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 : 2002**

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) State Newton's law of gravitation. Use the law to derive Kepler's third law.

Newton's law of gravitation states that any two masses in the universe attract each other with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between them, $F = GMm/r^2$.

For a planet of mass m orbiting a star of mass M at radius r, the gravitational force provides the centripetal force, $GMm/r^2 = mv^2/r$.

Since $v = 2\pi r/T$, substituting gives $GMm/r^2 = m(4\pi^2 r^2/T^2)/r$.

Simplifying, $T^2 = (4\pi^2/GM)r^3$.

This is Kepler's third law which states that the square of the orbital period is proportional to the cube of the mean distance from the sun.

1. (a) (ii) Explain why Newton's equation of universal gravitation does not hold for bodies falling near the surface of the earth.

Near the earth's surface, the distance between the falling body and the center of the earth remains almost constant compared to the radius of the earth. Thus the force of gravity is effectively constant, and we use $F = mg$ rather than Newton's inverse-square law.

1. (b) (i) With regard to the Earth-Moon system discuss the formation of tides.

Tides are formed due to the gravitational pull of the moon and to a lesser extent the sun. On the side of the earth facing the moon, the gravitational pull is stronger and pulls the water creating a bulge. On the opposite side, the pull is weaker and inertia causes another bulge. As the earth rotates, these bulges produce high and low tides at different places.

1. (b) (ii) A satellite of mass 600 kg is in a circular orbit at a height of 2×10^7 m above the earth's surface. Calculate the orbital speed, the kinetic energy and its gravitational potential energy.

Radius of orbit = Re + h

$= 6.37\times10^6 + 2\times10^7$

$= 2.637\times10^7$ m.

Orbital speed $v = \sqrt{(GM/r)}$

$= \sqrt{((6.67\times10^{-11} \times 5.97\times10^{24})/2.637\times10^{7})}$

= 3887 m/s.

Kinetic energy $KE = \frac{1}{2}mv^2 = 0.5 \times 600 \times (3887)^2 = 0.5 \times 600 \times 1.51\times10^{7} = 4.54\times10^{9}$ J.

Gravitational potential energy $U = -GMm/r = -(6.67\times10^{-11} \times 5.97\times10^{24} \times 600)/2.637\times10^{7} = -9.08\times10^{10}$ J.

1. (c) Jupiter has a mass 318 times that of the earth, its radius is 11.2 times that of the earth's radius. Use this information to estimate the escape velocity of a body from Jupiter's surface if the escape velocity from the earth's surface is 11.2 km/s.

Escape velocity $v_e = \sqrt{(2GM/R)}$. Ratio ve(Jupiter)/ve(Earth)

$= \sqrt{[(MJ/ME)\times(REarth/RJ)]}$.

$= \sqrt{[318 \times (1/11.2)]}$. $= \sqrt{(28.39)}$

= 5.33. So ve(Jupiter) = 5.33 × 11.2 km/s = 59.7 km/s.

2. (a) State and write down the equation of continuity as applied to fluid dynamics.

The equation of continuity states that for an incompressible fluid flowing in a tube of varying cross-sectional area, the product of cross-sectional area and velocity is constant. $A_1v_1 = A_2v_2$.

2. (b) (i) Write down Bernoulli's equation and state the conditions under which it is applicable.

Bernoulli's equation is $P + \frac{1}{2}\rho v^2 + \rho gh$ = constant. It applies to incompressible, non-viscous, steady flow along a streamline.

2. (b) (ii) Air flows over the upper surfaces of the wings of a jet plane at a speed of 340 m/s and past the lower surface at 280 m/s. Determine the 'lift' force on the jet plane if it has a total wing area of 50 m². The density of air is 1.29 kg/m³.

Pressure difference $\Delta P = \frac{1}{2}\rho(v^2_{upper} - v^2_{lower})$.

$= 0.5 \times 1.29 \times (340^2 - 280^2)$.

$= 2.40\times10^4$ Pa.

Lift force = $\Delta P \times A = 2.40\times10^4 \times 50 = 1.20\times10^6$ N.

2. (c) What is the difference between (i) Turbulent flow and laminar flow (ii) Rotational and irrotational flows?

Turbulent flow is irregular, chaotic flow with mixing and eddies, while laminar flow is smooth and orderly with parallel layers of fluid. Rotational flow is where fluid elements have angular velocity, while irrotational flow is where fluid elements move without any rotation about their center of mass.

2. (d) Water flows steadily along a horizontal pipe which narrows at a constriction, the speed at the narrow part is 12 m/s. If the cross-sectional area at the constriction part is ¼ of the original cross-section area of the pipe, compute the pressure difference between the two parts in Nm^{-2}.

By continuity, $v_1A_1 = v_2A_2$.

Let $A_2 = \frac{1}{4}A_1$, so $v_1 = (v_2A_2)/A_1$

$= (12 \times \frac{1}{4}A_1)/A_1 = 3$ m/s.

Using Bernoulli: $\Delta P = \frac{1}{2}\rho(v_2^2 - v_1^2)$.

$= 0.5 \times 1000 \times (144 - 9) = 500 \times 135$

$= 6.75\times10^4$ Pa.

3. (a) (i) Define the angular velocity of a rotating body and give its SI unit.

Angular velocity is the rate of change of angular displacement with time. SI unit is radian per second.

3. (a) (ii) A car wheel has its angular velocity changing from 2 rad/s to 10 rad/s in 20 seconds. If the radius of the wheel is 400 mm calculate (i) the angular acceleration (ii) the tangential linear acceleration of a point on the rim of the wheel.

Angular acceleration $\alpha = (\omega - \omega_0)/t = (10 - 2)/20 = 0.4$ rad/s². Tangential acceleration $a = r\alpha = 0.4 \times 0.4 = 0.16$ m/s².

3. (b) A large wheel of radius 40 cm having 10 spokes on it is made to spin about an axle at 3 rev/s. A 25 cm long arrow is shot parallel to the axle but perpendicular to the surface of the rotating wheel without hitting any of the spokes and enters at a point where one of the spokes has just passed. (i) What minimum speed should the arrow have? (ii) Does it matter where between the axle and the rim you aim?

Wheel speed = 3 rev/s = 18.85 rad/s. Time between two spokes passing = $(2\pi/10)/18.85 = 0.0334$ s. Arrow must traverse its length 0.25 m in this time. Minimum speed = 0.25/0.0334 = 7.49 m/s. It does not matter where you aim, since the spokes rotate uniformly across the radius.

3. (c) (i) A recording disc rotates steadily at 45 rev/min. When a small mass of 0.02 kg is dropped gently onto the disc at a distance of 0.04 m from its axis of rotation and sticks, the rate of revolution falls to 36 rev/min. Calculate the moment of inertia of the disc about its centre. (ii) State and write down the principle used in your calculation in (i) above.

Initial angular velocity $\omega_1 = 45\times2\pi/60 = 4.71$ rad/s.

Final $\omega_2 = 36\times2\pi/60 = 3.77$ rad/s.

Conservation of angular momentum: $I\omega_1 = (I + mr^2)\omega_2$.

So $I = (mr^2\omega_2)/(\omega_1 - \omega_2)$. $= (0.02 \times 0.04^2 \times 3.77)/(4.71 - 3.77)$.

$= (1.21\times10^{-4})/(0.94) = 1.29\times10^{-4}$ kg·m².

Principle: conservation of angular momentum.

4. (a) A cylinder in fig. 1a holds a volume $V_1 = 1000$ cm³ of air at an initial pressure of $P_1 = 1.1\times10^5$ Pa and temperature $T_1 = 300$ K. Assume the air behaves like an ideal gas. (i) AB – the air is heated to 375 K at constant pressure. Calculate the new volume.

By Charles' law $V_2/V_1 = T_2/T_1$.

$V_2 = V_1T_2/T_1 = 1000\times375/300$

$= 1250$ cm³.

(ii) BC – the air is compressed isothermally to volume V_1. Calculate the new pressure P_3.

$P_1V_2 = P_3V_1$. $P_3 = P_1V_2/V_1 = 1.1\times10^5 \times 1250/1000 = 1.375\times10^5$ Pa.

(iii) Calculate the root mean square speed of nitrogen molecules at a temperature of 27 °C.

T = 300 K. $V_{rms} = \sqrt{(3kT/m)}$. For nitrogen molar mass = 28 g/mol = 4.65×10^{-26} kg. $V_{rms} = \sqrt{(3\times1.38\times10^{-23} \times 300 / 4.65\times10^{-26})}$. $= \sqrt{(1.24\times10^{-20} / 4.65\times10^{-26})}$. $= \sqrt{(2.67\times10^5)} = 516$ m/s.

4. (b) State 1st law of thermodynamics and write down its equation. What does the law express?

The first law states that energy cannot be created or destroyed, only converted from one form to another. For a thermodynamic system $\Delta Q = \Delta U + W$. It expresses the principle of conservation of energy.

4. (c) A litre of air initially at 25 °C and 760 mmHg is heated at constant pressure until the volume is doubled. Determine (i) the final temperature (ii) the external work done by the air in expanding it (iii) the quantity of heat supplied.

Initial T = 298 K. Since $V \propto T$, final T = 2×298

= 596 K. External work = $P\Delta V$. Pressure = 760 mmHg

$= 1.01\times10^5$ Pa.

$\Delta V = V_2 - V_1 = 2\times10^{-3} - 1\times10^{-3}$

$= 1\times10^{-3}\ m^3$.

Work $= 1.01\times10^5 \times 1\times10^{-3}$

= 101 J.

For 1 mole of air, $C_v = 5/2R$, $C_p = 7/2R$.

Heat supplied $Q = nC_p\Delta T = 1\times(7/2\times8.31)\times(298)$. = 29.1×298

= 8670 J.

5. (a) What are the necessary conditions for interference of light to be observable?

The sources of light must be coherent, meaning they should maintain a constant phase difference over time.

The sources must emit light of the same frequency and preferably of equal or nearly equal amplitude to produce clear fringes.

The light waves should overlap in the same region of space and have the same polarization direction.

The path difference between the interfering waves should be within a range comparable to the wavelength of light.

5. (b) Why does a small oil patch on the tarmac road often show almost circular coloured rings?

An oil patch on the road forms a thin film of varying thickness when spread over water or tarmac.

When white light falls on the film, part of it reflects from the top surface of the oil while another part reflects from the bottom surface at the oil–air or oil–water boundary.

The two reflected waves overlap and interfere with each other.

Since the film thickness varies, different wavelengths of light undergo constructive or destructive interference at different points, producing circular coloured rings.

5. (c) In a Young's double slit experiment the distance between the centre of the interference pattern and the tenth bright fringe on either side is 3.44 cm and the distance between the slits and the screen is 2 m. If the wavelength of the light used was 5.89×10^{-7} m, determine (i) the slit separation (ii) the path difference.

The distance to the 10th bright fringe from the centre is 3.44 cm, which equals 0.0344 m. Since this corresponds to 10 fringe widths, one fringe spacing is $0.0344/10 = 3.44 \times 10^{-3}$ m.

Using the fringe spacing formula $\Delta y = \lambda L/d$, where $L = 2$ m and $\lambda = 5.89 \times 10^{-7}$ m, the slit separation is $d = \lambda L/\Delta y = (5.89 \times 10^{-7} \times 2)/(3.44 \times 10^{-3}) = 3.43 \times 10^{-4}$ m.

The path difference at the 10th bright fringe is $n\lambda = 10 \times 5.89 \times 10^{-7} = 5.89 \times 10^{-6}$ m.

5. (d) (i) Explain what is meant by diffraction.

Diffraction is the bending and spreading of waves as they pass through a narrow opening or around the edges of an obstacle, causing the waves to deviate from their original direction.

5. (d) (ii) Derive the width of the diffraction pattern for the case of a single slit.

Consider a single slit of width a illuminated by monochromatic light of wavelength λ.

The condition for the first minimum is $a \sin\theta = \lambda$, where θ is the angle of diffraction.

For small angles, $\sin\theta \approx \tan\theta = y/L$, where y is the distance of the minimum from the central maximum on a screen at distance L.

Therefore, the width of the central diffraction maximum is $2y = 2\lambda L/a$.

6. (a) (i) Define "Self inductance" of a coil.
Self inductance is the property of a coil by which it opposes any change in current flowing through it by inducing an emf in itself.

6. (a) (ii) A current of 1.5 A flows in a circuit in which there is a coil of 2.1 H. The electric energy in the inductor is wholly stored in a capacitor whose terminals are maintained at 350 V. Determine the capacitance of the capacitor.
Energy stored in inductor = $\frac{1}{2}LI^2 = 0.5 \times 2.1 \times (1.5)^2 = 2.36$ J.
Energy in capacitor = $\frac{1}{2}CV^2$. So, $C = (2\times2.36)/(350^2)$. $= 4.72/122500 \approx 3.85\times10^{-5}$ F = 38.5 μF.

6. (b) (i) Briefly explain the factors upon which the "throw" of a ballistic galvanometer depends.
The throw of a ballistic galvanometer depends on the charge passing through it, the damping in the coil, the restoring torque provided by the suspension, and the moment of inertia of the coil system.

8. (a) What are the outputs when (i) L is connected to M (ii) M is connected to N?
(i) When L is connected to M, the transistor saturates, allowing current through Rc, so output is low.
(ii) When M is connected to N, the transistor cuts off, no current flows through Rc, so output is high.

8. (b) (i) How can this circuit be used as a switching circuit? Explain.

When the input voltage is high enough to forward bias the transistor base-emitter junction, the transistor saturates, acting as a closed switch. When the input is low, the transistor is off, acting as an open switch.

(ii) Through what range of input voltage could this circuit be used as an amplifier?**

It can be used as an amplifier when the input voltage keeps the transistor in the active region, i.e., base-emitter voltage around 0.6–0.7 V for silicon transistors.

(iii) Mention and discuss one application of the transistor as a switch.**

A common application is in relay driving circuits where the transistor controls a large current to operate motors or lamps using a small control signal.

8. (c) Suppose L in fig a is connected to M and the transistor operates with a collector current of 5 mA while its power supply is 6 V. Find the values of (i) the base bias resistor RB (ii) the load resistor RC.

(i) Base current IB = IC/β = 5 mA / 100 = 0.05 mA. Base-emitter voltage VBE = 0.6 V. Voltage across RB = 6 – 0.6 = 5.4 V. RB = 5.4/0.00005 = 108 kΩ.

(ii) Voltage across RC = VCC – VCE = 6 – 3 = 3 V (assuming VCE = ½ VCC). RC = 3/0.005 = 600 Ω.

9. (a) What is meant by the following terms: (i) Atomic mass unit (a.m.u) (ii) Binding energy (iii) Mass defect

(i) One atomic mass unit is defined as one twelfth the mass of a carbon-12 atom.

(ii) Binding energy is the energy required to completely separate nucleons of a nucleus.

(iii) Mass defect is the difference between the sum of masses of separate nucleons and the actual mass of the nucleus.

Calculate the binding energy per nucleon for phosphorus ${}^{31}_{15}P$ given that ${}^{31}_{15}P$ = 30.97376 a.m.u, ${}^{1}n$ = 1.00865 a.m.u, ${}^{1}H$ = 1.00782 a.m.u.

Mass of nucleons = 15×1.00782 + 16×1.00865 = 31.25222 a.m.u.

Mass defect = 31.25222 – 30.97376 = 0.27846 a.m.u.

In kg = 0.27846 × 1.66×10^{-27} = 4.62×10^{-28} kg.

Binding energy = $\Delta mc^2 = 4.62\times10^{-28} \times (3\times10^8)^2 = 4.16\times10^{-11}$ J.

Per nucleon = $4.16\times10^{-11}/31 = 1.34\times10^{-12}$ J = 8.4 MeV.

9. (b) It is observed that thorium nucleus $^{226}_{90}Th$ at rest decays to form a radium nucleus Ra, an α-particle and a γ-ray. (i) Write down the equation for the disintegration.

$^{226}_{90}Th \rightarrow ^{222}_{88}Ra + ^{4}_{2}He + \gamma$.

(ii) Determine the energy of the γ-ray, if the α-particle is emitted with an energy of 2.38 MeV.

Mass of Th = 226.0249 a.m.u, Ra = 222.0154 a.m.u, α = 4.0026 a.m.u.

Mass difference = 226.0249 – (222.0154 + 4.0026) = 0.0069 a.m.u.

Energy = 0.0069 × 931 = 6.42 MeV.

Total available = 6.42 MeV. If α has 2.38 MeV, γ = 6.42 – 2.38 = 4.04 MeV.

9. (c) When a nucleus of deuterium (hydrogen-2) fuses with a nucleus of tritium (hydrogen-3) to give a helium nucleus and a neutron, 2.88×10^{-12} J of energy are released. The equation is $^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$. Calculate the mass of helium nucleus produced.

Energy released = 2.88×10^{-12} J = $\Delta m\, c^2$.

Mass loss = $E/c^2 = 2.88\times10^{-12} / 9\times10^{16}$

= 3.2×10^{-29} kg.

Mass of reactants = 2.014 u + 3.016 u = 5.030 u.

Mass of products = $^{4}He + ^{1}n$ = ? + 1.009 u.

So helium mass = 5.030 – 1.009 – Δm/u.

In a.m.u, $\Delta m = 3.2\times10^{-29} / 1.66\times10^{-27} = 0.019$ u.

Hence helium mass ≈ 4.002 u.

10. (a) (i) State the three Bohr's postulates of the hydrogen atom.

Electrons revolve around nucleus in certain stable orbits without radiating energy.

Angular momentum of electron is quantized, $mvr = nh/2\pi$.

Radiation is emitted or absorbed when electron jumps between two orbits with energy difference $\Delta E = hf$.

(ii) Calculate the shortest wavelengths of the Balmer series.

For Balmer series, $n_1 = 2$, shortest λ corresponds to $n_2 = \infty$.

$1/\lambda = R(1/2^2 - 1/\infty^2) = R/4$. $\lambda = 4/R = 4/1.097\times10^7 = 3.64\times10^{-7}$ m = 364 nm.

10. (b) Use the Bohr's theory for the hydrogen atom to determine (i) the radius of the 1st orbit.

$r_1 = 0.529$ Å $= 5.29\times10^{-11}$ m.

(ii) The velocity of the electron in the 1st orbit.

$v = \alpha c = 2.18\times10^6$ m/s.

10. (c) (i) What is ionization potential of an atom?

It is the minimum potential required to remove an electron from the ground state of the atom to infinity.

(ii) Show that the ionization potential of hydrogen atom is 13.6 eV.

Energy of electron in nth orbit $E_n = -13.6/n^2$ eV. For n=1, $E_1 = -13.6$ eV. Thus energy required to remove electron = 13.6 eV, which equals the ionization potential.

(iii) How can you account for the chemical behaviour of atoms on the basis of the atomic electrons shell model?

The chemical behaviour depends on the arrangement of electrons in shells. Atoms with full outer shells are inert, while atoms with incomplete outer shells are chemically reactive, tending to lose, gain, or share electrons to achieve stability.