Biological Chemistry Laboratory
Biology 3515/Chemistry 3515
Spring 2023

Lecture 2:
Units and Dimensions

Concentration and pH

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©David P. Goldenberg
University of Utah
goldenberg@biology.utah.edu

How to Succeed in this Class

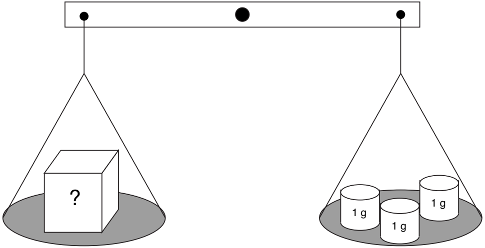
- Come to lectures *prepared to participate*.
  - Review the slides from the previous lecture.
  - Bring questions about what you don't understand.
- Participate in class.
- Come to lab sessions *prepared to work efficiently*.
  - Carefully read protocols ahead of time.
  - Thoughtfully write the protocol outlines.
- Make the most of the early labs and computer sessions.
  - First few weeks are designed to build skills.
  - Subsequent labs and lab reports will be much more challenging!
  - Mastering skills early will pay off!

How to Succeed in this Class

- Do the lab reports to learn.
  - Start early.
  - Work with a group.
  - Work with a group the smart way: Don’t rely on the “smart” person!
- Use the quizzes and exams from previous years to learn.
  - Answers will not be provided.
  - Work on your own to solve the problems.
  - Ask classmates, TAs and instructor for help.
- If you have questions or concerns come talk to me!

A Bit on Units and Conversion Factors

- All measurements are comparisons.



- Units of measurement are defined by the reference for comparison.
- Suppose that we want to use other units, such as mg or ounces? (what kind of ounces?)

Conversion Factors

- As instructions:
  - To convert from g to mg, multiply by 1,000
  - To convert from g to ounces (U.S.), divide by 28.349
- As equations:
  - $1\,\mathrm{g} = 1,000\,\mathrm{mg}$
  - $1\,\mathrm{oz} = 28.349\,\mathrm{g}$
- As ratios equal to 1:

$$\frac{1\,\mathrm{g}}{1,000\,\mathrm{mg}} = 1 \qquad \frac{1,000\,\mathrm{mg}}{1\,\mathrm{g}} = 1$$

$$\frac{1\,\mathrm{oz}}{28.349\,\mathrm{g}} = 1 \qquad \frac{28.349\,\mathrm{g}}{1\,\mathrm{oz}} = 1$$

We can always multiply or divide by 1 without changing anything!

Conversion by Multiplication (or Division?)

- Convert 3 g to ounces

  - Divide

$$3\,\mathrm{g} \div \frac{28.349\,\mathrm{g}}{1\,\mathrm{oz}} = 0.1\,\mathrm{oz}$$

  - or Multiply?

$$3\,\mathrm{g} \times \frac{28.349\,\mathrm{g}}{1\,\mathrm{oz}} = 85\,\mathrm{g}^2/\mathrm{oz}$$

- Units can be treated as algebraic entities (and should cancel sensibly in the result!)
- “Dimensional analysis” or “unit factor analysis”

Clicker Question #1

"English" units for mass:

- 1 Lb = 16 oz (avoirdupois)
- 1 oz = 28.349523125 g
- 1 stone = 14 Lb

If someone weighs 11 stone, what is that person's mass in kg?

A) $\sim 50\,\mathrm{kg}$

B) $\sim 70\,\mathrm{kg}$

C) $\sim 90\,\mathrm{kg}$

D) $\sim 110\,\mathrm{kg}$

Stones to kg

$$11\,\text{stone} \times 14\,\text{Lb/stone} = 154\,\text{Lb}$$

$$154\,\text{Lb} \times 16\,\text{oz/Lb} = 2.46 \times 10^3\,\text{oz}$$

$$2.46 \times 10^3\,\text{oz} \times 28.35\,\text{g/oz} = 6.98 \times 10^4\,\text{g}$$

$$6.98 \times 10^4\,\text{g} \div 1000\,\text{g/kg} \approx 70\,\text{kg}$$

$$1\,\text{kg} \approx 2.2\,\text{Lb}$$

Units of Concentration

- Most convenient: amount of solute per volume of solution
  - g/L (= mg/mL): 1 g solute in 1 L final volume of solution
  - molar (M) = mole/L: 1 mole of solute in 1 L final volume of solution
- What is a mole?

  1 mole = amount of a substance containing Avogadro's number, N_A, of atoms or molecules
- What is Avogadro's number?
  - Before 20 May 2019: N_A = the number of atoms in 12 g of pure ^{12}C.
  - After 20 May 2019: $N_A = 6.02214076 \times 10^{23}\ \mathrm{mol}^{-1}$, exactly!

  Definition of the kilogram was also changed, as of 20 May 2019.

Silicon Sphere Used to Establish Avogadro's Number (1 of 2)

- 99.995% pure ^{28}Si, determined by mass spectrometry.
- World's roundest and most precisely measured objects. Cost about $3.2 million.
- Atomic spacings determined by X-ray crystallography.

Cho, A. (2018). World poised to adopt new metric units. *Science*, 362, 625–626.
http://doi.org/10.1126/science.362.6415.625
Photograph from the Physikalisch-Technische Bundesansttalt (PTB), Germany.

Units of Concentration

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- Some less commonly used units of concentration:
  - molal: 1 mole of solute dissolved in 1 kg solvent
  - 1%(m/v): 1 g solute in 100 mL final volume of solution
  - 1%(v/v): 1 mL pure liquid in 100 mL final volume of solution

A Source of Confusion: Units for “Molecular Weight”

- Molecular weight or molecular mass:
  - The mass of a single molecule
  - Units: atomic mass unit (u or amu) *or* dalton (Da) or kilodalton (kDa)

    1 amu = 1 Da = mass of one atom of $^{12}C \div 12$
  - Units are often not included, because it is a relative mass, M_r.
  - amu is commonly used in mass spectrometry
  - Da and kDa are very commonly used in biochemistry and molecular biology, especially for proteins and other macromolecules.
- Molar mass:
  - Mass of one mole of a compound
  - Units: g/mol (which doesn’t completely make sense)
- Molecular mass of 100 Da $\longrightarrow$ molar mass of 100 g/mol

To Calculate the Amount of Solute in a Solution

- The number of grams in 53 mL of a 5 g/L solution:

$$53\,\text{mL} \times 0.001\,\text{L}/\text{mL} = 0.053\,\text{L}$$
$$0.053\,\text{L} \times 5\,\text{g}/\text{L} = 0.26\,\text{g}$$

- The number of moles in 1.3 L of a 15 mM solution ($1\,\text{mM} = 0.001\,\text{M}$):

$$15\,\text{mM} \times 0.001\,\text{M}/\text{mM} = 0.015\,\text{M} = 0.015\,\text{mol}/\text{L}$$
$$1.3\,\text{L} \times 0.015\,\text{mol}/\text{L} = 0.0195\,\text{mol}$$

- The number of molecules in 1.3 L of a 15 mM solution:

$$1\,\text{mol} = 6.02 \times 10^{23}\,\text{molecules}$$
$$0.0195\,\text{mol} \times 6.02 \times 10^{23}\,\text{molecules}/\text{mol} = 1.17 \times 10^{22}\,\text{molecules}$$

Clicker Question #2

How many moles of water molecules ($M_\mathrm{r} = 18$) are in 1 L ($\approx 1000\,\mathrm{g}$)?

A) ~ 10

B) ~ 30

C) ~ 50

D) ~ 70

How Many Moles of Water in 1 L?

- Liters to grams:

$$1\,\mathsf{L} \times 1,000\,\mathsf{ml/L} = 1,000\,\mathsf{mL}$$

$$1,000\,\mathsf{mL} \times 1\,\mathrm{g}/\mathsf{mL} = 1,000\,\mathrm{g}$$

- Grams to moles:

$$\begin{aligned} 1,000\,\mathrm{g} \div 18\,\mathrm{g}/\mathsf{mol} &= 1,000\,\mathrm{g} \times 1\,\mathsf{mol}/(18\,\mathrm{g}) \\ &= 56\,\mathsf{mol} \end{aligned}$$

Other Units of Concentration Commonly Used in Biochemistry

- Based on molar units:
  - 1 mM = 1×10^{-3} M
  - 1 μM = 1×10^{-6} M = 1×10^{-3} mM
  - 1 nM = 1×10^{-9} M = 1×10^{-3} μM
  - 1 pM = 1×10^{-12} M = 1×10^{-3} nM
- Based on mass units:
  - 1 mg/mL = 1 g/L
  - 1 μg/mL = 1×10^{-3} mg/mL = 1×10^{-3} g/L
  - 1 μg/μL = 1 mg/mL = 1 g/L

A Special Measure of Concentration for Hydrogen Ions

- Hydrogen ion concentration expressed as pH

$$\mathrm{pH} = -\log{[\mathrm{H}^+]}$$

  with $[\mathrm{H}^+]$ expressed in molar units

- To convert from pH to molar concentration:

$$[\mathrm{H}^+] = 10^{-\mathrm{pH}}\mathrm{M}$$

- Why does H^+ concentration get special treatment?

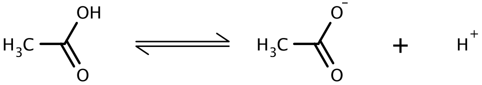
H^+ Concentration Determines Equilibria Between Protonated and De-protonated Species

- General representation of an acid-base equilibrium:

$$AH \rightleftharpoons A^- + H^+$$

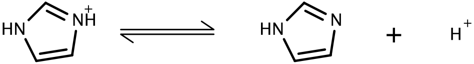
- Brønsted definition of acids and bases:
  - Acids release H^+ ions to solution. (AH)
  - Bases accept H^+ ions from solution. (A^-)

- Some examples:
  - Acetic acid/acetate



(AH) (A^-)

  - Imidazole



(AH) (A^-)

- Chemical properties of protonated and de-protonated functional groups are radically different!

The Equilibrium Between Protonated and De-protonated Species Also Depends on Affinity for H^+ Ions

$$AH \rightleftharpoons A^- + H^+$$

- The acid dissociation constant:

$$K_a = \frac{[H^+][A^-]}{[HA]}$$

  A **large** value of K_a means that HA likes to give up its H^+.

- Commonly expressed in logarithmic form:

$$pK_a = -\log K_a$$

  by analogy to pH:

$$pH = -\log [H^+]$$

  But, don't confuse pK_a and pH!

  A **small** value of pK_a means that HA likes to give up its H^+.

Why pH Requires Special Attention

- Why not just add H^+ ions to the desired concentration?
  - The H^+ concentration is usually very low. pH 7 $\rightarrow 10^{-7}$ M
  - Adding H^+ ions will shift equilibria:

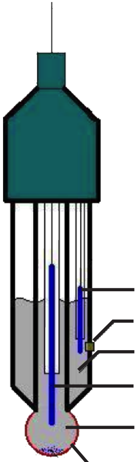
$$H^+ + A^- \rightleftharpoons AH$$

$$H^+ + OH^- \rightleftharpoons H_2O$$

  Generally, the H^+ concentration will increase less than expected from the addition of H^+.

- Two special means of dealing with pH:
  - pH meter, directly measures pH of solution
  - pH buffers, compounds added to solutions to establish and maintain pH

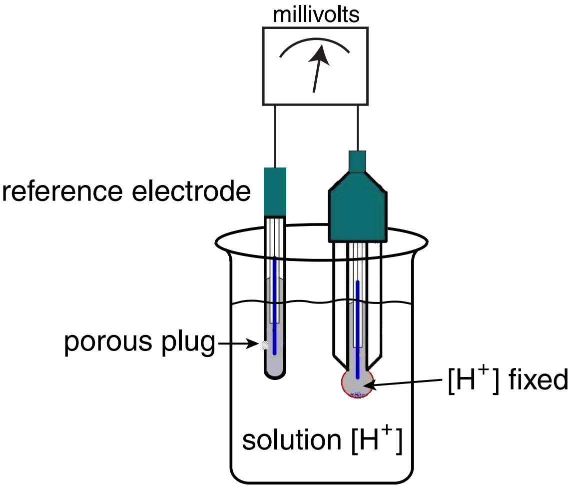
A Combination pH Electrode



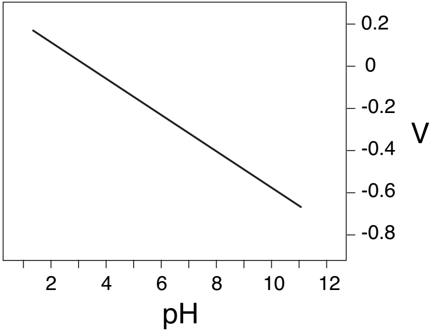
- Contains 2 electrodes:
  - pH-sensitive electrode
  - Reference electrode
- Reference electrode is electrically connected to test solution (porous plug)
- H^+ ions cannot cross glass membrane of bulb.
- $[H^+]$ inside bulb is fixed.

Figure adapted from Wikipedia: http://en.wikipedia.org/wiki/Glass_electrode

Separate pH and Reference Electrodes



- Difference in $[H^+]$ creates voltage difference across glass membrane.



- Electrode has to be calibrated to establish slope and intercept.

Figure adapted from Wikipedia: http://en.wikipedia.org/wiki/Glass_electrode