“ppm” and related units for liquids and solids (but not for gases!)

LIQUIDS

1. A liquid sample (or a solution) is made up of the solute, the minor component that is dissolved, and the solvent, the dissolving medium. Common environmental samples include river water, seawater, groundwater, rainwater.

2. Commonly encountered concentration units for solutions:
   A. MOLE and VOLUME: e.g.,
   (mol solute)/(L solution) = molarity = M
   (mmol solute)/(L solution) = mM = 10^{-3} M
   (μmol solute)/(L solution) = μM = 10^{-6} M
   (nmol solute)/(L solution) = nM = 10^{-9} M, etc.

   B. MASS and VOLUME: e.g.,
   (g solute)/(L solution)
   (mg solute)/(L solution)
   (μg solute)/(L solution)
   (ng solute)/(L solution)

   C. MASS and MASS: e.g.,
   (g solute)/(kg solution)
   (mg solute)/(kg solution) = ppm (parts per million; 10^6)
   (μg solute)/(kg solution) = ppb (parts per billion; 10^9)
   (ng solute)/(kg solution) = ppt (parts per trillion; 10^{12})

3. It is convenient to express concentrations of dilute solutions using parts per million. For liquids, “part” can be expressed in any unit of mass, given that the same unit is used for the solute and solution. For example, if a drinking water has a Pb content of 1 ppm, it means that there is 1 μg of Pb in every 10^6 μg of drinking water, or 1 ton of Pb in every 10^6 tons of drinking water. It simply means that the ratio of the mass of Pb to the mass of water is one to a million:

\[
1 \text{ppm Pb in drinking water} = \frac{1 \mu g \text{ of Pb}}{10^6 \mu g \text{ water}} = \frac{1 \mu g \text{ of Pb}}{1 \text{ g water}} = \frac{1 \text{ mg Pb}}{10^6 \text{ mg water}} = \frac{1 \text{ mg Pb}}{1 \text{ kg water}}, \text{ etc.}
\]

4. The density of freshwater is very close to 1 g mL^{-1}. Therefore, 2-B and 2-C are ~equivalent and often used interchangeably:

1 g water ≈ 1 mL of water
1 kg of water ≈ 1000 mL of water = 1 L of water

1 ppm of Pb in tapwater then becomes:

\[
1 \text{ppm Pb in tapwater} = \frac{1 g \text{ of Pb}}{10^6 g \text{ water}} = \frac{1 g \text{ of Pb}}{10^6 mL \text{ water}} = \frac{1 \text{ mg Pb}}{1 \text{ L water}}, \text{ etc.}
\]

SOLIDS

1. Solid environmental samples include soils, plant tissue, animal tissue, food. Concentrations of various substances are commonly expressed in units of (mass anlayte)/(mass sample); see 2-C above.

2. You can express dilute concentrations of any given analyte in a solid using the same rule as described in #3 for liquids (“solute and solution” now becomes “analyte and solid sample”)

CHEM/ENVS 380
“ppm” and related units for gases (but not for liquids and solids!)

Gases behave differently from liquids and solids. Gases are usually not quantified by weight as is the case for liquid and solids, but by volume, moles (or molecules), or pressure.

Most commonly used dimensionless "parts per" units for concentrations in samples of gas:

- parts-per-million volume = ppmv (or ppm)
- parts-per-billion volume = ppbv (or ppb)
- parts-per-trillion volume = pptv (or ppt)

Note that the “v” at the end stands for “volume” and re-enforces the fact that these gas concentrations are expressed as ratios of volumes, moles, molecules, or partial pressure (all inter-related) and not in mass.

Many gases in the atmosphere show properties similar to those of an ideal gas. In other words, they obey (not strictly, but close enough) the Ideal Gas Law:

\[ PV = nRT \]

where \( R \) is Gas Constant, \( 0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1} \)

\( P \) is pressure (atm)
\( V \) is volume (L)
\( T \) is temperature (K)
\( n \) is moles

This means that the volume \( V \) of a gas \( G \) in an air sample is related to the number of moles \( n \) of \( G \), and the partial pressure exerted by \( G \) at a given temperature \( T \). Use this relationship to manipulate “parts-per” units to whatever other units of your liking.

The concentration of a pollutant gas (called “G”) in the atmosphere is \( X \) ppm. This is equivalent to:

\[ X \text{ ppm} = \frac{X \text{ molecules} G}{10^6 \text{ molecules air}} = \frac{X \text{ cm}^3 G}{10^6 \text{ cm}^3 	ext{ air}} = \frac{X \text{ atm} G}{10^6 \text{ atm air}} = \text{etc...} \]

The concentration of CO\(_2\) in the atmosphere is about 400 ppm. This is equivalent to:

\[ 400 \text{ pp m CO}_2 = \frac{400 \text{ mol CO}_2}{10^6 \text{ mol air}} = \frac{400 \text{ molecules CO}_2}{10^6 \text{ molecules air}} = \frac{400 \text{ L CO}_2}{10^6 \text{ L air}} = \frac{400 \times 10^{-6} \text{ atm CO}_2}{1 \text{ atm air}} = \text{etc...} \]

Take a step further. Suppose you have 1 L of air sample (at 25°C at 1 atm pressure), and you want to know how many grams of CO\(_2\) are present in it. If the CO\(_2\) concentration is 400 ppm, we see in the equation above that you will find 400 moles of CO\(_2\) in \( 10^6 \) moles of this air. You can figure out the mass of 400 moles of CO\(_2\) using the molecular weight of CO\(_2\):

mass of 400 moles of CO\(_2\) = \( 400 \text{ mol CO}_2 \times (44 \text{ g/mol CO}_2) = 1.7600 \times 10^4 \text{ g CO}_2 \)

Next, using the Ideal Gas Law, you can find out what volume \( 10^6 \) moles of air occupies at 25°C and at 1 atm pressure:

\[ V_{air} = \frac{nRT}{P} = \frac{(10^6 \text{ mol air})(0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1})(298 \text{ K})}{1 \text{ atm}} = 24.47 \times 10^6 \text{ L} \]

We now know that in 24.47 x \( 10^6 \) L of air, you will find 1.7600 x \( 10^4 \) g of CO\(_2\) if the concentration of CO\(_2\) is 400 ppm (at 25°C and at 1 atm pressure). So, in 1 L of this air, simply divide 1.7600 x \( 10^4 \) g of CO\(_2\) by 24.47 x \( 10^6 \) L of air to get 7.19 x \( 10^4 \) g CO\(_2\)/L air.
**Practice Problems**

**Practice problem-1:** Assume that the concentration of cadmium in a given tap water is 2.0 ppb, and that its average concentration in various Cd-containing foods (such as rice, potatoes, green leafy vegetables, offal) is 30.0 ppb. If a person ingests 2.0 L of tap water and 1.0 kg of Cd-containing foods daily, how much of the metal does this person ingest daily? What fraction is coming from foods as opposed to water?

**Practice problem-2:** The acceptable daily intake of a toxin “Tox” is 10 µg per day for an adult weighing 60 kg. If the concentration of Tox in striped bass is 0.2 ppm, how much of this fish can an adult weighing 60 kg eat daily without exceeding this limit?

**Practice problem-3:** A sample of San Francisco city tap water was found to contain fluoride (F) at a concentration of 49.85 µmol L⁻¹. Assuming that the density of tap water is 1.00 g mL⁻¹, re-express this value in units of (a) ppm and (b) ppb. The molar mass of F is 19.00 g mol⁻¹.

**Practice problem-4:** 6.481 mg of lead (Pb) was extracted from 1.035 g of paint chips sampled from the exterior of a building constructed in the 1950s. What is the concentration of Pb in this paint chip sample in units of (a) %, and (b) ppm?

**Practice problem-5:** The concentration of CO₂ in the atmosphere is currently about 400 ppm.

(a) If you have an air sample in a container having total pressure of 1 atm, what is the partial pressure exerted by CO₂ in your sample?

(b) If your sample of air contained a total of 2 million gas molecules, how many of them will be CO₂?

(c) The molecular weight of CO₂ is 44 g mol⁻¹. What is the mass of CO₂ in your sample?

**Practice problem-6:** A sample of air has a volume of 25 cm³. Concentration of pollutant P in this sample is 12 ppm. How many cm³ of P is present in this sample?

**Practice problem-7:** If P from problem-6 has a molecular weight of 36 g mol⁻¹, how many grams of P are present in the sample described in problem-4? Assume 1 atm pressure and 25°C.