1} $°C^{-1}$. What is the molar heat capacity at constant pressure?

For an ideal gas, $C_p - C_v = R$.
Here $C_v = 20.2$, $R = 8.3$ J mol^{-1} $°C^{-1}$.
So $C_p = 20.2 + 8.3 = 28.5$ J mol^{-1} $°C^{-1}$.

(b) (i) In an industrial refrigerator, ammonia is vaporised in the cooling unit to produce a low temperature. Why should the evaporation of ammonia reduce the temperature in the refrigerator?

Evaporation requires latent heat. When ammonia evaporates, it absorbs heat from the surroundings (the refrigerator compartment). This removal of heat lowers the temperature inside the refrigerator.

(ii) How much energy is needed to convert 150 g of water at 20 °C into steam at 100 °C?

Energy = $mc\Delta\theta + mL$.
$m = 0.150$ kg, $c = 4200$ J/kgK, $\Delta\theta = 80$ K, $L = 2.26 \times 10^6$ J/kg.

Heating to 100 °C: $Q_1 = 0.150 \times 4200 \times 80 = 50{,}400$ J.
Vaporizing: $Q_2 = 0.150 \times 2.26 \times 10^6 = 339{,}000$ J.

Total = 389,400 J $\approx 3.9 \times 10^5$ J.

7. (a) (i) What is meant by the terms wave motion and wavelength?

Wave motion is the transfer of energy from one point to another through a medium or space without actual movement of the particles of the medium.

Wavelength is the distance between two consecutive points of a wave that are in the same phase, for example crest to crest or trough to trough.

(ii) If the speed of sound in air is 340 m/s, calculate the wavelength of sound when its frequency is 256 Hz.

$\lambda = v/f = 340 / 256 = 1.33$ m.

(b) Given that the velocity v of transverse waves along a stretched string is related to tension T and mass per unit length μ,

(i) derive an equation in terms of T and μ. Hence deduce an expression for natural frequencies of a string of length ℓ when fixed at both ends.

For a stretched string: $v = \sqrt{(T/\mu)}$.

For fundamental frequency, $f_1 = v / 2\ell = (1 / 2\ell) \sqrt{(T/\mu)}$.
For nth harmonic, $f_n = n/2\ell \sqrt{(T/\mu)}$.

(ii) Calculate the tension in the string along which waves move with speed of 8 cm/s if its mass per unit length is 0.05 kg per metre and constant of proportionality is 2.

Using $v = \sqrt{(T/\mu)}$.
$T = \mu v^2$.

Here v = 8 cm/s = 0.08 m/s, $\mu = 0.05$ kg/m.
$T = 0.05 \times (0.08)^2 = 0.05 \times 0.0064 = 3.2 \times 10^{-4}$ N.

8. (a) State Kirchhoff's laws of electrical network.

Kirchhoff's first law (junction rule): The algebraic sum of currents meeting at a junction is zero. This means total current entering a junction equals total current leaving.

Kirchhoff's second law (loop rule): In any closed loop of a circuit, the algebraic sum of the potential differences (emf and voltage drops) is zero.

(b) Study the circuit diagram in figure 2 below and answer the questions that follow:

Where $R_1 = 100\ \Omega$, $R_2 = R_3 = 50\ \Omega$, $R_4 = 75\ \Omega$, and $E = 6.0$ V.

(i) Determine the equivalent resistance of the network diagram in figure 2.

R_2, R_3, and R_4 form a parallel network.

For parallel combination:

$1/R_p = 1/R_2 + 1/R_3 + 1/R_4$

$= 1/50 + 1/50 + 1/75$

$= 0.02 + 0.02 + 0.0133$

$= 0.0533$

So $R_p = 18.75\ \Omega$.

Now R_p is in series with R_1:

$R_{eq} = R_1 + R_p = 100 + 18.75 = 118.8\ \Omega$.

(ii) Determine the current that flows through R_4.

Total current in circuit = $E / R_{eq} = 6 / 118.8 = 0.0506$ A.

Current through $R_1 = 0.0506$ A (same, since series).

So voltage across $R_p = IR_1 = 0.0506 \times 100 = 5.06$ V.

Now R_p has 5.06 V across it.

Current through $R_4 = V / R_4 = 5.06 / 75 = 0.0675$ A.

So current through $R_4 \approx 0.068$ A.

(c) A voltmeter, connected across the terminals of a battery, shows a potential difference of 1.3 V when the current taken from the battery is 0.2 A and 1.0 V when it is 0.4 A. Find the:

(i) e.m.f.

Using $V = E - Ir$.
Case 1: $1.3 = E - 0.2r$
Case 2: $1.0 = E - 0.4r$

Subtract: $0.3 = 0.2r \rightarrow r = 1.5\ \Omega$.
Now substitute: $1.3 = E - 0.2 \times 1.5 = E - 0.3$.
So $E = 1.6$ V.

(ii) internal resistance of the battery.

$r = 1.5\ \Omega$.

9. (a) What is an inductor? Give the expression of the energy stored in an inductor.

An inductor is a coil of wire which resists changes in current by producing a back e.m.f. due to self-induction.

Energy stored = $\frac{1}{2} L I^2$, where L is inductance and I is current.

(b) (i) Calculate the inductance of a toroid having 200 turns and length 20 cm, that is uniformly wound over an iron alloy core of 1.0 cm² cross-sectional area and permeability 1.0×10^{-2} Hm^{-1}.

Formula: $L = \mu N^2 A / l$.
$N = 200$, $A = 1.0\ cm^2 = 1.0 \times 10^{-4}\ m^2$, $l = 0.20$ m, $\mu = 1.0 \times 10^{-2}$.

$L = (1.0 \times 10^{-2} \times 200^2 \times 1.0 \times 10^{-4}) / 0.20$.
$= (1.0 \times 10^{-2} \times 40000 \times 10^{-4}) / 0.20$.
$= (4 \times 10^{-2}) / 0.20 = 0.20$ H.

(ii) What would the self-induced e.m.f be when the current in the toroid is changing at 1.0 As^{-1}?

E = L (dI/dt).

= 0.20 × 1.0 = 0.20 V.

(iii) How much energy is stored by the inductor when it carries a current of 100 mA?

Energy = ½ L I^2 = 0.5 × 0.20 × $(0.1)^2$.

= 0.1 × 0.01 = 0.001 J.

10. (a) (i) What is meant by transistor biasing?

Transistor biasing is the process of applying external voltages to a transistor so that it operates at the desired region of its characteristic curve, usually in the active region.

(ii) List three different ways of transistor biasing.

Fixed bias.

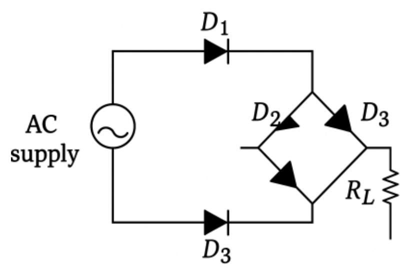
Voltage divider bias.

Collector-to-base bias.

(iii) Why is the base region of a transistor made thin?

The base is thin so that most of the charge carriers injected from the emitter pass into the collector, ensuring efficient transistor action.

(b) (i) Draw a circuit diagram representing a bridge rectifier.



(ii) List down two advantages and two disadvantages of using bridge rectifiers.

Advantages:

Higher output DC voltage compared to half-wave rectifiers.

Transformer utilization is better, no wasted half cycle.

Disadvantages:

Requires four diodes instead of one.

More power loss due to two diodes conducting in series per half cycle.

11. (a) (i) Define capacitance.

Capacitance is the ability of a capacitor to store charge per unit potential difference across its plates. It is given by $C = Q/V$, where Q is charge and V is potential difference.

(ii) The capacitor C_1 in figure 3 initially has a charge Q_0 and a voltage V_0 across its plates while capacitor C_2 is uncharged. After closing switches S_1 and S_2, the voltage across the plates of each capacitor is found to be V. Evaluate the ratio V_0/V.

Initially: charge on $C_1 = Q_0 = C_1V_0$, C_2 uncharged.

When connected, charge is shared. Total charge = Q_0.
Final voltage across each capacitor = V.
So total charge = $C_1V + C_2V = (C_1 + C_2)V$.

Equating: $Q_0 = C_1V_0 = (C_1 + C_2)V$.
So $V_0/V = (C_1 + C_2)/C_1$.

(b) A charge of +2 μC is placed at one corner of an equilateral triangle and a charge of –2 μC at another corner. The sides of the triangle are 1.5 m long.

(i) What is the size of the electric field and electric potential at the corner of the triangle without a charge?

Electric field due to one charge: $E = kQ/r^2$.
$= (9 \times 10^9 \times 2 \times 10^{-6})/(1.5^2)$.
$= (18 \times 10^3)/(2.25) = 8.0 \times 10^3$ N/C.

Since charges are equal and opposite, fields at the third corner are in opposite directions, so they add vectorially. The angle between them is 60°, so resultant field $= \sqrt{(E^2 + E^2 + 2E^2\cos 120°)}$.
$= \sqrt{(2E^2 - E^2)} = E = 8.0 \times 10^3$ N/C.

Potential at that corner $= V = kQ/r + k(-Q)/r = 0$.

So electric field $= 8.0 \times 10^3$ N/C, potential = 0.

(ii) Calculate the potential difference which could be applied between two parallel plates 3.0 mm apart to cause the same electric field as in 11(b)(i).

$V = Ed = 8.0 \times 10^3 \times 0.003 = 24$ V.

12. (a) (i) State Faraday's laws of electrolysis.

First law: The mass of substance deposited or liberated at an electrode is directly proportional to the quantity of electricity passed.

Second law: The masses of different substances deposited by the same quantity of electricity are proportional to their equivalent weights.

(ii) Define back e.m.f. with reference to electrolysis.

Back e.m.f. is the opposing voltage developed within an electrolytic cell due to polarization, which reduces the effective e.m.f. available for electrolysis.

(iii) Briefly explain the conduction of electricity in gases.

In gases, conduction occurs when gas molecules are ionized. Positive ions move toward the cathode and electrons move toward the anode, allowing current to pass. At normal conditions gases are insulators, but under low pressure or high voltage, ionization enables conduction.

(b) Chromium is deposited on steel by electrolysis, represented at the cathode by:
$Cr^{3+}(aq) + 3e^{-} \rightarrow Cr(s)$.

(i) Calculate the mass of chromium deposited when a current of 150 A is used for ten hours.

Charge = It = 150 × (10 × 3600) = 150 × 36,000 = 5.4×10^{6} C.
From data: 52 g deposited by 289,500 C.
So mass deposited = (52/289,500) × 5.4×10^{6}.
= 52 × 18.65 = 968 g ≈ 0.97 kg.

(ii) Calculate the average thickness of chromium deposited if the hub has surface area of 2000 cm^2.

Mass = 968 g = 968/6.4 = 151.25 cm^3 (using density 6.4 g/cm^3).
Thickness = volume / area = 151.25 / 2000 = 0.0756 cm ≈ 0.76 mm.

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

The work function is the minimum energy required to liberate an electron from the surface of a metal.

(b) Radiation of wavelength 360 nm is incident on a photocell. Potential difference of –2 V stops photoelectrons.

(i) Maximum KE of photoelectrons.

$KE = eV = 1.6 \times 10^{-19} \times 2 = 3.2 \times 10^{-19}$ J.

(ii) Work function of emitter.

Energy of photon $E = hc/\lambda$.
$= (6.63 \times 10^{-34} \times 3 \times 10^{8})/(360 \times 10^{-9})$.
$= 5.52 \times 10^{-19}$ J.

Work function = E – KE = $5.52 \times 10^{-19} - 3.2 \times 10^{-19} = 2.32 \times 10^{-19}$ J.

(c) A proton and an α-particle are accelerated through the same potential difference before entering a magnetic field at right angles. Radius of proton's path = 15 cm. Find radius of α-particle.

$r = \sqrt{2mV/qB^2}$.

For same V and B: $r \propto \sqrt{m/q}$.

So $r_\alpha / r_p = \sqrt{(m_\alpha/q_\alpha)/(m_p/q_p)}$.
$= \sqrt{(4m_p / 2e)/(m_p / e)}$.
$= \sqrt{2} \approx 1.41$.

So $r_\alpha = 1.41 \times 15 = 21.2$ cm.

14. (a) (i) State two ways by which seismic waves may be produced.

By earthquakes due to sudden movement of tectonic plates.
By volcanic eruptions releasing energy waves.

(ii) What is seismic prospecting?

It is a method of exploring underground rock structures and resources by generating artificial seismic waves and studying their reflection and refraction.

(b) (i) Discuss briefly the importance of the lowest layer of the atmosphere and the ionosphere.

The lowest layer, the troposphere, contains most of the air and weather phenomena essential for life. The ionosphere reflects radio waves, making long-distance communication possible.

(ii) Sketch the temperature against altitude curve for the atmosphere indicating important atmospheric layers.

A sketch would show: troposphere temperature decreasing with height, stratosphere increasing, mesosphere decreasing, thermosphere increasing.

(iii) The average velocity of P-waves through earth's solid core is 8 km/s. Average density of earth's rock = 5.5×10^3 kg/m^3. Find the average bulk modulus of earth's rock.

Velocity of P-waves $v = \sqrt{(K/\rho)}$.

$K = \rho v^2$.

$= 5.5 \times 10^3 \times (8 \times 10^3)^2$.

$= 5.5 \times 10^3 \times 64 \times 10^6$.

$= 3.52 \times 10^{11}$ Nm^{-2}.

So bulk modulus = 3.5×10^{11} Pa.