Molality

Sometimes, it is convenient to express concentration in terms of moles of solute per kilogram of solvent. Molarity is a function of temperature. This is because the quantity of solution is based on volume, and volume is a function of temperature. For a variety of applications it is necessary to have a solution unit that is independent of temperature. The obvious unit is one in which *both* quantities, solute and solvent, are stated by mass. The mass of a substance is independent of temperature. A particularly useful unit is molality, in which the amount of solute is given in moles and the quantity of solvent (not solution) in kilograms. A solution that contains 1 mole of solute in each 1000 g of solvent is called a one-molal (1 m or 1 mol/kg) solution. This solution differs from a one-molar (1M or 1 mol/L) solution, which contains 1 mole of solute in 1 L of solution. Molality is most useful in studying the colligative properties of solutions.

Example: If 52.0 g of potassium carbonate are dissolved in 518 g of water, what is the molality of the solution?

Molality = $\underline{\text{moles of solute}}$ moles = $\underline{\text{mass}}$
                    kg of solvent   molar mass

moles of K_2CO_3 = $\underline{\quad 52.0 \text{ g} \quad}$ = 0.376 mol   molality = $\underline{0.376 \text{ mol}}$ = 0.726 m or 0.726 mol/kg
                              138.2052 g/mol   0.518 kg

Questions:

1. Calculate the molality of the following solutions:
   a) 199 g of nickel(II) bromide in 500.0 g of water
   b) 92.3 g of potassium fluoride in 1000.0 g of water
   c) 98.0 g of rubidium bromide in 824 g of water
   d) 85.2 g of tin(II) bromide in 140.0 g of water
   e) 10.0 g of silver chlorate in 201 g of water
   f) 1.50 g of p-dichlorobenzene ($C_6H_4Cl_2$) in 35.0 g of benzene (C_6H_6)

2. Calculate the mass of solute required to make the following solutions.
   a) iron(III) oxalate to be added to 1000.0 g of water for a 0.851 m solution
   b) $VOBr_3$ to be added to 1000.0 g of water for a 0.534 m solution
   c) lithium permanganate to be added to 500.0 g of water for a 0.614 m solution
   d) iodine to be dissolved in 250.0 mL of carbon tetrachloride (density = 1.595 g/mL) to produce a 0.175 m iodine solution

3. An aqueous solution of hydrofluoric acid is 30.0% HF by mass. What is the molality of the solution?

Colligative Properties

Colligative properties are determined by the number of particles in solution rather than by the type of particle in solution. The properties that are affected are vapour pressure, freezing point, boiling point, and the rate of diffusion through a membrane.

Boiling Point and Freezing Point

When a solute is dissolved in a liquid solvent, some of the solute particles take up space on the liquid surface normally occupied by the solvent particles. These solute particles decrease the opportunity for the solvent particles to escape (evaporate) from the liquid surface. The presence of nonvolatile solute particles at the surface causes the boiling point of a solution to be raised. The boiling point of the liquid is the temperature at which the vapour pressure of the liquid equals the atmospheric pressure. In a solution, then, a higher temperature is needed to put enough solvent particles into the vapour phase to equal atmospheric pressure. The boiling point of a solution is, therefore, **_higher_** than that of the pure solvent.

The freezing point is the temperature at which the vapour pressure of the solid and liquid are equal. Since the addition of solute particles lowers the vapour pressure, the vapour pressures of the solid and liquid will be equal at a lower temperature. Solutions, then, will freeze at a **_lower_** temperature than the pure solvent alone.

$\Delta T_{FP} = (m)(K_{FP})$ $\Delta T_{BP} = (m)(K_{BP})$

ΔT_{FP} = the change in the freezing point ΔT_{BP} = the change in the boiling point
m = molality   m = molality
K_{FP} = the freezing point constant (of the solvent) K_{BP} = the boiling point constant (of the solvent)

Example: **Covalent solute** (does not dissociate)
If 85.0 g of sugar ($C_{12}H_{22}O_{11}$) are dissolved in 392 g of water, what will be the boiling point and freezing point of the resulting solution?

Example: **Ionic solute** (dissociates)

If 26.4 g of nickel(II) bromide are dissolved in 224 g of water, what will be the boiling point and freezing point of the resulting solution? Assume 100% dissociation and no interaction between ions.

Questions:

4. Compute the boiling and freezing points of the following solutions.
    a)   25.5 g of $C_7H_{11}NO_7S$ (4-nitro-2-toluenesulfonic acid dihydrate) in 100.0 g of water.
    b)   100.0 g of $C_{10}H_8O_6S_2$ (1,5-naphthalenedisulfonic acid) in 100.0 g of water.
    c)   21.6 g of nickel(II) sulfate in 100.0 g of water.
    d)   77.0 g of magnesium chlorate in 200.0 g of water.
    e)   41.3 g of $C_{15}H_9NO_4$ (2-methyl-1-nitroanthraquinone) in 100.0 g of $C_6H_5NO_2$ (nitrobenzene).
    f)   97.5 g of $C_{12}H_{22}O_{11}$ (sucrose) in 185 g of water.
    g)   14.0 g of $C_{10}H_8$ (naphthalene) in 25.0 g of C_6H_6 (benzene).
    h)   250.0 g of $C_7H_4BrNO_4$ (3-bromo-2-nitrobenzoic acid) in 500.0 g of C_6H_6 (benzene)
    i)   60.0 g of C_9H_{18} (propylcyclohexane) in 100.0 g of acetic acid.

Experimental Determination of Molecular Mass From Freezing Point and/or Boiling Point

Molecular mass of a solute may be determined by using boiling point elevation or freezing point depression. A known mass of the solute is added to a known mass of a solvent. The resulting shift in the boiling or freezing point is then measured.

Example: 99.0 g of nonionizing solute are dissolved in 669 g of water, and the freezing point of the resulting solution is –0.960°C. What is the molecular mass of the solute?

Questions

5. Calculate the molecular mass of the nonionic solutes.
   a) 8.02 g of solute in 861 g of water lower the freezing point to –0.430°C.
   b) 64.3 g of solute in 390.0 g of water raise the boiling point to 100.680°C.
   c) 20.8 g of solute in 128 g of acetic acid lower the freezing point to 13.5°C.
   d) 10.4 g of solute in 164 g of phenol lower the freezing point to 36.3°C.
   e) 2.53 g of solute in 63.5 g of nitrobenzene lower the freezing point to 3.40°C.
   f) 5.60 g of solute in 104 g of water lower the freezing point to –0.603°C.

Molal Freezing and Boiling Point Constants (in °C/mol/1000 g solvent)				
Substance	Freezing Point (°C)	Molal Freezing Point Constant	Boiling Point (°C)	Molal Boiling Point Constant
Acetic Acid	16.604	–3.90	117.9	3.07
Benzene	5.5	–4.90	80.1	2.53
Camphor	198.8	–37.7	204	5.95
Cyclohexane	6.55	–20.0	80.74	2.79
Nitrobenzene	5.7	–7.00	210.8	5.24
Phenol	43	–7.40	181.75	3.56
Water	0.00	–1.86	100.00	0.512