Physical Principles in Biology

Biology 3550

Spring 2025

Lecture 3:

More on Measurement and Units
and a
Brief Introduction to Randomness

Friday, 10 January 2025

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Clicker Question #1

Which of the following is a “basic” unit in the International System (SI)?

A) smoot

B) kilogram

C) joule

D) Liter

E) newton

Basic Dimensions in the Current Metric System

International System of Units (SI)

Dimension	Symbol	SI Unit
Length	L	meter (m)
Mass	M	kilogram (kg)
Time	t	second (s)
Thermodynamic temperature	T	kelvin (K)
Electric current	I	ampere (A)
Amount of substance	?	mole (mol)
Luminous intensity	I_v	candela (cd)

Clicker Question from Last Time

How many hydrogen ions (H^+) are within a typical bacterium?

A) 1

B) 100

C) 1 thousand

D) 1 million (10^6)

E) 1 billion (10^9)

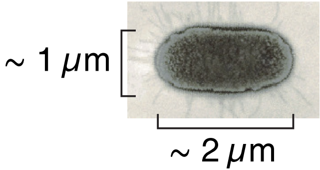
All answers count (for now)!

How Many Hydrogen Ions Are in a Typical Bacterium: Poll Results

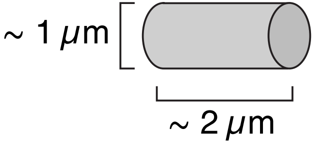
1	A	0
10^2	B	0
10^3	C	3 *(25%)*
10^6	D	3 *(25%)*
10^9	E	6 *(50%)*

Scale and Dimensions of a Bacterial Cell

- A typical bacterium found in the human gut: *Escherichia coli*



- Approximate this as a cylinder



- Volume $\approx 1.6 \times 10^{-18}\,\mathrm{m}^3 = 1.6 \times 10^{-15}\,\mathrm{L}$

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

    1 mole = amount of substance containing Avogadro's number, N_A, of atoms, molecules or ions.
- 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: $N_A = 6.02214076 \times 10^{23}$, exactly!

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 really 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
- 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:

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

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

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

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

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

Clicker Question #2

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

A) ~ 10

B) ~ 30

C) ~ 50

D) ~ 70

- $1000\,\mathrm{g} \div 18\,\mathrm{g/mol} = 56\,\mathrm{mol}$

A Special Measure of Concentration for Hydrogen Ions

- Dissociation of water

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

- Hydrogen ion concentration expressed as pH

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

with $[H^+]$ expressed in molar units

- To convert from pH to molar concentration:

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

- In a neutral solution, $[H^+] = [OH^-]$

This happens when $pH = 7$.

$[H^+] = 10^{-7}$ M

How Many H^+ Ions Are There in a Bacterium?

- Volume = 1.6×10^{-15} L
- $[H^+]$ = $10^{-pH}\,M = 10^{-7}$ M
- Moles of H^+:

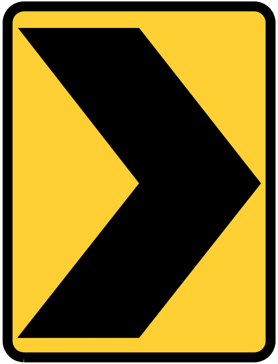
$$1.6 \times 10^{-15}\,L \times 10^{-7}\,mol/L = 1.6 \times 10^{-22}\,moles$$

- Number of ions:

$$1.6 \times 10^{-22}\,moles \times 6.02 \times 10^{23}\,ions/mol \approx 100\,H^+\,ions$$

- Some bacteria grow at pH 9. How many hydrogen ions are in one of these bacteria?

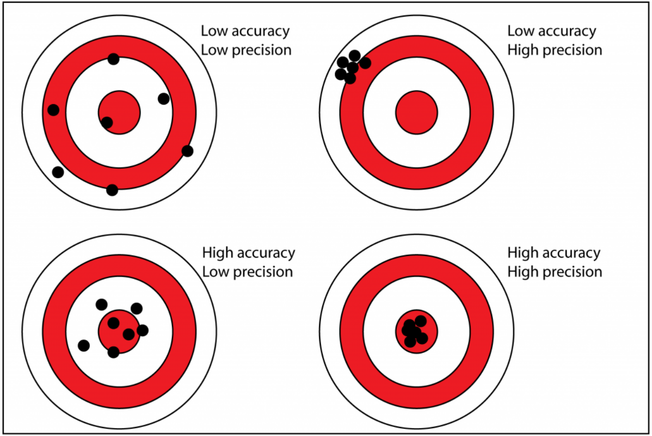
Warning!



Direction Change

Precision and Accuracy

Precision and Accuracy as Target Practice



http://www.antarcticglaciers.org/glacial-geology/dating-glacial-sediments-2/precision-and-accuracy-glacial-geology/

Precision and Accuracy in Measurement

Precision

- Reproducibility of individual measurements.
- Determined by making multiple measurements and comparing them.

Accuracy

- Consistency with an accepted value.
- Requires comparison with an accepted standard.
- Also requires multiple measurements to determine precision.

Significant Figures

- The basic idea: The number of digits used to report a measurement should reflect the precision of the measurement.
- Reporting more digits than justified by the measurements is dishonest!
- A precise definition of ‘significant figures’ is not so simple!

https://en.wikipedia.org/wiki/Significant_figures

Rules for Significant Figures

- All non-zero digits are significant.

number	sig. figs.
12	2
12.5	3

- Zeros between non-zero digits are significant.

number	sig. figs.
102	3
12.05	4

Rules for Significant Figures

- Trailing zeros to the right of a decimal point are significant.

number	sig. figs.
12.00	4
12.500	5

- Leading zeros to the left are *not* significant.

number	sig. figs.
012	2
0.0012	2

- What about trailing zeros without a decimal point?

number	sig. figs.
1200	2?

Rules for Significant Figures

- Avoid Ambiguity with Scientific Notation

number	sig. figs.
1200	2?
1.2×10^3	2
1.20×10^3	3
1.200×10^3	4
1200.	4

Rules for Significant Figures

- Numbers with unlimited significant figures:
  - Integers or ratios of integers (rational numbers), such as 2, $1/2$ or $2/3$.
  - Defined irrational numbers, such as $\sqrt{2}$, π or e.
  - Other numbers that are not derived from measurements, including most conversion factors.

Rules for Significant Figures

- Multiplication and division:

  The calculated result should contain the number of significant figures of the measured quantity with the smallest number of significant figures.

$$15\,\text{g} \div 121.1\,\text{g/mol} = 0.12\,\text{mol}$$

$$\begin{aligned} 15\,\text{mM} \times 25\,\mu\text{L} &= 0.015\,\text{moles/L} \times 2.5 \times 10^{-5}\,\text{L} \\ &= 3.8 \times 10^{-7}\,\text{moles} \\ &= 0.38\,\mu\text{moles} \end{aligned}$$

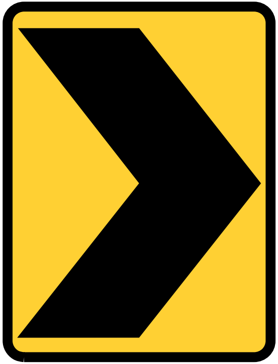
Rules for Significant Figures

- For addition and subtraction:
  - The last decimal place of the result is determined by the last decimal place of the measured quantity with the smallest number of decimal places.

$$125\,\mathrm{g} + 0.035\,\mathrm{g} = 125\,\mathrm{g}$$

  - Adding a more precise value to a less precise one doesn't increase the precision of the sum!

Warning!



Direction Change

Randomness

Random Motion of Latex Beads in Water

Brownian Motion Movie

- What makes them move?

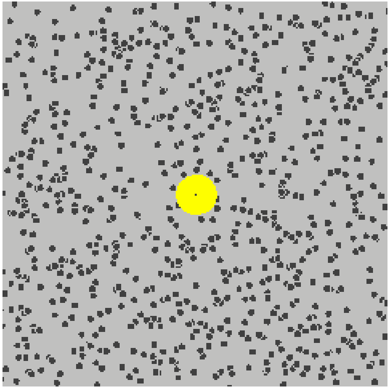
YouTube movie: https://www.youtube.com/watch?v=cDcprgWiQEY

Robert Brown

1773-1858

- Scottish botanist, explorer of Australia and exceptional microscopist.
- In 1827, observed random motions of small (1 μm) particles within pollen grains.
- Are they alive?

Simulation of Brownian Motion



- A detailed, realistic molecular simulation is very difficult!

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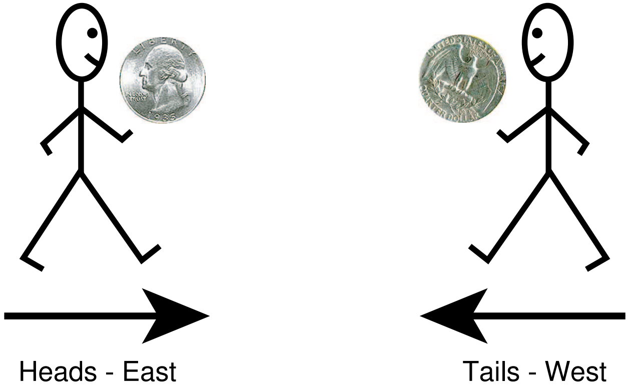
https://en.wikipedia.org/wiki/Brownian_motion
http://weelookang.blogspot.com/2010/06/ejs-open-source-brownian-motion-gas.html

A Random Walk in One Dimension



A Special Assignment: 5 Clicker Points

1) Find a coin.
2) Flip the coin.
   Record “H” for heads or “T” for tails.
3) Repeat step 2, for a total of 20 flips.
   Walking is optional!
4) Submit the string of “H”s and “T”s on Canvas.
   All in one line of text without spaces:
   HHHTHHTHHTHTTHTHHTTH
5) Due 11:59 PM, Sunday, 12 January.