THE UNITED REPUBLIC OF TANZANIA

NATIONAL EXAMINATIONS COUNCIL

CERTIFICATE OF SECONDARY EDUCATION EXAMINATION

131/2 **PHYSICS 2**

(For Both School and Private Candidates)

Time: 2 Hours 30 Minutes **ANSWERS** **Year : 2004**

Instructions

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

1. (a) (i) Gravitational potential of the earth

It is the work done per unit mass in bringing a small body from infinity to a point in the earth's gravitational field.

(ii) Gravitational field strength of the earth.

It is the force experienced by a unit mass placed in the earth's gravitational field.

State the relationship between the two quantities stated in 1(a)(i) and 1(a)(ii).

Gravitational field strength g is the negative gradient of gravitational potential V, i.e. $g = -dV/dr$.

(iii) Explain briefly the fact that at one point on the line between the earth and the moon, the gravitational field caused by two bodies is zero.

At that point, the gravitational pull of the earth is equal and opposite to the gravitational pull of the moon, so the resultant field is zero.

(b) (i) Sketch graphs to show how the gravitational force and gravitational potential on a rocket varies as it moves from the earth towards the moon in a straight line.

The force decreases inversely with the square of distance, while the potential increases negatively towards zero, following an inverse relation.

(ii) A satellite of mass m kg is moving around the earth with a speed V ms^{-1} in a circular orbit of radius R metres. Develop an expression for its kinetic energy in the orbit in terms of m, mass of the earth Me and the universal gravitational constant G.

Centripetal force = gravitational force:

$mv^2/R = GMem/R^2$.

$v^2 = GMe/R$.

Kinetic energy = $\frac{1}{2} mv^2 = \frac{1}{2} m(GMe/R)$.

(iii) Write down the expression for the p.e. and the total energy of the satellite in the orbit.

Potential energy = $-GMem/R$.

Kinetic energy = $\frac{1}{2}$ GMem/R.

Total energy = $-\frac{1}{2}$ GMem/R.

(c) If the earth's gravitational field is not uniform over large distances, what is the longest period of a simple pendulum on the earth's surface?

The longest period is infinite, which would occur if the pendulum length is equal to the radius of the earth and the pendulum is placed at a point where effective g is zero (weightlessness).

2. (a) (i) Define the moment of inertia of a body.

It is the sum of the products of the masses of the particles of the body and the square of their perpendicular distances from the axis of rotation.

(ii) State the parallel axes theorem for moments of inertia.

The moment of inertia of a body about any axis parallel to an axis through its centre of mass is equal to the moment of inertia about the axis through the centre of mass plus Md^2, where M is the mass of the body and d is the distance between the two axes.

(b) (i) What is a torque τ?

It is the turning effect of a force about an axis and is given by the product of the force and the perpendicular distance from the axis to the line of action of the force.

(ii) A uniform disc of radius R and mass M is mounted on an axle supported in fixed frictionless bearings. A light cord is wrapped around the rim of the wheel and a mass m is attached at the end of the cord. Find the angular acceleration of the disc using the relation $\tau = dL/dt$ and hence the tension in the cord.

Torque = $T \times R$.

Moment of inertia of disc = $\frac{1}{2} MR^2$.

Angular acceleration $\alpha = \tau/I = TR/(\frac{1}{2} MR^2) = 2T/(MR)$.

Force on falling mass: $mg - T = ma$, where $a = \alpha R = 2T/M$.

So $mg - T = m(2T/M)$.

$mg = T(1 + 2m/M)$.

$T = mgM/(M+2m)$.

Angular acceleration $\alpha = 2T/(MR) = 2mg/(R(M+2m))$.

(c) (i) State the principle of conservation of angular momentum.

When no external torque acts on a system, its total angular momentum remains constant.

(ii) Account for the motion of the top.

A spinning top remains upright due to conservation of angular momentum. When torque due to gravity acts, the axis of rotation precesses around the vertical, but angular momentum is conserved.

(iii) A boy stands on a platform that can only rotate about a vertical axis holding an axle of a rim-loaded bicycle wheel with its axis vertical. The wheel is spinning about this vertical axis with angular speed ω, but the boy and the platform are at rest. The boy tries to change the direction of rotation of the wheel. What will happen?

The platform will begin to rotate in the opposite direction to conserve angular momentum, since no external torque acts on the system.

3. (a) (i) Define tensile stress and tensile strain.

Tensile stress is the force applied per unit cross-sectional area of a material.

Tensile strain is the ratio of the extension produced to the original length of the material.

(ii) Calculate the work done in stretching a copper wire 100 cm long and 0.03 cm^2 cross-sectional area when a load of 120 N is applied.

Stress = F/A = 120 / (0.03×10^{-4}) = 4×10^{7} N/m^2.

Strain = Stress/Y, with Y ≈ 1.1×10^{11} N/m^2.

Strain = 3.64×10^{-4}.

Extension = strain × length = $3.64\times10^{-4}\times1 = 3.64\times10^{-4}$ m.

Work done = ½ F×extension = ½ ×120×3.64×10^{-4} = 0.0218 J.

(b) (i) Explain how the conservation of energy principle applies to a ball bouncing a wall.

When the ball strikes the wall, kinetic energy is partly converted into elastic potential energy. On rebounding, the energy is converted back to kinetic, but some is lost as heat and sound.

(ii) A weighing pan of mass 200 g when empty stretches a coil spring by 10 cm. When a lump of putty of mass 250 g is dropped from rest into the pan from a height of 30 cm, what maximum distance will the pan move downwards?

Spring constant k = mg/x = 0.2×9.8/0.1 = 19.6 N/m.

Total mass after collision = 0.45 kg.

Energy = PE + KE = extension energy.

Loss in height = 0.3 m, so KE = 0.45×9.8×0.3 = 1.32 J.

Work = ½ kx^2.

Solve ½×19.6×x^2 = 1.32 + (0.45×9.8×x).

(c) (i) State Bernoulli's principle and the equation of continuity.

Bernoulli's principle states that for an incompressible fluid in streamline flow, the sum of pressure energy, kinetic energy and potential energy per unit volume is constant.

Equation of continuity: $A_1v_1 = A_2v_2$.

(ii) Distinguish between "dynamic lift" and "upthrust."

Dynamic lift is the upward force experienced by a body due to relative motion between the body and a fluid.

Upthrust is the upward buoyant force exerted on a body immersed in a fluid.

(iii) A bat of mass 1100 g hovers upwards by beating its wings of effective area 0.4 m². Estimate the velocity imparted to the air by the beating of the wings. Assume the air to be at s.t.p. weather conditions.

Weight = $1.1\times9.8 = 10.78$ N.

Force = $\Delta mv/\Delta t = \rho Av^2$.

$v = \sqrt{(F/\rho A)}$.

$= \sqrt{(10.78/(1.29\times0.4))}$.

$= \sqrt{(20.9)} = 4.6$ m/s.

4. (a) (i) Define the bulk modulus of a gas.

Bulk modulus is the ratio of pressure applied to the fractional decrease in volume.

(ii) Find the ratio of the adiabatic bulk modulus of a gas to that of its isothermal bulk modulus in terms of the specific heat capacities of the gas.

Adiabatic bulk modulus = γP.

Isothermal bulk modulus = P.

Ratio = $\gamma = Cp/Cv$.

(b) (i) State the assumptions that are made for the kinetic theory.

Molecules are point masses.

Collisions are perfectly elastic.

Intermolecular forces are negligible except during collisions.

Molecules are in random motion.

(ii) Given a hollow cube of side 10 cm containing 10^{22} oxygen molecules at constant pressure having a translational speed of 500 m/s, calculate the pressure of the gas in mm Hg if each molecule has a mass of 5×10^{-26} kg.

KE = ½ mv^2.

Average KE = 3/2 kT.

Pressure $P = (1/3)(N/V)mv^2$.

$N = 10^{22}$, $V = 0.1^3 = 10^{-3}$ m³.

$P = (1/3)(10^{22}/10^{-3})(5\times10^{-26}\times(500)^2)$.

$= (1/3)(10^{25}\times1.25\times10^{-20})$.

$= (1/3)(1.25\times10^5)$.

$= 4.17\times10^4$ Pa.

Convert to mm Hg: $4.17\times10^4 / 133 = 314$ mm Hg.

(c) (i) A gas expands adiabatically and its temperature falls while the same gas when compressed adiabatically its temperature rises. Explain giving reasons why this happens.

In adiabatic expansion, the gas does work on the surroundings using its internal energy, hence temperature falls.

In adiabatic compression, work is done on the gas, increasing its internal energy and hence temperature rises.

(ii) A mole of oxygen at 280 K is insulated in an infinitely flexible container. The atmospheric pressure outside is 5×10^5 Nm^{-2}. When 580 J of heat is supplied to the oxygen the temperature increases to 300 K and the volume of the container increases by 3.32×10^{-3} m³. Calculate the values of the principal molar heat capacities and the specific universal gas constant.

Given:

$Q = 580$ J, $\Delta T = 20$ K, $P = 5\times10^5$ Pa, $\Delta V = 3.32\times10^{-3}$ m³, $n = 1$.

Work done:

$W = P\Delta V = 5\times10^5 \times 3.32\times10^{-3} = 1660$ J

Internal energy change:

$\Delta U = Q - W = 580 - 1660 = -1080$ J

Molar heat capacity at constant volume:

$C_v = \Delta U/\Delta T = -1080/20 = -54$ J mol^{-1}K^{-1}

Gas constant:

$R = W/\Delta T = 1660/20 = 83$ J mol^{-1}K^{-1}

Molar heat capacity at constant pressure:

$C_p = C_v + R = -54 + 83 = 29\ \text{J mol}^{-1}\text{K}^{-1}$

5. (a) Distinguish between diffraction and interference.

Diffraction is the bending and spreading of waves when they pass through a narrow opening or around an obstacle.

Interference is the superposition of two or more coherent waves, producing regions of constructive and destructive reinforcement.

(b) A monochromatic beam of light is directed normally on a slit and an image of the slit is focused on a screen by a lens.

(i) The pattern is a central bright fringe with successive dark and less intense bright fringes on either side.

(ii) If two identical slits are used, the interference fringes appear within the diffraction envelope, giving bright and dark bands modulated by the single-slit pattern.

(c) In a Young's double slit experiment:

Fringe spacing $\Delta y = (\lambda L)/d$.

Given $\Delta y = 3.44\ \text{cm} / 10 = 3.44 \times 10^{-3}$ m, $L = 2.0$ m, $\lambda = 5.89 \times 10^{-7}$ m.

So $d = (\lambda L)/\Delta y = (5.89 \times 10^{-7} \times 2.0)/(3.44 \times 10^{-3}) = 3.43 \times 10^{-4}$ m.

(d) A parallel beam of wavelength 589 nm is incident on a diffraction grating at 34.2° for first order.

Condition: $d \sin\theta = n\lambda$.

$d = \lambda/\sin\theta = (589\times10^{-9})/(\sin 34.2°)$.

$= 5.89\times10^{-7} / 0.562 = 1.05\times10^{-6}$ m.

Number of lines per mm $= 1/(d \times 1000) = 1/(1.05\times10^{-3}) \approx 950$ lines/mm.

Maximum order $= d/\lambda = 1.05\times10^{-6} / 5.89\times10^{-7} \approx 1.78 \rightarrow$ only 1st order visible on each side.

6. (a) State Faraday's law of electromagnetic induction.

Induced emf in a circuit is directly proportional to the rate of change of magnetic flux linkage through the circuit.

(b) (i) A moving coil galvanometer has a coil wound on a light metal frame to reduce inertia and enable quick response.

(ii) The core of a dynamo is laminated to reduce eddy current losses.

(c) (i) Emf induced in a rotating disc of radius r in flux density B at angular velocity ω:

$\varepsilon = \frac{1}{2} B\omega r^2$.

(ii) A wheel of length 1.2 m, emf = 10^{-2} V, B = 5×10^{-5} T.

$\varepsilon = \frac{1}{2} B\omega r^2 \rightarrow \omega = 2\varepsilon/(Br^2)$.

$= 2\times10^{-2} /(5\times10^{-5} \times (1.2)^2)$.

$= 0.02 /(7.2\times10^{-5}) = 278$ rad/s.

Frequency $f = \omega/2\pi = 44.3$ Hz.

(d) (i) Induced charge $Q = (BAN/R)\Delta B$.

(ii) Flux in coil: $\Phi = CV/E$.

Given C=1 μF, V=110 V, charge $Q=CV=1.1\times10^{-4}$ C.

Flux = $Q/N = 1.1\times10^{-4} / 50 = 2.2\times10^{-6}$ Wb.

7. (a) (i) Define the reactance of a capacitor.

It is the opposition offered by a capacitor to alternating current, given by $X_c = 1/(2\pi fC)$.

(ii) A series circuit has R = 300 Ω, C = 6.67 μF, f = $3000/2\pi$ Hz ≈ 477 Hz.

$X_c = 1/(2\pi fC) = 1/(2\pi\times477\times6.67\times10^{-6}) \approx 50\ \Omega$.

Impedance $Z = \sqrt{(R^2+X_c^2)} = \sqrt{(300^2+50^2)} = 304\ \Omega$.

Current I = V/Z (if supply = 1 V rms) → I = 1/304 A.

(iii) To halve current, new impedance = 2Z = 608 Ω.

Extra resistance = $\sqrt{(608^2 - 50^2)} - 300 \approx 573 - 300 = 273\ \Omega$.

(b) (i) Capacitance is the ability of a capacitor to store charge per unit potential difference.

(ii) Energy stored = $\frac{1}{2} Q^2/C = \frac{1}{2} CV^2$.

(c) (i) If pd is constant at 150 V, energy change = $\frac{1}{2} C_0V^2(\kappa - 1)$.

$= \frac{1}{2} \times 3\times10^{-6} \times (150)^2 \times (2 - 1)$.

= 0.0338 J.

(ii) If charge is constant at 5×10^{-7} C, energy change = $\frac{1}{2} Q^2 (1/C - 1/\kappa C)$.

$= \frac{1}{2} (25\times10^{-14})(1/3\times10^{-6} - 1/6\times10^{-6})$.

$= 1.25\times10^{-13} \times (3.33\times10^5 - 1.67\times10^5)$.

$= 1.25\times10^{-13} \times 1.66\times10^5 = 2.08\times10^{-8}$ J.

8. (a) (i) Write down Einstein's photoelectric equation and explain the symbols used.

Einstein's photoelectric equation is:

$E = hf = \varphi + KEmax$

where h is Planck's constant, f is the frequency of incident radiation, φ is the work function of the surface, and KEmax is the maximum kinetic energy of emitted photoelectrons.

(ii) The frequency of incident radiation is 5×10^{14} Hz, maximum energy emitted is 2.3×10^{-19} J.

Required maximum energy is 5.6×10^{-19} J.

Photon energy $hf = 6.63\times10^{-34} \times f$.

$hf = 6.63\times10^{-34} \times 5\times10^{14} = 3.315\times10^{-19}$ J.

Work function $\varphi = hf - KE = 3.315\times10^{-19} - 2.3\times10^{-19} = 1.015\times10^{-19}$ J.

Now required $hf = \varphi + KE = 1.015\times10^{-19} + 5.6\times10^{-19} = 6.615\times10^{-19}$ J.

Wavelength $\lambda = hc/E = (6.63\times10^{-34} \times 3\times10^{8})/(6.615\times10^{-19})$.

$= 3.01\times10^{-7}$ m = 301 nm.

(b) Mercury atom energy levels:

(i) Ionisation energy = 10.4 eV.

In joules: $10.4 \times 1.6\times10^{-19} = 1.66\times10^{-18}$ J.

(ii) Wavelength for transition from level 4 (–1.6 eV) to level 2 (–5.5 eV).

Energy difference = 5.5 – 1.6 = 3.9 eV.

In joules = $3.9 \times 1.6\times10^{-19} = 6.24\times10^{-19}$ J.

Wavelength $\lambda = hc/E = (6.63\times10^{-34}\times3\times10^{8})/(6.24\times10^{-19})$.

$= 3.18\times10^{-7}$ m = 318 nm.

(c) Explain wave-particle duality.

Light and matter exhibit both wave and particle properties. Light shows diffraction and interference (wave property) and photoelectric effect (particle property). Similarly, electrons show diffraction (wave) and have discrete impacts (particle).

(d) Calculate de Broglie wavelength:

(i) Electron with KE = 54 eV = $54\times1.6\times10^{-19} = 8.64\times10^{-18}$ J.

Momentum $p = \sqrt{(2mE)} = \sqrt{(2\times9.11\times10^{-31} \times 8.64\times10^{-18})}$.

$= \sqrt{(1.57\times10^{-47})} = 1.25\times10^{-23}$ kg·m/s.

$\lambda = h/p = 6.63\times10^{-34} / 1.25\times10^{-23} = 5.3\times10^{-11}$ m.

(ii) Golf ball of 45 g = 0.045 kg at 25 m/s.

p = mv = 0.045×25 = 1.125 kg·m/s.

$\lambda = 6.63\times10^{-34} / 1.125 = 5.9\times10^{-34}$ m.

9. (a) (i) Mass difference is the difference between the total mass of separate nucleons and the actual mass of the nucleus. Binding energy is this mass difference converted into energy by $E = \Delta mc^2$.

(ii) Reaction: $^{238}U \rightarrow {}^{234}Th + {}^{4}He + 6.768\times10^{-13}$ J.

Mass of Th = mass of U – mass of He – Δm.

Mass equivalent of energy = $6.768\times10^{-13} / (9\times10^{16}) = 7.52\times10^{-30}$ kg = 4.5×10^{-6} u.

Mass of Th ≈ 238 – 4 – 0.0000045 ≈ 233.9999955 u.

(b) Distinguish between an LED and a photodiode.

LED emits light when current passes through it in forward bias.

Photodiode generates current when exposed to light, usually operated in reverse bias.

(c) (i) Circuit Fig.1, LED just glows at 1.5 V, current = 24 μA.

Power P = VI = $1.5 \times 24\times10^{-6} = 3.6\times10^{-5}$ W.

(ii) Rate of electrons: n = I/e = $24\times10^{-6} / 1.6\times10^{-19} = 1.5\times10^{14}$ s^{-1}.

(iii) Energy per electron = Power/n = $(3.6\times10^{-5})/(1.5\times10^{14}) = 2.4\times10^{-19}$ J.

(d) For Fig.2 transistor circuit:

Given R = 150 kΩ, RL = 750 Ω, current gain β = 80, supply = 9 V.

Base current = Vin/R. Collector current Ic = βIb.

VCE = 9 – IcRL.

10. (a) (i) Laser light

It is light produced by stimulated emission of radiation, which is monochromatic, coherent, and highly directional.

(ii) Mean life time of excited atom

It is the average time an excited atom remains in that state before returning to a lower energy state by emitting radiation.

(iii) Metastable state

It is an excited state of an atom where electrons remain for a relatively long time compared to other excited states, enabling population inversion in lasers.

(b) Four characteristics of laser light

Monochromatic – consists of a single wavelength.

Coherent – all waves are in phase.

Directional – spreads very little over distance.

High intensity – very concentrated beam.

(c) (i) Isotope

Atoms of the same element with the same number of protons but different numbers of neutrons.

(ii) X-ray powder photography in crystalline structure determination

When a powdered crystal is exposed to X-rays, diffraction occurs due to regular arrangement of atoms. The resulting diffraction pattern (rings or spots) is analyzed to determine interatomic spacing and crystalline structure.

(d) (i) Given data

$\lambda_1 = 4046$ Å $= 4046\times10^{-10}$ m, stopping potential $V_1 = 1.6$ V

$\lambda_2 = 5769$ Å $= 5769\times10^{-10}$ m, stopping potential $V_2 = 0.45$ V

Photoelectric equation:

$eV = hc/\lambda - \varphi$

So for the two wavelengths:

$eV_1 = hc/\lambda_1 - \varphi$

$eV_2 = hc/\lambda_2 - \varphi$

Subtract:

$e(V_1 - V_2) = hc(1/\lambda_1 - 1/\lambda_2)$

$h = e(V_1 - V_2) / [c(1/\lambda_1 - 1/\lambda_2)]$

$= (1.6\times10^{-19} \times (1.6 - 0.45)) / [3\times10^8 (1/4.046\times10^{-7} - 1/5.769\times10^{-7})]$

$= (1.6\times10^{-19} \times 1.15) / [3\times10^8 (2.47\times10^6 - 1.73\times10^6)]$

$= 1.84\times10^{-19} / (3\times10^8 \times 0.74\times10^6)$

$= 1.84\times10^{-19} / 2.22\times10^{14}$

$\approx 8.3\times10^{-34}$ Js

This is close to the accepted Planck's constant 6.63×10^{-34} Js.

(ii) Work function φ

Use $eV_2 = hc/\lambda_2 - \varphi$.

$\varphi = hc/\lambda_2 - eV_2$.

$hc/\lambda_2 = (6.63\times10^{-34} \times 3\times10^8)/(5.769\times10^{-7}) = 3.45\times10^{-19}$ J.

$eV_2 = 0.45 \times 1.6\times10^{-19} = 7.2\times10^{-20}$ J.

$\varphi = 3.45\times10^{-19} - 7.2\times10^{-20} = 2.73\times10^{-19}$ J.

Work function $\approx 2.7\times10^{-19}$ J (≈ 1.7 eV).