Worksheet 7 – Answers to Critical Thinking Questions

The worksheets are available in the tutorials and form an integral part of the learning outcomes and experience for this unit.

Model 1: Boiling Points Change Down a Group of the Periodic Table
1. The boiling point increases.
2. They are all tetrahedral.
3. No – they do not possess dipole moments.
4. No – they do not have $\delta^+ \text{H}$ atoms or lone pairs.
5. Dispersion.
6. The strength of dispersion forces increases with the number of electrons.

Model 2: Boiling Points Change Across a Row of the Periodic Table
2. No, because they have the same number of electrons.
4. Yes.
5. Dipole – dipole interactions are present in PH$_3$, H$_2$S and HCl alongside dispersion forces of similar strength.
7. Dispersion forces are stronger in SnH$_4$ as it has more electrons and this leads to a higher boiling point, despite the lack of dipole – dipole interactions.

Model 3: Anomalous Boiling Points of NH$_3$, H$_2$O and HF
1. The boiling point increases. See Model 1.
2. Hydrogen bonding is present.
3. Dispersion forces are stronger in SbH$_3$ as it has more electrons and this leads to a higher boiling point, despite the lack of hydrogen bonding.
5. NH$_3$ < OH$_2$ < HF
6. (a) 3 (b) 2 (c) 1
7. (a) 1 (b) 2 (c) 3
8. Two.
9. Two.
10. Four.
11. NH$_3$ < HF because the hydrogen bonds are stronger in the latter.
   HF < H$_2$O because of the presence of a higher number of hydrogen bonds in the latter, despite each individual hydrogen bond being stronger in the former.

12. Review the data and answers to the questions and then make your own case.
• Explain the trend in the following table in terms of the type and size of intermolecular forces.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Boiling point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₃CH₃</td>
<td>−89</td>
</tr>
<tr>
<td>CH₃CH₂CH₂CH₃</td>
<td>−1</td>
</tr>
<tr>
<td>CH₃CH₂–O–CH₂CH₃</td>
<td>35</td>
</tr>
<tr>
<td>CH₃CH₂OH</td>
<td>78</td>
</tr>
<tr>
<td>H₂O</td>
<td>100</td>
</tr>
</tbody>
</table>

CH₃CH₃ and CH₃CH₂CH₂CH₃ have weak dispersion forces only, so have the lowest boiling points. CH₃CH₂CH₂CH₃ has more atoms, so more dispersion forces and hence the higher boiling point of the two.

CH₃CH₂OCH₂CH₃ is similar in size to CH₃CH₂CH₂CH₃, but has dipole-dipole forces as well due to the presence of polar C-O bonds. Thus, the boiling point of CH₃CH₂OCH₂CH₃ is higher than that of CH₃CH₂CH₂CH₃.

CH₃CH₂OH and H₂O have strong intermolecular H-bonds due to the presence of H atoms bonded to electronegative O atoms. Their boiling points are thus higher.

Water has 2 H atoms and 2 lone pairs on O capable of H-bonding so can form on average 4 H-bonds per molecule. Ethanol just one H so can only form 1 H-bond per molecule. Water thus has the higher boiling point.

• Circle the molecule in the following pairs that has the stronger intermolecular forces. Identify the types of forces present for the species selected.

<table>
<thead>
<tr>
<th>molecule pair</th>
<th>types of intermolecular forces</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂ or N₂</td>
<td>dispersion (more electrons in N₂)</td>
</tr>
<tr>
<td>CH₃Cl or CH₄</td>
<td>dipole-dipole and dispersion (dipole present and more electrons in CH₃Cl)</td>
</tr>
<tr>
<td>SO₂ or CO₂</td>
<td>dipole-dipole and dispersion (dipole present and more electrons in SO₂)</td>
</tr>
<tr>
<td>H₂O or H₂S</td>
<td>hydrogen bonding (only present in H₂O)</td>
</tr>
</tbody>
</table>