7.014 Problem Set 3Answer Key

Question 1

When soy sauce was first shipped to Europe, Asian producers tried the same method they had used for shipping the sauce relatively short distances within Asia—simply filtering the sauce and putting it into non-airtight containers. However, the sauce always spoiled before reaching European destinations. The problem was solved when the producers started to boil the sauce and placing it into airtight bottles before shipment.

a) Why was placing soy sauce in airtight bottles more successful for long-distance shipping than simply placing it into barrels?

Boiling the sauce kills the majority of remaining organisms, stopping metabolism. Airtight bottles prevent any new microbes from entering and metabolizing molecules in the sauce for food. Any remaining aerobic organisms would die once they use up remaining oxygen. If any nonaerobic organisms remain, they would continue to ferment. Original method of filtering allowed greater number of microbes to survive and more could enter during shipping because the barrels were not hermetically sealed. These organisms could use molecules in soy sauce for metabolism. For shorter trips, this still worked because the sauce would be delivered before microbes caused it to spoil.

b) If the sauce was bottled but not boiled before bottling, the bottles sometimes burst during the voyage. What do you think caused this?

If a large population of anaerobic organisms remained, some of them would continue the ethanol fermentation process. This would lead to a CO_2 buildup inside the bottles. The pressure exerted by the gas could cause weak or damaged bottles to explode.

c) Boiled soy sauce does not taste the same as fresh soy sauce. Explain on the molecular level why the taste changes with boiling?

Boiling may irreversibly affect the structure, and therefore, taste (function), of some of the molecules that enhance the flavor of soy sauce. In addition, any organisms that survive the boiling may continue to grow and make products that affect the taste.

d) In modern times, to preserve flavor of the soy sauce, the sauces are not boiled, but are pasteurized (heated to about 60°C) before bottling. Pasteurized soy sauce tastes better than boiled. Why do you think pasteurization achieves the goal of preventing soy sauce spoilage while also preserving taste?

Pasteurization still kills off many microbes (but not all). However, it is not so hot that flavor-enhancing molecules irreversibly loose their structure.

e) To preserve soy sauce once a bottle is opened, it should be stored in the refrigerator. Explain why in terms of existing and potential molecular populations.

Once the bottle has been opened, new microbes can get in. Once they (and any surviving microbes still in the bottle) begin metabolizing the molecules in soy sauce, the sauce can spoil. Storing the sauce in the refrigerator slows the growth of microbes and rate of fermentation because many enzymes are inactive at lower temperatures.

Question 2

You have just won the lottery and you and 10 friends decide to sail around the world in your new yacht. Unfortunately, due to stormy seas in the Pacific, you find yourselves shipwrecked on a remote island near Micronesia. Several other species of life inhabit this island and its immediate surroundings: in the waters there are blue-green algae (cyanobacteria), and fish; and on the island there are trees and edible plants, plant-eating boars, lions, and now you.

a) Indicate which of the above species (on land and water) are autotrophs and which are heterotrophs. What is the source of energy for each group?

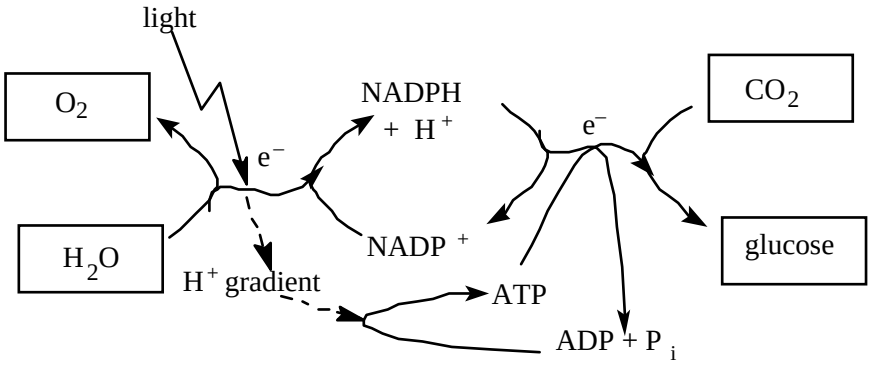
Autotrophs

Species	Energy
blue-green algae	*sun*
trees	*sun*
edible plants	*sun*

Heterotrophs

Species	Energy
fish	*organic carbon*
plant-eating boars	*organic carbon*
lions	*organic carbon*
you	*organic carbon*

b) The following diagram represents the metabolism of a particular organism on the island.



i) Fill in the boxes using the following starting materials for carbon metabolism (Note that the metabolism you propose may produce compounds not on the list, but it may only consume compounds on the list).

Fe^{3+} H_2O Mn^{4+} glucose CO_2 H^+

Question 2, continued

ii) What type of metabolism does this represent?
Oxygenic (non-cyclic) Photosynthesis

iii) Is this organism autotrophic or heterotrophic? Explain why. What organisms on the island are using this form of metabolism?
Autotrophic because this organism can fix CO_2 into glucose using energy from the sun.

One of the edible plants on the island is so tasty that you set out to identify what makes the plant so good. You discover the pathway that results in the production of molecule F that gives the plant its unusual taste. You also discover that the first step in the pathway is the reaction A + B → C + D.
Under standard conditions, the reaction A + B → C + D has a positive ΔG_o.
The reaction C + D → A + B has a negative ΔG_o.

c) The cell needs to convert A and B into C and D. Based on the information above,

i) Is the reaction A + B → C + D spontaneous? Why or why not?
It is not spontaneous because it has a positive ΔG_o.

ii) What effect if any, would adding a catalyst have on the progress of this reaction?
It would have no effect because catalysts can't make unfavorable reactions proceed.

iii) What "trick" might be used in the cell to ensure that A + B is converted to C + D?
This reaction may be coupled to another, favorable, reaction (such as ATP hydrolysis) in the cell, such that the new, combined reaction has a negative ΔG_o.

Question 3

Martians, tired of hiding from our spacecraft, send their own spacecraft to Earth with some single-celled Martian organisms. They are willing to give these to NASA on the condition that we leave Mars alone.

Instead of having only 4 bases, their DNA has 8 different bases: B, C, D, E, W, X, Y, and Z. Chemical analysis of a single-celled Martian organism reveals that its genome is composed of:

B: 13% C:7% D: 13% E:19%
W:19% X:11% Y:7% Z: 11%

a) Identify which bases pair with each other.

B - D *C –Y* *E – W* *X - Z*

Question 3, continued

X-ray diffraction of Martian genetic material looks very similar to that of Earth DNA. The diffraction patterns show a long helix of uniform width. Further examination of the material shows that four of the Martian bases have two rings and four have three rings.

b) Formulate a hypothesis about what each Martian base pair looks like and about the relative shapes and sizes of all the Martian base pairs. Explain why your hypothesis is consistent with the data you have.
Our hypothesis is that in each Martian base pair one base has two rings and one base has three rings. This is consistent with the data because this would provide for each base pair to have five rings, and thus, for the entire molecule to be a helix of uniform width, as indicated by the diffraction patterns.

Question 4

Speedy, Jerry, and Mickey are three mice that live in your apartment. One night you notice that Speedy, less speedy than usual, is the last mouse to reach the cheese that you dropped on the floor. The next week he approaches your frosted flakes with a swaggering gate and unusual twitching. Two days later you find Speedy dead. You pick him up, gently place him in a plastic sandwich bag and take him to the lab where you are a UROP. The following week Mickey meets the same fate.

Your labmate believes that the mice died from bacterial infections of the fluid in the spinal cord and brain, but you believe that they may have suffered from a prion disease (http://science-education.nih.gov/nihHTML/ose/snapshots/multimedia/ritn/prions/prions1.html). You perform the following experiment independently on each dead mouse.

1. Remove the brain.
2. Suspend brain matter in liquid.
3. Divide the suspended brain matter into three different samples.
4. Label the samples and treat each sample in the following way.

    Sample 1: treat with an agent that destroys nucleic acid
    Sample 2: treat with a protease
    Sample 3: do not treat
5. Inject each of three new mice with a different sample and wait.

Question 4, continued

a) You observe the mice treated with the samples from Speedy's brain and find that…

- the mouse treated with sample 1 gets sick and dies.
- the mouse treated with sample 2 stays healthy.
- the mouse treated with sample 3 gets sick and dies

Are these results consistent with death by a bacterial infection, a prion disease or neither? Explain using the results seen with both sample 1 and 2.

These results are consistent with death from a prion disease. Prions are infectious proteins, and as such, they would be unaffected by an agent that destroys DNA, hence mice injected with sample 1 would get sick. However, if the infectious agent was bacterial, then treatment with an agent that destroys DNA would kill the bacteria and mice injected with sample 1 would stay healthy. On the other hand, protease would destroy prions, and so the mouse treated with sample 2 would stay healthy.

b) You observe the mice treated with samples from Mickey's brain and find that…

- the mouse treated with sample 1 stays healthy.
- the mouse treated with sample 2 stays healthy.
- the mouse treated with sample 3 gets sick and dies

Are these results consistent with death by a bacterial infection, a prion disease or neither? Explain using the results seen with both sample 1 and 2.

These results are consistent with death from a bacterial infection disease. If the infectious agent is bacterial, then treatment with an agent that destroys DNA would kill the bacteria and mice injected with sample 1 would stay healthy. In addition, treatment with an agent that destroys protein would also kill the bacteria so mice injected with sample 2 would stay healthy.

c) You think that the causative agent of a prion disease may be abnormal cheeseheadin (CHN), a protein that localizes to synapses in the brain. For the primary, tertiary, and quaternary structure of normal and prion form of CHN, please indicate whether they are same or different. Justify your answer in each case.

Primary (same) different

Justify your answer

Prions are abnormally folded proteins, so the primary structure of normal and prion form of the same protein would be the same.

Tertiary same (different)

Justify your answer

Prions have altered shapes, i.e. tertiary structure different from that of normal form of the same protein.

Quaternary same (different)

Justify your answer

Since the tertiary structure is different, the quaternary structure would have to be different as well.

Question 5

In both cyclic and non-cyclic photophosphorylation, energy from the sun can drive the conversion of CO_2 into glucose.

a) Explain why respiration is sometimes referred to as the opposite of photosynthesis.
Photosynthesis = CO_2 → glucose and Respiration = glucose → CO_2
Photosynthesis produces O_2 and Respiration use it.

b) Even though respiration is sometimes referred to as the opposite of photosynthesis, there are many similarities in these two processes. ATP is generated by a similar mechanism in respiration, cyclic and non-cyclic photophosphorylation. Explain how the movement of electrons from one protein complex to another results in the formation of ATP in these processes.
Electrons are passed from one protein to another more electronegative one. Some of these proteins are proton pumps that pass H^+ ions across a membrane creating a charge and concentration gradient. The H^+ ions then flow down this gradient through the ATP synthase, such that that movement is coupled to the formation of ATP from ADP.

c) Explain why the evolution of non-cyclic photophosphorylation was a prerequisite to the evolution of respiration.
Until the evolution of Non-cyclic photophosphorylation, there was no oxygen in the atmosphere. Non-cyclic photophosphorylation obtains electrons from H_2O forming O_2. Respiration requires O_2 to act as the final electron acceptor.