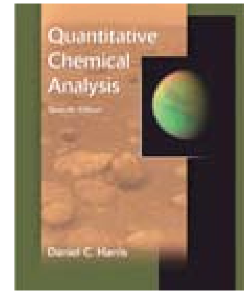
# Quantitative Chemical Analysis

# Welcome to Analytical Chemistry

**The textbook for this course is**

***Quantitative Chemical Analysis***
***Seventh Edition***

**by Dan Harris**



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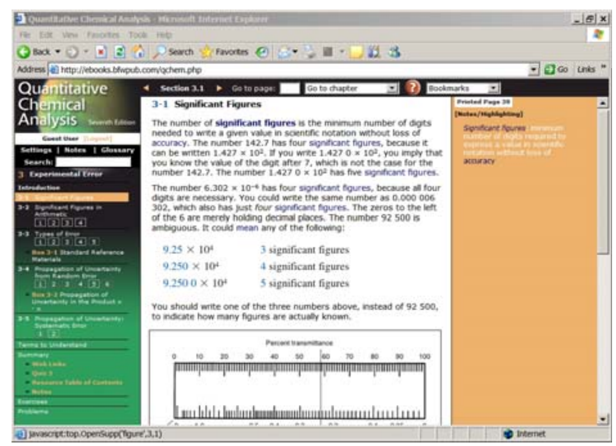

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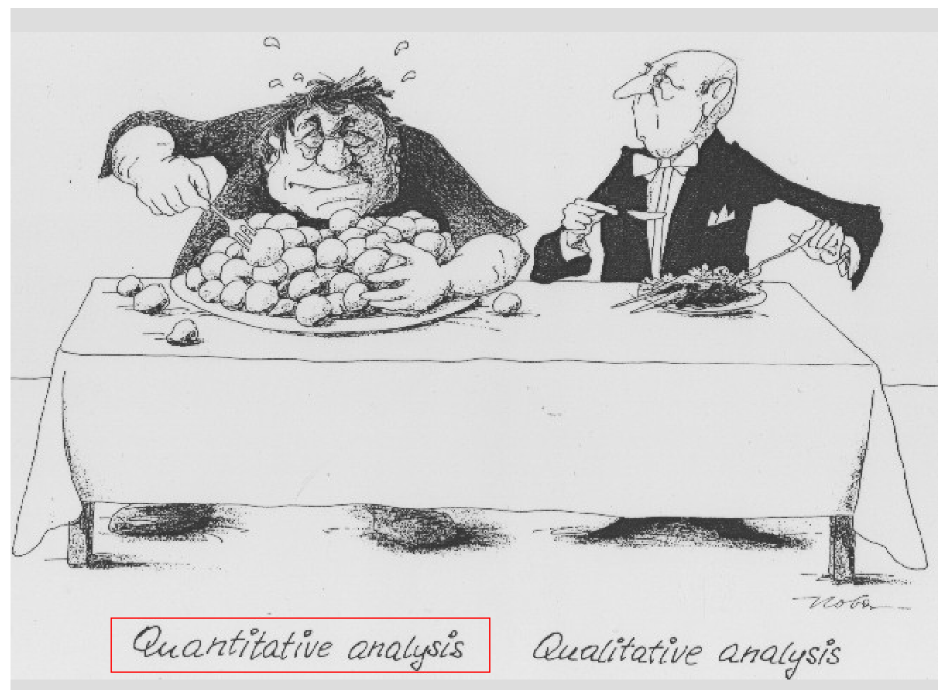
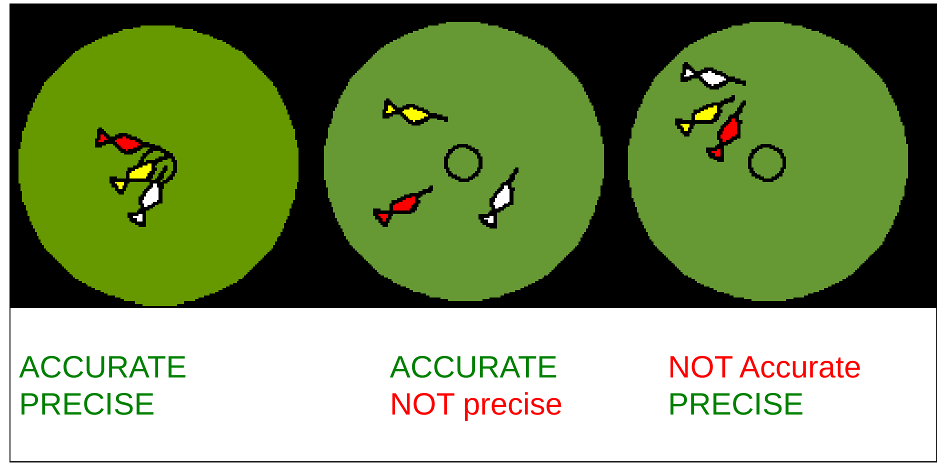


# Numbers count

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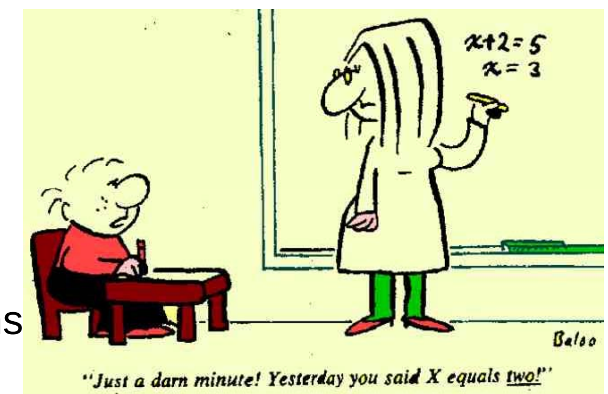
## Required math skills:

- Add
- Subtract
- Multiply
- Divide
- Powers
- Logarithms




- Orders of magnitude
- Estimation
- Units
- Conversions
- Powers of 10
- Prefixes
- Errors
- Statistics

*Estimation and orders of magnitude:*

How many piano tuners are there in Chicago?

*Estimation and orders of magnitude:*

What is the national debt?

*Estimation and orders of magnitude:*

What is the world population?

*Estimation and orders of magnitude:*

# How many water molecules in 1000 droplets?

*Estimation and orders of magnitude:*

A cube – 1” on a side → $(2.6)^3$ $cm^3$ ~ 18 cc

18 cc = 18 cc (1 g/1 cc) = 18 g

18 g = 18 g (1 molecule/ (18 x $1.66 \times 10^{-24}$ g)) = 6.022 x $10^{23}$ molecules

*Estimation and orders of magnitude: powers of 10*

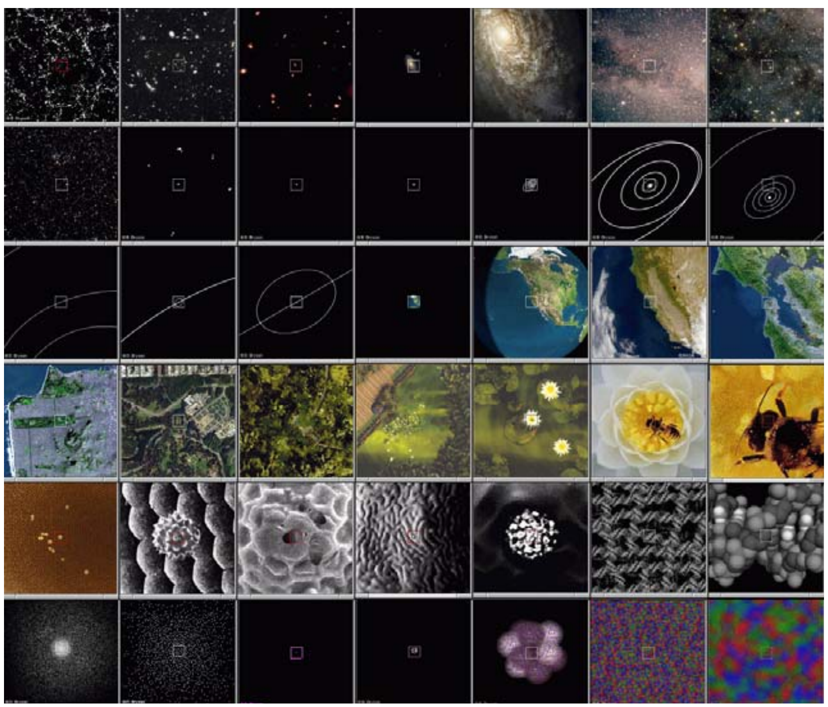


**Table 1-3 Prefixes**

| Prefix | Symbol | Factor | Prefix | Symbol | Factor |
|---|---|---|---|---|---|
| yotta | Y | $10^{24}$ | deci | d | $10^{-1}$ |
| zetta | Z | $10^{21}$ | centi | c | $10^{-2}$ |
| exa | E | $10^{18}$ | milli | m | $10^{-3}$ |
| peta | P | $10^{15}$ | micro | μ | $10^{-6}$ |
| tera | T | $10^{12}$ | nano | n | $10^{-9}$ |
| giga | G | $10^{9}$ | pico | p | $10^{-12}$ |
| mega | M | $10^{6}$ | femto | f | $10^{-15}$ |
| kilo | k | $10^{3}$ | atto | a | $10^{-18}$ |
| hecto | h | $10^{2}$ | zepto | z | $10^{-21}$ |
| deca | da | $10^{1}$ | yocto | y | $10^{-24}$ |

Table 1-3
*Quantitative Chemical Analysis, Seventh Edition*

**Table 1-1 Fundamental SI units**

| Quantity | Unit (symbol) | Definition |
|---|---|---|
| Length | meter (m) | One meter is the distance light travels in a vacuum during $\frac{1}{299\,792\,458}$ of a second. |
| Mass | kilogram (kg) | One kilogram is the mass of the prototype kilogram kept at Sèvres, France. |
| Time | second (s) | One second is the duration of 9 192 631 770 periods of the radiation corresponding to a certain atomic transition of $^{133}Cs$. |
| Electric current | ampere (A) | One ampere of current produces a force of $2 \times 10^{-7}$ newtons per meter of length when maintained in two straight, parallel conductors of infinite length and negligible cross section, separated by 1 meter in a vacuum. |
| Temperature | kelvin (K) | Temperature is defined such that the triple point of water (at which solid, liquid, and gaseous water are in equilibrium) is 273.16 K, and the temperature of absolute zero is 0 K. |
| Luminous intensity | candela (cd) | Candela is a measure of luminous intensity visible to the human eye. |
| Amount of substance | mole (mol) | One mole is the number of particles equal to the number of atoms in exactly 0.012 kg of $^{12}C$ (approximately $6.022\,141\,5 \times 10^{23}$). |
| Plane angle | radian (rad) | There are $2\pi$ radians in a circle. |
| Solid angle | steradian (sr) | There are $4\pi$ steradians in a sphere. |

Table 1-1
*Quantitative Chemical Analysis, Seventh Edition*


**Table 1-2 SI-derived units with special names**

| Quantity | Unit | Symbol | Expression in terms of other units | Expression in terms of SI base units |
|---|---|---|---|---|
| Frequency | hertz | Hz | | l/s |
| Force | newton | N | | $m \cdot kg/s^2$ |
| Pressure | pascal | Pa | $N/m^2$ | $kg/(m \cdot s^2)$ |
| Energy, work, quantity of heat | joule | J | $N \cdot m$ | $m^2 \cdot kg/s^2$ |
| Power, radiant flux | watt | W | J/s | $m^2 \cdot kg/s^3$ |
| Quantity of electricity, electric charge | coulomb | C | | $s \cdot A$ |
| Electric potential, potential difference, electromotive force | volt | V | W/A | $m^2 \cdot kg/(s^2 \cdot A)$ |
| Electric resistance | ohm | Ω | V/A | $m^2 \cdot kg/(s^2 \cdot A^2)$ |
| Electric capacitance | farad | F | C/V | $s^4 \cdot A^2/(m^2 \cdot kg)$ |

Table 1-2
*Quantitative Chemical Analysis, Seventh Edition*


**Table 1-4 Conversion factors**

| Quantity | Unit | Symbol | SI equivalent[a] |
|---|---|---|---|
| Volume | liter | L | $*10^{-3} m^3$ |
| | milliliter | mL | $*10^{-6} m^3$ |
| Length | angstrom | Å | $*10^{-10} m$ |
| | inch | in. | *0.025 4 m |
| Mass | pound | lb | *0.453 592 37 kg |
| | metric ton | | *1 000 kg |
| Force | dyne | dyn | $*10^{-5} N$ |
| Pressure | bar | bar | $*10^{5} Pa$ |
| | atmosphere | atm | *101 325 Pa |
| | torr (= 1 mm Hg) | Torr | 133.322 Pa |
| | pound/in.$^2$ | psi | 6 894.76 Pa |
| Energy | erg | erg | $*10^{-7} J$ |
| | electron volt | eV | $1.602\,176\,53 \times 10^{-19} J$ |
| | calorie, thermochemical | cal | *4.184 J |
| | Calorie (with a capital C) | Cal | *1000 cal = 4.184 kJ |
| | British thermal unit | Btu | 1 055.06 J |
| Power | horsepower | | 745.700 W |
| Temperature | centigrade (= Celsius) | °C | *K − 273.15 |
| | Fahrenheit | °F | *1.8(K − 273.15) + 32 |

*a. An asterisk (*) indicates that the conversion is exact (by definition).*

Table 1-4
*Quantitative Chemical Analysis, Seventh Edition*


## Chemical concentrations

**Molarity** = Moles of solute/Liters of Solution (M)

**Molality** = Moles of solute/Kg of Solvent (m)

**Mole Fraction** = Moles solute/total number of moles

**Mass %** = Mass solute/total mass x 100

**Volume %** = volume solute/total volume x 100

**ppm** = parts per million *
**ppb** = parts per billion *

** mass for solutions, volume for gasses*

## Chemical concentrations

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**ppm** = parts per million *
**ppb** = parts per billion *

* *mass for solutions, volume for gasses*


A sample of $NaNO_3$ weighing 8.5 grams is placed in a 500 ml volumetric flask and distilled water was added to the mark on the neck of the flask. Calculate the Molarity of the resulting solution.

Convert the given grams of solute to moles of solute by dividing by the molecular weight of $NaNO_3$: 1 mole $NaNO_3$ = Molecular mass of $NaNO_3$ expressed in grams = 23 + 14 + 3(16) = 85 grams

(8.5 grams $NaNO_3$) X (1 mole NaNO3 / 85 grams NaNO3) = 0.1 mole NaNO3

Convert given ml of solution to liters by dividing by 1000: 1 liter = 1000 ml

(500 ml) X (1 liter / 1000 ml) = 0.500 liters

Apply the definition for Molarity: Molarity = moles $NaNO_3$ / volume of the solution in liters

M = 0.1 mole / .500 liters = 0.200 Molar $NaNO_3$


## Chemical concentrations

**Molarity** = Moles of solute/Liters of Solution (M)

**Molality** = Moles of solute/Kg of Solvent (m)

**Mole Fraction** = Moles solute/total number of moles

**Mass %** = Mass solute/total mass x 100

**Volume %** = volume solute/total volume x 100

**ppm** = parts per million *
**ppb** = parts per billion *

* *mass for solutions, volume for gasses*

**Determine the molality of 3000 grams of solution containing 37.3 grams of Potassium Chloride KCl.**

**1. Convert grams KCl to moles KCl using the molecular weight of KCl**

**(37.3 grams KCl) X (1 mole KCl / 74.6 grams KCl) = 0.5 mole KCl**

**2. Determine the grams of pure solvent from the given grams of solution and solute**

**Total grams = 3000 grams = Mass of solute + Mass of solvent**

**Mass of pure solvent = (3000 - 37.3) gram**

**= 2962.7** gram

**3. Convert grams of solvent to kilograms**

**(2962.7 grams solvent) X (1 kg / 1000 grams) = 2.9627 kg**

**Determine the molality of 3000 grams of solution containing 37.3 grams of Potassium Chloride KCl.**

**4. Apply the definition for molality**

**molality = moles of KCl / kilograms of solvent =**

**0.5 / 2.9627 = <u>0.169 m</u>**

Chemical concentrations

**Molarity** = Moles of solute/Liters of Solution (M)

**Molality** = Moles of solute/Kg of Solvent (m)

**Mole Fraction** = Moles solute/total number of moles

**Mass %** = Mass solute/total mass x 100

**Volume %** = volume solute/total volume x 100

**ppm** = parts per million *

**ppb** = parts per billion *

** mass for solutions, volume for gasses*

**Determine the mole fraction of KCl in 3000 grams of aqueous solution containing 37.3 grams of Potassium Chloride KCl.**

**1. Convert grams KCl to moles KCl using the molecular weight of KCl**

**(37.3 grams KCl) X (1 mole KCl) / (74.6 grams KCl) = 0.5 mole KCl**

**2. Determine the grams of pure solvent water from the given grams of solution and solute**

**Total grams = 3000 grams = Mass of solute + Mass of water**

**Mass of pure solvent = (3000 - 37.3) gram**

**= 2962.7** gram

**Determine the mole fraction of KCl in 3000 grams of aqueous solution containing 37.3 grams of Potassium Chloride KCl.**

**3. Convert grams of solvent $H_2O$ to mols**
**(2962.7 grams water) X (1 mol / 18.0 grams) = 164.6 mols $H_2O$**

**4. Apply the definition for mole fraction mole fraction = moles of KCl / Total mols of KCl and water =**
**0.5 / (0.5 + 164.6) = 0.5 / 165.1 = <u>0.00303</u>**

Chemical concentrations

**Molarity** = Moles of solute/Liters of Solution (M)

**Molality** = Moles of solute/Kg of Solvent (m)

**Mole Fraction** = Moles solute/total number of moles

**Mass %** = Mass solute/<u>total</u> mass x 100

**Volume %** = volume solute/total volume x 100

**ppm** = parts per million *
**ppb** = parts per billion *

* *mass for solutions, volume for gasses*

**Determine the mass % of a NaCl solution if 58.5 grams of NaCl was dissolved in 50 ml of water (assume the density of water to be 1 g/ml)**

**Convert ml of water to grams**
**mass = (50 ml) X (1 g/ml) = 50 grams water**

**Determine total mass of solution**
**Mass of solution = mass of solute + mass of solvent = 58.5 + 50 = 108.5 g**

**Apply the definition of mass percent mass % =**
**58.5 (100) / 108.5 = <u>53.9% NaCl</u>**

Chemical concentrations

**Molarity** = Moles of solute/Liters of Solution (M)

**Molality** = Moles of solute/Kg of Solvent (m)

**Mole Fraction** = Moles solute/total number of moles

**Mass %** = Mass solute/total mass x 100

**Volume %** = volume solute/total volume x 100

**ppm** = parts per million *
**ppb** = parts per billion *

* *mass for solutions, volume for gasses*

**Assuming the density of water to be 1 g/mL we approximate the density of a dilute aqueous solution to be 1 g/mL**

→ **1 ppm = 1 µg/mL = 1 mg/L**

→ **1 ppb = 1 ng/mL = 1 µg/L**

**Determine the ppm of a NaCl solution if 58.5 grams of NaCl was dissolved in 50 ml of water (assume the density of water to be 1 g/ml)**

**Convert ml of water to grams**

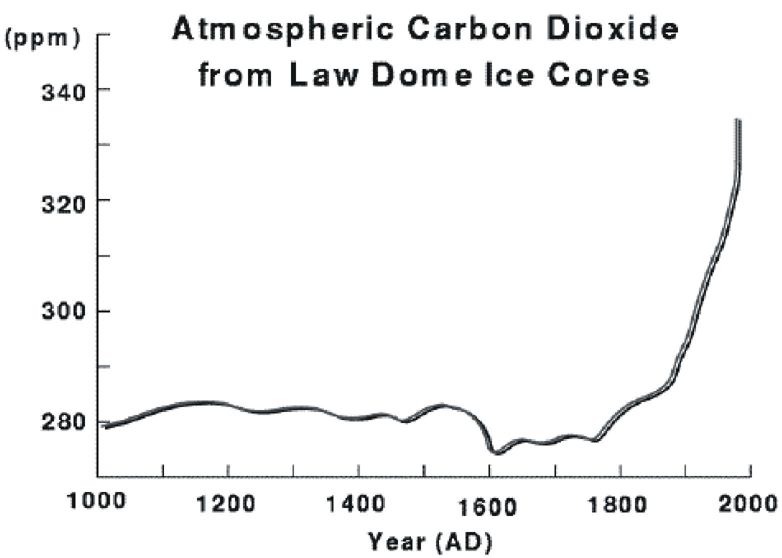
**mass = (50 ml) X (1 g/ml) = 50 grams water**

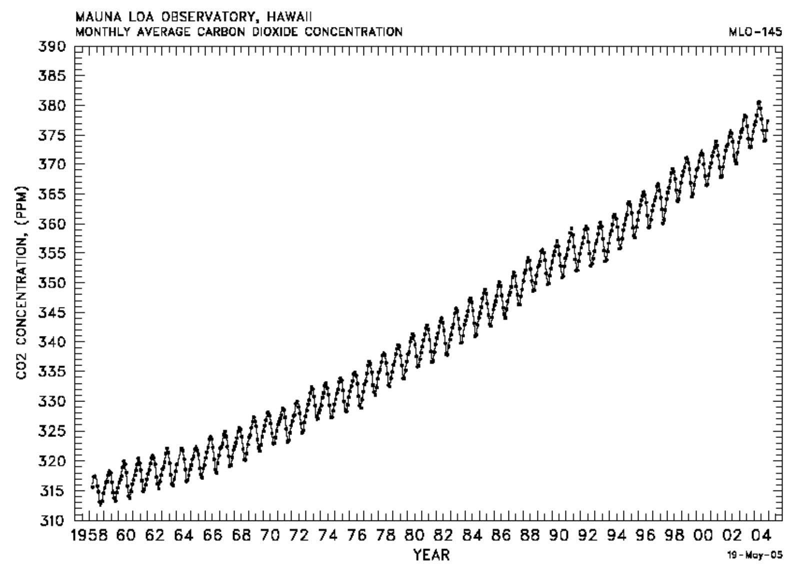
**Determine total mass of solution**

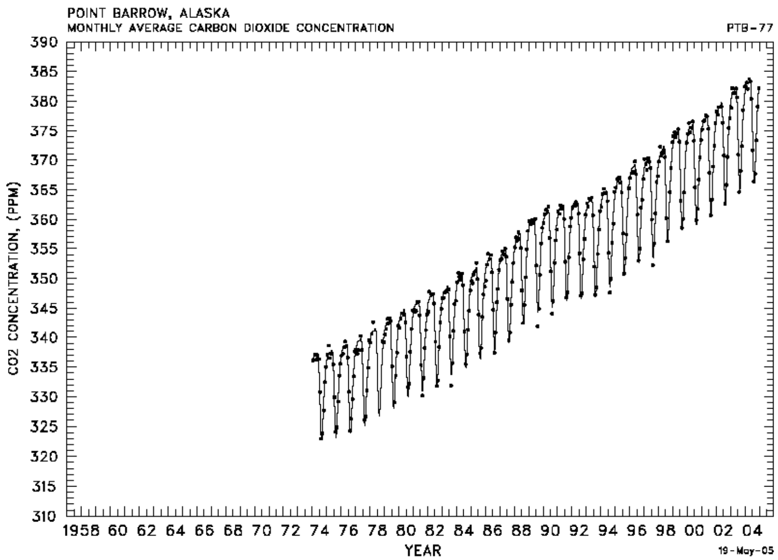
**Mass of solution = mass of solute + mass of solvent = 58.5 + 50 = 108.5 g**

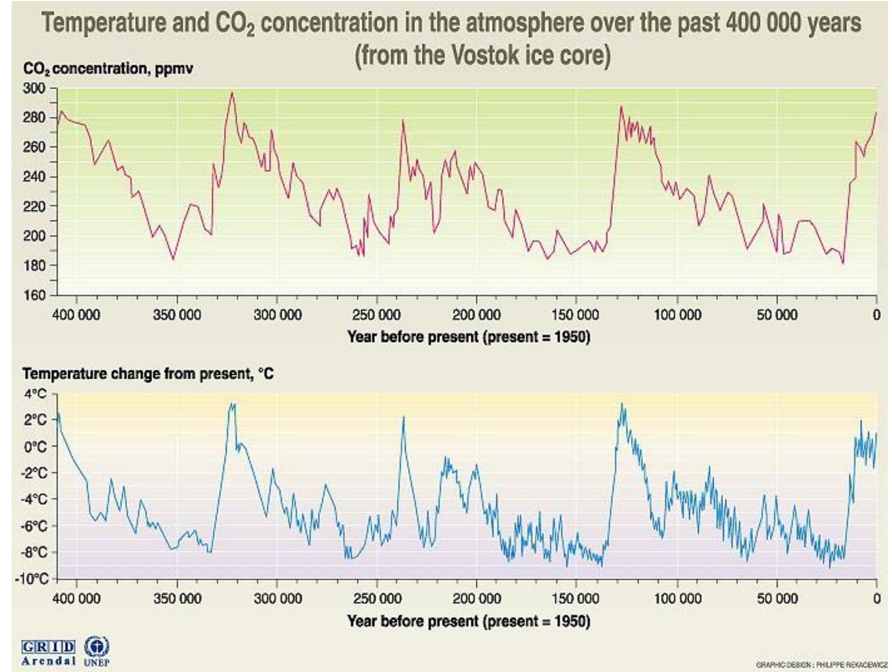
**Apply the definition of ppm**

**58.5 ($10^6$) / 108.5 = <u>5.39 x $10^5$ ppm NaCl</u>**






Source: J.R. Petit, J. Jouzel, et al. Climate and atmospheric history of the past 420 000 years from the Vostok ice core in Antarctica, Nature 399 (3JUne), pp 429-436, 1999.