Year 13 Science: Melting, boiling, solubility and spontaneity

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. Butane (a straight chain) and 2-methylpropane (branched) are both C_4H_{10}. Which has the higher boiling point?

2. Which is more soluble in water: sodium chloride or iodine?

3. What is the sign of ΔS (system) for $H_2O(l) \rightarrow H_2O(g)$?

4. What is the sign of ΔS (system) for $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$?

5. A reaction is endothermic and its system entropy decreases. When is it spontaneous?

6. Magnesium oxide melts at 2825 °C and iodine at 114 °C. Explain the difference in terms of the particles and the attractions between them.

7. Explain why iodine dissolves in hexane but hardly at all in water.

8. Hydrogen peroxide decomposes: $2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g)$, $\Delta rH = -196$ kJ mol^{-1}. State the sign of the entropy change of the system, and decide whether the reaction is spontaneous at all temperatures.

9. Dinitrogen tetroxide decomposes: $N_2O_4(g) \rightarrow 2NO_2(g)$, $\Delta rH = +57$ kJ mol^{-1}. Using the entropy change of the system and of the surroundings, justify why it happens on its own only at higher temperatures.

Fix the mistake

10. Correct this statement: "Iodine melts at 114 °C because its covalent I–I bonds are weak."

11. Correct this statement: "Endothermic reactions cannot be spontaneous."

12. Correct this statement: "Iodine does not dissolve in water because iodine is non-polar and repels water."

13. Correct this statement: "$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$ has a positive ΔS because the SO_3 molecules are bigger."

Answer key (for parents and tutors)

1. Butane (a straight chain) and 2-methylpropane (branched) are both C_4H_{10}. Which has the higher boiling point?
   Butane: the same number of electrons, but the straight chain has more surface contact, so stronger temporary dipole attractions (it boils at −0.5 °C against −12 °C).

2. Which is more soluble in water: sodium chloride or iodine?
   Sodium chloride: water's polar molecules form ion–dipole attractions with Na^+ and Cl^-, while non-polar iodine cannot replace water's hydrogen bonds.

3. What is the sign of ΔS (system) for $H_2O(l) \rightarrow H_2O(g)$?
   Positive: gas particles are far more spread out than liquid.

4. What is the sign of ΔS (system) for $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$?
   Negative: 4 mol of gas become 2 mol.

5. A reaction is endothermic and its system entropy decreases. When is it spontaneous?
   Never: the system's entropy falls and the surroundings' entropy falls too, so the total cannot increase at any temperature.

6. Magnesium oxide melts at 2825 °C and iodine at 114 °C. Explain the difference in terms of the particles and the attractions between them.
   MgO is an ionic lattice of Mg^{2+} and O^{2-} ions; melting must overcome very strong electrostatic attractions between ions with 2+ and 2− charges throughout the lattice, which needs a great deal of energy. Iodine is molecular: melting overcomes only the temporary dipole attractions between I_2 molecules, which are much weaker, so far less energy is needed (Merit names both particles and both attractions; Excellence compares their strengths).

7. Explain why iodine dissolves in hexane but hardly at all in water.
   Iodine and hexane are both non-polar with only temporary dipole attractions, so the attractions formed between I_2 and hexane are similar to those broken, and iodine dissolves. To dissolve in water, I_2 would have to break water's hydrogen bonds but could form only weak temporary dipole attractions with water, so it hardly dissolves.

8. Hydrogen peroxide decomposes: $2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g)$, $\Delta rH = -196$ kJ mol^{-1}. State the sign of the entropy change of the system, and decide whether the reaction is spontaneous at all temperatures.
   Positive: 2 mol of liquid produce 2 mol of liquid and 1 mol of gas. It is exothermic, so the entropy of the surroundings also increases; both increase, so the total entropy always increases and the reaction is spontaneous at all temperatures (it is slow without a catalyst).

9. Dinitrogen tetroxide decomposes: $N_2O_4(g) \rightarrow 2NO_2(g)$, $\Delta rH = +57$ kJ mol^{-1}. Using the entropy change of the system and of the surroundings, justify why it happens on its own only at higher temperatures.
   One mole of gas becomes two, so the entropy of the system increases. The reaction is endothermic, so it absorbs heat from the surroundings and their entropy decreases; this decrease is larger when the surroundings are cold. At low temperature the surroundings' decrease outweighs the system's increase, so total entropy falls and the reaction is not spontaneous; at higher temperature the surroundings' decrease is smaller, the system's increase wins, and the reaction is spontaneous (Excellence weighs both changes and links them to temperature).

10. Correct this statement: "Iodine melts at 114 °C because its covalent I–I bonds are weak."
    Melting overcomes the temporary dipole attractions between I_2 molecules; the I–I bond inside each molecule does not break.

11. Correct this statement: "Endothermic reactions cannot be spontaneous."
    An endothermic change is spontaneous if the system's entropy increase outweighs the surroundings' decrease, like ice melting at 10 °C.

12. Correct this statement: "Iodine does not dissolve in water because iodine is non-polar and repels water."
    Dissolving would break strong hydrogen bonds between water molecules and replace them with only weak attractions to I_2.

13. Correct this statement: "$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$ has a positive ΔS because the SO_3 molecules are bigger."
    Three moles of gas become two, so the system's entropy decreases and ΔS is negative.