- Ammonia (NH$_3$) has a boiling point of –33 °C and phosphine (PH$_3$) has a boiling point of –83 °C. Explain the difference in these boiling points in terms of the intermolecular forces present.

Although PH$_3$ is a larger molecule with greater dispersion forces than ammonia, NH$_3$ has very polar N-H bonds leading to strong hydrogen bonding. This is the dominant intermolecular force and results in a greater attraction between NH$_3$ molecules than there is between PH$_3$ molecules.
- Explain, in terms of chemical bonding and intermolecular forces, the following trend in melting points: \( \text{CH}_4 < \text{I}_2 < \text{NaCl} < \text{silica (SiO}_2\text{)} \)

| There are only dispersion forces between the molecules in \( \text{CH}_4 \) and \( \text{I}_2 \). The I atom is a large, many-electron atom so its electron cloud is more easily polarised than the C or H in \( \text{CH}_4 \) and therefore \( \text{I}_2 \) has stronger dispersion forces and the higher melting point. NaCl is an ionic compound with strong coulombic attraction between the \( \text{Na}^+ \) ions and the \( \text{Cl}^- \) ions packed together in the solid. Silica is a covalent network solid. Melting it requires breaking of the very strong covalent Si–O bonds, so it has the highest melting point. |
• Explain briefly, in terms of intermolecular forces, why an analogue of DNA could not be made with phosphorus atoms replacing some nitrogen atoms, while still retaining a double-helical structure.

The double helical structure is held together by hydrogen bonding between the cytosine and guanine (C≡G) and the adenine and thymine (A=T) base pairs.

No H-bonding would occur if the electronegative N atoms in these bases were replaced with P atoms.
Explain, in terms of chemical bonding and intermolecular forces, the following trend in melting points: $\text{CH}_4 < \text{I}_2 < \text{NaCl} < \text{silica (SiO}_2\text{)}$.

The intermolecular forces in I$_2$ and CH$_4$ are weak dispersion forces. Iodine is a much larger atom than H or C and hence has more electrons and these are held further from the nucleus. The electron cloud in I$_2$ is, therefore, much more polarisable leading to stronger dispersion forces in I$_2$, and a higher melting point.

NaCl has relatively strong ionic bonds between all of the Na$^+$ and Cl$^-$ ions in the lattice.

SiO$_2$ is a covalent network compound with a very high melting point as strong covalent bonds need to be broken.
What physical state would water adopt under ambient conditions (1 atm and 25 °C) if it did not possess hydrogen bonding? Explain.

Water would be a gas. The other hydrides of group 16 elements increase in boiling point as the molar mass increases, due to the increase in dispersion forces. \( \text{H}_2\text{S} \) is a gas. As the dispersion forces in water are weaker, it would be a gas too. \( \text{H}_2\text{O} \) has an anomalously high boiling point due to its H-bonds. Without H-bonds it would have a boiling point below that of \( \text{H}_2\text{S} \).
Glycine, NH$_2$CH$_2$COOH, the simplest of all naturally occurring amino acids, has a melting point of 292 °C. The pK$_a$ of the acid group is 2.35 and the pK$_a$ associated with the amino group is 9.78. Draw a Lewis structure that indicates the charges on the molecule at the physiological pH of 7.4.

![Lewis structure of glycine](image)

Use your structure to illustrate the concept of resonance.

![Resonance structures of glycine](image)

Describe the hybridisation of the two carbon atoms and the nitrogen atom in glycine and the molecular geometry of the atoms surrounding these three atoms.

N: $sp^3$ hybridised; tetrahedral geometry  
CH$_2$: $sp^3$ hybridised; tetrahedral geometry  
CO$_2$–: $sp^2$ hybridised; trigonal planar geometry

Glycine has an unusually high melting point for a small molecule. Suggest a reason for this.

In its zwitterionic state, glycine has very strong electrostatic attractions (i.e. ionic bonds) between the NH$_3^+$ and CO$_2^-$ groups giving it very high melting point.

Do you expect glycine to be water soluble? Give a reason for your answer.

Yes. It is ionic so dissolves in the very polar solvent water.