MCB137L/237L: Physical Biology of the Cell
Spring 2024
Homework 11:
(Due 4/16/24 at 2:00pm)

Hernan G. Garcia

1 Energy and Life

One of the strongest things we can say about the properties of living organisms that distinguish them from inorganic materials such as the rocks that make up the face of Half Dome is that they are always consuming energy. Figure 1 shows a number of biological processes as viewed through the prism of energy consumption.

(a) Write a brief, thoughtful paragraph about the meaning of the energy scale k_BT .

(b) In this problem, choose three of the entries in the figure and make your own calculation of the relevant energy scale and see to what extent you agree with the reported numbers. Make sure that at least two of the problems you choose do not correspond to examples we explored in class. Further, dont nd a way to get the same numbers as are in the figure. Rather, do this yourself and get your own number. Make sure you carefully report your thought process and assumptions.

2 Leaky Membranes: The Cost of Defying Diffusion

As we saw in class, some ionic species are at a higher concentration inside the cell than outside the cell. As a result of this concentration gradient, there will be a flux of ions leaving the cell given by the concentration difference and the permeability which can be written as

$$\text{flux} = P(c_{in} - c_{out}) \tag{1}$$

where P is the permeability as illustrated in Figure 2.

(a) Calculate the number of ions of a species such as K^+ that leave the cell per second due to the permeability of the membrane. Essentially, this tells us about the leakiness of the cell membrane to ions which will over time lead to a complete dissipation of the gradient. You

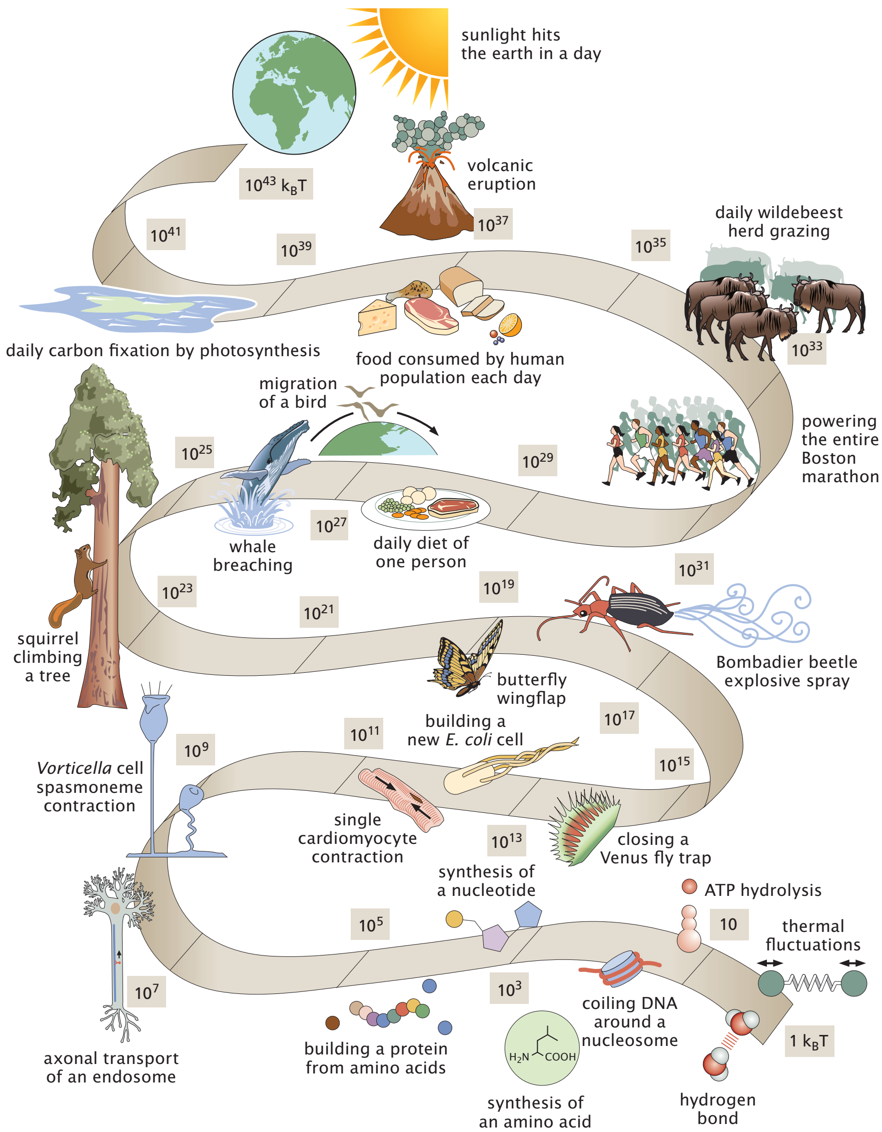

Figure 1: Energy scales of biology. From top to bottom, the energetic cost of the process of interest increases. All energies are measured in units of $k_B T$.

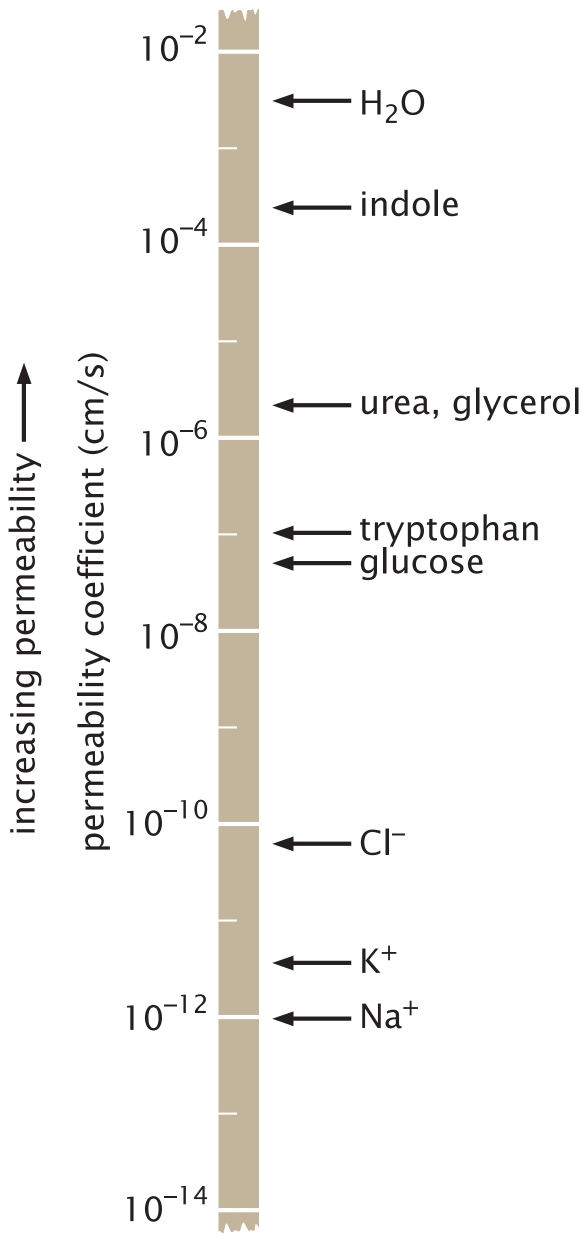

Figure 2: Permeability of various ions and molecules across membranes.

might find it useful to read up on permeability in Section 11.1.3 of PBoC2.

(b) Using ideas worked out in class about the protonmotive force, make an estimate of the power in ATP/s or k_BT/s that it costs to maintain the concentration gradient against the perpetual leakiness of the membrane. Make sure you spell out the quantitative details of how you make this estimate.

(c) How does the energy necessary to maintain the K^+ gradient compare to that required to build a bacterial cell?

3 Breaking the 2nd Law and Rectifying Thermal Noise

In a great *Physics Today* article (provided on the course website), Chris Jarzynski and colleagues state that "A liter of ordinary air weighs less than half a US penny, but it contains enough thermal energy to toss a 7-kg bowling ball more than 3 m off the ground. A gadget able to harvest that abundant energy by converting the erratic movement of colliding molecules into directed motion could be very useful indeed."

Check his assertion about the weight of the air in the room and the energy within it. Remember the meaning of k_BT as the energy scale of the particles in our system.

4 Proteomic data on bacteria in different growth conditions.

Read the paper by Schmidt and Heinemann and co-workers in which they use mass spectrometry to take the census of *E. coli* under a variety of different growth conditions. The outcome of this work was a census of the number of copies of roughly half of the proteins in this important bacterium.

(a) Using the data in the spreadsheet available with this homework, examine the numbers for the subunits of ATP-synthase. Write a short paragraph describing what ATP synthase is and what it does. Then, make an estimate of the number of ATPs it takes to make a new cell. In light of the number of ATP synthases counted by Heinemann and his group, are there enough to make all the ATPs needed to build a cell?

(b) Comment on the units on the y-axis of figure 2b of the Schmidt *et al.* paper. Specifically, justify those units in terms of what you know about the total number of proteins and the mass per protein. Do you think that the measurements pass the street fighters sanity check? Explain your conclusions.