

APh161: Physical Biology of the Cell
Homework 5
Due Date: Friday, February 26, 2010

“To do successful research, you don’t need to know everything. You just need to know of one thing that isn’t known.” – A. L. Schawlow

1. Photosynthesis: Your Turn.

(a) Write a two-paragraph description of the nature of photosynthesis that would be appropriate for readers of “Scientific American”. Key points that you should touch upon include: relevance of photosynthesis to life on Earth and the mechanisms of photosynthesis. Your essay should be readable by an interested high-school student.

(b) Make a syllabus for 5 lectures on photosynthesis. Your syllabus should say what topics you will cover. Make sure that this includes some statement of what estimates you would do, what experiments you would describe and what calculations you would do. Try to view this with a fresh perspective and don’t feel the need to do anything the same way that I did. This should be one paragraph or less. You are making a syllabus with bullets.

(c) Experiments and photosynthesis. Give a brief description (1-paragraph maximum) of three experiments that have shed light on the nature of photosynthesis. Make sure to say the concept of the experiment, how it was implemented and the nature of the resulting data.

NOTE: this problem will be graded by Rob. You must submit this part of the problem by email to the three TAs and to Rob.

2. Respiration and Photosynthesis: A Feeling for the Macroscopic Numbers.

Most of this problem was motivated by the outstanding book **Guesstimation** by Lawrence Weinstein and John Adam. I highly recommend this book to all of you and believe strongly that even if you think estimates of this kind are “trivial”, they are well worth your time. Some of the most

important and interesting episodes in the history of science having involved estimates. Two of the most important are: i) when Newton estimated the acceleration of the moon as it “falls” around the Earth and compared it to the acceleration at the Earth. He found that they differed by nearly a factor of 3600, corresponding to the 60-fold difference in distance from the center of the Earth, suggesting the inverse square law, ii) Kelvin’s estimates of the age of the Earth and the lifetime of the sun. Both of Kelvin’s estimate were inconsistent with geology and foreshadowed the discovery of radioactivity.

In problems like this, I want to see clear statements of your assumptions, the key orders of magnitude that dictate your estimates and some sort of summarizing statement about what the estimates mean. Further, these estimates should involve very little looking stuff up online.

(a) The Keeling curve shows two extremely interesting features of the overall CO₂ budget of the Earth. First, it is most famous for illustrating the impact of humanity on the atmospheric composition, revealed through the trend of increasing CO₂ over time. However, the second interesting feature of the Keeling curve is the annual variation in CO₂ concentrations which reflect the summer-winter cycle of the greener northern Hemisphere. Keeling’s son Ralph has now made it his mission to make careful measurements of the time evolution of atmospheric oxygen.

Several interesting links on this stuff are:

<http://www.scivee.tv/node/4611>

http://explorations.ucsd.edu/Features/Keeling_Curve/

and the Scripps feature posted with this homework.

Spend a little time thinking about atmospheric oxygen by making a simple estimate of how long it would take for the breathing of humans to use up the atmospheric oxygen if photosynthetic organisms were not around to perform carbon fixation. There are a variety of different ways to approach this. First, in class I already worked out the number of molecules in the atmosphere (and its mass) so you could figure out how much O₂ there is that way. Alterna-

tively, you could just try to figure out how long it would take for all humans to have breathed in the whole atmosphere and by thinking about what fraction of the O_2 is combusted. For the purposes of this estimate, just imagine that with each breath you are burning glucose (you might want to write down the relevant reaction). Figure out the mass per breath and use that to figure out the number of breaths in the atmosphere (given the atmospheric mass). Weinstein and Adam point out that we can use CPR and sustain someone in life, so we don't exhaust all of the oxygen with each breath. Again, you should not have to look up very much to solve this problem.

(b) Make an estimate of the amount of CO_2 absorbed per year by the growth of a new forest on one km^2 of land. Hint: figure out the number of trees in a $1 km^2$ area and average over the time from when the trees are saplings to fully grown to figure out how much carbon was used to make the trees.

Though it is not critical to the estimate, you might enjoy taking a look at the Earth Observatory to get a sense of the leaf area index:

<http://earthobservatory.nasa.gov/Observatory/Datasets/lai.modis.html>.

A second way to do this problem that you should also try is to figure out the area per tree. Now, imagine that the roughly $1000 W/m^2$ of power resulting from incident sunlight is used to fix carbon (with some efficiency depending both upon what fraction of the day the sunlight is present and the actual efficiency of light absorption and energy usage - use the geometric mean rule by trying to make an upper and lower bound on how efficient this can be). Then use the rule of thumb that ten photons are needed for each carbon fixed. NOTE: in the solutions, we will give you the best current estimates of this number resulting from measurements on tree plantations.

(c) There is much discussion about deforestation and its impact on the environment. Make an estimate of the total CO_2 released into the atmosphere as a result of burning of forests for as long as man has used fire. Work out this number in parts per million for atmospheric CO_2 and compare this to the numbers you see in the Keeling curve. In addition, make a simple estimate of the total energy released by such burning.

3. A Synthetic Transcriptional Oscillator.

Read the paper that was the basis of Professor Elowitz's PhD thesis from *Nature* that is posted with the homework. Then, write a one-paragraph summary of the paper in a fashion that could be read and understood by an ambitious and scientifically passionate high-school student.

(a) Rederive with clear pedagogical explanations the dynamical equations for the repressilator given in section 19.3.3 of PBoC and derive these equations in their dimensionless form.

(b) Reproduce the corrected version of fig. 19.31 for repressilator. You need to do this numerically either using Matlab or Mathematica or some other numerical technique. We will post the corrected figure.

(c) EXTRA CREDIT (but worth 20% of the grade for this homework). Reproduce the derivations in section 19.3.3 of PBoC starting where you left off at the end of part (a) culminating in eqn. 19.67. This means that you need to explain the dynamical equations describing the messenger RNA and protein concentrations, the rewriting of the differential equations in dimensionless form given in 19.46 and the linear stability analysis that follows. I have instructed the TAs to not even bother looking at your solution if you do not explain in a clear, pedagogical fashion what is going on in the derivation. NOTE: there is a mistake in eqn. 19.52. There should be an m^{n-1} in the numerator instead of just an m.