Chapter 12

Solutions

Concept Check 12.1

Identify the solute(s) and solvent(s) in the following solutions.

a. 80 g of Cr and 5 g of Mo
b. 5 g of $MgCl_2$, dissolved in 1000 g of H_2O
c. 39% N_2, 41% Ar, and the rest O_2

Solution

In each case, the component present in the greatest amount is the solvent.

a. Mo is the solute, and Cr is the solvent.
b. $MgCl_2$ is the solute, and water is the solvent.
c. N_2 and O_2 are the solutes, and Ar is the solvent.

Concept Check 12.2

The hypothetical ionic compound, AB_2, is very soluble in water. Another hypothetical ionic compound, CB_2, is only slightly soluble in water. The lattice energies for these compounds are about the same. Provide an explanation for the solubility difference between these compounds.

Solution

The two main factors to consider when determining the solubility of an ionic compound in water are: ionic size and lattice energy. In this case the lattice energy for the two compounds is the same; you can discount its effects. Since a smaller cation will have a more concentrated electric field leading to a larger energy of hydration, you would expect AB_2 to have a greater energy of hydration: AB_2 is the more soluble compound.

Concept Check 12.3

Most fish have a very difficult time surviving at elevations much above 3500 m. How could Henry's law be used to account for this fact?

Solution

As the altitude increases, the percent of oxygen in air decreases, and thus the partial pressure decreases. Above 3500 m, the partial pressure of oxygen in air has decreased to the point that not enough will dissolve in the water to sustain the fish.

Concept Check 12.4

You need to boil a water-based solution at a temperature lower than 100°C. What kind of liquid could you add to the water to make this happen?

Solution

In order to boil at a lower temperature than water, the vapor pressure of the solution (water + liquid) must be greater than water. In order to make this solution, you must add a liquid that is both soluble in water and chemically similar to water. It must have a higher vapor pressure than water and a boiling point lower than 100°C. One possible liquid is ethanol, with a boiling point of 78.3°C (Table 12.3).

Concept Check 12.5

Explain why pickles are stored in a brine (salt) solution. What would the pickles look like if they were stored in water?

Solution

By the principle of osmosis, in brine solution, water will flow out of the pickle (lower concentration of ions) into the brine (higher concentration of ions). If the pickles were stored in a water solution, the water (lower concentration of ions) would flow into the pickle (higher concentration of ions) and cause it to swell up and probably burst.

Concept Check 12.6

Each of the following substances is dissolved in a separate 10.0-L container of water: 1.5 mol NaCl, 1.3 mol of Na_2SO_4, 2.0 mol $MgCl_2$, and 2.0 mol KBr. Without doing extensive calculations, rank the boiling points of each of the solutions from highest to lowest.

Solution

Each of these solutions is a water solution of identical volume (normal boiling point 100 °C) containing a different number of moles of solute. The boiling point of a solution can be determined by the formula $\Delta T_b = iK_bm$. The solution with the largest ΔT_b will have the highest boiling point. Since K_b is a constant, this will be the compound with the largest factor of i • m. Also, since the volume is constant, the factor reduces to i • moles. Ideally, all of the compounds will dissolve completely, so NaCl and KBr have i = 2, and Na_2SO_4 and $MgCl_2$ have i = 3. This gives

For NaCl, i • moles = 2 x 1.5 = 3.0

For Na_2SO_4, i • moles = 3 x 1.3 = 3.9

For $MgCl_2$, i • moles = 3 x 2.0 = 6.0

For KBr, i • moles = 2 x 2.0 = 4.0

The result is given from highest boiling point to lowest boiling point:

$MgCl_2$ > KBr > Na_2SO_4 > NaCl

Concept Check 12.7

If electrodes that are connected to a direct current (DC) source are dipped into a beaker of colloidal iron(III) hydroxide, a precipitate collects at the negative electrode. Explain why this happens.

Solution

Iron(III) hydroxide is a hydrophobic colloid. As the colloid forms in water, an excess of iron(III) ion (Fe^{3+}) is present on the surface, giving each crystal an excess of positive charge. These positively charged crystals repel one another, so aggregation to larger particles of iron(III) hydroxide is prevented. When the electrodes are dipped into the colloidal solution, iron(III) hydroxide precipitates because electrons from the negative electrode neutralize the excess positive charge on the iron(III) hydroxide, allowing larger particles to form (precipitate).

Conceptual Problem 12.21

Even though the oxygen demands of trout and bass are different, they can exist in the same body of water. However, if the temperature of the water in the summer gets above about 23°C, the trout begin to die, but not the bass. Why is this the case?

Solution

The amount of oxygen dissolved in water decreases as the temperature increases. Thus, at the lower temperatures, there is enough oxygen dissolved in the water to support both bass and trout. But, as the temperature rises above 23°C, there is not enough dissolved oxygen in the warm water to support the trout who need more O_2.

Conceptual Problem 12.22

You want to purchase a salt to melt snow and ice on your sidewalk. Which one of the following salts would best accomplish your task using the least amount: KCl, $CaCl_2$, PbS_2, $MgSO_4$, or AgCl?

Solution

The salt that would best accomplish the task would be the salt that lowers the freezing point of water the most. This in turn would be the salt with the largest *i* factor. Ideally, if each salt dissolved completely, KCl, $MgSO_4$, and AgCl would have $i = 2$. Similarly, $CaCl_2$ and PbS_2 would have $i = 3$. Of the latter two salts, $CaCl_2$ is more soluble than PbS_2, so its *i* factor is closer to 3. Therefore, the salt with the largest *i* factor is $CaCl_2$, so it would lower the freezing point of water the most and would best accomplish the task.

Conceptual Problem 12.23

Ten grams of the hypothetical ionic compounds XZ and YZ are each placed in a separate 2.0 L beaker of water. XZ completely dissolves, whereas YZ is insoluble. The energy of hydration of the Y^+ ion is greater than the X^+ ion. Explain this difference in solubility.

Solution

The two main factors to consider when determining the solubility of an ionic compound in water are ionic size and lattice energy. Ionic size is inversely related to the energy of hydration; the smaller the ion, the greater the energy of hydration. Keep in mind that the greater the energy of hydration, the more likely it is for a compound to dissolve. The amount of lattice energy is directly related to the solubility of the compound; the lower the lattice energy, the more likely it is for the compound to dissolve.

Taking into account these factors, in order to increase the solubility of a compound you need to decrease the ionic size and decrease the lattice energy. Since the energy of hydration of the Y+ ion is greater than that of the X+ ion (making XZ less soluble), in order for XZ to be more soluble than YZ the lattice energy must be less for the XZ compound.

Conceptual Problem 12.24

Small amounts of a nonvolatile, nonelectrolyte solute and a volatile solute are each dissolved in separate beakers containing 1 kg of water. If the number of moles of each solute is equal:

a. Which solution will have the higher vapor pressure?
b. Which solution will boil at a higher temperature?

Solution

a. According to Raoult's law, the addition of a nonvolatile, nonelectrolyte to a solvent will lower the vapor pressure of the solvent, so we would expect the vapor pressure of such a solution to be lower than that of the pure solvent (water in this case). When a volatile solute is added to a solvent, the vapor pressure of the solution is dependent upon the mole fraction of the solute and solvent and the vapor pressures of both the solute and solvent. Since the solute is volatile (a high vapor pressure relative to water), the solution must have a higher vapor pressure than pure water.
b. Keeping in mind that a solution will boil when the vapor pressure equals the pressure pushing on the surface of the solution, the solution with the greater vapor pressure will boil at a lower temperature. In this case, it is the solution with the volatile solute.

Conceptual Problem 12.25

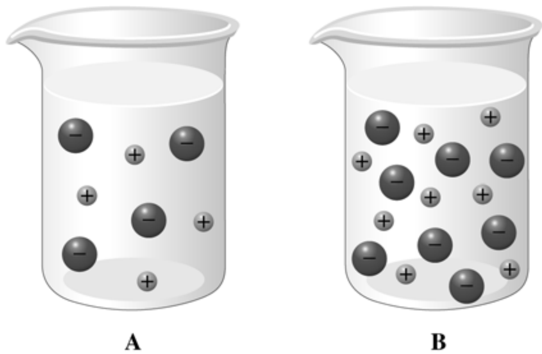
A Cottrell precipitator consists of a column containing electrodes that are connected to a high-voltage direct current (DC) source. The Cottrell precipitator is placed in smokestacks to remove smoke particles from the gas discharged from an industrial plant. Explain how you think this works.

Solution

Smoke particles carry a small net charge, preventing them from forming larger particles that would settle to the bottom of the smokestack. The charged smoke particles are neutralized by the current which then allows them to aggregate into large particles. These large particles are too big to be carried out of the stack.

Conceptual Problem 12.26

Consider the following dilute NaCl(*aq*) solutions.



a. Which one will boil at a higher temperature?
b. Which one will freeze at a lower temperature?
c. If the solutions were separated by a semipermeable membrane that allowed only water to pass, which solution would you expect to show an increase in the concentration of NaCl?

Solution

a. Since beaker B contains more solute particles, according to Raoult's law, it will boil at a higher temperature than beaker A.
b. More particles in solution lead to a lower vapor pressure, which in turn lowers the freezing point of a solution. Since beaker B contains more solute particles, it will freeze at a lower temperature than beaker A.
c. When separated by a semipermeable membrane, the solvent from the less concentrated solution flows into the more concentrated solution. Because of this, the water will flow from beaker A to beaker B causing an increase in the concentration of NaCl in beaker A.

Conceptual Problem 12.27

A green leafy salad wilts if left too long in a salad dressing containing vinegar and salt. Explain what happens.

Solution

Vinegar is a solution of acetic acid (solute) and water (solvent). Because the salt concentration outside the lettuce leaf is higher than inside, water will pass out of the lettuce leaf into the dressing via osmosis. The result is that the lettuce will become wilted.

Conceptual Problem 12.28

People have proposed towing icebergs to arid parts of the earth as a way to deliver fresh water. Explain why icebergs do not contain salts although they are formed by the freezing of ocean water (i.e., saltwater).

Solution

As a solution freezes, pure solvent forms without any of the solute present. This means that as ocean water freezes to make icebergs, it freezes as pure water without the salt present.