Exit assignment

"So much of science proceeds by telling stories." Stephen Jay Gould

General Guidelines

This assignment is entirely optional; however, should you choose to do any or all of it, we would love to read your thoughts. Please send your responses to us at:

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In the event that you do the assignment, there are *zero* exceptions to the serious expectation that your answers are yours alone, and as usual **you may *not* use ChatGPT or other AI-based tools in your work.**

Exercise 1

Write a single sentence, beginning with the words "I wonder", that describes something about life and the living world which you are curious about.

Exercise 2

What is the relevance of physical biology for scientists, and should it be considered or *not* considered an essential part of their core curriculum? Write arguments for both viewpoints.

Exercise 3

The section **Order-of-Magnitude Buffet** is a sampling of 42 different estimation problems. Select **10 estimates of your choosing** to complete.

Provide your answers in the form of well-reasoned estimates in the style we've been doing during the class. Remember that we are not fixated on your literal answer so much as on the clarity of your work and assumptions; your skill with $1, f, 10$ arithmetic; your common sense and intuition; and your earnest effort. Please do not provide estimates with multiple meaningless "significant" digits. Be thoughtful about what you know (and what you don't). You may use the Bionumbers database, http://bionumbers.hms.harvard.edu, to look up key numbers; examples include the masses of amino acids (BNID 104877) and nucleotides (BNID 103828), or the speed of the ribosome (BNID 100059). However, if you do so, we ask that you provide a citation to each quantity as shown above. Similarly, if you use another resource for your quantities, please cite it. That said, the essence of these problems is to do simple estimates by pure thought and clear reasoning — not to look everything up!
If after your estimate you want to comment on data (and how your results jibe with that data), brief discussions are welcome and appreciated.

Exercise 4

Following the approach of the previous exercise, create your own order-of-magnitude estimation problem and solve it. Clearly explain your reasoning and the assumptions made in your estimation.

Exercise for extra credit

Write a 10-week syllabus for what you would cover in a core course on the study of life. You have three hours per week. Explain what topics you would cover and why. Would there be computational problem sets? Would there be memorization? Would you have students read papers from the original literature? Would there be exams? Would you cover the broad sweep of biology, or just focus on specific case studies such as virology or immunology or evolution?

Order-of-Magnitude Buffet

Question 1: Phosphorus matters.

What is the fraction of the mass of a bacterial cell that is phosphorus?

Question 2: Cows and dairy.

How many cows are needed to meet the dairy needs of the world?

Question 3: Cows and meat.

How many cows are needed to meet the beef needs of the world?

Question 4: pH.

At the typical pH of a bacterial cell, how many hydrogen ions does it contain?

Question 5: Glucose in a tube.

After 24 hours, a 1 mL tube seeded with a single cell will have roughly 10^9 bacteria in it. What mass of glucose was needed in the growth media to support that many cells?

Question 6: Lipids per cell.

How many lipid molecules are there in a typical bacterial cell?

Question 7: Current in ion channels.

The ion channels that conduct charge across cell membranes (and give rise to the action potentials that are the basis of thought and muscle action) open transiently. What is the current across such an ion channel (in units of picoamps)?

Question 8: Watering California.

How much water is used to irrigate the crops in California's Central Valley every year?

Question 9: Mass of mRNA and protein.

What is the mass of a typical mRNA molecule? What is the mass of the corresponding protein?

Question 10: Thirsty bacteria.

How many water molecules are taken up each second during the growth of a (rapidly growing) bacterium?

Question 11: Cholera.

When infected by cholera, patients suffer from terrible secretory diarrhea which continues even after halting food intake. How much water is contained in the monolayer of cells coating your small intestine?

Question 12: DNA length.

What is the length of DNA contained in a single one of your human cells?

Question 13: DNA length, but bigger.

How many light-years of DNA will your body synthesize over the course of a typical human lifetime?

Question 14: Aspirin.

How many molecules of aspirin are in a single pill? How many molecules of medicine does this correspond to for each cell in your body?

Question 15: Photoreceptors.

How many photoreceptors do you have in your retina?

Question 16: Fertilizer.

How many tons of fertilizer are used worldwide every year?

Question 17: Phosphorus in fertilizer.

How many tons of phosphorus are in all of that fertilizer?

Question 18: Sequence space, in space.

If you wanted to translate a single copy of every possible 300 amino acid protein, how much volume would they take up? How does this value compare with the volume of our known universe?

Question 19: Genomes in history.

How many genomes have existed in the history of life on Earth?

Question 20: DNA and body mass.

What fraction of your body's mass is DNA?

Question 21: Chickens.

How many chickens are slaughtered by humans every year?

Question 22: Human births.

How many humans are born every year? Make the spurious assumption that the human population is at steady-state, and employ Little's Theorem.

Question 23: Earthworms.

Consider a single hectare of land. What is the mass of dirt in that area that gets turned over by earthworms every year?

Question 24: Oxygen in a tube.

After 24 hours, a tube containing 5 mL of liquid medium seeded with a single cell will have roughly 5×10^9 bacteria in it. How many mL of headspace is needed in order to provide enough oxygen to grow those cells? (Note that cells are grown by shaking them continuously at 37 degrees Celsius.)

Question 25: CO_2 production.

How many molecules of CO_2 are produced per cell cycle by a typical *E. coli* cell?

Question 26: Human poop.

How much human poop was generated yesterday on Earth?

Question 27: Cow poop.

How much cow poop was generated yesterday on Earth?

Question 28: Land (and poop).

How much cropland could be fertilized using all the poop generated by humans and cows every year?

Question 29: Concentration rule-of-thumb.

If a single *E. coli* cell contains just one copy of a particular protein, what is the concentration of that protein (in molar units)?

Question 30: Your volume.

What is the volume of a typical human body (in units of m^3)?

Question 31: Your blood.

How many erythrocytes (red blood cells) are there in a typical human body?

Question 32: SARS-CoV-2.

At the height of the COVID-19 pandemic, how many SARS-CoV-2 virions were circulating in the human population? What was their total mass?

Question 33: Diffusion down a neuron.

How long does it take for a protein to diffuse the length of an axon?

Question 34: Translation-ception.

How long does it take a ribosome to translate all the proteins that are needed to make another ribosome?

Question 35: Bar-tailed godwits.

How many grams of mass are lost by a bar-tailed godwit in its migratory flight from Alaska to New Zealand?

Question 36: Are we human?

Your body is home to many bacterial cells. Assuming (crudely) that they are all *E. coli*-like, what is their total combined surface area? Their volume? Repeat the calculations for all your human cells. How do these values compare?

Question 37: Bacteria as power plants.

If the production of ATP could be efficiently harnessed to meet humans' urban needs, how many bacteria would you need to power the entire city of Los Angeles?

Question 38: The mountaineer's diet.

What is the maximum height of a mountain you can climb after eating just a bowl of instant ramen?

Question 39: Rapid descents by small mammals.

A popular urban myth claims that squirrels can survive falls from any height, since their terminal velocities are low enough not to cause them great injury. Is this plausible?

Question 40: Stomping microbes.

There are about 10^{30} bacteria on Earth. How many bacteria will you inadvertently step on during a one-mile run through the countryside?

Question 41: Houseplants and air.

Using what you know about how fast plants grow, and about respiration (turning say glucose and oxygen into carbon dioxide and water) and photosynthesis (the reverse), estimate the rate at which your houseplant "cleans your air" by generating oxygen and adsorbing carbon dioxide. Is this big or small compared to your own body's contribution?

Question 42: How high can trees grow?

Take the compressive yield stress of wood parallel to its grain to be $\sigma_c^{\|} 50 \times 10^6\ Pa$, and infer a reasonable value for the density ρ_{wood} of wood from your daily experience (e.g. your familiarity with paper). If a (columnar) tree were limited only by wood's ability to resist compressive stress, how tall h could a tree of radius R grow? From your estimate and colloquial experience, do you think tree height is limited by this risk of axial compressive failure?