2.4 How solubility changes with temperature

LEARNING OUTCOMES

At the end of this topic you should be able to:

- explain the terms solubility and saturated solution
- describe how solubility changes with temperature
- use solubility curves to answer problems involving solubility and mass of substance deposited on cooling saturated solutions.

Solubility

If a solvent dissolves a particular substance, we say that the substance is very soluble in that solvent. If the solute does not appear to dissolve in the solvent, we say that the substance is insoluble. Solubility depends on both the solute and the solvent. Some substances may be insoluble in water but soluble in other solvents. For example, sulfur is insoluble in water but dissolves in some organic solvents.

If, at constant temperature, a solution can dissolve more solute, we say that the solution is unsaturated. If the solution cannot dissolve any more solid and excess solid is present, we say that the solution is saturated.

The **solubility** of a solute in a solvent is the number of grams of solute needed to form a saturated solution per 100 grams of solvent used. The temperature must always be quoted. This is because solubility varies with temperature.

DID YOU KNOW?

Some solutions can hold more solute than in a saturated solution. We call these solutions *supersaturated*. Hydrated sodium thiosulfate contains water of crystallisation in its structure. When this compound is heated gently, it dissolves in its own water of crystallisation. This solution contains more sodium thiosulfate than a saturated solution of sodium thiosulfate in water. Adding a speck of dust or tiny crystal to the supersaturated solution results in the whole solution crystallising.

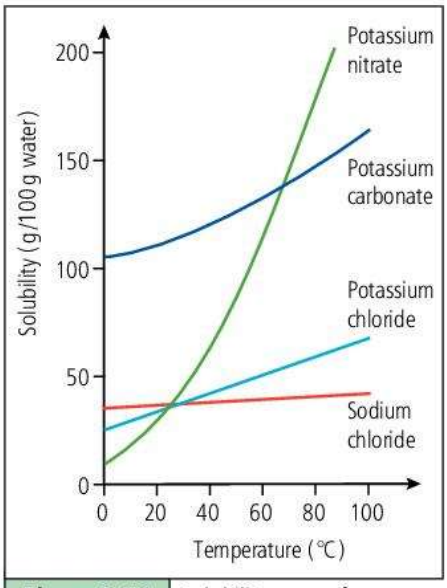


Figure 2.4.1 Solubility curves for potassium nitrate, potassium carbonate, potassium chloride and sodium chloride

The effect of temperature on solubility

When we warm saturated solutions of most substances, the solutions become unsaturated. For most solutes in water, solubility increases as temperature increases.

A **solubility curve** shows the mass of solute dissolved to form a saturated solution per 100 grams of solvent at different temperatures. The solubility curves for a number of different solutes in water are shown in Figure 2.4.1.

From these graphs we can see that:

- At 0 °C, potassium carbonate is the most soluble in water and potassium nitrate is the least soluble.
- At 80 °C, potassium nitrate is the most soluble and sodium chloride is the least soluble.
- The increase in solubility with temperature is greatest for potassium nitrate.

- Sodium chloride shows only a very small increase in solubility as the temperature is increased.
- The increase in solubility with temperature is usually a smooth curve or an almost straight line.

Calculations using solubility curves

The solubility curve for potassium nitrate is shown in Figure 2.4.2. We can use information from this curve to deduce:

- the temperature at which crystals start to form when a saturated solution is cooled
- the mass of solid deposited when a saturated solution is cooled.

1 At what temperature does a saturated solution containing 140 g potassium nitrate first form crystals as it is cooled from 80 °C?

- Draw a line XY from 140 g on the vertical axis to join the curve.
- The line YZ gives the temperature at which potassium nitrate is just soluble. So 70 °C is the maximum temperature at which crystals will start to form.

2 Calculate the mass of potassium nitrate that would come out of solution when a saturated solution of potassium nitrate is cooled from 80 °C to 40 °C.

- At 80 °C a mass of 170 g of potassium nitrate dissolves (lines ABC).
- At 40 °C a mass of 65 g of potassium nitrate dissolves (lines DEF).
- On cooling from 80 °C to 40 °C the mass of potassium nitrate that comes out of solution is (170 g – 65 g) = 105 g.

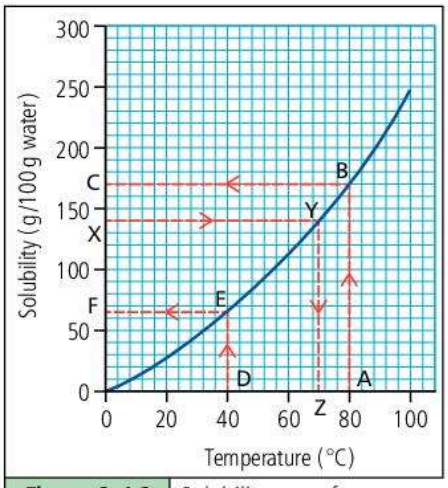


Figure 2.4.2 Solubility curve for potassium nitrate

Fractional crystallisation

Fractional crystallisation can be used to separate two dissolved substances which have different solubilities at different temperatures. A warm concentrated solution containing the two solutes is cooled. A larger proportion of the solute with the lower solubility crystallises out. The solute with the higher solubility remains in solution. The crystals still contain a small amount of the solute with higher solubility. So the procedure is repeated several times to improve the purity. Filtration is used to separate the crystals from the solution.

EXAM TIP

If you are asked to draw a solubility curve or similar curves from data provided, make sure that you draw the curve of best fit and do not draw straight lines from one point to another.

KEY POINTS

1. The solubility of a solute in a solvent is the number of grams of solute needed to form a saturated solution per 100 grams of solvent used.
2. The solubility of most substances increases with temperature
3. The information from solubility curves can be used to calculate the mass of solid deposited when a saturated solution is cooled.