THE UNITED REPUBLIC OF TANZANIA

NATIONAL EXAMINATIONS COUNCIL OF TANZANIA

ADVANCED CERTIFICATE OF SECONDARY EDUCATION EXAMINATION

131/1 **PHYSICS 1**

(For Both School and Private Candidates)

Time: 2:30 Hours **ANSWERS** **Year: 2007**

Instructions

1. This paper consists of sections Section A, B and C with total of fourteen questions.
2. Answer ten questions choosing four questions from section A and three questions from each of section B and C.

1. (a) (i) What is a systematic error?

A systematic error is a consistent and repeatable error associated with faulty equipment, poor calibration, or experimental procedures, leading to incorrect measurements in the same direction each time.

(ii) The smallest divisions for the voltmeter and ammeter are 0.1 V and 0.01 A, respectively. If V = IR, find the relative error in the resistance R, when V = 2V and I = 0.1A.

Relative error formula:

$\Delta R/R = \Delta V/V + \Delta I/I$

Given:
$\Delta V = 0.1V$, $V = 2V$
$\Delta I = 0.01A$, $I = 0.1A$

$\Delta R/R = (0.1/2) + (0.01/0.1)$
$\Delta R/R = 0.05 + 0.1$
$\Delta R/R = 0.15$

Relative error = 15%

(b) (i) Mention two uses of dimensional analysis.

1. To check the correctness of equations by ensuring dimensional consistency.
2. To derive formulas by analyzing the relationship between physical quantities.

(ii) The frequency f of a note given by an organ pipe depends on the length l, the air pressure P, and the air density D. Use the method of dimensions to find a formula for the frequency.

Let $f = k\, l^a P^b D^c$

Dimensional analysis:
$[f] = T^{-1}$, $[l] = L$, $[P] = ML^{-1}T^{-2}$, $[D] = ML^{-3}$

Equating dimensions:
$T^{-1} = L^a (ML^{-1}T^{-2})^b (ML^{-3})^c$

Solving:
$a - b - 3c = 0$
$b + c = 0$
$-2b = -1$

$b = 1/2$, $c = -1/2$, $a = 1$

$f = k\,l\,P^{(1/2)} D^{(-1/2)}$

(iii) What will be the new frequency of a pipe whose original frequency was 256 Hz if the air density falls by 2% and the pressure increases by 1%?

$f = k\,P^{(1/2)} D^{(-1/2)}$

New frequency:

$f_{new} / f_{old} = (P_{new} / P_{old})^{(1/2)} (D_{new} / D_{old})^{(-1/2)}$

$P_{new} = 1.01P$, $D_{new} = 0.98D$

$f_{new} / 256 = (1.01)^{(1/2)} (0.98)^{(-1/2)}$

$f_{new} = 256 \times (1.00498 \times 1.0102)$
$f_{new} = 259$ Hz

2. (a) (i) What is meant by the term "projectile" as applied to projectile motion?

A projectile is any object that is thrown into the air and moves under the influence of gravity and its initial velocity, following a curved trajectory.

(ii) Give two practical applications of projectile motion at your locality.

1. Basketball shots, where the ball follows a parabolic trajectory.
2. Water fountains, where the water stream follows projectile motion.

(b) (i) A ball is thrown towards a vertical wall from a point 2 m above the ground and 3 m from the wall. The initial velocity of the ball is 20 ms^{-1} at an angle of 30° above the horizontal. If the collision of the ball with the wall is perfectly elastic, how far behind the thrower does the ball hit the ground?

Time to reach the wall:
$x = v_0 \cos\theta\, t$
$t = x / (v_0 \cos\theta)$
$t = 3 / (20 \cos 30°)$
$t = 3 / (20 \times 0.866)$
$t = 0.173$ s

Height at wall:
$y = y_0 + v_0 \sin\theta\, t - 1/2\, g t^2$

$y = 2 + (20 \sin 30° \times 0.173) - (4.9 \times 0.173^2)$
$y = 2 + 1.73 - 0.147$
$y = 3.58$ m

The ball will hit the ground symmetrically at the same distance behind the thrower, meaning the total distance is $2 \times 3 = 6$ m.

(ii) The ceiling of a long hall is 25 m high. Determine the maximum horizontal distance that a ball thrown with a speed of 40 ms^{-1} can go without hitting the ceiling of the wall.

Max height:

$h = v_0^2 \sin^2\theta / (2g)$
Solving for max θ:
$h = (40^2 \sin^2\theta) / (2 \times 9.81) \leq 25$

$\sin^2\theta \leq 25 \times 2 \times 9.81 / 1600$
$\sin^2\theta \leq 0.306$
$\theta \leq \sin^{-1}(0.553)$
$\theta \leq 33.6°$
Horizontal range:

$R = v_0^2 \sin 2\theta / g$
$R = (40^2 \sin 67.2°) / 9.81$
$R = 1600 \times 0.924 / 9.81$
$R = 150.7$ m

3. (a) Explain why when catching a fast-moving ball, the hands are drawn back while the ball is being brought to rest.
Drawing the hands back increases the time of impact, reducing the force exerted on the hands according to impulse-momentum theorem, thereby reducing pain.

(b) (i) Supposing the combustion products are ejected at a constant speed V_0 relative to the rocket, show that a fuel burn that reduces the total mass from M to m results in an increase in speed to v given by

$v - V = V_0 \ln (M/m)$
Using conservation of momentum:

$d(mv) = -V_0\, dm$
Integrating:

$\int dv = -\int(V_0\, dm / m)$
$v - V = V_0 \ln(M/m)$

(ii) Supposing that 2.1×10^6 kg of fuel are consumed during a burn lasting 1.5×10^2 seconds and given that there is a constant force on the rocket of 3.4×10^7 N, calculate V_0 and the increase in speed resulting from the burn if $M = 2.8 \times 10^6$ kg.

$V_0 = F / \dot{m}$

$\dot{m} = 2.1 \times 10^6 / 150$
$\dot{m} = 1.4 \times 10^4$ kg/s

$V_0 = (3.4 \times 10^7) / (1.4 \times 10^4)$
$V_0 = 2428.57$ m/s

Increase in speed:

$v - V = 2428.57 \ln(2.8/0.7)$
$v - V = 2428.57 \ln(4)$
$v - V = 3365$ m/s

(iii) What is the initial vertical acceleration imparted to the rocket when launched if initial mass is 2.8×10^6 kg?

$a = F / M$

$a = (3.4 \times 10^7) / (2.8 \times 10^6)$
$a = 12.14$ m/s^2

4. (a) (i) What is meant by centripetal force?
Centripetal force is the inward force required to keep an object moving in a circular path, directed towards the center of rotation.

(ii) Derive the expression $a = v^2 / r$.
Using Newton's second law:
$F = ma$
For circular motion, $F = mv^2 / r$
Dividing both sides by m:
$a = v^2 / r$

(b) (i) A ball of mass 0.5 kg attached to a string rotates in a vertical circle with a radius of 0.75 m at 5 ms^{-1}.
Speed at lowest point:
$v = \sqrt{(2gh)}$
$= \sqrt{(2 \times 9.81 \times 1.5)}$
$= 5.42$ m/s

Tension:
$T = mg + mv^2/r$
$= (0.5 \times 9.81) + (0.5 \times 5^2 / 0.75)$
$= 4.9 + 16.67$
$= 21.57$ N

(ii) Work done = $\Delta KE + \Delta PE$

$W = 1/2\ m\ (v^2 - u^2) + mg\ (h_2 - h_1)$
$W = 0.5 \times 0.5 \times (0 - 25) + (0.5 \times 9.81 \times 1.5)$
$W = -6.25 + 7.36$
$W = 1.11$ J

5. (a) (i) What is meant by a thermometric property of a substance?
A thermometric property is a physical property of a substance that varies with temperature in a predictable manner and can be used to measure temperature.

(ii) What qualities make a particular property suitable for use in practical thermometers?
- It should vary continuously and uniformly with temperature.
- It should be sensitive to small temperature changes.
- It should be reproducible and give consistent readings.
- It should cover a wide range of temperatures.

(b) (i) Explain why at least two fixed points are required to define a temperature scale.
Two fixed points are required to establish a standard reference for calibration. These points ensure consistency across different thermometers and provide a basis for interpolation and extrapolation.

(ii) Mention the type of thermometer which is most suitable for calibration of thermometers.
A standard gas thermometer is most suitable for calibration as it follows the ideal gas law, providing accurate and reproducible temperature measurements.

(c) When a metal cylinder of mass 2.0×10^{-2} kg and specific heat capacity 500 J kg^{-1} K^{-1} is heated at constant power, the initial rate of rise of temperature is 3.0 K min^{-1}. After some time the heater is switched off and the initial rate of fall of temperature is 0.3 K min^{-1}. What is the rate at which the cylinder gains heat energy immediately before the heater is switched off?

Heat energy gained is given by:

$Q = mc\Delta T / t$
where $m = 2.0 \times 10^{-2}$ kg, $c = 500$ J kg^{-1} K^{-1}, $\Delta T/\Delta t = 3.0$ K min^{-1} $= 3.0 / 60$ K s^{-1}
$Q = (2.0 \times 10^{-2}) \times 500 \times (3.0 / 60)$
$Q = 0.5$ J/s

The rate at which the cylinder loses heat immediately after the heater is switched off is:
$Q\_loss = mc\Delta T / t$
where $\Delta T/\Delta t = 0.3\ K\ min^{-1} = 0.3 / 60\ K\ s^{-1}$
$Q\_loss = (2.0 \times 10^{-2}) \times 500 \times (0.3 / 60)$
$Q\_loss = 0.05$ J/s

At steady state, heat gained is equal to heat lost:
$Q\_net = Q\_gain - Q\_loss$
$Q\_net = 0.5 - 0.05$
$Q\_net = 0.45$ J/s
Thus, the rate at which the cylinder gains heat energy immediately before switching off is 0.45 J/s.

6. (a) (i) What is blackbody radiation of a given body?

Blackbody radiation is the electromagnetic radiation emitted by an idealized object that absorbs all incident radiation and re-emits it based only on its temperature, following Planck's law.

(ii) Explain why heat may just mean infrared.

Heat transfer by radiation primarily occurs in the infrared spectrum because most thermal radiation emitted by objects at typical temperatures falls within the infrared range of the electromagnetic spectrum.

(iii) State Prévost's theory of heat exchange.

Prévost's theory states that all bodies, regardless of their temperature, continuously emit and absorb thermal radiation. A body in thermal equilibrium emits as much radiation as it absorbs, maintaining a constant temperature.

(b) (i) Explain why in cold climates, windows of modern buildings are double glazed, i.e., there are two pieces of glass with a small air space between them.

Double glazing reduces heat transfer by conduction and convection. The air gap between the glass panes acts as an insulator, minimizing heat loss from inside the building while reducing cold air infiltration from outside.

(ii) What is Wien's displacement law?

Wien's displacement law states that the wavelength at which a blackbody emits maximum radiation is inversely proportional to its absolute temperature. It is given by:

$\lambda\_max \times T = b$

where $b = 2.898 \times 10^{-3}$ m·K.

(iii) The sun's surface temperature is about 6000 K. The sun's radiation is maximum at a wavelength of 0.5×10^{-6} m. A certain light bulb filament emits radiation with a maximum wavelength of 2×10^{-6} m. If both the surface of the sun and the filament have the same emissive characteristics, what is the temperature of the filament?

Using Wien's displacement law:

$T_1 \lambda_1 = T_2 \lambda_2$

$6000 \times (0.5 \times 10^{-6}) = T_2 \times (2 \times 10^{-6})$

$T_2 = (6000 \times 0.5 \times 10^{-6}) / (2 \times 10^{-6})$
$T_2 = (3000 \times 10^{-6}) / (2 \times 10^{-6})$
$T_2 = 1500$ K

(c) (i) State Newton's law of cooling and give one limitation of the law.

Newton's law of cooling states that the rate of heat loss of a body is proportional to the temperature difference between the body and its surroundings, provided the difference is small.

Limitation: The law is accurate only when the temperature difference is small, and it does not account for heat loss by radiation at high temperatures.

(ii) A body initially at 70°C cools to a temperature of 55°C in 5 minutes. What will be its temperature after 10 minutes given that the surrounding temperature is 31°C? Assume Newton's law of cooling holds true.

Newton's law of cooling:

$T - T_a = (T_0 - T_a) e^{-kt}$

Let $T_0 = 70°C$, $T_a = 31°C$, $T_1 = 55°C$ at $t = 5$ min.

$55 - 31 = (70 - 31) e^{-5k}$

$24 = 39 e^{-5k}$

$e^{-5k} = 24/39$
$e^{-5k} = 0.615$

Taking natural log:

$-5k = \ln(0.615)$
$k = -\ln(0.615) / 5$
$k = 0.0972$

For t = 10 min:

$T - 31 = 39\, e^{-10} \times 0.0972$
$T - 31 = 39 \times e^{-0}.972$
$T - 31 = 39 \times 0.379$
$T = 45.8°C$

7. (a) (i) Give two differences between progressive and standing waves.

1. A progressive wave transfers energy from one point to another, whereas a standing wave does not transfer energy beyond its fixed points.
2. In a progressive wave, all particles oscillate with the same amplitude, whereas in a standing wave, nodes have zero amplitude, and antinodes have maximum amplitude.

(ii) Two progressive waves traveling along the same line in a medium are represented by
$Y_1 = 10 \sin(wt + \pi/2)$ and $Y_2 = 10 \sin(wt + \pi/6)$.

If the two progressive waves form a standing wave, determine the resultant amplitude and phase angle of the wave formed.

Using the resultant amplitude formula:

$A = \sqrt{(A_1^2 + A_2^2 + 2A_1A_2 \cos\Phi)}$

where $A_1 = A_2 = 10$, $\Phi = (\pi/2 - \pi/6) = \pi/3$

$A = \sqrt{(10^2 + 10^2 + 2 \times 10 \times 10 \times \cos(\pi/3))}$
$A = \sqrt{(100 + 100 + 200 \times 0.5)}$
$A = \sqrt{(100 + 100 + 100)}$
$A = \sqrt{300}$
$A = 17.32$

Phase angle:

$\tan\theta = (A_1 \sin\Phi) / (A_1 + A_2 \cos\Phi)$

$\tan\theta = (10 \times \sin(\pi/3)) / (10 + 10 \cos(\pi/3))$
$\tan\theta = (10 \times 0.866) / (10 + 10 \times 0.5)$

$\tan\theta = 8.66 / 15$
$\theta = \tan^{-1}(0.577)$
$\theta = 30°$

(b) (i) State the modes of vibrations in closed and open pipes.

Closed pipes:
- Fundamental mode (first harmonic)
- Third harmonic
- Fifth harmonic

Open pipes:
- Fundamental mode (first harmonic)
- Second harmonic
- Third harmonic

(ii) A meter-long tube at one end, with a movable piston at the other end, shows resonance with a fixed frequency tuning fork of 340 Hz when the tube length is 25.5 cm or 79.3 cm. Estimate the speed of sound in air at the temperature of the experiment (ignore edge effects).

Resonance occurs at:

$L_1 = (1/4)\lambda$, $L_2 = (3/4)\lambda$

$L_2 - L_1 = (3/4)\lambda - (1/4)\lambda$
$\lambda = 2(L_2 - L_1)$

$\lambda = 2(79.3 - 25.5)$ cm
$\lambda = 2(53.8)$ cm
$\lambda = 107.6$ cm $= 1.076$ m

Speed of sound:

$v = f\lambda$
$v = 340 \times 1.076$
$v = 365.8$ m/s

(c) The shortest length of the resonance tube closed at one end which responds to a fork of frequency 256 Hz is 32.0 cm. The corresponding length for a fork of frequency 384 Hz is 20.8 cm. Determine the end correction for the tube and the velocity of sound in air.

For the first frequency:

$L_1 = (1/4)\lambda_1$
$\lambda_1 = 4L_1$
$\lambda_1 = 4 \times 32.0$
$\lambda_1 = 128.0$ cm = 1.28 m

For the second frequency:

$L_2 = (1/4)\lambda_2$
$\lambda_2 = 4L_2$
$\lambda_2 = 4 \times 20.8$
$\lambda_2 = 83.2$ cm = 0.832 m

Velocity of sound:

$v_1 = f_1\lambda_1$
$v_1 = 256 \times 1.28$
$v_1 = 327.7$ m/s

$v_2 = f_2\lambda_2$
$v_2 = 384 \times 0.832$
$v_2 = 319.5$ m/s

Taking the average:

$v = (327.7 + 319.5) / 2$
$v = 323.6$ m/s

End correction:

$e = (L_1 - L_2) / 3$
$e = (32.0 - 20.8) / 3$
$e = 3.73$ cm

Thus, the velocity of sound is 323.6 m/s, and the end correction is 3.73 cm.

8. (a) (i) Define the internal resistance (r) of a cell and the terminal potential difference.

Internal resistance (r) of a cell is the resistance offered by the electrolyte and internal components of the cell to the flow of current. It causes a voltage drop when current flows through the cell.

Terminal potential difference (V) is the voltage across the terminals of a cell when it is delivering current to an external circuit. It is given by:

V = E - Ir

where E is the emf of the cell and I is the current.

(ii) The e.m.f. of a cell is a special terminal potential difference. Comment.

Emf (E) is the maximum potential difference a cell can provide when no current is drawn (open circuit). It differs from terminal potential difference, which depends on the internal resistance and the current drawn.

(b) Calculate the reading on the high resistance voltmeter V in figure 1.0 below.

Applying Kirchhoff's Voltage Law in loop ABCD:

Net emf = 12V - 8V = 4V

Total resistance in loop:

$R\_total = 2\Omega + 4\Omega = 6\Omega$

Current in the loop:

$I = V/R = 4V / 6\Omega$
$I = 0.667$ A

Voltage across 4Ω resistor:

$V = IR = 0.667 \times 4$
$V = 2.67$ V

Voltmeter across BD measures this voltage:

Reading = 2.67 V

(c) (i) State Kirchhoff's laws of electrical network.

1. Kirchhoff's Current Law (KCL): The sum of currents entering a junction is equal to the sum of currents leaving the junction.
2. Kirchhoff's Voltage Law (KVL): The sum of the voltage drops around a closed loop is equal to the sum of the emf sources in that loop.

(ii) Calculate the currents I_1, I_2, and I_3 flowing in the circuit in figure 2.0 below.

Applying Kirchhoff's laws:

Loop 1 (ABFA):

$24V - (2\Omega \times I_1) - 6\Omega(I_2) = 0$

$24 = 2I_1 + 6I_2 \rightarrow (1)$

Loop 2 (FCDE):

$27V - (6\Omega \times I_2) - (8\Omega \times I_3) = 0$

$27 = 6I_2 + 8I_3 \rightarrow (2)$

At junction F:

$I_1 = I_2 + I_3 \rightarrow (3)$

Solving equations simultaneously:

From (3):

$I_3 = I_1 - I_2$

Substituting in (2):

$27 = 6I_2 + 8(I_1 - I_2)$
$27 = 6I_2 + 8I_1 - 8I_2$
$27 = 8I_1 - 2I_2 \rightarrow (4)$

Solving (1) and (4):

Multiply (1) by 4:

$96 = 8I_1 + 24I_2 \rightarrow (5)$

Adding (4) and (5):

$96 + 27 = 8I_1 + 24I_2 + 8I_1 - 2I_2$
$123 = 16I_1 + 22I_2$

Solving for I_1 and I_2,

$I_1 = 4.5$ A

$I_2 = 2.5$ A
$I_3 = I_1 - I_2 = 2.0$ A

9. (a) (i) List three classes of magnetic materials on the basis of magnetic susceptibility and give one example for each class.

- Diamagnetic materials (negative susceptibility) - Example: Bismuth
- Paramagnetic materials (small positive susceptibility) - Example: Aluminum
- Ferromagnetic materials (large positive susceptibility) - Example: Iron

(ii) How are the magnetic susceptibility and relative permeability of a magnetic material related to each other?

Relative permeability (μr) and magnetic susceptibility (χ) are related by:

$\mu r = 1 + \chi$

where χ is the magnetic susceptibility and μr is the ratio of the material's permeability to the permeability of free space.

(b) (i) Define the magnetic field intensity.

Magnetic field intensity (H) is the measure of magnetizing force applied to a material per unit length. It is given by:

$H = NI / L$

where N is the number of turns, I is the current, and L is the length.

(ii) A long solenoid has 10 turns per cm and carries a current of 2.0 A. Calculate the magnetic field intensity at its center.

$H = nI$

where n = 10 turns/cm = 1000 turns/m

$H = 1000 \times 2.0$
$H = 2000$ A/m

(c) An a.c. generator consists of a coil of 50 turns and an area of 2.5 m^2, rotates at an angular speed of 60 rad/s in a uniform magnetic field of 0.30 T between two fixed pole pieces. The resistance of the circuit including that of the coil is 500 Ω.

(i) What is the maximum current that can be drawn from the generator?

Maximum emf:

$E_{max} = NBA\omega$

$E_{max} = (50 \times 0.30 \times 2.5 \times 60)$
$E_{max} = 225$ V

Maximum current:

$I_{max} = E_{max} / R$

$I_{max} = 225 / 500$
$I_{max} = 0.45$ A

(iii) What is the magnetic flux through the coil if the current is maximum?

Magnetic flux:

$\Phi = B \times A$

$\Phi = 0.30 \times 2.5$
$\Phi = 0.75$ Wb

10. (a) How does the arrangement of the energy level in a semiconductor differ from that of an insulator?

In semiconductors, the energy gap between the valence band and the conduction band is small, allowing some electrons to jump to the conduction band at room temperature. In insulators, the energy gap is large, preventing electron movement under normal conditions.

(b) Using the notion of energy bands, explain the following optical properties of solids.

(i) All metals are opaque to light of all wavelengths.

Metals have free electrons in the conduction band, which absorb and re-emit incident light, making them opaque.

(ii) Semiconductors are transparent to infrared light although opaque to visible light.

Semiconductors have a small energy gap, allowing infrared photons to pass through while absorbing higher-energy visible photons, making them opaque to visible light.

(iv) Most insulators are transparent to visible light.

Insulators have a large bandgap, so visible photons do not have enough energy to excite electrons to the conduction band, allowing them to pass through.

(c) In the circuit shown below (figure 3.0), LDR is a light-dependent resistor, whose resistance varies from 1 MΩ in the dark to 5 MΩ in sunlight. The transistor has a current amplification factor β of about 80. The voltmeter takes a negligible current.

(i) Over what range of resistance would the LDR take if the voltmeter reads 5 V or more? What if it reads 1 V or less?

Applying voltage divider rule:

$V = (500\Omega / (500\Omega + R_{LDR})) \times 6V$

For $V \geq 5V$:

$5 = (500 / (500 + R_{LDR})) \times 6$
$5(500 + R_{LDR}) = 3000$
$2500 + 5R_{LDR} = 3000$
$5R_{LDR} = 500$
$R_{LDR} = 100\Omega$

For $V \leq 1V$:

$1 = (500 / (500 + R_{LDR})) \times 6$
$1(500 + R_{LDR}) = 3000$
$500 + R_{LDR} = 3000$
$R_{LDR} = 2500\Omega$

(ii) At what light intensity measured in terms of the resistance of LDR, would the circuit be most sensitive to small changes of intensity? (Assume that $V_{BE} = 0$ volts).

The circuit is most sensitive when the transistor operates in its active region, which occurs when the base current changes significantly with small changes in LDR resistance. This happens when R_{LDR} is around 1 MΩ, as the voltage divider produces a moderate base-emitter voltage, controlling the transistor efficiently.

11. (a) What is the potential at the center of the square of side 1.0 m, due to charges $q_1 = +1.0 \times 10^{-6}$ C, $q_2 = -2.0 \times 10^{-6}$ C, $q_3 = +3.0 \times 10^{-6}$ C, and $q_4 = +2.0 \times 10^{-6}$ C situated at the corners of the square?

Potential due to a point charge:

$V = kq / r$

where $r = (\sqrt{2} / 2) \times 1 = 0.707$ m for all charges.

Total potential:

$V\_total = k (q_1 + q_2 + q_3 + q_4) / r$

$V\_total = (9 \times 10^9) \times [(1 - 2 + 3 + 2) \times 10^{-6}] / 0.707$
$V\_total = (9 \times 10^9 \times 4 \times 10^{-6}) / 0.707$
$V\_total = 50.9 \times 10^3$ V
$V\_total = 50.9$ kV

(b) What do you understand by an electrostatic generator?

An electrostatic generator is a device that generates high-voltage static electricity by accumulating and storing charge using electrostatic induction or friction, such as a Van de Graaff generator.

(c) The belt of a Van de Graaff generator carries a charge of 100 μC per meter. If the diameter of the lower pulley is 10 cm and its angular velocity is 5 rad/s, what potential will the upper conductor attain in 5 minutes if its capacitance to ground is 5×10^{-12} F and if there is no leakage of charge?

Charge transfer per second:

q = charge per meter × belt speed

Belt speed = radius × angular velocity

$r = 0.1 / 2 = 0.05$ m
$v = 0.05 \times 5 = 0.25$ m/s

Charge per second:

$q = 100 \times 10^{-6} \times 0.25$
$q = 2.5 \times 10^{-5}$ C/s

Charge in 5 minutes:

$Q = q \times \text{time}$
$Q = (2.5 \times 10^{-5}) \times (5 \times 60)$
$Q = 7.5 \times 10^{-3}$ C

Potential:

$V = Q / C$
$V = (7.5 \times 10^{-3}) / (5 \times 10^{-12})$
$V = 1.5 \times 10^{9}$ V

12. (a) Two similar balls of mass m are hung from silk thread of length "a" and carry a similar charge q. Assume θ is small enough that tan θ ≈ sin θ. To this approximation, show that

$X = [(q^2 a) / (2\pi\varepsilon_0 mg)]^{(1/3)}$, where X is the distance of separation.

From equilibrium:

Electrostatic force = gravitational force component

$F_e = mg \tan\theta$

Coulomb's law:

$F_e = (1 / 4\pi\varepsilon_0) \times (q^2 / X^2)$

For small angles:

$\tan\theta \approx X / (2a)$

Thus:

$(q^2 / (4\pi\varepsilon_0 X^2)) = mg (X / 2a)$

Rearrange:

$q^2 / (4\pi\varepsilon_0 mg) = X^3 / 2a$

Solve for X:

$X = [(q^2 a) / (2\pi\varepsilon_0 mg)]^{(1/3)}$

(b) A charge Q is distributed over the concentric hollow spheres of radii r and R (R > r) such that the surface densities are the same. Calculate the potential at the common center of the two spheres.

Surface charge density:

$\sigma = Q / (4\pi R^2) = Q / (4\pi r^2)$

Total potential at center:

$V = V_R + V_r$

Potential due to each sphere:

$V_R = (1 / 4\pi\varepsilon_0) \times (Q / R)$
$V_r = (1 / 4\pi\varepsilon_0) \times (Q / r)$

$V_{total} = (1 / 4\pi\varepsilon_0) Q (1/R + 1/r)$

13. (a) (i) Make a well-labeled diagram of the cathode ray oscilloscope and explain briefly how a sinusoidal voltage signal is displayed on its screen.

A cathode ray oscilloscope (CRO) consists of:
- An electron gun that emits electrons.
- Deflecting plates that control the movement of the beam.
- A fluorescent screen that displays the signal.

A sinusoidal voltage signal applied to the vertical deflection plates causes the electron beam to move up and down periodically. A time base circuit moves the beam horizontally at a constant speed, resulting in a waveform representation of the signal.

(ii) Mention three practical applications of the cathode ray oscilloscope.

- Measuring electrical signals in laboratories.
- Observing and analyzing waveforms in communication systems.
- Diagnosing faults in electronic circuits and devices.

(b) An electron having 450 eV of energy enters at right angles to a uniform magnetic field of strength 1.50×10^{-3} T. Show that the path traced by the electron in a uniform magnetic field is circular and estimate its radius.

Kinetic energy of the electron:

$KE = 450\ eV = 450 \times 1.6 \times 10^{-19}\ J$

$KE = 7.2 \times 10^{-17}$ J

Velocity of the electron:

$KE = 1/2\ m\ v^2$

$v = \sqrt{(2KE / m)}$
$m = 9.11 \times 10^{-31}$ kg

$v = \sqrt{(2 \times 7.2 \times 10^{-17} / 9.11 \times 10^{-31})}$
$v = \sqrt{(1.58 \times 10^{14})}$
$v = 1.26 \times 10^{7}$ m/s

Radius of circular motion:

$r = (m\ v) / (q\ B)$

$q = 1.6 \times 10^{-19}$ C
$B = 1.50 \times 10^{-3}$ T

$r = (9.11 \times 10^{-31} \times 1.26 \times 10^{7}) / (1.6 \times 10^{-19} \times 1.50 \times 10^{-3})$
$r = 4.8 \times 10^{-2}$ m
$r = 4.8$ cm

Thus, the path is circular with a radius of 4.8 cm.

(c) A charged oil drop of mass 6.0×10^{-15} kg falls vertically in air with a steady velocity between two long parallel vertical plates 5.0 mm apart. When a potential difference of 3000 V is applied between the plates, the drop falls with a steady velocity at an angle of 58° to the vertical. Determine the charge Q on the oil drop.

Electric force = mg tanθ

$F_e = qE$
$E = V/d = 3000 / (5.0 \times 10^{-3})$
$E = 6.0 \times 10^{5}$ V/m

$q = mg \tan\theta / E$

$q = (6.0 \times 10^{-15} \times 9.81 \times \tan 58°) / (6.0 \times 10^{5})$
$q = (5.89 \times 10^{-14} \times 1.6) / (6.0 \times 10^{5})$
$q = (9.42 \times 10^{-14}) / (6.0 \times 10^{5})$
$q = 1.57 \times 10^{-19}$ C

14. (a) (i) What are the differences between P and S waves?

- P-waves (primary waves) are longitudinal, whereas S-waves (secondary waves) are transverse.
- P-waves travel faster and pass through solids, liquids, and gases, while S-waves travel only through solids.
- P-waves arrive first in an earthquake, whereas S-waves arrive later.

(ii) Explain how the two terms of waves (P and S) can be used in studying the internal structure of the earth.

By analyzing the speed and paths of P and S waves during earthquakes, scientists determine the composition and state of Earth's layers. The absence of S-waves in the outer core indicates that it is liquid.

(b) Write short notes on the following terms in relation to changes in the Earth's magnetic field: long-term (secular) changes, short-period (regular) changes, and short-term (irregular) changes.

- Long-term (secular) changes: Gradual variations in Earth's magnetic field over hundreds to thousands of years due to slow movements in the Earth's core.
- Short-period (regular) changes: Daily or yearly variations caused by solar activity and interactions between the Earth's field and the solar wind.
- Short-term (irregular) changes: Sudden magnetic storms or anomalies caused by solar flares and geomagnetic disturbances.

(c) (i) What is geomagnetic micropulsation?

Geomagnetic micropulsation refers to small, periodic fluctuations in the Earth's magnetic field caused by interactions between solar wind and the magnetosphere.

(ii) Give a summary of location, constitution, and practical uses of the stratosphere, ionosphere, and mesosphere.

- Stratosphere: Located 10-50 km above Earth, mainly composed of ozone, and protects against harmful UV radiation. Used in aviation for smooth flights.
- Ionosphere: Found 50-1000 km above Earth, composed of ionized gases that reflect radio waves, making global communication possible.
- Mesosphere: Located 50-85 km above Earth, composed of cold, thin air. It burns up meteors and contributes to atmospheric chemistry.