

Physical Principles in Biology
Biology 3550
Fall 2018

Lecture 3:
More on Measurement and Units

Friday, 24 August 2018

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Discussion/Problem Solving Sessions

■ Times

- Tuesdays, 11:00 AM – noon.
- Wednesdays, 8:30 – 9:30 AM.

■ Room locations to be announced.

■ Office hours:

- Tuesdays: 9:30 - 11:00 AM
- Wednesdays: 2:30 - 3:30 PM
- Other times by appointment.
Send me an e-mail message!
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Clicker Question #1

Which of the following are “basic” units in the International System (SI)?

(Choose up to two.)

1 smoot

2 kilogram

3 meter

4 Liter

5 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)

Examples of Derived SI Units

Dimension	Symbol	SI Unit
Area	$A = L^2$	m^2
Volume	$V = L^3$	m^3
Velocity	$v = L/t$	m/s
Acceleration	$a = v/t = L/t^2$	m/s^2
Force	$f = ma = m \cdot L/t^2$	newton (N) = $kg \cdot m/s^2$
Energy	$E = f \cdot L$	J = Nm = $kg \cdot m^2/s^2$

Clicker Question #2

Which of these equations does *not* make sense:

A) $1 \text{ mg} = 1 \text{ g}/1,000$

B) $1 \text{ mile} = 1.609344 \text{ km}$

C) $1 \text{ kg} = 1 \text{ liter}$

D) $1 \text{ meter/s} = 1,196.9 \text{ feet/hour}$

- To make sense, the **dimensions** on the two sides of the equations have to be consistent.

The **units** do not have to be the same.

Why isn't "1 kg = 1 liter" a Valid Equation?

- A true statement:
1 L of water has a mass of 1 kg (within about 0.01 g at 4°C).
- Another true statement:
The density of water, d_w has a density of 1 kg/L, or:

$$d_w = 1 \text{ kg/L}$$

- A valid equation to calculate the mass of a given volume of liquid:

$$\begin{aligned} \text{mass} &= \text{volume} \times \text{density} \\ &= 1 \text{ L} \times 1 \text{ kg/L} = 1 \text{ kg} \end{aligned}$$

- In mathematics, equality has a very specific meaning: Two things, after evaluation, are completely interchangeable.
- Mass and volume are not the same thing!

Algebraic Rearrangement of a Conversion Factor

$$1 \text{ km} = 1,000 \text{ m}$$

$$\frac{1 \text{ km}}{1,000 \text{ m}} = 1$$

$$\frac{1,000 \text{ m}}{1 \text{ km}} = 1$$

$$1 \text{ m} = 0.001 \text{ km}$$

- All of these equations are valid and equivalent.
- Any quantity can be multiplied (or divided) by 1 to give the same value.

Conversion by Multiplication

- Convert 37 miles to kilometers

$$1 \text{ mi} = 1.609344 \text{ km}$$

$$1.609344 \text{ km/mi} = 1$$

$$\begin{aligned} 37 \text{ mi} \times 1.609344 \text{ km/mi} &= 59.6 \text{ mi} \cdot \text{km/mi} \\ &= 59.6 \text{ km} \end{aligned}$$

- What if we divide instead of multiply?

$$37 \text{ mi} \div 1.609344 \text{ km/mi} = 23 \text{ mi}^2/\text{km}$$

This is correct algebraically, but it doesn't make much sense physically!

Clicker Question #3

“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?

- 1 ~ 50 kg
- 2 ~ 70 kg
- 3 ~ 90 kg
- 4 ~ 110 kg

Stones to kg

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

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

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

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

$$1 \text{ kg} \approx 2.2 \text{ lb}$$

Clicker Question #4

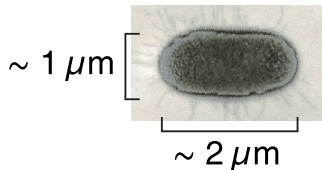
How many hydrogen ions (H^+) are within a typical bacterium?

- 1 1
- 2 100
- 3 1 thousand
- 4 1 million (10^6)
- 5 1 billion (10^9)

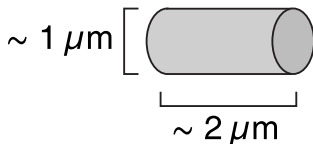
All answers count (for now)!

Scale and Dimensions of a Bacterial Cell

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



- Approximate this as a cylinder



- Volume of cylinder = $L \times A$

L = length of cylinder

A = area of cap = $\pi \times R^2$

Volume of Cylinder Representing a Bacterium

- Using units of μm :

$$\begin{aligned}V &= L \times A = L \times \pi \times R^2 \\ &= 2\mu\text{m} \times \pi \times (0.5\mu\text{m})^2 \\ &= 1.6\mu\text{m}^3\end{aligned}$$

- Convert to m^3

$$1\mu\text{m} = 10^{-6}\text{m}$$

$$1.6\mu\text{m}^3 \times (10^{-6}\text{m}/\mu\text{m})^3 = 1.6 \times 10^{-18}\text{m}^3$$

- What about liters or milliliters?

From Cubic Meters to Liters

■ An easy-to-remember factoid: 1 cm^3 (“cc”) = $1 \text{ mL} = 10^{-3} \text{ L}$

■ And, $1 \text{ cm} = 10^{-2} \text{ m}$

$$1 \text{ cm}^3 \times (10^{-2} \text{ m/cm})^3 = 10^{-6} \text{ m}^3$$

$$1 \text{ mL} = 10^{-6} \text{ m}^3$$

$$1 \text{ L} = 10^3 \text{ mL} \times 10^{-6} \text{ m}^3/\text{mL} = 10^{-3} \text{ m}^3$$

■ For our bacterium:

$$1.6 \times 10^{-18} \text{ m}^3 \times 10^3 \text{ L/m}^3 = 1.6 \times 10^{-15} \text{ L}$$

$$1.6 \times 10^{-15} \text{ L} \times 10^3 \text{ mL/L} = 1.6 \times 10^{-12} \text{ mL}$$

■ How many bacteria would fit into 1 mL? In one $1 \mu\text{L}$?

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 a substance containing the number of atoms or molecules equal to the number of atoms in 12 g of ^{12}C .

Number of atoms or molecules in 1 mole of a substance is called Avogadro's number, $N_A \approx 6.02 \times 10^{23}$

■ Some less convenient (for purposes of calculation) 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)
Defined by saying that the atomic mass of 1 atom of ^{12}C is exactly 12 amu or 12 Da.
 $1 \text{ amu} = 1 \text{ Da} = \text{mass of one atom of } ^{12}\text{C} \div 12$
- 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:

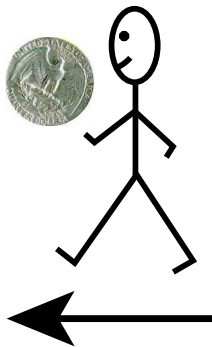
- Mass of one mole of a compound
- Units: g/mol

■ Molecular mass of 100 Da \rightarrow molar mass of 100 g/mol

A Random Walk in One Dimension



Heads - East



Tails - West

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:
HHHTHHTHHTHTTTHTHHTTH
- 5) Due 6:00 PM, Sunday, 26 August.