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 : 2005**

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) (i) What is the meaning of the terms "precision" and "accuracy" as used in experimental physics?

Precision refers to how closely repeated measurements agree with each other, regardless of whether they are correct.

Accuracy refers to how close a measured value is to the true or accepted value.

(ii) In an experiment to determine the volume of glass in a length of glass tubing the following readings were recorded:
Length $\ell = (40 \pm 1)$ mm
External diameter $D = (12.0 \pm 0.2)$ mm
Internal diameter $d = (10.0 \pm 0.2)$ mm

If the volume of glass is calculated using the relation $V = \frac{1}{4}\pi\ell(D^2 - d^2)$, determine the numerical value for the volume V.

$D^2 - d^2 = 12^2 - 10^2 = 144 - 100 = 44\ \text{mm}^2$.
So $V = \frac{1}{4} \times \pi \times 40 \times 44 = \frac{1}{4} \times \pi \times 1760$.
$= 1382.3\ \text{mm}^3$.

So the volume of glass is about $1382\ \text{mm}^3$.

(b) (i) Distinguish between derived quantities and fundamental quantities.

Fundamental quantities are basic physical quantities that cannot be expressed in terms of others, for example mass, length, and time.

Derived quantities are those obtained by combining fundamental quantities, for example speed (length/time) or force (mass × acceleration).

(ii) A small liquid drop is disturbed from its spherical shape and then set oscillating. The frequency f of oscillation is given by $f^2\rho r^3 = k\gamma$, where ρ is the density of the liquid drop, r is its radius, γ is the surface tension of the liquid. Show by dimensional analysis that k is a dimensionless constant.

Dimensions of left-hand side: $f^2 \rho r^3$.

$f^2 \rightarrow T^{-2}$.

$\rho \rightarrow M L^{-3}$.

$r^3 \rightarrow L^3$.

So total = $M T^{-2}$.

Dimensions of right-hand side: γ.

Surface tension γ = force/length = $(MLT^{-2})/L = M T^{-2}$.

So both sides are $M T^{-2}$. Therefore k has no dimensions, meaning it is a dimensionless constant.

2. (a) Show that the trajectory of a body projected with an initial velocity V_0 at an angle θ to the horizontal is a parabola.

Horizontal displacement: $x = V_0\cos\theta \times t$.

Vertical displacement: $y = V_0\sin\theta \times t - \frac{1}{2}gt^2$.

From $x = V_0\cos\theta\, t \rightarrow t = x / (V_0\cos\theta)$.

Substitute into y:

$y = x \tan\theta - (g/2V_0^2\cos^2\theta)x^2$.

This is of the form $y = Ax - Bx^2$, which is a parabola.

(b) While standing on an open truck moving at a velocity of 35 ms^{-1} a man sees a duck flying directly overhead. The man shoots an arrow at the duck and misses it. The arrow leaves the bow with a vertical velocity of 98.0 ms^{-1}. The truck accelerates to a constant speed of 40 ms^{-1} in the same direction just after the man has shot at the duck. If the truck open board at which the man is standing is 2.0 m above the ground:

(i) How long will the arrow remain in air before hitting the ground?

Equation of motion: $y = 2 + 98t - 4.9t^2$.

Solve for y = 0: $4.9t^2 - 98t - 2 = 0$.

Time = $[98 + \sqrt{(98^2 + 4\times4.9\times2)}] / (2\times4.9)$.

$= (98 + \sqrt{9620})/9.8 \approx (98 + 98.0)/9.8$.

$= 196/9.8 \approx 20.0$ s.

So the arrow remains in the air for about 20 seconds.

(ii) Where will the arrow land in relation to the position of the truck?

Horizontal distance of arrow = $V_x \times$ time = $35 \times 20 = 700$ m.

Truck starts at 35 m/s but accelerates to 40 m/s "just after" shooting. For simplicity, take constant 40 m/s during the 20 s.

Distance of truck = $40 \times 20 = 800$ m.

So the arrow lands 100 m behind the truck.

3. (a) (i) Explain why a coiled water hose-pipe tends to straighten when water flows through it.

When water flows, it exerts pressure on the walls. The curved shape causes higher force on the inner side than outer side, producing a torque that tends to straighten the hose.

(ii) If action and reaction are always equal in magnitude and opposite in direction, why don't they always cancel each other and leave no net force for acceleration of the body?

Because the action and reaction act on different bodies, not on the same body. Therefore they do not cancel each other.

(iii) State the principle of conservation of linear momentum and show that it can be obtained from Newton's laws.

The principle of conservation of momentum states that if no external force acts on a system, the total momentum of the system remains constant.

From Newton's third law, forces between interacting bodies are equal and opposite, so the changes in momentum of the two bodies cancel, leaving total momentum constant.

(b) What is an impulse of a force?

Impulse is the product of force and the time it acts, equal to the change in momentum of the body.

A rifle of mass 5.0 kg is used to fire a bullet of mass 0.15 kg with a muzzle velocity of 600 ms^{-1}. Calculate the:

(i) velocity with which the rifle starts to recoil.

From momentum conservation: $m_1v_1 + m_2v_2 = 0$.
$5vr + 0.15 \times 600 = 0 \rightarrow vr = -(90/5) = -18$ m/s.

So the rifle recoils at 18 m/s backward.

(ii) average force required, if the recoil is to be reduced to zero in a distance of 5.0 cm.

Work-energy principle: Force × distance = $\frac{1}{2}mv^2$.
$F \times 0.05 = \frac{1}{2} \times 5 \times 18^2 = 810$ J.
$F = 810/0.05 = 16{,}200$ N.

So average force ≈ 16.2 kN.

4. (a) (i) Define "free surface energy" in relation to the liquid surfaces.

Free surface energy is the work required to increase the surface area of a liquid by unit area, due to intermolecular forces.

(ii) Explain what will happen if two bubbles of unequal radii are joined by a tube without bursting.

Air will flow from the smaller bubble to the larger one because the pressure inside a smaller bubble is greater.

(iii) A spherical drop of mercury of radius 5.0 mm falls on the ground and breaks into 1000 equal droplets. Calculate the amount of work done in breaking the drop.

Work done = increase in surface energy = surface tension × increase in area.

Initial area = $4\pi R^2 = 4\pi(5\times10^{-3})^2 = 3.14\times10^{-4}$ m².

Volume of drop = $(4/3)\pi R^3$. Each small drop volume = total/1000.

Radius of small drop r = R / 10 = 0.5 mm = 5×10^{-4} m.

Total surface area of small drops = $1000 \times 4\pi r^2 = 1000 \times 4\pi(5\times10^{-4})^2 = 3.14\times10^{-3}$ m².

Increase in area = $3.14\times10^{-3} - 3.14\times10^{-4} = 2.83\times10^{-3}$ m².

If surface tension T = 0.5 N/m (assume standard), work done = $T \times \Delta A = 0.5 \times 2.83\times10^{-3} = 1.42\times10^{-3}$ J.

(b) (i) Two capillary tubes of radii r and R are placed in a beaker containing a liquid of density ρ. Show from first principles in which tube the liquid will rise highest, given that r < R.

Capillary rise $h = 2T\cos\theta / (\rho g r)$.

Since $h \propto 1/r$, the liquid rises higher in the smaller radius tube (r).

(ii) Suppose the xylem tubes in a growing tree are uniform cylinders, rising of sap is entirely by capillarity with contact angle 45° and surface tension 5×10^{-2} Nm^{-1}. Maximum radius for water to rise 20 m is:

$h = 2T\cos\theta / (\rho g r)$.

Rearrange for r: $r = 2T\cos\theta / (\rho g h)$.

$= (2\times5\times10^{-2}\times0.707) / (1000\times9.8\times20)$.

$= 0.0707 / 196{,}000 \approx 3.6\times10^{-7}$ m.

So maximum radius ≈ 3.6×10^{-7} m.

5. (a) (i) What is the difference between ice point and triple point of water?

The ice point is the temperature at which pure ice melts under standard atmospheric pressure, taken as 0 °C.

The triple point is the unique temperature and pressure at which ice, liquid water, and water vapour coexist in equilibrium. For water it is 0.01 °C at 611 Pa.

(ii) Several cooking utensils for sale are rated at "HIGH" or "LOW" in terms of their thermal efficiency for the following properties:

thermal conductivity

specific heat capacity

coefficient of expansion

melting point

Explain briefly the thermal ratings you would observe with respect to each property in purchasing a cooking utensil.

Utensils with high thermal conductivity heat up quickly and distribute heat evenly, making them more efficient.

Utensils with low specific heat capacity require less heat to rise in temperature, so they heat faster.

A low coefficient of expansion is desirable to avoid warping when heated.

A high melting point ensures the utensil remains safe at high cooking temperatures.

(b) A calorimeter of thermal capacity 30 JK^{-1} contains 100 cm^3 of glycerine and it cools from 80 °C to 70 °C in 3.5 minutes, room temperature being 20 °C. When the glycerine is replaced by 100 cm^3 of water, the water cools from 43 °C to 33 °C in 16.5 minutes. Determine the specific heat capacity of glycerine.

Heat lost per second is proportional to $(C + mc)(\Delta\theta/\Delta t)$.

For glycerine:
Heat loss rate = $(30 + \rho V c_g) \times (10/210)$.

For water:
Heat loss rate = $(30 + 100 \times 4.2) \times (10/990)$.

Here water's mass = 100 g = 0.1 kg, c = 4200 J/kgK → mc = 420 J/K.

So denominator = 30 + 420 = 450.

So for water: loss rate = 450 × (10/990) = 4.55.

Equating ratio for glycerine and water:

$(30 + \rho V c_g) \times (10/210) = 4.55$.

ρ of glycerine = 1.26 g/cm^3 → mass of 100 cm^3 = 0.126 kg.

So $(30 + 0.126c_g) \times (10/210) = 4.55$.
$(30 + 0.126c_g) = 95.6$.
$0.126c_g = 65.6$.
$c_g = 65.6 / 0.126 = 520$ J/kgK.

So specific heat of glycerine ≈ 520 J/kgK.

6. (a) (i) How does heat transfer by convection differ from that by conduction?

In conduction, heat is transferred through a material by direct molecular collisions without actual movement of matter.

In convection, heat is transferred by the actual movement of fluid (liquid or gas) from one place to another.

(ii) State Newton's law of cooling and Stefan's law. For each law state one significant limitation.

Newton's law of cooling: The rate of loss of heat of a body is proportional to the temperature difference between the body and its surroundings, provided the difference is small. Limitation: It does not hold for large temperature differences.

Stefan's law: The total energy radiated per unit surface area of a black body is proportional to the fourth power of its absolute temperature, $E = \sigma T^4$. Limitation: Only valid for ideal black bodies, not for real surfaces which have emissivity less than 1.

(iii) State and illustrate how an increase in temperature affects the radiation spectrum of a blackbody.

As temperature increases, the total energy radiated increases and the peak of the spectrum shifts to shorter wavelengths (higher frequency). This is explained by Wien's displacement law.

(b) Given that the solar constant has a value of 1350 W m^{-2}:

(i) Estimate the total direct solar energy which enters the Tanzanian atmosphere from 06.55 a.m. to 05.05 p.m. on a sunny day. Neglect changes in the solar beam between the earth's atmosphere and the sun-earth midpoint.

Duration = 10 h 10 min = 36,600 s.
Energy per m^2 = $1350 \times 36,600 = 4.94 \times 10^7$ J.

So each square metre receives about 4.9×10^7 J.

(ii) What is the total rate at which the sun emits out energy?

Solar constant S = 1350 W/m^2 = Power per area at earth.
Earth-sun distance $R = 1.5 \times 10^{11}$ m.
Surface area of sphere = $4\pi R^2$.

Total power = $1350 \times 4\pi(1.5 \times 10^{11})^2$.
$= 1350 \times 4\pi \times 2.25 \times 10^{22}$.

$= 1350 \times 28.3 \times 10^{22}$.
$= 3.82 \times 10^{26}$ W.

So the sun emits about 3.8×10^{26} W.

7. (a) (i) Distinguish between longitudinal and transverse wave motion and give an example of each.

In longitudinal waves, particles of the medium vibrate parallel to the direction of wave propagation, e.g. sound waves in air.

In transverse waves, particles of the medium vibrate perpendicular to the direction of wave propagation, e.g. waves on a string or water surface ripples.

(ii) Show the relationship between the frequency f, wavelength λ and velocity of propagation v, of a wave motion.

By definition, wave velocity is the distance a wave travels per second.
Distance covered in one oscillation = wavelength λ.
Time for one oscillation = 1/f.
So $v = \lambda / (1/f) = f\lambda$.

(b) (i) Draw a sketch diagram showing the positions of nodes and antinodes in the vibrations of an air column in a pipe closed at one end when giving the second overtone. Calculate the frequency of this second overtone if the effective length of the pipe is 72 cm.

For a closed pipe: only odd harmonics occur.
First harmonic = fundamental = λ = 4L.
Second overtone corresponds to 5th harmonic (3rd allowed mode).
So $\lambda = 4L/5$.

$L = 0.72$ m, so $\lambda = (4 \times 0.72)/5 = 2.88/5 = 0.576$ m.
Frequency $f = v/\lambda$.
If $v = 340$ m/s, $f = 340/0.576 \approx 590$ Hz.

(ii) A small loudspeaker is placed near the open end of a pipe of length 400 mm closed at the other end. The minimum frequency at which the pipe resonates is 215 Hz. Estimate the speed of sound in the pipe and calculate the next frequency for resonance.

For first resonance in closed pipe: $f_1 = v/4L$.
L = 0.400 m.
So $v = 4Lf_1 = 4 \times 0.400 \times 215 = 344$ m/s.

Next resonance is 3rd harmonic ($3f_1$).
$= 3 \times 215 = 645$ Hz.

8. (a) (i) State Coulomb's law.

Coulomb's law states that the force between two point charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them, acting along the line joining the charges.

(ii) A spherical metal of radius r carries a charge Q. Sketch a graph showing the variation of electric potential V with the distance x from the centre of the sphere for points inside and outside. Also, give reason for the shape.

For $x \geq r$: $V = kQ/x$ → decreases inversely with distance.
For $x < r$: $V = kQ/r$ → constant.
So the graph is constant inside, then falls as $1/x$ outside.

(b) (i) Name the physical properties of a capacitor that affect its capacitance, and write the relation.

Capacitance depends on the area of plates A, separation d, and dielectric constant ε.
$C = \varepsilon_0 \varepsilon r A/d$.

(ii) Show that the energy stored per unit volume of a parallel plate capacitor is given by $\frac{1}{2}\varepsilon_0 \varepsilon r E^2$ where symbols carry their usual meaning.

Energy stored = $\frac{1}{2}CV^2$.
$C = \varepsilon_0 \varepsilon r A/d$, $V = Ed$.

So $W = \frac{1}{2}(\varepsilon_0\varepsilon_r A/d)(E^2d^2)$.

$= \frac{1}{2}\varepsilon_0\varepsilon_r AE^2d$.

Energy density = W/volume = W/Ad = $\frac{1}{2}\varepsilon_0\varepsilon_r E^2$.

9. (a) Define an equipotential surface.

An equipotential surface is a surface where every point has the same electric potential, so no work is done in moving a charge along the surface.

(ii) What is the work done on a test charge when it is moved from one point to another along an equipotential surface?

The work done is zero.

(b) (i) Two small spheres A and B are fixed on the x-axis with their centres at distances $x_A = 4$ cm and $x_B = 12$ cm from the origin. Charges: $Q_A = +20\times10^{-9}$ C, $Q_B = -12\times10^{-9}$ C. Determine the electric potential V and the electric field strength E at the origin.

Potential:

$V_A = kQ/r = (9\times10^9 \times 20\times10^{-9})/0.04 = 180/0.04 = 4500$ V.

$V_B = (9\times10^9 \times -12\times10^{-9})/0.12 = -108/0.12 = -900$ V.

Total V = 3600 V.

Electric field:

$E_A = kQ/r^2 = (9\times10^9 \times 20\times10^{-9})/(0.04)^2 = 180/0.0016 = 1.125\times10^5$ N/C (directed away from A).

$E_B = (9\times10^9 \times 12\times10^{-9})/(0.12)^2 = 108/0.0144 = 7500$ N/C (directed toward B).

Net $E = 1.125\times10^5 - 7500 = 1.05\times10^5$ N/C to the left.

(ii) A capacitor of capacitance 2.0 μF is charged using 0.4 V from a cell and discharges through a meter. The meter gives a charge deflection of 6.4 cm. What is the sensitivity of the meter in mC/cm?

Charge $Q = CV = 2.0\times10^{-6} \times 0.4 = 8\times10^{-7}$ C.

Deflection = 6.4 cm.

Sensitivity = Q/deflection = $8\times10^{-7} / 6.4$.

$= 1.25\times10^{-7}$ C/cm = 0.125 μC/cm = 0.000125 mC/cm.

10. (a) (i) Explain why an electric bulb turns on as soon as the switch is closed, though drift velocity of electrons in a metallic conductor is very small.

When the switch is closed, an electric field is established almost instantly throughout the circuit at the speed of light. This field causes all electrons in the conductor to start drifting simultaneously, so the bulb lights immediately even though individual electron drift velocity is slow.

(ii) The current in a wire varies with time as $I = 4 + 2t^2$, where I is in amperes and t in seconds.

How many charges pass a cross-section of the wire in the interval between t = 5 s and t = 10 s?

Charge = $\int I\,dt$ from 5 to 10.

= $\int (4 + 2t^2)\,dt = [4t + (2/3)t^3]$ from 5 to 10.

At 10: 40 + (2/3)(1000) = 40 + 667 = 707.

At 5: 20 + (2/3)(125) = 20 + 83.3 = 103.3.

Difference = 603.7 C.

(iii) What constant current would transport the same charge in the same time interval?

Time interval = 5 s.

Equivalent current = Q/t = 603.7/5 = 121 A.

(b) What is the velocity of the charge carriers when a current of 1 A passes through a copper wire with cross-sectional area 1 mm^2. Assume each copper atom donates one electron. Density of copper atoms = $8.5\times10^{28}\ m^{-3}$.

Current I = nAve.

So ve = I / (nAe).

$n = 8.5\times10^{28}$, $A = 1\ mm^2 = 1\times10^{-6}\ m^2$, $e = 1.6\times10^{-19}$.

$ve = 1 / (8.5\times10^{28} \times 1\times10^{-6} \times 1.6\times10^{-19})$.

$= 1 / (1.36\times10^4)$.

$= 7.35\times10^{-5}$ m/s.

So drift velocity = 7.4×10^{-5} m/s.

11. (a) (i) What is a semiconductor?

A semiconductor is a material whose electrical conductivity lies between that of a conductor and an insulator, and can be controlled by impurities or external conditions.

(ii) Write down two physical properties of semiconductors that distinguish them from other types of materials.

Their conductivity increases with temperature (unlike metals).
Their conductivity can be controlled by doping with impurities.

(iii) Explain briefly the effects of applying a forward bias and reverse bias to the junction diode.

Forward bias lowers the potential barrier, allowing current to flow.
Reverse bias increases the barrier, so almost no current flows (except a small leakage current).

(b) Discuss the mode of action of a light dependent resistor (LDR) and light emitting diode (LED). State two uses of each.

An LDR decreases resistance when light intensity increases, due to generation of charge carriers. Used in automatic lighting systems, camera light meters.

An LED emits light when forward biased, due to recombination of electrons and holes releasing photons. Used in indicators, digital displays.

12. (a) Write down an expression for the forces on an electron when moving perpendicular to (i) an electric field, (ii) a magnetic field. Explain all symbols.

Force in electric field: $F = eE$, where e is charge, E is field strength.
Force in magnetic field: $F = evB$, where v is velocity, B is magnetic flux density.

(b) An electron in a circular path is travelling at 2.0×10^{6} ms^{-1} at right angles to a magnetic field of flux density 1.2×10^{-2} T.

(i) Radius of the circle.

$r = mv / eB$.

$= (9.11\times10^{-31} \times 2\times10^{6}) / (1.6\times10^{-19} \times 1.2\times10^{-2})$.

$= 1.82\times10^{-24} / 1.92\times10^{-21} = 9.5\times10^{-4}$ m.

(ii) Frequency of circular motion.

$f = v / 2\pi r = 2\times10^{6} / (2\pi \times 9.5\times10^{-4})$.

$\approx 3.35\times10^{8}$ Hz.

(iii) Wavelength of emitted radiation and part of spectrum.

$\lambda = c/f = 3\times10^{8} / 3.35\times10^{8} = 0.896$ m.

This lies in the radio wave region.

(iv) How would this wavelength be affected by a decrease in speed of electron?

If speed decreases, frequency decreases, so wavelength increases.

13. (a) (i) What is meant by the term work function of a metal?

It is the minimum energy required to remove an electron from the surface of a metal.

(ii) Write down and explain the equation connecting photon energy, work function of the metal and the maximum KE of the electron.

Einstein's photoelectric equation: $hf = \varphi + KE_{max}$.

Where hf is photon energy, φ is work function, KEmax is maximum kinetic energy of emitted electron.

(b) Light of wavelength 5.9×10^{-7} m is shone onto a potassium surface.

(i) Determine if there will be emission of electrons.

Energy of photon $= hc/\lambda = (6.63\times10^{-34} \times 3\times10^{8})/(5.9\times10^{-7})$.

$= 3.37\times10^{-19}$ J ≈ 2.1 eV.

Work function of potassium = 2.3 eV.
Since photon energy < work function, no emission occurs.

(ii) Calculate the work function of potassium.

$\varphi = 2.3 \text{ eV} = 2.3 \times 1.6\times10^{-19} = 3.68\times10^{-19}$ J.

(iii) What will the maximum KE of the electron emitted be when light of wavelength 5×10^{-7} m is shone onto the surface?

Photon energy = $hc/\lambda = (6.63\times10^{-34} \times 3\times10^{8})/(5\times10^{-7}) = 3.98\times10^{-19}$ J = 2.48 eV.
KE = 2.48 – 2.3 = 0.18 eV = 2.88×10^{-20} J.

(iv) Why, for photons of a given energy, are electrons emitted with a range of velocities?

Because electrons in the metal are bound with different energies. Those bound more tightly need more energy to escape, leaving less kinetic energy, while loosely bound electrons come out with higher kinetic energy.

14. (a) Define the following terms:

(i) Epicentral distance
It is the distance measured along the surface of the earth between the epicenter of an earthquake and the location of the seismic recording station.

(ii) Body wave
These are seismic waves that travel through the interior of the earth. They include primary (P) waves and secondary (S) waves.

(iii) Seismograph
A seismograph is an instrument used to detect and record the vibrations caused by seismic waves during earthquakes.

(b) (i) Explain the meaning of reflection seismology and state its application.

Reflection seismology is a technique in which seismic waves are generated and their reflections from underground layers are recorded. The time taken for reflections to return gives information about the depth and structure of rocks.
It is mainly applied in oil, gas, and mineral exploration to locate deposits beneath the earth's surface.

(ii) Show how the magnetic field within the atmosphere is generated.

The magnetic field is generated by movements of molten iron and other conducting materials in the earth's outer core. These movements create electric currents, and by dynamo action, these currents produce the earth's magnetic field, which extends into the atmosphere.

(c) (i) Name the lowest layers of the atmosphere and the ionosphere.

The lowest layer of the atmosphere is the troposphere.
The ionosphere is a higher layer composed of ionized gases, starting above the mesosphere.

(ii) State their importance.

The troposphere contains most of the air and weather systems, making it essential for life and climate.

The ionosphere reflects radio waves, enabling long-distance radio communication and also shields the earth from harmful solar radiation.