

For the sake of clarity, in some applications this may be written as “% w/w,” where w stands for “weight,” a substitute for mass. For example, a toothpaste tube may be labeled “0.5% sodium fluoride %w/w.”

Molarity

In scientific applications, chemists are not interested in the grams present but rather in the moles present. Remember, the number of moles represents the number of molecules, not their mass. Since the solute molecules are the most important, it is the solute moles that are calculated (by dividing the mass of solute, in grams, by the molar mass of the solute, in grams per mole). The easily measured unit for a liquid solution is the volume of that solution in liters, and so **molarity** is expressed as moles of solute in 1 liter (exactly) of solution. For example, a solution containing 5.85 grams of sodium chloride (molar mass = 58.5 g/mol) in 1 liter (exactly) of a salt solution has a concentration of 0.100 *M*. The *M* stands for the unit of molarity (moles/liter).

Molality

Some of the physical properties of solutions, such as boiling point or freezing point, are dependent on the relative numbers of moles of solute and solvent. These properties are called **colligative properties**. A unit known as **mole fraction** expresses this exactly. However, chemists decided they needed a simpler way to communicate how properties change with concentration. For a specific solvent, the mass present is a direct measure of the number of moles, and so the **molality** unit was developed by using a fixed mass of solvent. Concentration in molality units is the number of moles of solute dissolved in 1 kilogram (exactly) of solvent. Molality tracks physical properties in a linear manner. As an example, consider that if a 0.100 molal solution of sugar in water freezes at $-0.186\text{ }^{\circ}\text{C}$, a solution that is 0.200 molal will freeze at $2 \times (-0.186) = -0.372\text{ }^{\circ}\text{C}$.

Raoult's Law and Colligative Properties

Colligative properties of solutions are properties that depend on the amounts of substances present, i.e., the concentrations of solutions. These properties include boiling point (temperature), freezing point, and osmotic pressure. The French chemist François Raoult (1830–1901) formulated specific rules to explain this behavior, and these rules became known as Raoult's law. Raoult established that the key factor determining



Reverse osmosis was selected as the desalination method for the desalination plant in Carlsbad, California.

the physical properties of a solution was the relative number of moles of solute in the solution.

For example, if you dissolve 1.80 grams (0.010 mol) of glucose ($\text{C}_6\text{H}_{12}\text{O}_6$, molar mass = 180 g/mol) in 1 kilogram of water, you will change the freezing point of the water from $0.0000\text{ }^{\circ}\text{C}$ to $-0.0186\text{ }^{\circ}\text{C}$, and if you add ten times that amount (18.0 grams or 0.10 mol), you will change the freezing point by ten times as much, or to $-0.186\text{ }^{\circ}\text{C}$. If you use any other kind of sugar, you will get the same effect from 0.01 mol or 0.10 mol; the chemical doesn't matter, only the moles do. The same impact is seen on the boiling point, except that the temperature at which the solution boils is raised, rather than lowered, by a fixed (but different) amount.

The explanation for this change in melting or boiling point lies in the effect that any solute has on the vapor pressure of a solvent as is shown in the phase diagram in Figure 56.

The solute particles interfere with the ability of solvent molecules to enter the vapor phase, thus shifting the temperatures at which the phase changes will be observed. The diagram shows the shifts in the freezing point, ΔT_f , and boiling point, ΔT_b , of a solution compared to the pure solvent.

However, an intriguing effect is observed when salts are dissolved in water. In such cases, larger than expected changes occur, given the number of moles added. For example, 1 mole of sodium chloride, NaCl, added to water causes a change in boiling point twice the amount that would otherwise be expected. This increase is readily explained since NaCl completely ionizes in water, forming Na^+ and Cl^- ions. Thus,

FIGURE 68

1 1A											13 3A	14 4A	15 5A	16 6A	17 7A	18 8A				
1 H +1 -1											5 B +3	6 C +4 +2 -4	7 N +5 +4 +3 +2 +1 -3	8 O +2 -1/2 -1 -2	9 F -1	10 Ne				
2 2A	3 Li +1	4 Be +2											11 Na +1	12 Mg +2	13 Al +3	14 Si +4 -4	15 P +5 +3 -3	16 S +6 +4 +2 -2	17 Cl +7 +6 +5 +4 +3 +1 -1	18 Ar
		3 3B	4 4B	5 5B	6 6B	7 7B	8 8B		9 9B	10 10B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A		
	19 K +1	20 Ca +2	21 Sc +3	22 Ti +4 +3 +2	23 V +5 +4 +3 +2	24 Cr +6 +5 +4 +3 +2	25 Mn +7 +6 +4 +3 +2	26 Fe +3 +2	27 Co +3 +2	28 Ni +2	29 Cu +2 +1	30 Zn +2	31 Ga +3	32 Ge +4 -4	33 As +5 +3 -3	34 Se +6 +4 -2	35 Br +5 +3 +1 -1	36 Kr +4 +2		
	37 Rb +1	38 Sr +2	39 Y +3	40 Zr +4	41 Nb +5 +4	42 Mo +6 +4 +3	43 Tc +7 +6 +4	44 Ru +8 +6 +4 +3	45 Rh +4 +3 +2	46 Pd +4 +2	47 Ag +1	48 Cd +2	49 In +3	50 Sn +4 +2	51 Sb +5 +3 -3	52 Te +6 +4 -2	53 I +7 +5 +1 -1	54 Xe +6 +4 +2		
	55 Cs +1	56 Ba +2	57 La +3	72 Hf +4	73 Ta +5	74 W +6 +4	75 Re +7 +6 +4	76 Os +8 +4 +3	77 Ir +4 +3	78 Pt +4 +2	79 Au +3 +1	80 Hg +2 +1	81 Tl +3 +1	82 Pb +4 +2	83 Bi +5 +3	84 Po +2	85 At -1	86 Rn		

Possible oxidation numbers for the elements.

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relationship applying rules (5) and (6). For example, in the neutral compound potassium permanganate, KMnO_4 , using rules (1) and (2), K is +1 and O is -2. So, to determine the oxidation number of the Mn, we can let Mn be x , and we can set up the equation: $1 + x + 4(-2) = 0$. Therefore, $x = +7$.

Once oxidation numbers are determined, it is then possible to determine how many electrons are involved in changing from one form of an atom to another. For instance, if during a reaction Ag^+ ($\text{Ag} = +1$) is changing to Ag ($\text{Ag} = 0$), a one-electron change is observed as one electron must be added to reduce the positive silver ion (cation) to its neutral atom.