

Period 3 trends in radius, energy and melting

Chemistry grades 11-12 (A Level · IB · Class 11-12) · Worksheet answers

Full methods are given for each problem. Check your reasoning against the structure, the force involved and the numbers, and make sure every explanation names the particles and the forces rather than just stating the trend.

Level: Chemistry grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** A Level 3.2.1

Problem 1 Period 3 roll call

1. **Na, Mg, Al, Si, P, S, Cl, Ar.**
2. Sodium: $1s^2 2s^2 2p^6 3s^1$. Chlorine: $1s^2 2s^2 2p^6 3s^2 3p^5$.
3. Argon is $3s^2 3p^6$, so its 3s and 3p subshells are full. The next element, potassium, starts the 4s subshell, so a new period begins.

Problem 2 Which way does it go?

1. Increases (+11 to +17).
2. **Stays the same** (three shells).
3. Decreases (186 pm to 99 pm).
4. Increases (1 to 7).

Result: **charge up, shells constant, radius down, outer electrons up.**

Problem 3 Reading the radius chart

1. Na = 186 pm, Cl = 99 pm.
2. Decrease = $186 - 99 = 87$ pm. Percentage = $87 / 186 \times 100 = 46.8 \%$.
3. Mean = $87 / 6 = 14.5$ pm per step.

Problem 4 Pull of the nucleus

1. Na: $11 - 10 = +1$. Cl: $17 - 10 = +7$.
2. $7 / 1 = 7$ times.
3. Chlorine's outer electrons are pulled much harder, so the chlorine atom is smaller than sodium.

Problem 5 Ionisation data

1. Highest: **argon** (1521). Lowest: **sodium** (496).
2. Mg to Al: $738 - 578 = 160$ kJ/mol. P to S: $1012 - 1000 = 12$ kJ/mol.
3. **$Al(g) \rightarrow Al^+(g) + e^-$** .

Problem 6 Kelvin conversions

1. Na 371 K, Mg 923 K, Al 933 K, Si 1683 K.
2. $Mg - Na = 923 - 371 = \mathbf{552\ K}$. $Al - Mg = 933 - 923 = \mathbf{10\ K}$. (A difference in °C equals the same difference in K.)

Problem 7 Match structure to element

1. A: giant metallic lattice. B: giant covalent lattice. C: simple molecular.
2. **Mg = A, Si = B, S₈ = C.**
3. A: attraction between cations and delocalised electrons. B: strong covalent bonds. C: weak London forces between molecules.

Problem 8 Conductors and insulators

1. Magnesium has delocalised electrons that are free to move and carry charge.
2. Sulfur is made of neutral S₈ molecules with all electrons held in bonds or lone pairs, so there are no mobile charge carriers.
3. **It does not conduct:** liquid chlorine consists of neutral Cl₂ molecules with no mobile ions or electrons.

Problem 9 Charge on the metal ions

1. Na⁺ (1 electron), Mg²⁺ (2 electrons), Al³⁺ (3 electrons).
2. More delocalised electrons and a higher ion charge, with smaller ions, give stronger attraction in the metallic lattice, so more energy is needed to melt it.
3. **Below 371 K:** potassium ions are larger, so the attraction to the single delocalised electron is weaker.

Problem 10 Phosphorus and sulfur

1. P₄: $4 \times 15 = \mathbf{60}$. S₈: $8 \times 16 = \mathbf{128}$.
2. The larger electron cloud in S₈ is more polarisable, giving stronger London forces between molecules, so more energy is needed to separate them.
3. **London (instantaneous dipole-induced dipole) forces.**

Problem 11 Ranking molecular elements

1. P₄ 60; S₈ 128; Cl₂ 34; Ar 18.
2. **S₈ > P₄ > Cl₂ > Ar** (388 K, 317 K, 172 K, 84 K).
3. All have only London forces, which strengthen as the number of electrons rises.

Problem 12 Why silicon is hard to melt

1. Strong covalent bonds, each silicon atom being bonded to four others in a giant lattice.

2. Melting phosphorus needs only weak London forces between P_4 molecules to be overcome, which takes far less energy.
3. $1683 / 317 = \mathbf{5.31 \text{ times}}$.

Problem 13 Argon versus sodium

1. $1521 / 496 = \mathbf{3.07 \text{ times}}$.
2. Ar +18 and Na +11, both with three shells.
3. Argon's 3p electrons feel a much larger nuclear charge at a smaller radius, while sodium's single 3s electron is far out and shielded by 10 inner electrons.

Problem 14 Period 2 dips

1. Be 900, B 801, N 1402, O 1314 kJ/mol.
2. Be to B: **99 kJ/mol**. N to O: **88 kJ/mol**.
3. B: the outer electron is in a 2p subshell, higher in energy than 2s and shielded by the 2s electrons. O: two electrons share one 2p orbital, and their repulsion makes removal easier than from the half-filled $2p^3$ of nitrogen.

Problem 15 Interpolating silicon

1. $(143 + 110) / 2 = \mathbf{126.5 \text{ pm}}$.
2. Error = $126.5 - 118 = 8.5 \text{ pm}$; $8.5 / 118 \times 100 = \mathbf{7.2 \%}$.
3. The trend is not perfectly linear, and aluminium's radius is a metallic radius while silicon's is covalent.

Problem 16 Identify the element

1. **Aluminium**: $3s^2 3p^1$ gives three delocalised electrons.
2. **Argon**: full $3p^6$ subshell, 1521 kJ/mol.
3. **Phosphorus**: $3s^2 3p^3$ has five outer electrons.
4. **Magnesium**: $3s^2$ gives two outer electrons.

Problem 17 Shape of the melting point graph

1. More delocalised electrons per atom, higher ion charge and smaller ions strengthen metallic bonding.
2. Silicon has a giant covalent lattice, so strong covalent bonds must be broken: **the highest melting point, 1683 K**.
3. P_4 , S_8 , Cl_2 and Ar need only weak London forces overcome. Argon is monatomic with the fewest electrons (18), so its forces are weakest and its melting point lowest (84 K).

Problem 18 Charge density

1. Na^+ : $1 / 102 = \mathbf{0.00980 \text{ e/pm}}$. Mg^{2+} : $2 / 72 = \mathbf{0.0278 \text{ e/pm}}$.

2. $0.0278 / 0.00980 = \mathbf{2.83 \text{ times}}$.

3. Mg^{2+} ions attract the sea of electrons much more strongly (and each atom contributes two electrons), so the lattice is stronger and magnesium melts 552 K higher.

Problem 19 Evaluate a claim

1. Sulfur's radius (104 pm) is smaller than phosphorus (110 pm), so the claim is **false**.

2. In sulfur ($3p^4$) two electrons occupy the same 3p orbital; their repulsion makes one easier to remove than an unpaired electron in phosphorus ($3p^3$).

3. **Higher**: chlorine has one more proton in the same shell, so its outer electrons are held more strongly (1251 against 1000 kJ/mol).

Problem 20 Spot the errors

1. Radius **decreases**: the extra electrons go into the same shell while nuclear charge rises.

2. A larger atom would have the lower value. The real reason is that **aluminium's outer electron is in a higher-energy, shielded 3p subshell**.

3. Silicon has a **giant covalent lattice**; strong covalent bonds must be broken.

4. Only the **weak London forces between S_8 molecules** are overcome; covalent bonds stay intact.