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: 2004**

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 meant by the term "dimensions of a physical quantity?"

The dimensions of a physical quantity refer to the powers to which fundamental units (mass, length, time, etc.) must be raised to represent that quantity.

(ii) Give two uses of dimensional analysis.
1. To check the correctness of equations by ensuring dimensional consistency.
2. To derive relationships between physical quantities when their dependence is known.

(iii) Use the method of dimensions to obtain the relationship between the lift force per unit wingspan on an aircraft wing of width L moving with velocity v through air of density ρ on the parameters L, v, and ρ.

Let $F/L = k L^a v^b \rho^c$
Writing dimensions:
$[F/L] = MLT^{-2} / L = MLT^{-2}L^{-1} = MLT^{-2}L^{-1}$
$[L] = L$
$[v] = LT^{-1}$
$[\rho] = ML^{-3}$

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

$M^1 L^1 T^{-2} = M^c L^{a+b-3c} T^{-b}$

Comparing powers:
For M: 1 = c
For L: 1 = a + b - 3c
For T: -2 = -b

Solving:
c = 1
b = 2
a + 2 - 3(1) = 1
a = 2
Thus, $F/L = k L^2 v^2 \rho$

(b) (i) Distinguish between systematic and random errors in the measurement of a physical quantity.

Systematic errors are consistent and predictable deviations due to flaws in measuring instruments or experimental procedures, whereas random errors arise unpredictably due to uncontrollable variations in measurement conditions.

(ii) In an experiment to determine the Young's modulus for steel, a student recorded the following measurements:
length l of the wire = 3.25 ± 0.005 m
diameter d of the wire = 0.63 ± 0.02 mm
force F on the wire = 26.5 ± 0.1 N
extension e produced = 1.40 ± 0.05 mm
Calculate the Young's modulus of the wire from these measurements and its corresponding error.

Young's modulus formula:
$Y = (FL) / (Ae)$

$A = \pi d^2 / 4$
Substituting values:
$A = (\pi \times (0.63 \times 10^{-3})^2) / 4$
$A = 3.12 \times 10^{-7}\ m^2$

$Y = (26.5 \times 3.25) / (3.12 \times 10^{-7} \times 1.40 \times 10^{-3})$
$Y = (86.13) / (4.37 \times 10^{-10})$
$Y = 1.97 \times 10^{11}$ Pa

Relative error:

$\Delta Y/Y = (\Delta F/F) + (\Delta L/L) + (\Delta d/d) + (\Delta e/e)$

$\Delta Y/Y = (0.1/26.5) + (0.005/3.25) + 2(0.02/0.63) + (0.05/1.40)$
$\Delta Y/Y = 0.00377 + 0.00154 + 0.06349 + 0.03571$
$\Delta Y/Y = 0.1045$

Error in Y:

$\Delta Y = 0.1045 \times 1.97 \times 10^{11}$
$\Delta Y = 2.06 \times 10^{10}$ Pa

Thus, $Y = (1.97 \pm 0.21) \times 10^{11}$ Pa

2. (a) (i) Give two examples of projectiles and describe their trajectories in a Cartesian coordinate system.

- A thrown ball follows a parabolic trajectory in the xy-plane.
- A bullet fired at an angle follows a curved path under gravity.

(ii) Show that the maximum range of a projectile of fixed initial speed is obtained when it is launched at an angle of 45° to the horizontal (ignoring the effects of air resistance).

Range formula:

$R = (v_0^2 \sin 2\theta) / g$

For maximum R, $\sin 2\theta = 1$, which occurs at $2\theta = 90°$ or $\theta = 45°$.

(b) A stone is projected horizontally with velocity 3.0 cm/s from the top of a vertical cliff 200 m high. Calculate:

(i) The time it takes to reach the ground.

Using $h = (1/2)\, g\, t^2$

$200 = (1/2) \times 9.81 \times t^2$
$t^2 = (200 \times 2) / 9.81$
$t = \sqrt{40.77}$
$t = 6.39$ s

(ii) Its distance from the foot of the cliff.

$x = v_0\, t$

$x = 3.0 \times 10^{-2} \times 6.39$
$x = 0.1917$ m

(iii) Its vertical and horizontal components of velocity when it hits the ground.

Vertical velocity:

$v_y = gt = 9.81 \times 6.39$
$v_y = 62.7$ m/s

Horizontal velocity remains constant:
$v_x = 3.0$ cm/s $= 0.03$ m/s

3. (a) Define surface tension in a liquid and state its SI unit.

Surface tension is the force per unit length acting at the surface of a liquid, minimizing its surface area. Its SI unit is N/m.

(b) (i) When raindrops fall on a greasy glass surface, the water drops bounce off without wetting the surface. This is due to high surface tension and weak adhesive forces between water and grease, preventing wetting.

(ii) Soap solution is sometimes used in gardener's solution for spraying the leaves of plants to increase the wetting nature of the solution.

Soap reduces the surface tension of water, allowing better spreading and adhesion to plant leaves.

(c) (i) Discuss how the rise of water in a capillary tube is used to determine the surface tension of water.

Capillary rise is given by:

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

Measuring h, r, and ρ allows determination of T.

(ii) A column of mercury with length L = 20 cm is in the middle of a horizontal capillary tube evacuated and soldered at both ends. If the capillary tube is placed vertically, the mercury column shifts through ΔL = 10 cm. Determine the pressure at which the capillary tube was evacuated.

Pressure difference:

$P = \rho g h$

$\rho = 13.6 \times 10^3 \text{ kg/m}^3$
$h = 10 \text{ cm} = 0.1 \text{ m}$
$g = 9.81 \text{ m/s}^2$

$P = (13.6 \times 10^3 \times 9.81 \times 0.1)$
$P = 1.33 \times 10^4 \text{ Pa}$

Thus, the pressure in the tube was 1.33×10^4 Pa.

4. (a) (i) Define simple harmonic motion (shm) and describe the terms amplitude, period, and frequency as applied to shm.

Simple harmonic motion (shm) is a type of periodic motion in which an object moves back and forth about a fixed equilibrium position under the influence of a restoring force. The restoring force is directly proportional to its displacement from the equilibrium position and is always directed towards the equilibrium position.

- Amplitude (A): This is the maximum displacement of the oscillating object from its equilibrium position. It represents how far the object moves from the center position in either direction.
- Period (T): This is the time taken for the object to complete one full cycle of oscillation. It is measured in seconds.

- Frequency (f): This is the number of oscillations completed per unit time. It is the reciprocal of the period and is measured in hertz (Hz).

The relationship between period and frequency is given by:

$f = 1 / T$

(ii) Explain what is responsible for the continual interchange of potential energy and kinetic energy in a mechanical oscillation. At what points in shm is the acceleration greatest? Where is it least?

In simple harmonic motion, the total mechanical energy remains constant, but it oscillates between kinetic energy (KE) and potential energy (PE). This continual interchange is due to the restoring force acting on the system.

- At maximum displacement (amplitude), the object is momentarily at rest, meaning kinetic energy is zero and all energy is stored as potential energy.
- As the object moves towards the equilibrium position, potential energy is converted into kinetic energy.
- At the equilibrium position, the object has maximum kinetic energy and zero potential energy.
- As the object moves past the equilibrium towards the opposite extreme, kinetic energy starts converting back into potential energy.

The acceleration of the object in shm is given by the equation:

$a = -\omega^2 x$

where:
a = acceleration
ω = angular frequency
x = displacement from equilibrium

From this equation, acceleration is:
- Greatest when displacement x is maximum (i.e., at the amplitude).
- Zero when displacement x is zero (i.e., at the equilibrium position).

4. (b) A small mass of 200 g is attached to one end of a helical spring and produces an extension of 15 mm. The mass is now set into oscillation of amplitude 10 mm. Calculate the

(i) period of oscillation

Given data:

mass, m = 200 g = 0.2 kg
extension of spring, x = 15 mm = 0.015 m

amplitude, A = 10 mm = 0.01 m
acceleration due to gravity, g = 9.81 m/s²

First, we calculate the spring constant k using Hooke's Law:

$F = kx$

Since the force acting on the spring is due to gravity, we use:

$k = mg / x$

Substituting the values:

$k = (0.2 \times 9.81) / 0.015$
$k = 1.962 / 0.015$
$k = 130.8$ N/m

The period of oscillation is given by:

$T = 2\pi \sqrt{(m/k)}$

Substituting the values:

$T = 2\pi \times \sqrt{(0.2 / 130.8)}$
$T = 2\pi \times \sqrt{(0.00153)}$
$T = 2\pi \times 0.0391$
$T = 0.246$ s

Answer: period of oscillation T = 0.246 seconds

(ii) velocity of the system as it passes the equilibrium point

The velocity at the equilibrium position is given by:

$v_{max} = \omega A$

where ω (angular frequency) is given by:

$\omega = \sqrt{(k/m)}$

Substituting the values:

$\omega = \sqrt{(130.8 / 0.2)}$

$\omega = \sqrt{(654)}$
$\omega = 25.58$ rad/s

Now, using $v_{max} = \omega A$:

$v_{max} = 25.58 \times 0.01$
$v_{max} = 0.256$ m/s

Answer: velocity at equilibrium $v_{max} = 0.256$ m/s

(iii) maximum kinetic energy of the system
Maximum kinetic energy is given by:
$KE_{max} = \frac{1}{2} m v_{max}^2$

Substituting the values:
$KE_{max} = \frac{1}{2} \times 0.2 \times (0.256)^2$
$KE_{max} = 0.1 \times 0.0655$
$KE_{max} = 0.00654$ J
Answer: maximum kinetic energy $KE_{max} = 0.00654$ J

(iv) potential energy of the spring when the mass is 5 mm below the center of oscillation

Potential energy stored in a stretched or compressed spring is given by:
$PE = \frac{1}{2} k x^2$
where x = 5 mm = 0.005 m.

Substituting the values:
$PE = \frac{1}{2} \times 130.8 \times (0.005)^2$
$PE = 0.5 \times 130.8 \times 0.000025$
$PE = 0.00164$ J

Answer: potential energy at 5 mm below equilibrium PE = 0.00164 J

5. (a) (i) The difference between the Kelvin temperature scale and the Celsius temperature scale is that the Kelvin scale is an absolute temperature scale, starting from absolute zero (0 K), while the Celsius scale is based on the freezing and boiling points of water, with 0°C as the freezing point. The two scales are related by the equation:

$$T(K) = T(°C) + 273.15$$

(ii) Given the equation:
$$E = A\theta + B\theta^2$$

where E is the emf and θ is the temperature difference.
Data provided:
- At $\theta = 100°C$, $E = 4.28$ mV
- At $\theta = 200°C$, $E = 9.29$ mV

Substituting the first set of values:
$4.28 = A(100) + B(100)^2$
$4.28 = 100A + 10000B$ ----(1)

Substituting the second set of values:

$9.29 = A(200) + B(200)^2$
$9.29 = 200A + 40000B$ ----(2)

Solving equations (1) and (2) simultaneously:
$100A + 10000B = 4.28$
$200A + 40000B = 9.29$

Multiply equation (1) by 2:
$200A + 20000B = 8.56$
Subtract from equation (2):

$(200A + 40000B) - (200A + 20000B) = 9.29 - 8.56$
$20000B = 0.73$
$B = 0.73 / 20000$
$B = 3.65 \times 10^{-5}$
Substituting B into equation (1):

$100A + 10000(3.65 \times 10^{-5}) = 4.28$
$100A + 0.365 = 4.28$
$100A = 3.915$
$A = 3.915 / 100$
$A = 0.03915$

Therefore,
$A = 0.03915$ V/°C
$B = 3.65 \times 10^{-5}$ V/°C²

(b)(i) Temperature gradient is the rate of change of temperature with respect to distance in a given direction. It is expressed as dT/dx, where T is temperature and x is the position.

(ii) The sketch graphs of temperature variation along the length of the rod depend on the surface condition:

- Lagged: The graph will be more linear, as insulation reduces heat loss, making temperature distribution more uniform.
- Coated with soot: Soot is a good absorber and emitter of heat, leading to a steeper temperature drop due to increased radiation losses.
- Polished: A polished surface reflects heat and reduces emissivity, causing a more gradual temperature drop along the rod.

Qualitative explanation:
The temperature distribution is influenced by surface properties. A lagged rod retains heat, leading to a uniform temperature distribution. A rod coated with soot has higher emissivity, causing rapid cooling and a steeper gradient. A polished rod has lower emissivity, leading to slower heat loss and a less steep gradient.

6(a)(i) What is a black body?

A black body is an idealized object that absorbs all incident electromagnetic radiation, regardless of frequency or angle of incidence. It does not reflect or transmit any radiation. When in thermal equilibrium, it emits radiation characteristic of its temperature, described by Planck's law.

6(a)(ii) State Wien's Law and Stefan's law for black body radiation.

- Wien's Law states that the wavelength at which the emission of a black body is maximized is inversely proportional to its absolute temperature. It is given by:

$\lambda_{max} = b / T$

where b is Wien's constant (2.93×10^{-3} mK).

- Stefan's Law states that the total power radiated per unit area of a black body is proportional to the fourth power of its absolute temperature. It is given by:

$P = \sigma T^4$

where σ is the Stefan-Boltzmann constant (5.7×10^{-8} W/m²K⁴).

6(a)(iii) If the radiated power per nanometer wavelength from the sun peaks at 490 nm, estimate the temperature of the sun's surface assuming the sun to radiate as a black body and that Wien's constant is 2.93×10^{-3} mK.

Given:

- Peak wavelength of the sun's radiation, $\lambda_{max} = 490$ nm $= 490 \times 10^{-9}$ m
- Wien's constant, $b = 2.93 \times 10^{-3}$ mK

Using Wien's Law:

$T = b / \lambda_{max}$
$T = (2.93 \times 10^{-3}) / (490 \times 10^{-9})$
$T = (2.93 \times 10^{6}) / 490$
$T = 5.98 \times 10^{3}$ K

Therefore, the estimated temperature of the sun's surface is 5980 K.

6(b) What is Prevost's theory of heat exchanges?

Prevost's theory of heat exchanges states that all bodies, regardless of their temperature, continuously emit and absorb thermal radiation. The rate of emission depends on the temperature and nature of the surface. A body at a higher temperature emits more radiation than it absorbs, while a body at a lower temperature absorbs more than it emits until thermal equilibrium is reached.

6(c) A cube of side 0.01 m has a surface which gives 50% of the emission of a black body at the same temperature. If the temperature of the cube is 700°C,

6(c)(i) Calculate the power radiated by the cube.

Given:

- Side length of the cube, s = 0.01 m
- Temperature, T = 700°C = (700 + 273) K = 973 K
- Emissivity, e = 0.5
- Stefan's constant, $\sigma = 5.7 \times 10^{-8}$ W/m^2K^4

Surface area of the cube, $A = 6s^2$
$A = 6 \times (0.01)^2$
$A = 6 \times 10^{-4}$ m^2

Using Stefan's Law:

$P = e\sigma AT^4$
$P = (0.5) \times (5.7 \times 10^{-8}) \times (6 \times 10^{-4}) \times (973)^4$

Calculating step by step:

$973^4 = (973 \times 973 \times 973 \times 973) = 8.9 \times 10^{11}$
$P = 0.5 \times 5.7 \times 10^{-8} \times 6 \times 10^{-4} \times 8.9 \times 10^{11}$

$P = 0.5 \times 5.7 \times 6 \times 8.9 \times 10^{-1}$
$P = 15.2$ W

Therefore, the power radiated by the cube is 15.2 W.

6(c)(ii) If the same power in 6(c)(i) above is given by a black body sphere at 300°C, what would its diameter be?

Given:

- Power, $P = 15.2$ W
- Temperature, $T = 300°C = (300 + 273)$ K $= 573$ K
- Emissivity, $e = 1$ (black body)
- Stefan's constant, $\sigma = 5.7 \times 10^{-8}$ W/m^2K^4

Using Stefan's Law:

$P = e\sigma AT^4$

Surface area of the sphere, $A = 4\pi r^2$

Substituting:

$15.2 = (1) \times (5.7 \times 10^{-8}) \times (4\pi r^2) \times (573)^4$
$573^4 = (573 \times 573 \times 573 \times 573) = 1.08 \times 10^{11}$
$15.2 = 5.7 \times 10^{-8} \times 4\pi r^2 \times 1.08 \times 10^{11}$
$15.2 = 7.7 \times 10^5 \pi r^2$
$r^2 = 15.2 / (7.7 \times 10^5 \pi)$

$r^2 = 6.3 \times 10^{-6}$

$r = \sqrt{(6.3 \times 10^{-6})}$
$r = 2.5 \times 10^{-3}$ m

Diameter, $d = 2r = 2 \times 2.5 \times 10^{-3}$

$d = 5 \times 10^{-3}$ m

Therefore, the diameter of the sphere is 5 mm.

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

- **Longitudinal waves**: The particles of the medium vibrate parallel to the direction of wave propagation. Example: Sound waves in air.
- **Transverse waves**: The particles of the medium vibrate perpendicular to the direction of wave propagation. Example: Light waves or water waves.

7(a)(ii) A plane wave traveling in a medium along the x-direction is described by the equation $y = a \sin (wt - kx)$ where y is the displacement at a time t and a distance x from the origin. Write the equation of an identical wave traveling in the opposite direction.

For a wave traveling in the opposite direction, the equation is given by:
$y = a \sin (wt + kx)$.

7(a)(iii) If $a = 1.5 \times 10^{-6}$ m, $w = 600\ s^{-1}$, and $k = 6 \times 10^{-3}$ m, find the frequency, the amplitude, and the wave speed.

Given:
- Amplitude, $a = 1.5 \times 10^{-6}$ m
- Angular frequency, $w = 600\ s^{-1}$
- Wave number, $k = 6 \times 10^{-3}\ m^{-1}$

Frequency:
Angular frequency is related to frequency by the equation:

$w = 2\pi f$
$f = w / 2\pi$
$f = 600 / (2 \times 3.1416)$
$f \approx 95.5$ Hz

Amplitude
The amplitude is already given as 1.5×10^{-6} m.

Wave speed
Wave speed (v) is given by:

$v = w / k$
$v = 600 / (6 \times 10^{-3})$
$v = 100000$ m/s

7(b)(i) How is it possible to hear a sounding flute or a vibrating string of a musical instrument?

When a flute or a vibrating string produces sound, it sets up standing waves in the air. These waves cause periodic variations in air pressure, which travel as sound waves. The human ear detects these pressure variations and interprets them as sound.

7(b)(ii) A sonometer wire is stretched by hanging a metal cylinder of density 8000 kg/m³ at the end of the wire. A fundamental note of frequency 256 Hz is sounded when the wire is plucked. Calculate the frequency of vibration of the same length of wire when a vessel of water is placed such that the metal cylinder is totally immersed in water.

Given
- Initial frequency, $f_1 = 256$ Hz
- Density of metal cylinder, $\rho_m = 8000$ kg/m³
- Density of water, $\rho_w = 1000$ kg/m³

When the metal cylinder is fully immersed, the effective weight is reduced due to the buoyant force.

Effective weight = Original weight – Buoyant force

Buoyant force = weight of displaced water = volume × density of water × g

Since frequency f is proportional to the square root of tension in the wire,

New frequency, $f_2 = f_1 \times \text{sqrt}(\text{effective weight / original weight})$

The new frequency of vibration when the metal cylinder is fully immersed in water is approximately 239.47 Hz.
changes with voltage or current. Example: A diode or a filament bulb.

8(a)(i) Differentiate between an ohmic conductor and a non-ohmic conductor giving an example for each.

Ohmic conductor: A material that follows Ohm's law, meaning the current through it is directly proportional to the applied voltage, provided the temperature remains constant. Example: A metallic wire like copper or aluminum.

Non-ohmic conductor: A material that does not follow Ohm's law, meaning the resistance changes with voltage or current. Example: A diode or a filament bulb.

8(a)(ii) Define the terms “resistivity” and “conductivity” for a conductor.

Resistivity (ρ): The property of a material that quantifies how strongly it resists the flow of electric current. It is given by:

$\rho = R A / L$

where R is the resistance, A is the cross-sectional area, and L is the length of the conductor.

Conductivity (σ): The reciprocal of resistivity, representing how easily a material allows the flow of electric current. It is given by:

$\sigma = 1 / \rho$.

8(b) A resistance wire of length 20 m has a diameter of 0.62 mm and a resistance of 12 Ω. Calculate:

8(b)(i) Its resistivity and its conductivity.

Given:
- Length, L = 20 m
- Diameter, $d = 0.62 \text{ mm} = 0.62 \times 10^{-3}$ m
- Radius, $r = d / 2 = (0.62 \times 10^{-3}) / 2$
- Resistance, R = 12 Ω

Cross-sectional area:

$A = \pi r^2$

Resistivity:

$\rho = R A / L$

Conductivity:

$\sigma = 1 / \rho$

Values calculated earlier:
- Resistivity, $\rho \approx 1.81 \times 10^{-7}$ Ωm
- Conductivity, $\sigma \approx 5.52 \times 10^{6}$ S/m

8(b)(ii) The length of another wire of the same diameter and material which when joined in parallel will give a total resistance of 8 Ω.

Given:
- Resistance of the original wire, $R_1 = 12\ \Omega$
- Total resistance after adding another wire in parallel, $R_{total} = 8\ \Omega$

For parallel resistance:

$$1 / R_{total} = 1 / R_1 + 1 / R_2$$

Rearrange to find R_2:

$$1 / R_2 = 1 / R_{total} - 1 / R_1$$

Since resistance is proportional to length for a given material and cross-sectional area,

$$R_2 / R_1 = L_2 / L_1$$

$$L_2 = (R_2 / R_1) \times L_1$$

Values calculated earlier:
- Required resistance of the second wire, $R_2 \approx 24\ \Omega$
- Required length of the second wire, $L_2 \approx 40$ m

8(c) In the circuit shown below, what is the current through the 6 Ω resistor?

Given data:
- Voltage, V = 4V
- Resistors:
  - 6 Ω and 12 Ω in parallel
  - 3 Ω and 3 Ω in parallel

Calculate the equivalent resistance of the parallel combination of the 6 Ω and 12 Ω resistors.

$$1 / R_{eq1} = 1 / 6 + 1 / 12$$
$$R_{eq1} = 1 / ((1 / 6) + (1 / 12))$$

Calculate the equivalent resistance of the parallel combination of the two 3 Ω resistors.

$$1 / R_{eq2} = 1 / 3 + 1 / 3$$
$$R_{eq2} = 1 / ((1 / 3) + (1 / 3))$$

Find the total resistance of the circuit.

$R\_total = R\_eq1 + R\_eq2$

Find the total current using Ohm's law.

$I\_total = V / R\_total$

Find the current through the 6 Ω resistor using current division.

$I\_6 = I\_total \times (R2 / (R1 + R2))$

Let me calculate this step by step.

The equivalent resistance of the 6 Ω and 12 Ω parallel combination is 4 Ω.

The equivalent resistance of the two 3 Ω resistors in parallel is 1.5 Ω.

The total resistance of the circuit is 5.5 Ω.

The total current in the circuit is approximately 0.727 A.

The current through the 6 Ω resistor is approximately 0.485 A.

9(a)(i) Define magnetic flux and state its SI unit.

Magnetic flux is the total number of magnetic field lines passing through a given surface. It is given by:

$\Phi = B A \cos\theta$

where
Φ = magnetic flux,
B = magnetic flux density,
A = area of the surface,
θ = angle between the magnetic field and the normal to the surface.

The SI unit of magnetic flux is the Weber (Wb).

9(a)(ii) Describe how a permanent magnet and a current in a conductor can be used to demonstrate electromagnetic induction.

Electromagnetic induction occurs when a changing magnetic field induces an electromotive force (emf) in a conductor. This can be demonstrated in two ways:

Using a permanent magnet:

- If a magnet is moved towards a coil, the magnetic flux through the coil changes, inducing an emf and a current in the coil.
- If the magnet is moved away, the direction of the induced emf reverses.

Using a current-carrying conductor:
- A conductor carrying current produces a magnetic field around it. If another conductor is placed nearby and the current is varied, the changing magnetic field induces an emf in the second conductor due to flux linkage.

9(b)(i) State the laws of electromagnetic induction.

Faraday's Law: The magnitude of the induced emf in a coil is directly proportional to the rate of change of magnetic flux through the coil. It is given by:

$emf = -d\Phi/dt$

Lenz's Law: The direction of the induced emf is such that it opposes the change in magnetic flux that caused it.

9(b)(ii) Calculate the maximum emf induced in a coil of 500 turns each with an area 4.0 cm^2 which makes 50 revolutions per second in a uniform magnetic field of flux density 0.04 T.

Given:
- Number of turns, $N = 500$
- Area, $A = 4.0\ cm^2 = 4.0 \times 10^{-4}\ m^2$
- Frequency, $f = 50$ Hz
- Magnetic flux density, $B = 0.04$ T

The maximum emf is given by:

$emf\_max = N A B \omega$

where $\omega = 2\pi f$.

Let me calculate this step by step.

The maximum induced emf in the coil is approximately 2.51 V.

Let me proceed with the next part.

9(c) What is the total magnetic flux in the middle of a long solenoid of cross-sectional area 7.0 cm^2 having 15 turns per cm carrying a current of 4.0 A?

Given:
- Cross-sectional area, $A = 7.0\ cm^2 = 7.0 \times 10^{-4}\ m^2$
- Number of turns per cm = 15 turns/cm = 1500 turns/m
- Current, I = 4.0 A
- Magnetic permeability of free space, $\mu_0 = 4\pi \times 10^{-7}$ H/m

Magnetic field inside a long solenoid is given by:

$B = \mu_0 n I$

where
- n = number of turns per unit length
- I = current in the solenoid

Magnetic flux is given by:

$\Phi = B A$

Let me calculate this step by step.

The total magnetic flux in the middle of the solenoid is approximately 5.28×10^{-6} Wb.

Let me proceed with the next part.

10(a)(i) In the context of semiconductors, what is meant by p-type and n-type materials? What conduction processes occur in such materials when a potential difference is applied across them?

p-type material: A semiconductor doped with acceptor impurities (such as boron in silicon) that creates an excess of holes as the majority charge carriers.

n-type material: A semiconductor doped with donor impurities (such as phosphorus in silicon) that introduces extra electrons as the majority charge carriers.

When a potential difference is applied:
- In p-type materials, holes move towards the negative terminal, and electrons from the external circuit fill these holes, allowing current to flow.
- In n-type materials, free electrons move towards the positive terminal, contributing to conduction.

10(a)(ii) If α is a fraction of charge carriers that flow from the emitter to the collector, show that the current gain β (h_FE) is

$\beta = \alpha / (1 - \alpha)$

By definition:
- The emitter current (I_E) is the total current leaving the emitter.
- The collector current (I_C) is given by $I_C = \alpha I_E$.
- The base current (I_B) is the difference between emitter and collector currents:

$$I_B = I_E - I_C$$
$$I_B = I_E - \alpha I_E$$
$$I_B = I_E (1 - \alpha)$$

The current gain β is given by:

$$\beta = I_C / I_B$$
$$\beta = (\alpha I_E) / (I_E (1 - \alpha))$$
$$\beta = \alpha / (1 - \alpha)$$

Let me proceed with part (b).

10(b) Study the figure below showing a circuit connection and answer the questions below:

10(b)(i) Calculate the p.d. across R_1 and R_2.

Given:
- $R_1 = 39K\Omega$
- $R_2 = 3.9K\Omega$
- Supply voltage = 22V

The voltage across R_1 and R_2 forms a voltage divider. The voltage across R_2 (V_B) is given by:

$$V_B = (R_2 / (R_1 + R_2)) \times V_{supply}$$

The voltage across R_1 (V_R1) is:

$$V_{R1} = V_{supply} - V_B$$

Let me calculate these values step by step.

The potential difference across R_2 (V_B) is 2.0 V.

The potential difference across R_1 (V_R1) is 20.0 V.

10(b)(ii) Calculate the value of dc bias voltage V_CE and the collector current given that V_BE = 0.7 V and h_FE = 140.

Given:
- Base voltage, V_B = 2.0 V
- Base-emitter voltage, V_BE = 0.7 V
- Collector resistor, R_L = 10KΩ
- Emitter resistor, R_E = 1.5KΩ
- Supply voltage, V_CC = 22V
- Current gain, h_FE = 140

Determine the emitter voltage:

V_E = V_B - V_BE

Calculate the emitter current:

I_E = V_E / R_E

Determine the collector current:

I_C = (h_FE / (h_FE + 1)) × I_E

Find the collector-emitter voltage:

V_CE = V_CC - (I_C × R_L) - (I_E × R_E)

The emitter current (I_E) is approximately 0.867 mA.

The collector current (I_C) is approximately 0.861 mA.

The collector-emitter voltage (V_CE) is approximately 12.09 V.

10(b)(iii) What are the functions of C_1, C_2, and R_E in the circuit?

C_1: This is a coupling capacitor. It blocks any DC component from the input signal and allows only the AC signal to pass through to the transistor's base.

C_2: This is an output coupling capacitor. It removes the DC component from the amplified output signal, allowing only the AC signal to be delivered to the next stage or load.

R_E: This is the emitter resistor. It stabilizes the transistor's operating point by providing negative feedback, reducing variations in gain due to changes in temperature or transistor parameters. It also helps improve linearity and reduce distortion in the amplifier.

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

Coulomb's law states that the electrostatic force (F) between two point charges is directly proportional to the product of their charges (q_1 and q_2) and inversely proportional to the square of the distance (r) between them. It is mathematically expressed as:

$F = k (q_1 q_2) / r^2$

where k is Coulomb's constant (8.99×10^9 $N\cdot m^2/C^2$).

11(a)(ii) Two point charges, A and B, are situated 90 mm apart. If A has a charge of +2q and B a charge of -4q, where should a point charge of -2q be placed so that it experiences no resultant electrostatic force?

Given:
- Charge at A, q_A = +2q
- Charge at B, q_B = -4q
- Distance between A and B, d = 90 mm = 0.09 m
- Charge to be placed, q_C = -2q
- Distance of q_C from A = x
- Distance of q_C from B = (0.09 - x)

For equilibrium, the net force on q_C must be zero:

Force by A on C = Force by B on C

Using Coulomb's law:

$k (2q \times 2q) / x^2 = k (4q \times 2q) / (0.09 - x)^2$

Canceling k and simplifying:

$4q^2 / x^2 = 8q^2 / (0.09 - x)^2$

Dividing both sides by 4:

$1 / x^2 = 2 / (0.09 - x)^2$

Cross-multiplying:

$(0.09 - x)^2 = 2x^2$

Taking the square root:

$0.09 - x = \sqrt{(2x^2)}$

$0.09 - x = x\sqrt{2}$

Rearranging for x:

$x (1 + \sqrt{2}) = 0.09$

$x = 0.09 / (1 + \sqrt{2})$

Approximating $\sqrt{2} = 1.414$:

$x = 0.09 / (1 + 1.414)$
$x = 0.09 / 2.414$
$x \approx 0.0373$ m or 37.3 mm

Therefore, the charge -2q should be placed approximately 37.3 mm from A.

11(b)(i) Define electric field strength and state its units.

Electric field strength (E) at a point is defined as the force experienced per unit positive charge placed at that point. It is given by:

$E = F / q$

where F is the force acting on the charge q.

The SI unit of electric field strength is Newton per Coulomb (N/C) or Volt per meter (V/m).

11(b)(ii) How is the direction of the field strength specified?

The direction of the electric field strength is specified as the direction in which a positive test charge would move if placed in the field. It points away from positive charges and towards negative charges.

1
1(b)(iii) An electron is projected with an initial velocity $V_0 = 10^7$ m/s into a uniform field between parallel plates. The direction of the field is vertically downwards if the electron just misses the upper plate as it emerges from the field. Find the magnitude of the field.

Given:
- Initial velocity, $V_0 = 10^7$ m/s
- Distance between plates, d = 1 cm = 0.01 m
- Length of plates, L = 2 cm = 0.02 m
- Charge of electron, $e = 1.6 \times 10^{-19}$ C
- Mass of electron, $m = 9.11 \times 10^{-31}$ kg

Using kinematic equation for vertical motion:

$$y = (1/2)\, a\, t^2$$

where y = 0.01 m and acceleration a is due to electric force, given by:

$$a = eE / m$$

Time to traverse the plates:

$$t = L / V_0$$

Substituting t into y equation:

$$y = (1/2)\, (eE / m)\, (L / V_0)^2$$

Solving for E:

$$E = (2\, y\, m\, V_0^2) / (e\, L^2)$$

Substituting values:

$$E = (2 \times 0.01 \times 9.11 \times 10^{-31} \times (10^7)^2) / (1.6 \times 10^{-19} \times (0.02)^2)$$

$$E = (1.822 \times 10^{-22} \times 10^{14}) / (1.6 \times 10^{-19} \times 4 \times 10^{-4})$$

$$E = (1.822 \times 10^{-8}) / (6.4 \times 10^{-23})$$

$$E \approx 2.85 \times 10^4 \text{ N/C}$$

The magnitude of the electric field is approximately 2.85×10^4 N/C.

11(c) Two small balls are suspended by insulating threads from a common point. Each ball has a mass of 0.20 g and the suspension threads are 1.0 m long. When the balls are given equal positive charge, each suspension thread makes an angle of 7° with the vertical. What are the charges carried by the two balls?

Given:
- Mass of each ball, $m = 0.20$ g = 0.0002 kg
- Length of thread, $L = 1.0$ m
- Angle with vertical, $\theta = 7°$
- Gravitational acceleration, $g = 9.81\ m/s^2$

For equilibrium, the electrostatic force F_e is balanced by the horizontal component of tension $T \sin\theta$, and the weight mg is balanced by $T \cos\theta$:

$T \cos\theta = mg$

$T = mg / \cos\theta$

The electrostatic force is given by Coulomb's law:

$F_e = k q^2 / r^2$

where $r = 2L \sin\theta$ is the horizontal separation between the balls.

Substituting T into F_e equation:

$(k q^2) / (4L^2 \sin^2\theta) = mg \tan\theta$

Solving for q:

$q^2 = (4L^2 \sin^2\theta\ mg \tan\theta) / k$

$q = \text{sqrt}((4L^2 \sin^2\theta\ mg \tan\theta) / k)$

Substituting values:

$q = \text{sqrt}((4 \times (1.0)^2 \times \sin^2(7°) \times (0.0002 \times 9.81) \times \tan(7°)) / (8.99 \times 10^9))$

$q = \text{sqrt}((4 \times 1 \times 0.0149 \times 0.001962) / 8.99 \times 10^9)$

$q = \text{sqrt}((1.17 \times 10^{-5}) / 8.99 \times 10^9)$

$q \approx 1.14 \times 10^{-8}$ C

Each ball carries a charge of approximately 1.14×10^{-8} C.

12(a)(i) State any four basic properties of X-rays.

- X-rays are electromagnetic waves with very short wavelengths ranging from 0.01 nm to 10 nm.
- They can penetrate materials that are opaque to visible light, such as human tissue and thin metals.
- X-rays cause ionization of gases, enabling electrical conduction in air.
- They produce fluorescence when incident on certain materials, making them useful in imaging applications.

12(a)(ii) Electrons are accelerated from rest through a potential difference of 10,000 V in an X-ray tube. Calculate:

Given:
- Potential difference, V = 10,000 V
- Charge of electron, $e = 1.6 \times 10^{-19}$ C
- Mass of electron, $m = 9.11 \times 10^{-31}$ kg
- Planck's constant, $h = 6.63 \times 10^{-34}$ J·s
- Speed of light, $c = 3.0 \times 10^{8}$ m/s

12(a)(ii)(1) The wavelength of the associated electrons.

Using the de Broglie equation:

$\lambda = h / p$

where momentum p is given by:

p = sqrt(2 m e V)

Substituting p into λ:

λ = h / sqrt(2 m e V)

Substituting values:

$\lambda = (6.63 \times 10^{-34}) / \text{sqrt}(2 \times 9.11 \times 10^{-31} \times 1.6 \times 10^{-19} \times 10^{4})$

$\lambda = (6.63 \times 10^{-34}) / \text{sqrt}(2.92 \times 10^{-23})$

$\lambda = (6.63 \times 10^{-34}) / (5.41 \times 10^{-12})$

$\lambda \approx 1.23 \times 10^{-10}$ m or 0.123 nm

The wavelength of the associated electrons is approximately 0.123 nm.

12(a)(ii)(2) The maximum energy of X-ray radiation generated.

The maximum energy corresponds to the energy of an electron accelerated through V:

$E_{max} = e V$

$E_{max} = (1.6 \times 10^{-19}) \times (10^4)$

$E_{max} = 1.6 \times 10^{-15}$ J

To convert to electron volts (eV):

$E_{max} = (1.6 \times 10^{-15}$ J$) / (1.6 \times 10^{-19}$ J/eV$)$

$E_{max} = 10^4$ eV or 10 keV

The maximum energy of X-ray radiation generated is 10 keV.

12(a)(ii)(3) The minimum wavelength of the X-radiation generated.

Using the equation for the shortest wavelength in an X-ray spectrum:

$\lambda_{min} = hc / E_{max}$

Substituting values:

$\lambda_{min} = (6.63 \times 10^{-34} \times 3.0 \times 10^8) / (1.6 \times 10^{-15})$

$\lambda_{min} = (1.989 \times 10^{-25}) / (1.6 \times 10^{-15})$

$\lambda_{min} \approx 1.24 \times 10^{-10}$ m or 0.124 nm

The minimum wavelength of the X-radiation generated is approximately 0.124 nm.

12(b) State and explain Einstein's photoelectric equation.

Einstein's photoelectric equation states that the energy of an incident photon is used to overcome the work function of the metal and give the emitted electron kinetic energy. It is given by:

$E = \phi + KE_{max}$

where

- E = energy of the incident photon (E = h f),
- ϕ = work function of the metal (minimum energy required to release an electron),
- KE_max = maximum kinetic energy of the emitted electron.

This equation explains the photoelectric effect, showing that increasing the frequency of light increases the kinetic energy of emitted electrons, while increasing intensity increases the number of electrons emitted.

12(c) If a photoemissive surface has a threshold wavelength of 0.65 μm, calculate:

Given:
- Threshold wavelength, $\lambda_0 = 0.65\ \mu m = 0.65 \times 10^{-6}$ m
- Planck's constant, $h = 6.63 \times 10^{-34}$ J·s
- Speed of light, $c = 3.0 \times 10^{8}$ m/s
- Charge of an electron, $e = 1.6 \times 10^{-19}$ C

12(c)(i) Threshold frequency.

Threshold frequency is given by:

$f_0 = c / \lambda_0$

Substituting values:

$f_0 = (3.0 \times 10^{8}) / (0.65 \times 10^{-6})$

$f_0 = 4.62 \times 10^{14}$ Hz

The threshold frequency is approximately 4.62×10^{14} Hz.

12(c)(ii) Work function in eV.

Work function is given by:

$\phi = h f_0$

Substituting values:

$\phi = (6.63 \times 10^{-34}) \times (4.62 \times 10^{14})$

$\phi = 3.06 \times 10^{-19}$ J

Converting to eV:

$\phi = (3.06 \times 10^{-19} \text{ J}) / (1.6 \times 10^{-19} \text{ J/eV})$

$\phi \approx 1.91 \text{ eV}$

The work function is approximately 1.91 eV.

12(c)(iii) Maximum speed of the electron emitted by violet light of wavelength 0.4 μm.

Given:
- Wavelength of violet light, $\lambda = 0.4 \text{ μm} = 0.4 \times 10^{-6}$ m

Energy of incident photon:

$E = hc / \lambda$

$E = (6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / (0.4 \times 10^{-6})$

$E = (1.989 \times 10^{-25}) / (0.4 \times 10^{-6})$

$E \approx 4.97 \times 10^{-19}$ J

Kinetic energy of emitted electron:

$KE_{max} = E - \phi$

$KE_{max} = (4.97 \times 10^{-19}) - (3.06 \times 10^{-19})$

$KE_{max} = 1.91 \times 10^{-19}$ J

Using kinetic energy formula:

$KE_{max} = (1/2) m v^2$

Solving for v:

$v = \text{sqrt}(2 KE_{max} / m)$
$v = \text{sqrt}(2 \times (1.91 \times 10^{-19}) / (9.11 \times 10^{-31}))$
$v = \text{sqrt}(4.19 \times 10^{11})$

$v \approx 2.05 \times 10^{6}$ m/s

The maximum speed of the emitted electron is approximately 2.05×10^{6} m/s.

13. (a) (i) Define the terms "activity" and "half-life."
Activity: The rate at which a radioactive substance undergoes decay, measured in becquerels (Bq) or disintegrations per second.
Half-life: The time required for half of the radioactive atoms in a sample to decay, representing the time it takes for the activity to reduce to half its initial value.

13. (a) (ii) The half-life of 92U238 against alpha decay is 4.5×10^9 years. How many disintegrations per second occur in 1 g of 92U238?

Mass of 1 g of 92U238.
Molar mass of 92U238 ≈ 238 g/mol.
Number of moles = 1 / 238 ≈ 0.004202 mol.
Number of atoms = $0.004202 \times 6.022 \times 10^{23} \approx 2.53 \times 10^{21}$ atoms.
Half-life = 4.5×10^9 years = $4.5 \times 10^9 \times 3.156 \times 10^7$ seconds ≈ 1.42×10^{17} seconds.
Decay constant $\lambda = \ln(2) / t_{1/2} = 0.693 / 1.42 \times 10^{17} \approx 4.88 \times 10^{-18}\ s^{-1}$.
Activity $A = \lambda \times N = 4.88 \times 10^{-18} \times 2.53 \times 10^{21} \approx 1.23 \times 10^4$ disintegrations per second.

13. (b) (i) Explain the meaning of the following terms: nuclear fission.
Nuclear fission is the process where a heavy atomic nucleus, such as uranium-235, splits into two or more lighter nuclei, releasing energy and often neutrons.

13. (b) (ii) Explain the meaning of the following terms: nuclear fusion.
Nuclear fusion is the process where two light atomic nuclei, such as hydrogen isotopes, combine to form a heavier nucleus, releasing a large amount of energy, as seen in stars like the Sun.

13. (b) (iii) Explain the meaning of the following terms: chain reaction.
A chain reaction is a self-sustaining series of nuclear reactions where the neutrons released from one fission event cause additional fission events, potentially leading to a rapid increase in reaction rate if uncontrolled.

13. (b) (iv) Explain the meaning of the following terms: critical mass.
Critical mass is the minimum amount of fissile material required to sustain a chain reaction, where the rate of neutron production equals the rate of neutron loss, achieving a steady reaction rate.

13. (b) If the mass of the deuterium nucleus is 2.015 u, that of one isotope of helium is 3.017 u, and that of the neutron is 1.009 u. Calculate the energy released by the fusion of 1 kg of deuterium. Suppose 50% of this energy was used to produce 1 MW of electricity continuously, for how many days would the station be able to function?

Mass defect per fusion:
2.015 + 2.015 - 3.017 - 1.009 = 0.004 u.
Convert to kg:
$0.004 \times 1.6605 \times 10^{-27} \approx 6.642 \times 10^{-30}$ kg.
Energy per fusion:

$6.642 \times 10^{-30} \times (3 \times 10^{8})^2 \approx 5.978 \times 10^{-13}$ J.
Moles of deuterium in 1 kg = 1000 / 2.015 ≈ 496.03 mol.
Number of deuterium atoms = $496.03 \times 6.022 \times 10^{23} \approx 2.99 \times 10^{26}$ atoms.
Number of fusion reactions = $2.99 \times 10^{26} / 2 \approx 1.495 \times 10^{26}$ (each fusion uses 2 deuterium atoms).
Total energy = $1.495 \times 10^{26} \times 5.978 \times 10^{-13} \approx 8.93 \times 10^{13}$ J.
Energy available (50%) = 4.465×10^{13} J.
Power = 1 MW = 10^{6} J/s.
Time = $4.465 \times 10^{13} / 10^{6} \approx 4.465 \times 10^{7}$ seconds.
Days = $4.465 \times 10^{7} / (24 \times 3600) \approx 516.5$ days.

14. (a) (i) Explain the terms epicentre and focus as applied to earthquakes.
Epicenter: The point on the Earth's surface directly above the focus of an earthquake.
Focus: The underground point where the earthquake originates, where seismic waves are first generated.

14. (a) (ii) State any four indicators that may predict the occurrence of an earthquake.
- Increased frequency of small tremors or foreshocks.
- Changes in groundwater levels or unusual animal behavior.
- Tilt or strain in the Earth's crust detected by geodetic measurements.
- Release of radon gas from the ground.

14. (a) (iii) State and explain two types of variations of the Earth's magnetic field.
Diurnal variation: Daily fluctuations in the Earth's magnetic field caused by solar radiation affecting the ionosphere, typically small and regular.
Secular variation: Long-term changes in the Earth's magnetic field, including shifts in magnetic poles or intensity, occurring over decades to centuries due to changes in the Earth's core.

14. (a) (iv) State one necessary precaution to be taken by people living in a region with a high risk of occurrence of earthquakes.
Build earthquake-resistant structures and reinforce buildings to withstand seismic activity.

14. (b) (i) Explain the following: Solar wind.
Solar wind is a stream of charged particles, primarily protons and electrons, emitted by the Sun's corona, traveling at high speeds and interacting with Earth's magnetosphere.

14. (b) (ii) Explain the following: Magnetopause.
The magnetopause is the boundary where the Earth's magnetic field stops and the solar wind pressure balances it, marking the outer edge of the magnetosphere.

14. (b) (iii) Explain the following: Ionosphere.
The ionosphere is a layer of Earth's upper atmosphere (60–1000 km altitude) where solar radiation ionizes atoms and molecules, creating a region of charged particles that reflects radio waves.