

# Solutions to 7.014 Quiz III

5/2/11

Class Ave = 54  
Standard Dev = 16

Approximate grade	Range	%
A	75 - 100	15.3%
B	57 - 74	28%
C	40 - 56	35.4%
D	26 - 39	16%
F	0 - 25	5.3%

## Question 1 (points)

The human immune system has the capacity to respond to a huge variety of pathogens and can even respond if the host has not been previously exposed to this pathogen.

a) Give an example of a type of immune system cell that can **non-specifically** recognize a pathogen.  
*Any cell that engulfs debris such as a macrophage or dendritic cell.*

b) Give an example of a type of immune system cell that can **specifically** recognize a unique feature of a pathogen. What surface protein associated with this cell type is responsible for this recognition?  
*Either a B cell with its surface bound antibody or a T cell with its T cell receptor.*

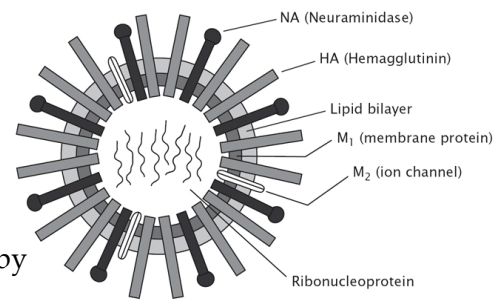
c) Briefly **describe** two mechanisms by which the immune system generates the diversity needed to ensure a response to previously unknown pathogens.

1) *Random DNA rearrangement that results in a unique combination of different V, D, and J regions for both the heavy and the light chains of the antibody.*

2) *Junctional diversity where the joining of V to D and D to J is not precise and results in the addition (or subtraction) of one or a few amino acids of each of the heavy and light chain polypeptides.*

3) *Somatic mutation of the rearranged heavy and light chain genes during clonal expansion.*

d) The ability of the influenza virus to mutate presents a challenge to the immune system and also to those designing vaccines against the flu. Each year, the virus causing seasonal flu is different than the one seen in previous years.

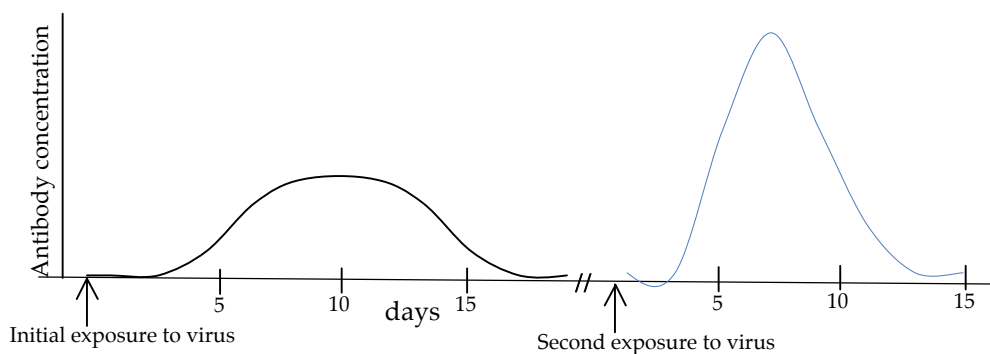


- The high mutation rate of the virus is due to errors made during replication. Do you expect the viral genome is replicated by host cell enzyme or by an enzyme encoded by the viral genome? Explain why you made this choice.

*The virus is likely replicated using an enzyme encoded by the viral genome. A virus that relies on the host cell proteins would copy its DNA using the host DNA polymerase. The host DNA polymerase has a high fidelity, and proofreading ability, which would decrease the mutation rate.*

- Mutation of viral gene or genes encoding which proteins (see diagram above) would decrease the effectiveness of the immune system memory? Explain why you made this choice.  
*Antibodies bind to the viral proteins exposed to the surface, so mutations in the genes encoding NA, HA, or M<sub>2</sub> would mean that the memory B cells previously generated would no longer be able to bind to the version of the proteins made by the mutated gene.*

e) On the graph below, sketch the curve predicted for the same individual if she is exposed to the same virus five years later.



## Question 1, continued

f) What type of cell secretes the antibodies seen with the secondary response? A plasma cell

This antibody-secreting cell descends from another type of cell called a memory B cell.

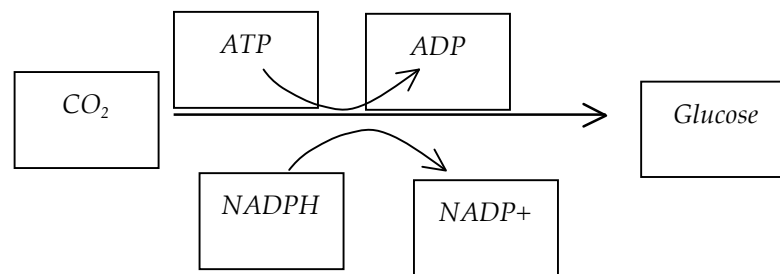
g) How does the presence of a large number of specific secreted antibodies act to control illness associated with infection by influenza A?

*The secreted antibodies will bind to the viral particles and coat them. This prevents the virus particles from adsorbing to the cell surface. In addition, the coated particles are much more likely to be targeted for destruction by macrophages or dendritic cells.*

## Question 2

A microbe, *Desulforudis audaxviator*, discovered nearly two miles deep in a 2.7-million-year-old rock formation is an organism that lives independently in total darkness and at high temperature by fixing carbon and nitrogen and reducing sulfate from its environment. *Desulforudis audaxviator* cannot survive in the presence of  $O_2$ .

a) Give the Calvin cycle *Desulforudis audaxviator* would use by completing the diagram below.



b) Given the information above, what compound (give the chemical formula) is used as an electron acceptor in *Desulforudis audaxviator* respiration? Justify your answer.

*Desulforudis audaxviator* is a sulfate reducing species and can not survive in the presence of  $O_2$ , so it must be undergoing anaerobic respiration. It will use  $SO_4^{2-}$  as the final electron acceptor.

c) While exploring for other new types of organisms, you discover a deep subterranean lake and wish to determine how many different species of microbes are present in this lake. You assume that some of the microbial species present cannot be cultured in laboratory. Outline a PCR experiment you could perform to determine how many different species are present by answering the following questions.

- You choose PCR primers that are specific to the DNA sequence encoding the small ribosomal RNA (rRNA) subunit. Explain why this is a good choice.  
*The gene encoding the small ribosomal subunit is found in every organism known. At least two regions of this gene are absolutely conserved among all known species, which gives us the sequence needed for PCR primers. In addition, other regions of this gene vary between all species and this allows the comparison.*

## Question 2, continued

## c) continued

- Once you have completed the PCR amplification, what steps must you follow to obtain DNA sequence information for all of the different rRNA sequences present in your sample?  
*You would ligate each of the PCR generated fragments into a cloning vector. Then you would transform the ligation mix into E. coli cells such that each cell obtained only one recombinant plasmid. You would select for cells that obtained a recombinant vector, and isolated the vector DNA from each transformed cell. You would then use dideoxy-DNA sequencing methods to sequence the insert region of the vector.*
- You find DNA sequence information for 1000 distinct rRNAs. Some of the genes encoding the rRNAs differ from each other by only 1 or 2 base pairs, while others can differ by more than 20 base pairs. What assumptions could you make about two species whose rRNA genes differ from each other by only 2 base pairs as compared to two species whose rRNA genes differ from each other by 18 base pairs?  
*You would assume that the species whose rRNA genes differ from each other by only 2 base pairs had a common ancestor more recently than did the two species whose rRNA genes differ from each other by 18 base pairs. The species whose rRNA genes differ from each other by only 2 base pairs are more closely related in an evolutionary sense than the two species whose rRNA genes differ from each other by 18 base pairs*

d) Regions of the rRNA accumulate mutations at different rates. Type A regions share the same sequence and length in all known organisms, Type B regions vary in sequence, but the length is conserved in all known organisms, Type C regions vary in sequence and in length.

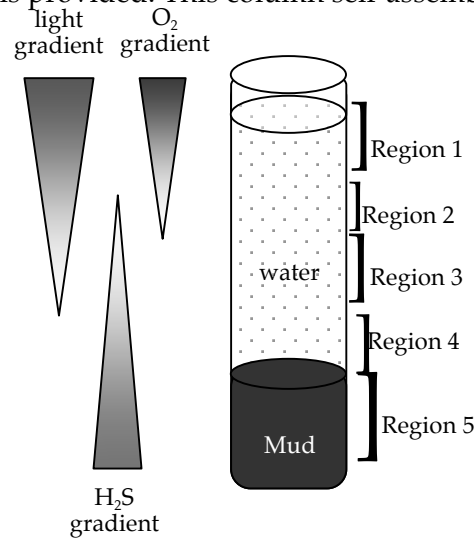
- The PCR primers you designed to complete this experiment would be complementary to which type of region? Explain why you made this choice.  
*Type A. You want to use a single set of PCR primers to amplify every ribosomal RNA present. PCR primers should be the exact complement of the targeted DNA sequence for efficient binding, so you would design primers that would bind to all ribosomal RNA genes present, thus you would choose a region that is identical across all species.*
- When making the comparison between rRNA sequences, one type of region is used to determine the proper alignment, a different type is used to estimate the evolutionary distance.

Which region is used to determine the proper alignment between sequences?  
*Type A.*

Which region is used to estimate the evolutionary distance between organisms?  
*Type B*

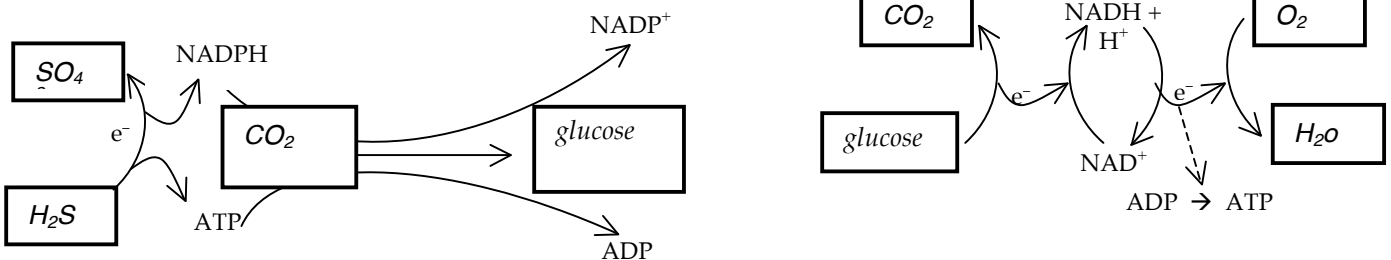
Question 3

A schematic of a Winogradsky column is shown below. It was created by mixing pond mud and water with a carbon source like dead plant matter and a sulfur source such as calcium sulfate ( $\text{CaSO}_4$ ). This mixture is sealed into a tall column or bottle and allowed to settle. A light source that penetrates only the top portion of the column is provided. This column self-assembles to form different chemical and biological layers.



a) Once the column is established, the chemosynthetic bacteria would be found in which region or regions? List all that apply Regions 2-5.

Complete one diagram or both diagrams as is appropriate for a type of chemosynthetic bacteria in your Winogradsky column.



b) Once the column is established, both oxygenic and anoxygenic photosynthesizing bacteria are found.

- The anoxygenic photosynthesizers would be found in which region or regions? Region 3.
- Compare oxygenic and anoxygenic photosynthesizers with respect to...

	oxygenic photosynthesizer	anoxygenic photosynthesizer
Carbon Source	$\text{CO}_2$	$\text{CO}_2$
Energy Source	<i>sunlight</i>	<i>sunlight</i>
Electron Donor	$\text{H}_2\text{O}$	$\text{H}_2\text{S}$

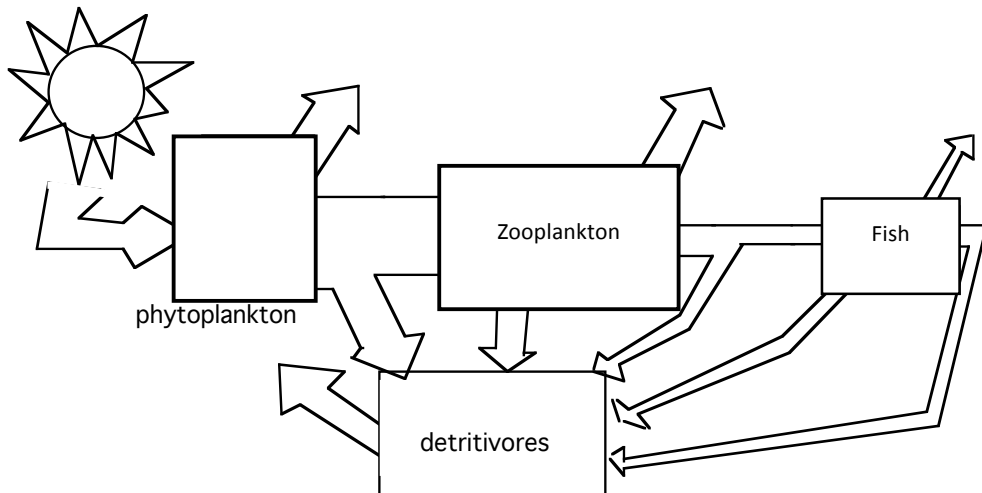
c) There is a wide array of aerobic heterotrophic bacteria in this column.

- What do these organisms use the oxygen for?  
 *$\text{O}_2$  is used as the final electron acceptor.*
- Given this is a sealed column, will the aerobic heterotrophic bacteria eventually die from lack of oxygen? Explain your answer.  
*No, The oxygenic photosynthesizers (and some chemosynthesizers) produce  $\text{O}_2$  which will be available for aerobic respiration.*

## Question 4 (points)

You have constructed a model marine food web in the laboratory. Your system has three trophic levels as seen in the schematic shown below. There are many different varieties of phytoplankton, three types of zooplankton, and two different kinds of fish, fish A and fish B. At steady state, you see the following values.

total phytoplankton production efficiency = 50%	Fish A exploitation efficiency = 30%
total zooplankton exploitation efficiency = 40%	Fish A assimilation efficiency = 40%
total zooplankton assimilation efficiency = 60%	Fish A production efficiency = 8%
total zooplankton production efficiency = 40%	Fish B exploitation efficiency = 40%
	Fish B assimilation efficiency = 20%
	Fish B production efficiency = 6%



a) If the Gross Primary Production (GPP) is 1000 kilograms of carbon, how many kilograms of carbon/week does fish A respire? Show your work.

$$1000 \text{ kilograms of carbon/week} \times 0.5 \times 0.4 \times 0.6 \times 0.4 \times 0.3 \times 0.4 = 5.76 \text{ kilograms of carbon/week Assimilated.}$$

$$1000 \text{ kilograms of carbon/week} \times 0.5 \times 0.4 \times 0.6 \times 0.4 \times 0.3 \times 0.08 = 0.46 \text{ kilograms of carbon/week Produced.}$$

$$\boxed{5.76 - 0.46 = 5.3 \text{ kilograms of carbon/week respired}}$$

b) Assume that your water becomes contaminated and 50% of the zooplankton suddenly die. In response, you expect that the overall amount of carbon ( $\text{CO}_2$ ) respired would suddenly decrease. However, you find the overall amount carbon ( $\text{CO}_2$ ) respired suddenly increases. How can you explain this observation?

*The sudden death of zooplankton increases the flow of organic carbon into the detritivore food web. This dramatically increases the respiration of the heterotrophic microbes, which more than compensates for the loss of respiration from the zooplankton and the fish. Thus you see an increase in  $\text{CO}_2$  respired.*

## Question 4, continued

c) The contamination affected only one type of zooplankton, and eliminated all individual organisms of this type. The biomass of the two remaining types of zooplankton increases until the total zooplankton production efficiency returns to 40%. You believe that your system has recovered until you observe that fish B exploitation efficiency has dropped to 5%. Fish A exploitation efficiency has not changed.

- What effect will the drop in fish B exploitation efficiency have on the total amount of carbon (CO<sub>2</sub>) respired from the fish trophic level? Explain.  
*If fish B exploits less zooplankton, then fish B will assimilate less carbon and respired less. Because fish A does not increase exploitation, there will be an overall decrease respiration from the fish trophic level.*
- Explain how the loss of 1 type of zooplankton could result in the decrease seen in the fish B exploitation efficiency.  
*This type of zooplankton must have been fish B's preferred food source. Perhaps this zooplankton was found in an area that fish B could exploit, and the others were not. Perhaps this zooplankton was of an appropriate size for fish B to exploit, and the others are not, or this zooplankton showed behavior that allowed exploitation by fish B and the others do not.*

d) By recombinant DNA technology, you engineer one of the zooplankton to express Proteorhodopsin, a light-driven proton pump.

- Briefly describe what the expression of Proteorhodopsin allows this zooplankton to do that it could not before, and explain how this is an advantage for the survival this zooplankton.  
*The presence of Proteorhodopsin allows the zooplankton to generate a proton gradient that can be used for ATP synthesis. This ATP can be used directly for metabolism, so the zooplankton expressing Proteorhodopsin need less food to build the same biomass and this would give them a selective advantage when food is limiting.*
- Which efficiency or efficiencies (see table on previous page) will change as a result of the presence of zooplankton that are using Proteorhodopsin? For each efficiency listed, indicate whether it would increase or decrease, **and** explain your reasoning.  
*Certainly the production efficiency of the zooplankton will increase as the presence of zooplankton using Proteorhodopsin increases. This is because zooplankton that use Proteorhodopsin will obtain more ATP for the amount of food consumed and lose less to respiration.*

## Question 5 (points)

In an “El nino” year the prevailing winds alter global weather patterns, particularly the coastal currents of South America. The fish population in this region declines dramatically during these years.

a) Explain why the fish population decreases in an “El nino” year.

*The prevailing wind in a normal year blows surface waters out to sea. This drives an inward coastal current that brings the nutrient-rich deep water to replace the water lost. This coastal upwelling along the coast, brings needed nutrients to the surface waters, and this in turn increases the primary production. In an “El nino” year, the prevailing wind direction is reversed which decreases coastal upwelling and nutrients become limiting. This decreases production from the primary producers. A decrease in the NPP affects all the other trophic levels and the population of fish declines.*

You are hired to determine which nutrient (either phosphorous, nitrogen, or iron) is limiting in these waters. You collect a large volume of water and divide the sample into four different experimental bottles. To each of three bottles you add either phosphorous, nitrogen, or iron. You add nothing to the fourth. After an incubation period, you measure the amount of chlorophyll in each bottle.

b) Why do you measure chlorophyll?

*Chlorophyll is found in autotrophs but not in heterotrophs. The amount of chlorophyll is proportional to the biomass of the primary producers, and thus can be used to measure growth of primary producers.*

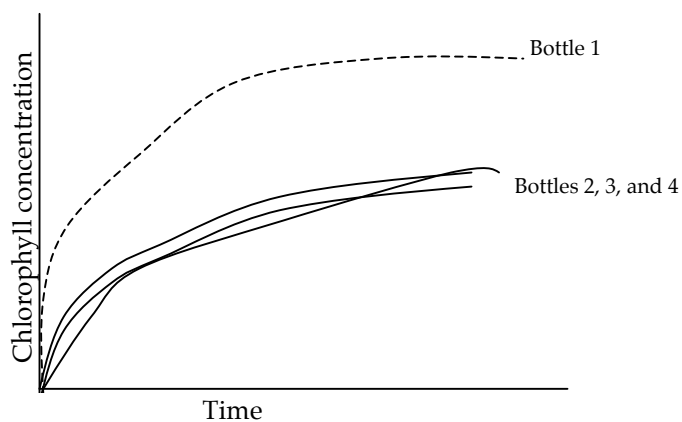
While waiting for your experiment, you remember that the Redfield ratio (i.e. the ratio of elements found in phytoplankton cells) is:

	Carbon	Nitrogen	Phosphorous	Iron
Redfield ratio	106	16	1	0.01

You measure the amount of Carbon, Nitrogen, Phosphorus, and Iron in parts per million from your water sample and find:

	Carbon	Nitrogen	Phosphorous	Iron
Water sample	200,000	15,000	1900	20

You complete your bottle experiment and see the following results.



c) Given the amount of carbon, nitrogen, phosphorus, and iron in your original water sample, what was added to bottle 1? Explain how you came to this conclusion or show your work.

*Nitrogen. The needed ratio of Nitrogen to Carbon = 1/6.6. In the sample we have 15,000:200,000 or 1/13.3, so nitrogen is limiting with respect to carbon. You need also to compare nitrogen to both phosphorous (need 16/1, have ~8/1) and to Iron (need 1600/1, have 750/1). So in each comparison, Nitrogen is limiting.*