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 : 2006**

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 and show that the speed v of a particle in an orbit of radius r around a planet of mass M is given by $v = \sqrt{GM/r}$.

Newton's law of gravitation states that the force of attraction between two masses M and m separated by distance r is $F = GMm/r^2$.

For circular orbit, centripetal force = gravitational force.

$mv^2/r = GMm/r^2$.

Simplify: $v^2 = GM/r$.

So $v = \sqrt{GM/r}$.

(ii) Define gravitational field strength and gravitational potential at a point on the earth's gravitational field. How are they related?

Gravitational field strength at a point is the force per unit mass acting on a small test mass placed at that point.

Gravitational potential is the work done per unit mass to bring a small test mass from infinity to the point.

They are related by: field strength is the negative gradient of potential with distance.

(iii) Given a graph of the variation of gravitational potential with distance away from the earth, how could the graph of gravitational field strength with distance be derived?

Since field strength is the negative slope of potential, the gradient of the potential-distance graph at each point gives the gravitational field strength.

(b) (i) At one point on a line between the earth and the moon the gravitational field caused by the two bodies is zero. Explain briefly why this is so.

Because the gravitational forces exerted by the earth and the moon on a test mass at that point are equal in magnitude and opposite in direction, so they cancel out.

(ii) The mass of moon is 1/81 the mass of earth and its radius is 1/4 that of earth. If acceleration due to gravity at the surface of the earth is 9.8 ms^{-2}, what is its value at the surface of the moon?

Acceleration due to gravity $g = GM/R^2$.

So $g_{moon} / g_{earth} = (M_{moon}/M_{earth}) \times (R_{earth}/R_{moon})^2$.

$= (1/81) \times (4/1)^2 = (1/81) \times 16 = 16/81$.

$g_{moon} = (16/81) \times 9.8 = 1.94\ ms^{-2}$.

(iii) The Apollo 11 space craft on its journey from the earth to the moon had a velocity of 5374 ms^{-1} when 26,306 km from the centre of the earth. What would have been its velocity at 50,000 km from the earth's centre if the space craft did not fire its motors during the journey?

By conservation of energy: $\frac{1}{2}mv_1^2 - GMm/r_1 = \frac{1}{2}mv_2^2 - GMm/r_2$.

So $v_2^2 = v_1^2 + 2GM(1/r_2 - 1/r_1)$.

Using $GM = gR^2 = 9.8 \times (6.37\times10^6)^2 = 3.99\times10^{14}$.

$v_2^2 = (5374)^2 + 2(3.99\times10^{14})(1/5\times10^7 - 1/2.63\times10^7)$.

Second term $\approx -1.21\times10^7$.

So $v_2^2 = 2.89\times10^7 - 1.21\times10^7 = 1.68\times10^7$.

$v_2 = \sqrt{1.68\times10^7} = 4100\ ms^{-1}$.

2. (a) (i) What is meant by the moment of inertia of a body?

It is the measure of the resistance of a body to angular acceleration about an axis, equal to the sum of products of mass elements and the square of their perpendicular distances from the axis.

(ii) State the perpendicular axes theorem for moment of inertia of a rigid body.

The theorem states that for a plane lamina lying in the xy-plane, the moment of inertia about an axis perpendicular to the plane (z-axis) is equal to the sum of its moments of inertia about two perpendicular axes in the plane passing through the same point: $I_z = I_x + I_y$.

Deduce an expression for the moment of inertia of a disc about an axis at its rim perpendicular to the axis through its centre if the moment of inertia of this disc about a diameter is $I = \frac{1}{4}MR^2$.

Using parallel axis theorem: $I = I_{cm} + Md^2$.

For axis through centre perpendicular to plane: $I = \frac{1}{2}MR^2$.

For axis at rim: $I = \frac{1}{2}MR^2 + MR^2 = 3/2\ MR^2$.

(b) (i) Define radius of gyration.

The radius of gyration is the distance from the axis of rotation at which the whole mass of a body may be assumed to be concentrated to give the same moment of inertia as the actual distribution.

(ii) Calculate the radius of gyration about an tangent of a sphere of radius 0.5 m parallel to its axis through its centre.

Moment of inertia of a sphere about its diameter $= 2/5MR^2$.

About tangent axis, $I = I_{centre} + MR^2 = 2/5MR^2 + MR^2 = 7/5MR^2$.

Radius of gyration $k = \sqrt{(I/M)} = \sqrt{(7/5R^2)} = R\sqrt{(7/5)}$.

$= 0.5 \times 1.183 = 0.592$ m.

(iii) A ballet dancer spins with 30 $revs^{-1}$ with arms outstretched, when the moment of inertia about the axis of rotation is I. With her arms folded the moment of inertia is 75% of I. What is the new angular velocity? State any assumptions made.

By conservation of angular momentum: $I\omega_1 = 0.75I\omega_2$.

$\omega_2 = (I/I0.75I)\omega_1 = (1/0.75)\omega_1 = 1.33\omega_1$.

$\omega_1 = 30\ revs^{-1} = 30\times2\pi$ rad/s = 188 rad/s.

$\omega_2 = 1.33 \times 188 = 250$ rad/s = 40 $revs^{-1}$.

Assumption: no external torque acts.

(c) A solid cylinder of mass M and radius r whose moment of inertia $I = Mk^2$ (k being radius of gyration) rolls down an inclined plane of angle θ to the horizontal, having a length ℓ and height h. Find its final velocity v when at the bottom in terms of (i) h, k, r and g (ii) θ, ℓ, k, g and r. What assumptions have you made?

By energy conservation: $Mgh = \frac{1}{2}Mv^2 + \frac{1}{2}I(v^2/r^2)$.

$= \frac{1}{2}Mv^2(1 + k^2/r^2)$.

So $v^2 = 2gh / (1 + k^2/r^2)$.

(i) $v = \sqrt{(2gh / (1 + k^2/r^2))}$.

(ii) $h = \ell\sin\theta$.

$v = \sqrt{(2g\ell\sin\theta / (1 + k^2/r^2))}$.

Assumptions: rolling without slipping, no energy loss to friction.

3. (a) (i) What is an ideal gas?

It is a hypothetical gas that obeys Boyle's law, Charles' law and Avogadro's law exactly at all temperatures and pressures.

(ii) Derive the perfect gas equation for a unit mass of a gas assuming Boyle's and Charles' laws.

Boyle's law: PV = constant at constant T.

Charles' law: V/T = constant at constant P.

Combining, PV/T = constant.

So PV = RT for unit mass of gas, where R is specific gas constant.

(b) (i) How was Boyle's law modified in deriving the gas equation for real gases?

The volume was corrected for finite size of molecules (V – b).

The pressure was corrected for intermolecular forces $(P + a/V^2)$.

So equation becomes $(P + a/V^2)(V - b) = RT$.

(ii) What is the absolute temperature of a gas moving at a speed (rms) of 500 ms^{-1} if the average mass of the molecule is 8×10^{-26} kg?

$v^2 = 3kT/m$.

$T = mv^2 / 3k$.

$= (8\times10^{-26} \times 500^2)/(3\times1.38\times10^{-23})$.

$= (2.0\times10^{-20})/(4.14\times10^{-23}) \approx 483$ K.

(c) A flask of 10^{-3} m^3 contains hydrogen gas at a pressure of 10^{-3} mmHg and a temperature of 27 °C. Calculate the:

(i) root mean square speed of the molecules.

$v_{rms} = \sqrt{(3RT/M)}$.

For H_2, $M = 2\times10^{-3}$ kg/mol, $R = 8.31$, $T = 300$ K.

$v_{rms} = \sqrt{(3\times8.31\times300 / 2\times10^{-3})}$.

$= \sqrt{(7480/0.002)} = \sqrt{3.74\times10^6} = 1934$ m/s.

(ii) number of molecules present in the flask.

$PV = NkT$.

$P = 10^{-3}$ mmHg $= 10^{-3}\times133.3 = 0.133$ Pa.

$N = PV/kT = (0.133\times10^{-3})/(1.38\times10^{-23} \times 300)$.

$= 1.33\times10^{-4} / 4.14\times10^{-21} = 3.2\times10^{16}$ molecules.

(iii) number of impacts per sec per unit area on the wall of the flask.

Collision rate per unit area = $\frac{1}{4}nv_{rms}$.

$n = N/V = 3.2\times10^{16}/10^{-3} = 3.2\times10^{19}$ m^{-3}.

$= \frac{1}{4} \times 3.2\times10^{19} \times 1934 = 1.55\times10^{22}$ impacts/s/m^2.

4. (a) State the first law of thermodynamics, defining all the terms involved.

The first law of thermodynamics states that the heat supplied to a system is equal to the sum of the increase in internal energy and the external work done by the system.

$Q = \Delta U + W$.

(b) An ideal gas is kept in thermal contact with a very large body of constant temperature T and undergoes an isothermal expansion in which its volume changes from V_1 to V_2. Derive an equation for the work done by the gas.

$W = \int PdV = \int(nRT/V)\, dV = nRT \ln(V_2/V_1)$.

(c) A heat engine carries 1 mole of an ideal gas around a cycle as shown in figure 1. Process 1–2 is at constant volume, process 2–3 is adiabatic and process 3–1 is at constant pressure of 1 atm. The value of γ for this gas is 5/3. Find the:

(i) pressure and volume at points 1, 2 and 3.

Point 1: $T_1 = 300$ K, $P = 1$ atm $= 1.01\times10^5$ Pa.

$V_1 = nRT/P = (1\times8.31\times300)/(1.01\times10^5) = 0.0247$ m³.

Point 2: $V_2 = V_1$, $T_2 = 600$ K.

$P_2 = nRT_2/V_2 = 2\times P_1 = 2.02\times10^5$ Pa.

Point 3: $P_3 = 1$ atm, $T_3 = 455$ K.

$V_3 = nRT_3/P = (1\times8.31\times455)/(1.01\times10^5) = 0.0374$ m³.

(ii) net work done by the gas in the cycle.

W = area enclosed on PV diagram.

$= P(V_3 - V_1) - nR(T_2 - T_1)$.

$= (1.01\times10^5)(0.0374 - 0.0247) - (8.31)(600 - 300)$.

$= 1280 - 2490 = -1210$ J.

So net work = 1210 J (approx).

(d) The door of a working refrigerator is left open. What effect will this have on the temperature of the room in which the refrigerator is kept? Explain.

If the refrigerator door is left open, the compressor will continuously pump heat from inside the fridge into the room. Since the work done by the compressor also generates heat, the net effect will be to warm up the room instead of cooling it.

5. (a) (i) In a Young's double slit experiment, interference occurs when diffraction of light takes place at each of the two slits. Explain with the aid a diagram the meaning of interference and diffraction in this case.

Diffraction is the spreading of light waves when they pass through narrow slits. In Young's experiment, each slit acts as a secondary source producing diffracted waves. When these diffracted waves from the two slits overlap on the screen, they superpose. At some points they reinforce each other (constructive interference giving bright fringes) and at other points they cancel (destructive interference giving dark fringes). The result is an interference pattern of alternating bright and dark bands.

(ii) In the double slit experiment using light of wavelength 6.0×10^{-7} m, the slits were 0.40 mm apart and the distance of the slits to the screen was 1.20 m. Find the separation of the fringes and the angles subtended by a central pair of the bright fringes at the slits.

Fringe separation $y = \lambda D/d = (6\times10^{-7} \times 1.20)/(0.40\times10^{-3}) = (7.2\times10^{-7})/(4\times10^{-4}) = 1.8\times10^{-3}$ m = 1.8 mm.

Angle subtended by one fringe = $\lambda/d = 6\times10^{-7} / 4\times10^{-4} = 1.5\times10^{-3}$ rad.

So angle between central pair = $2\times1.5\times10^{-3} = 3\times10^{-3}$ rad.

(b) Determine the slit separation if 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 2.0 m. The wavelength of the incident light is 5.89×10^{-7} m.

Distance to 10th bright fringe = 0.0344 m.

Fringe separation y = 0.0344/10 = 0.00344 m.

Slit separation $d = \lambda D/y = (5.89\times10^{-7} \times 2.0)/0.00344 = 1.178\times10^{-6} / 0.00344 = 3.43\times10^{-4}$ m = 0.343 mm.

(c) Two waves of equal frequency and amplitude travel in opposite directions in a medium. What is this resultant wave?

The two waves form a stationary wave with nodes where displacement is always zero and antinodes where amplitude is maximum.

(d) State two differences between a stationary and a progressive wave.

In a stationary wave, energy is not transmitted, while in a progressive wave energy is transferred.

In a stationary wave, amplitude varies from zero at nodes to maximum at antinodes, while in a progressive wave, amplitude is the same at all points.

6. (a) (i) Explain briefly the phenomena observed when an electric discharge passes through a gas at very low pressure. Illustrate your answer using a labelled diagram.

At very low pressure, gas becomes partially ionized and glows when a high potential is applied. At first a faint glow appears near the cathode, then the glow fills the tube, producing regions like cathode glow, dark space, and anode glow. This is called a glow discharge.

(ii) Draw a sketch graph showing clearly the breakdown potential. Hence define breakdown potential.

A graph of current against potential difference shows little current at first, then a sharp rise when breakdown occurs. Breakdown potential is the minimum voltage at which a gas becomes conducting by producing avalanche ionization.

(b) (i) What is lightning?

Lightning is a massive discharge of electricity occurring naturally between clouds or between a cloud and the ground due to potential differences created by charge separation in thunderclouds.

Explain two ways in which lightning may be harmful.

It can destroy property or injure people when it strikes.

It can cause fires in forests, houses, or installations.

(ii) The main discharge in lightning produces a current of 10^5 A for a short duration of 10^{-4} s. If the potential difference between cloud and ground is 10^8 V, calculate the amount of energy produced by the discharge.

Energy = VIt = $10^8 \times 10^5 \times 10^{-4} = 10^9$ J.

(iii) If some of the energy above is converted into heat when lightning strikes a tree having a resistance of $10^4\ \Omega$, how much heat will be produced in 10^{-4} s?

Power = $I^2R = (10^5)^2 \times 10^4 = 10^{14} \times 10^4 = 10^{18}$ W.

Energy = Power × time = $10^{18} \times 10^{-4} = 10^{14}$ J.

(c) (i) State Faraday's laws of electrolysis.

First law: The mass deposited is directly proportional to the quantity of electricity passed.

Second law: For the same charge passed, the masses deposited are proportional to their equivalent weights.

(ii) Calculate the mass of copper deposited in 30 minutes in a copper voltameter when a constant current of 2 A flows. (Take $M/zQ = 3.3 \times 10^{-8}$ kg C^{-1}).

Charge = It = 2 × 1800 = 3600 C.

Mass = (M/zQ) × Q = $3.3\times10^{-8} \times 3600 = 1.19\times10^{-4}$ kg = 0.119 g.

How much silver will be deposited if the same current flows for the same time through a silver nitrate voltameter, if 0.1 g of copper is deposited at one cathode?

From data: M(Cu)/z = 63.5/2 = 31.75, M(Ag)/z = 108/1 = 108.

Mass ratio = 108/31.75 = 3.4.

So mass of Ag = 0.1 × 3.4 = 0.34 g.

7. (a) Explain what is meant by:

(i) Self inductance

It is the property of a coil by which a change in current induces an emf in the same coil opposing the change.

(ii) Mutual inductance

It is the property where a change of current in one coil induces an emf in a nearby coil.

(b) (i) Define the terms impedance, inductive and capacitive reactance.

Impedance is the effective opposition to alternating current in a circuit containing resistance, inductance and capacitance.

Inductive reactance is the opposition due to an inductor, equal to $XL = \omega L$.

Capacitive reactance is the opposition due to a capacitor, equal to $XC = 1/\omega C$.

(ii) Using a phasor diagram show that the impedance of a R-L-C series circuit is given by $Z = \sqrt{(R^2 + (XL - XC)^2)}$.

From phasor representation, voltage across resistor is in phase with current, voltage across inductor leads current by 90°, and voltage across capacitor lags current by 90°. The resultant of inductive and capacitive voltages is (XL – XC). So $Z = \sqrt{(R^2 + (XL - XC)^2)}$.

(iii) Calculate the maximum potential difference across a R-L-C series circuit having a resistance of 10 Ω when a current of 4.5 A is flowing through.

$V = IR = 4.5 \times 10 = 45$ V.

(c) (i) A series circuit has a resistance of 75 Ω and an impedance of 150 Ω. What power is consumed in the circuit when a potential difference of 120 V is applied across it?

Power $P = V^2R/Z^2$.

$= (120^2 \times 75)/(150^2)$.

$= (14{,}400 \times 75)/22{,}500 = 48$ W.

(ii) How much energy is stored in the magnetic field of the coil in 7(c)(i) above in 10 seconds if the inductance of the coil is 2 H?

Energy stored in coil = $\frac{1}{2}LI^2$.

Current $I = V/Z = 120/150 = 0.8$ A.

Energy $= \frac{1}{2} \times 2 \times (0.8)^2 = 0.64$ J.

8. (a) Show how an operational amplifier may be arranged to be used as:

(i) An inverting amplifier

The input is connected to the inverting terminal (–) through a resistor, the non-inverting terminal (+) is grounded, and a feedback resistor is connected between the output and the inverting input.

(ii) A non-inverting amplifier

The input is connected directly to the non-inverting terminal (+), the inverting terminal (–) is connected to the output through a feedback resistor, and also to ground through another resistor.

How is the amplification calculated in each case?

For inverting amplifier: Gain = –Rf/Rin.

For non-inverting amplifier: Gain = 1 + (Rf/Rin).

(b) An ideal operational amplifier is used in the circuit as shown in figure 2 below with a constant input of 0.50 V and power supplies of +6.0 V and –6.0 V.

(i) Calculate the gain of the amplifier circuit.

Gain = –Rf/Rin = –68 kΩ / 6.8 kΩ = –10.

(ii) What is the output voltage Vout?

Vout = Gain × Vin = –10 × 0.50 = –5.0 V.

(iii) If the constant input is then changed from 0.5 V to a sinusoidal alternating voltage of 0.5 Vmax, calculate the peak value of the input voltage and the maximum and minimum values of the output voltage if the power supply remains as indicated.

Peak value of input = 0.5 V.

Output = –10 × 0.5 = –5 V peak.

So maximum output = +5 V, minimum = –5 V, limited by supply ±6 V.

(c) Produce a truth table for the gate combination shown below. Hence show that it behaves as a NAND gate.

Inputs A, B pass through NOT gates before OR. This is equivalent to NAND gate.

Truth table:

A=0, B=0 → Q=1

A=0, B=1 → Q=1

A=1, B=0 → Q=1

A=1, B=1 → Q=0

This matches NAND.

9. (a) (i) The work function of potassium is 3.52×10^{-19} J. What does the statement mean?

It means the minimum energy required to remove an electron from the surface of potassium is 3.52×10^{-19} J.

(ii) Yellow light has a wavelength of 6×10^{-7} m. How many photons are emitted per second by a yellow lamp rated 15 W?

Energy of one photon $E = hc/\lambda = (6.63\times10^{-34}\times3\times10^{8})/(6\times10^{-7}) = 3.315\times10^{-19}$ J.

Photons per second = Power/E = $15/3.315\times10^{-19} = 4.52\times10^{19}$ photons/s.

(b) (i) When radiation of a suitable frequency falls on a potassium surface, photoelectrons are emitted. Calculate the minimum frequency for this to occur.

$f_{min} = \varphi/h = (3.52\times10^{-19})/(6.63\times10^{-34}) = 5.31\times10^{14}$ Hz.

(ii) Calculate the maximum speed of the photoelectrons emitted when radiation of wavelength 4.0×10^{-7} m is incident on a potassium surface.

Photon energy $E = hc/\lambda = (6.63\times10^{-34}\times3\times10^{8})/(4\times10^{-7}) = 4.97\times10^{-19}$ J.

$KE = E - \varphi = 4.97\times10^{-19} - 3.52\times10^{-19} = 1.45\times10^{-19}$ J.

$v = \sqrt{(2KE/m)} = \sqrt{(2\times1.45\times10^{-19} / 9.11\times10^{-31})} = \sqrt{3.18\times10^{11}} = 5.64\times10^{5}$ m/s.

(c) (i) What is a photoemissive cell?

It is a device that converts light energy into electrical energy by emission of electrons from a photosensitive surface when illuminated.

Explain how photoemissive cell works. Give two examples for which photoemissive cells are useful.

Light falls on a photosensitive cathode, releasing electrons which are attracted to an anode, producing a current proportional to light intensity.

Uses: light meters, automatic switching devices, burglar alarms.

10. (a) (i) What is the difference between natural and artificial radioactivity?

Natural radioactivity occurs spontaneously in unstable nuclei found in nature.

Artificial radioactivity is induced by bombarding stable nuclei with particles to make them radioactive.

(ii) Name three applications of artificial radioactivity.

Used in medicine for cancer treatment (radiotherapy).

Used in industry for thickness and leak detection.

Used in agriculture for studying plant processes with tracers.

(b) (i) State two conditions for stability of nuclides referring to light nuclides and heavy nuclides.

Light nuclides are stable when neutron to proton ratio is close to 1:1.

Heavy nuclides require more neutrons than protons for stability.

(ii) Sketch a graph showing how binding energy per nucleon varies with mass number. Relate the graph to nuclear fission and nuclear fusion.

The graph rises steeply at low mass numbers, peaks around iron ($A \approx 56$), and then falls slowly for heavy elements.

Fusion of light nuclei increases binding energy per nucleon, releasing energy.

Fission of heavy nuclei also increases binding energy per nucleon, releasing energy.

(c) (i) Calculate the energy available when two nuclei of deuterium fuse together as shown:

$^{1}H^{2} + {}^{1}H^{2} \rightarrow {}^{2}He^{3} + {}^{0}n^{1}$.

Mass difference $\Delta m = (2\times2.014) - (3.016 + 1.009) = 4.028 - 4.025 = 0.003$ u.

Energy $= \Delta mc^2 = 0.003\times931 = 2.8$ MeV.

(ii) Given that 2 kg of deuterium contains 6×10^{26} deuterium nuclei, calculate the energy released per kilogram by the fusion reaction.

One reaction uses 2 nuclei, so number of reactions $= (6\times10^{26})/2 = 3\times10^{26}$.

Energy per reaction $= 2.8$ MeV $= 4.5\times10^{-13}$ J.

Total energy $= 3\times10^{26} \times 4.5\times10^{-13} = 1.35\times10^{14}$ J.

Energy per kg $= 1.35\times10^{14} / 2 = 6.75\times10^{13}$ J/kg.

In a fission reactor, 1.9×10^{13} J of energy are released when 6×10^{26} uranium nuclei (mass 240 kg) disintegrate. Compare the energy released per kilogram by the two processes.

Energy per kg in fission $= 1.9\times10^{13} / 240 \approx 7.9\times10^{10}$ J/kg.

Energy per kg in fusion = 6.75×10^{13} J/kg.

Fusion releases about 850 times more energy per kilogram than fission.