

Question 4. Conversion Factors (1.5 points)

Perform the following unit conversions using the chained conversion factors method. Express the final result in scientific notation if strictly necessary:

- (0.5 points) The cruising speed of a high-speed train is 300 km/h. Convert this value to the corresponding International System units.
- (0.5 points) The density of lead is 11.3 g/cm³. Convert this value to International System units (kg/m³), expressing the result in scientific notation.
- (0.5 points) An industrial water pump injects a flow rate of 120 L/min. Express this flow rate in International System units (m³/s).

Question 5. The Quantum-Mechanical Model (1.5 points)

- (0.5 points) State the **Pauli Exclusion Principle** and deduce from it the maximum capacity of electrons that a single atomic orbital can hold.
- (1 point) Indicate whether the following combinations of quantum numbers (n, l, m_l) are possible. If so, indicate which orbital they refer to. If unfeasible, physically justify why (0.25 pts/each):
 - (2, 1, -1)
 - (3, 3, 0)
 - (1, 0, +1)
 - (4, 2, -2)

Question 6. Electron Configuration and Periodicity (1.5 points)

Consider the elements Aluminum ($Z = 13$) and Fluorine ($Z = 9$).

- (0.5 points) Write the complete electron configuration for both elements in their ground state.
- (0.5 points) Identify the period, the group, and the name of the chemical family to which each belongs, basing your justification on the valence shell.
- (0.5 points) Justify, applying the octet rule, which is the most stable ion that each element will form.

Question 7. Bonds and Properties (1 point).

We have a solid, crystalline sample of Calcium Fluoride (CaF_2).

- Deduce the type of bond present in this compound, justifying your answer based on the nature of the elements that form it. Predict two macroscopic mechanical properties associated with this type of bond. (0.5 pts)
- Compare its melting point and its electrical conductivity (in solid and molten states) with those of a typical molecular covalent substance. (0.5 pts)

Question 8. Lewis Diagrams (1 point).

- Apply the formal method to draw the Lewis structure of Carbon Dioxide (CO_2) and Ammonia (NH_3) molecules. Graphically demonstrate compliance with the octet and duet rules as appropriate. Data: $Z(H) = 1, Z(C) = 6, Z(N) = 7, Z(O) = 8$. (1 pt)

ANSWER KEY AND GRADING CRITERIA

Question 1. Multiple Choice Questions (1 point)

- a) ii. **5.000 g (0.25 pts)**. Instrumental sensitivity requires expressing the measurement with all the decimal places that the device is capable of recording with empirical certainty, demonstrating the degree of precision of the reading.
- b) ii. **Sphere of positive charge with embedded electrons (0.25 pts)**. Thomson postulated the "plum pudding" model to justify the electrical neutrality of matter after his experimental discovery of the electron.
- c) iii. **Crystalline solids, hard but brittle (0.25 pts)**. Ions form a highly cohesive three-dimensional network (hardness), but when their planes are displaced by shear forces, they experience electrostatic repulsions that fracture the crystal (brittleness).
- d) i. **20 p⁺, 20 n⁰, 18 e⁻ (0.25 pts)**. Calcium has $Z = 20$ (20 protons). Its mass number is 40, so it has $40 - 20 = 20$ neutrons. Being a divalent cation (+2), it has lost 2 electrons relative to its neutral ground state, leaving it with $20 - 2 = 18$ electrons.

Question 2. Scientific Method and Graphs (1.5 points)

- a) (0.5 pts): The **independent variable** is the one the researcher manipulates; the Force (by hanging known masses). The **dependent variable** is the Elongation (x), which responds to that force.
- b) (1 pt): By dividing F/x , the quotient is constant ($5.0/0.10 = 50$; $10.0/0.20 = 50$). It is a **direct proportionality linear function**. General equation $F = k \cdot x$ (Hooke's Law). The constant is $k = 50 \text{ N/m}$.

Question 3. Theory of Errors (1 point)

- **Absolute error (E_a)**: $|9.65 - 9.81| = |-0.16| = 0.16 \text{ m/s}^2$. (0.4 pts)
- **Relative error (E_r)**: $(0.16/9.81) \cdot 100 = 1.63\%$. (0.4 pts)
- **Analysis**: Since the measured value is lower than the true theoretical value, it is an **underestimation** (error by defect). (0.2 pts)

Question 4. Conversion Factors (1.5 points)

- a) (0.5 points): SI Unit: m/s.

$$300 \frac{\text{km}}{\text{h}} \cdot \left(\frac{1000 \text{ m}}{1 \text{ km}} \right) \cdot \left(\frac{1 \text{ h}}{3600 \text{ s}} \right) = 83.3 \text{ m/s}$$

- b) (0.5 points): SI Unit explicitly: kg/m³.

$$11.3 \frac{\text{g}}{\text{cm}^3} \cdot \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \cdot \left(\frac{10^6 \text{ cm}^3}{1 \text{ m}^3} \right) = 1.13 \cdot 10^4 \text{ kg/m}^3$$

- c) (0.5 points): SI Unit: m^3/s . ($1 \text{ L} = 1 \text{ dm}^3 = 10^{-3} \text{ m}^3$).

$$120 \frac{\text{L}}{\text{min}} \cdot \left(\frac{10^{-3} \text{ m}^3}{1 \text{ L}} \right) \cdot \left(\frac{1 \text{ min}}{60 \text{ s}} \right) = 2 \cdot 10^{-3} \text{ m}^3/\text{s}$$

Question 5. The Quantum-Mechanical Model (1.5 points)

- a) (0.5 points): The **Pauli Exclusion Principle** states that no two electrons in an atom can have the same four identical quantum numbers. In a given orbital (n, l, m_l are fixed), the only difference lies in the spin quantum number ($m_s = \pm 1/2$). Therefore, the maximum capacity is **two electrons** with opposite (paired) spins.
- b) (1 point - 0.25/each):
 - i. (2, 1, -1): **Possible**. $l = 1 < n = 2$, $m_l = -1$ is between $[-l, +l]$. It represents a **2p** orbital.
 - ii. (3, 3, 0): **Unfeasible**. l must be strictly less than n . If $n = 3$, the maximum l is 2. The $3f$ subshell does not exist.
 - iii. (1, 0, +1): **Unfeasible**. If $l = 0$, the only permitted value for m_l is 0.
 - iv. (4, 2, -2): **Possible**. $l = 2 < n = 4$, $m_l = -2$ falls within the range. It represents a **4d** orbital.

Question 6. Electron Configuration and Periodicity (1.5 points)

- a) (0.5 points):
Aluminum ($Z = 13$): $1s^2 2s^2 2p^6 3s^2 3p^1$
Fluorine ($Z = 9$): $1s^2 2s^2 2p^5$
- b) (0.5 points):
Aluminum: Valence shell $3s^2 3p^1$. Highest level $n = 3$ (**Period 3**). 3 valence electrons in the p block → **Group 13 (Boron group)**.
Fluorine: Valence shell $2s^2 2p^5$. Highest level $n = 2$ (**Period 2**). 7 valence electrons in the p block → **Group 17 (Halogens)**.
- c) (0.5 points):
Aluminum: Metal; tends to lose its 3 valence electrons to achieve an internal octet. Forms the cation Al^{3+} .
Fluorine: Highly electronegative non-metal; tends to gain 1 electron to complete its outer octet. Forms the anion F^- .

Question 7. Bonds and Properties (1 point)

- a) (0.5 pts): Calcium is an alkaline earth metal and Fluorine is a highly electronegative halogen. An electron transfer will occur, forming an **ionic bond**. Mechanically, it will form a crystal that is **hard** (great electrostatic cohesive force) but **brittle** (when planes shift, ions of the same charge face each other and repel).
- b) (0.5 pts): CaF_2 has an **extremely high melting point** required to break the immense 3D ionic network, unlike molecular substances which melt easily (only weak intermolecular forces need to be overcome). CaF_2 is an **insulator in solid state** (immobilized ions) and a **conductor when molten** (free ions), whereas a typical covalent molecular substance is an insulator in both states as it lacks ions.

Question 8. Lewis Diagrams (1 point)

• a) (1 pt):

Carbon Dioxide (CO₂): C (4 valence e-) forms two **double bonds** with each O (6 valence e-). C achieves 8 shared e-. Each O is left with 4 shared e- and 4 unshared e- (2 lone pairs). Linear structure: $\text{:O}=\text{C}=\text{O:}$ (0.5 pts)

Ammonia (NH₃): N (5 valence e-) is the central atom and forms three **single bonds** with each H (1 valence e-). Each H fulfills its **duet**. N achieves 8 e- (6 shared, 2 in a free lone pair).

$\text{H}-\ddot{\text{N}}(\text{H})-\text{H}$ (0.5 pts)

