

7.014 Solution Set 5

Question 1

Organisms can use a variety of carbon and energy sources, depending on their availability in the environment. Oxidation and reduction reactions play critical roles in metabolism, and the relative favorability of these reactions often dictates the type of metabolism an organism will employ in a given situation. For example, organisms that conduct aerobic respiration (like humans) use organic carbon compounds (like glucose) as both their carbon source and their energy source.

- a) What compound is reduced by the transfer of electrons from glucose? What are the oxidized and reduced forms of this compound?

Electrons in glucose are transferred to reduce NAD^+ (oxidized) to $NADH$ (reduced).

Electrons are then passed down the electron transport chain, sequentially reducing proteins in the chain, in the process creating a proton gradient for ATP synthesis.

- b) What is the final electron acceptor for organisms performing aerobic respiration? Why do organisms need a final electron acceptor?

The terminal electron acceptor for aerobes is oxygen. The electrons that are being passed down ETC have to go somewhere so the chain doesn't get backed up, and that is why the final electron acceptor is needed.

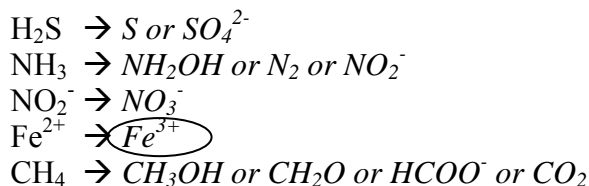
The reduction of oxygen is a very favorable reaction; in fact oxygen is the most favorable electron acceptor. Organisms conducting respiration in the absence of oxygen do so anaerobically, using other compounds as electron acceptors.

- c) Consider the following environments where different compounds are present. Circle the compound in each environment most likely to be used as an electron acceptor. Top portion of the table from the Redox handout has been reproduced on page 6 (last page) to help you decide.

Environment 1	Environment 2	Environment 3
NO_3^-	Fe^{3+}	CH_3OH
NO_2^-	NO_2^-	NO_3^-
O_2	NO_3^-	fumarate

Just as electron acceptors are selected in evolution based on thermodynamic favorability, so are electron donors. Whereas respiration uses organic compounds as electron donors, and photosynthesis uses water as an electron donor (to replace the electron excited by light), many organisms use inorganic compounds as electron donors and sources of energy.

- d) For each electron donor below, give the compound it will be converted to upon oxidation. Circle the compound that will yield the most energy upon oxidation.



Question 1, continued

- e) Organisms using the above compounds as electron donors are employing what type of metabolism? Are these organisms most likely prokaryotes, archaea, or eukaryotes (pick all that apply)?

These organisms are employing chemosynthesis. These organisms are likely to be bacteria or archaea.

Question 2

Curious about the *Sorcerer II* expedition of Craig Venter, you take your own research vessel to the Sargasso Sea to study the phytoplankton community there. At a particular location in the open ocean, you measure several environmental parameters (nutrient and light levels) down the water column as well as the relative abundances of two ecotypes (*i.e.* strains), I and II, of *Prochlorococcus*, a unicellular cyanobacterium.

Inexplicably, as you are returning to Woods Hole to analyze your data, your ship is raided by pirates, who steal your data on the abundance of the two ecotypes. Fortunately, the pirates did not take your data on nutrient and light levels. You remember that you have genome sequences for the two strains, providing you with information on which genes each ecotype has. Based on this genomic information (in the questions, below) and the depth profile data, answer the following questions.

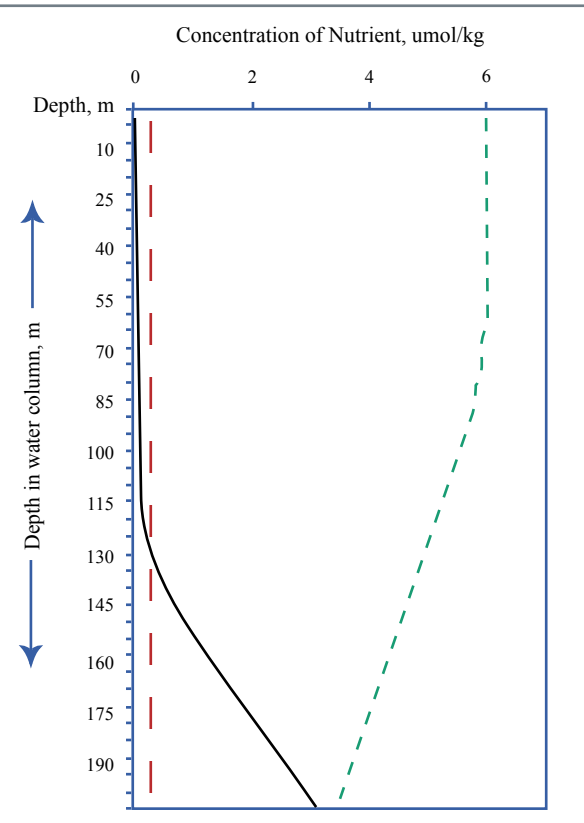


Figure: Depth profile for the region of the Sargasso Sea where you measured the abundance of two *Prochlorococcus* strains.

solid black line: dissolved NH_4^+ and urea
dashed black line: nitrate (NO_3^-)
solid gray line: phosphate (PO_4^{3-})

The genome of ecotype II appears to have nitrate reductase, allowing it to utilize nitrate as a nitrogen source. Ecotype I does not appear to have nitrate reductase.

Figure by MIT OCW.

- a) Based on this observation and the nitrogen data above, which ecotype should dominate which part of the water column (shallow/0-100 m or deep/100-200 m) and why?

Nitrate is more concentrated in the deep waters. And since ecotype II has the nitrate reductase gene, it is likely that ecotype II dominates deep water, while ecotype I dominates shallow water.

- b) Name two important molecules in the cell that require nitrogen for biosynthesis. In which redox form does the cell require its nitrogen, oxidized or reduced?

Proteins and DNA require nitrogen for biosynthesis. Both use nitrogen in its reduced form.

Question 2, continued

- c) Without using the graph, would you expect one or both of these ecotypes to have genes for phosphate transport proteins in their genomes? If yes, which one(s) and why? Why don't you need to use the graph?

Both ecotypes would need phosphate transport genes because phosphorus is an essential nutrient and no living organism is capable of getting phosphorus from the air. We do not need to use the graph because the need for phosphorus is universal and does not depend on the particular organisms in the graph.

Prochlorococcus possesses two types of chlorophyll, a and b. Chlorophyll a (Chl a) absorbs longer wavelengths (red) better than chlorophyll b (Chl b), whereas Chl b absorbs shorter wavelengths (blue) better than Chl a. Blue wavelengths penetrate deeper down the water column because they are scattered and absorbed less by water than red wavelengths. The operons for Chl a and Chl b biosynthesis are expressed at different levels in these two ecotypes, such that ecotype II has a higher Chl b/a ratio than ecotype I (ecotype I has a comparatively low Chl b/a ratio).

- d) Which ecotype would you expect to dominate shallow (0-100 m) water and which would you expect to dominate deep (100-200 m) water? Why?

Ecotype I would dominate shallow water because it is better suited to exploit longer wavelength light, and that is the light that is available in the shallow but not deep water. Ecotype II would dominate deep water because it is better suited to exploit shorter wavelength light, and any deep water photosynthesizer would have to rely primarily on this type of light. This is because the longer wavelength light does not penetrate well that deeply into the ocean.

In general, photosynthetic organisms, such as phytoplankton, grow faster under higher light intensity. However, as we just observed, one of these ecotypes has evolved to prefer a lower light intensity.

- e) Why has this ecotype evolved for optimal growth at low light intensity?

Because shallow water has brighter light and more available energy than deep water, it will be a competitive environment where nutrients are scarce. High-light-adapted ecotypes will have an advantage in the shallow water. Cyanobacteria that cannot compete with them, but can survive in darker conditions and exploit the nutrients there (e.g. ecotype II) will have an advantage in the deeper water. The unique genes and gene regulation mechanisms that allow ecotype II to take advantage of the deep water environment probably arose during the process of optimization for the deep water conditions.

Question 3

Walking down the infinite corridor one day, you and your friend are suddenly engulfed in a space-time distortion and transported to a barren world covered with fake-looking rocks and sparse vegetation, strikingly similar to a set from the original Star Trek. After an indeterminate period of blind panic, you and she realize you may be stuck there for a long time, and begin to assess the situation. You find that there are only three non-microbial organisms on the planet: raspberry bushes, ants, and anteaters. Having just finished 7.014, you both realize that your introduction into this ecosystem is bound to disrupt it and, to maximize your survival, you should be careful of what you eat. Your friend starts to study the situation, and she draws the following energy flow diagram to represent the ecosystem (next page):

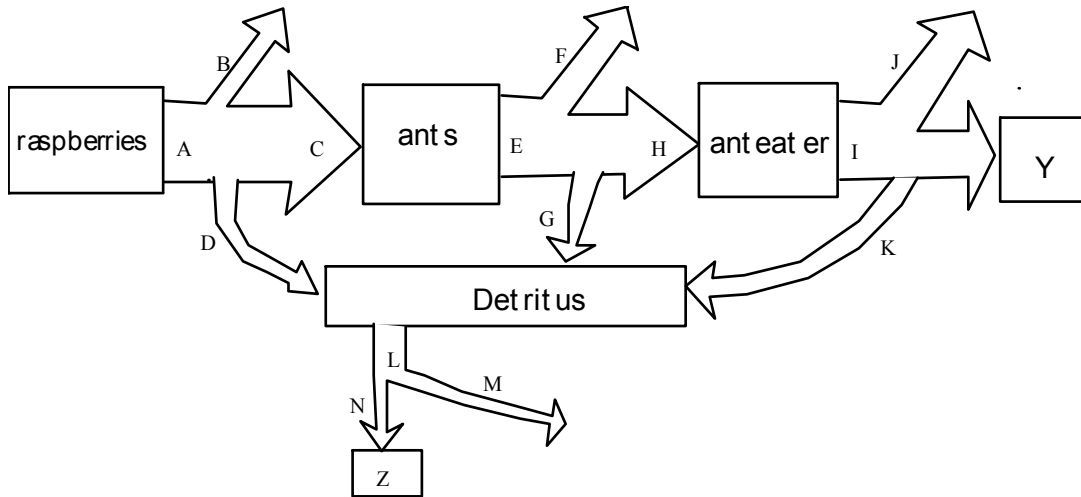
- a) You look at your friend's diagram

i) What do the arrows B, F, and J represent? *Respiration: B = raspberry; F = ant; J = anteater.*

ii) Why do both plants and animals "lose" energy by the process in part (i) above?

The process of respiration generates ATP by gradually capturing the energy of the breakdown of glucose into CO₂. That process is 60% efficient, while 40% of energy in glucose is lost to heat. The ATP generated is used to power the organism, and is thus, unavailable to the next trophic level.

Question 3, continued



iii) Assuming that the thickness of all lines is proportional to the amount of energy transferred by that route, what mistake has she made in drawing the diagram?
Energy is lost at each trophic level. She drew $A=E=I$, not $A>E>I$.

b) Write expressions for the following, using the variables (A, B, etc.) on the diagram.

i) Net Primary Productivity (NPP).

$A - B - D$ or $A - B$

ii) Net Ecosystem Productivity (NEP), include A in your formula.

$A - B - D - F - G - J - K (=Y)$

c) Her diagram contains more than is immediately visible in your environment (i.e. raspberries, ants, and anteaters)

i) What is "detritus"

All energy (reduced carbon) not in a living organism, but still available to detritovores

ii) What is represented by box "Z"?

Refractory carbon - reduced carbon that is unavailable to detritovores such as fossil fuels

d) Your friend starts to apply her knowledge from 7.014 to decide which you should eat to get the most out of the available food supply: raspberries, ants (yuck) or anteaters (tastes like chicken!).

i) As a human eating these three things, from which food source will you get the highest exploitation efficiency and why?

Ants because you can eat them whole and catch them easily.

ii) As a human eating these three things, from which food source will you get the highest assimilation efficiency and why?

Anteaters because they are most similar to humans, therefore will be most readily digestible.

Question 3, continued

iii) Which of these things will have the highest production efficiency (an intrinsic property of the organism)?

Plants would because they generate ATP by photophosphorylation, not just respiration, therefore less energy (reduced carbon) is spent on metabolism. Furthermore, they are sessile (don't move) and, therefore, don't spend energy on movement.

e) You realize that your friend has been wasting her time, because you know the answer without worrying about the analysis. What should you eat to get the highest ecological efficiency out of the system and why?

The lower the trophic level you eat, the less energy is lost to respiration and detritus, therefore you should eat raspberries.

Question 4

A fictional plant *Greenever* grows all year around, even in New England, and blooms in January. A patch of these plants is the only thing that brightened the view from your dorm window this winter. In talking to your friend about your favorite plant, you realize that your friend also has a *Greenever* plant patch outside of his window, but his did not bloom this winter. You consult Google, and verify that the blooming variety is indeed the wild type.

Intrigued, you cross the plants outside your window with those outside your friend's window. All resulting plants bloom next January.

a) You reason that the trait is caused by a single gene, Bloom, that you abbreviate to B1. What is the mode of inheritance of B1? Why?

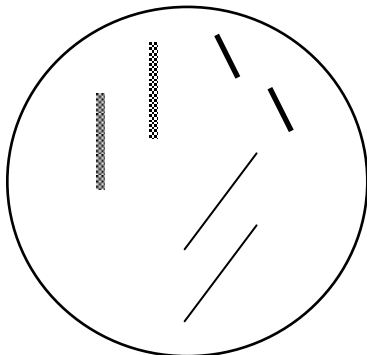
Not blooming is a recessive trait because all plants in the first generation are phenotypically wild type.

b) You cross first generation plants. What results do you expect to see? Why?

The cross would be B1b1 X B1b1. We would expect a standard 3:1 phenotypic ratio of wild-type: mutant plants. We would expect the genotypes of the phenotypically wild-type plants to be B1B1 and B1b1 in a 1:2 ratio, and the genotype of the mutant plants to be b1b1.

In addition to B1 gene, you manage to identify two other genes in *Greenever*, A and D.

A schematic of a diploid nucleus of the *Greenever* is drawn below. It contains three pairs of chromosomes ($2n = 6$). As drawn, it is about to begin the process of meiosis but has not yet replicated its DNA.

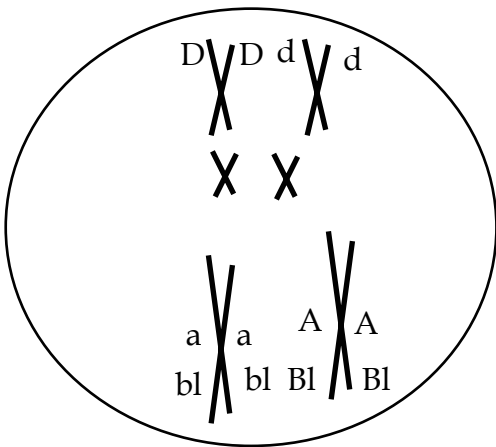


Question 4, continued

The cell that contains this nucleus

- has the genotype AaBbDd where
- the A and B alleles are linked (as are the a and b alleles) and
- the D gene is on a different chromosome.

Redraw the schematic of this nucleus when it is at metaphase prior to the first meiotic division. **Do not** include any crossovers. In your drawing, position the A, a, B, b, D, and d alleles consistent with the information given above.



Standard E° values (at 25° C and pH 7)

<i>Half-Reaction</i>	E_0 (V)
$1/2 \text{O}_2 + 2 \text{H}^+ + 2 \text{e}^- \Rightarrow \text{H}_2\text{O}$	0.816
$\text{Fe}^{3+} + \text{e}^- \Rightarrow \text{Fe}^{2+}$	0.771
$\text{NO}_3^- + 6 \text{H}^+ + 6 \text{e}^- \Rightarrow 1/2 \text{N}_2 + 3 \text{H}_2\text{O}$	0.75
$\text{NO}_3^- + 2 \text{H}^+ + 2 \text{e}^- \Rightarrow \text{NO}_2^- + \text{H}_2\text{O}$	0.421
$\text{NO}_3^- + 10 \text{H}^+ + 8 \text{e}^- \Rightarrow \text{NH}_4^+ + 3 \text{H}_2\text{O}$	0.36
$\text{NO}_2^- + 8 \text{H}^+ + 6 \text{e}^- \Rightarrow \text{NH}_4^+ + 2 \text{H}_2\text{O}$	0.34
$\text{CH}_3\text{OH} + 2 \text{H}^+ + 2 \text{e}^- \Rightarrow \text{CH}_4 + \text{H}_2\text{O}$	0.17
fumarate + 2 H^+ + 2 $\text{e}^- \Rightarrow$ succinate	0.031