1. (1 pt) Before the evolution of oxygenic photosynthesis, all life on earth was:
   a. microaerophilic   b. thermophillic   
   **c. anaerobic**   d. lithoheterotrophic

2. (1 pt) Put the following in order, from **oldest (1)** to **youngest (4)**.
   _4__ multicellular eukaryotes
   _3__ aerobic respiration in prokaryotes
   _1__ anaerobic prokaryotes
   _2__ photosynthetic prokaryotes

   The following is a list of nutritional types of prokaryotes:
   chemoorganoheterotroph    chemolithoautotroph    photoheterotroph
   chemolithoheterotroph    photoautotroph

   Fill in the most appropriate nutritional type for each of the following. If you think that more than one type is possible, pick only one and be sure to explain your answer.

3. (1 pt) Responsible for introducing O₂ to the earth's atmosphere
   photoauto

4. (1 pt) An organism that oxidizes NH₄⁺ and uses CO₂ for a carbon source
   chemolithoauto

5. (1 pt) Purple bacteria that get energy from the sun and electrons from organic acids
   photohetero or photoauto

6. (1 pt) An organism that oxidizes sugars and uses NO₃⁻ as an electron acceptor
   chemoorganohetero

7. (1 pt) A member of the Korearchaeota that is finally cultured, when provided with H⁺ and organic acids. The organisms did not grow when provided either H⁺ or organic acids alone. chemolithohetero

8. (1 pt) An organism growing in an atmosphere containing CH₄⁺ and CO₂ and on a medium containing no organic nutrients _chemolithoauto_________

9. (1 pt) Give an example of a chemolithotroph (genus)  **Beggiatoa, Nitrosomonas**

10. (1 pt) What is the terminal electron acceptor in aerobic respiration?  **O₂**

11. (1 pt) Give an example of a terminal electron acceptor used in anaerobic respiration  **NO₃⁻, SO₄²⁻, CO₂**
12. (1 pt) In the following metabolic reaction, which pathway (A or B) represents oxidation? ___A___ Which is reduction? ___B___

13. (1 pt) What is the electron donor? ___CH4_____ What is the electron acceptor? ___O2____

A variety of organisms, including E. coli, can metabolize glucose by several pathways:
- a. aerobic (oxidative) respiration
- b. denitrification
- c. fermentation

14. (1 pt) Which of the above pathway yields the most energy for the organism? ___A____

15. (1 pt) Enzymes of which pathway are not synthesized in the presence of O2? ___B____

16. (1 pt) In which pathway do glucose and its partially oxidized products act as e- donor and acceptor (no external e- acceptor)? ___C____

17. (1 pt) In respiratory phosphorylation: ___B____
- a) ATP synthesis involves the transfer of P from an organic molecule
- b) ATP synthesis depends upon formation of a charge separation (proton gradient) across a membrane
- c) ATP synthesis is coupled to glucose reduction
- d) ATP synthesis occurs on the coenzyme Q molecule

18. (1 pt) In substrate level phosphorylation: ___A____
- a) ATP synthesis involves the transfer of P from an organic molecule
- b) ATP synthesis depends upon formation of a charge separation (proton gradient) across a membrane
- c) ATP synthesis is coupled to glucose reduction
- d) ATP synthesis occurs on the coenzyme Q molecule

19. (1 pt) In photophosphorylation: ___B____
- a) ATP synthesis involves the transfer of P from an organic molecule
- b) ATP synthesis depends upon formation of a charge separation (proton gradient) across a membrane
- c) ATP synthesis is coupled to glucose reduction
- d) ATP synthesis occurs on the coenzyme Q molecule

20. (1 pt) The dominant product(s) of mixed acid fermentation is/are:
- a. pyruvate
- b. ethanol +2,3 butanediol
- c. acetate + NH4 + CO2
- d. lactate + CO2 + H2
21. (1 pt) The dominant product(s) of neutral fermentation is/are:
   a. pyruvate   b. ethanol + 2,3 butanediol
   c. acetate + NH₄ + CO₂   d. lactate + CO₂ + H₂

22. (1 pt) The dominant product(s) of the Stickland reaction is/are:
   a. pyruvate   b. ethanol + 2,3 butanediol
   c. acetate + NH₄ + CO₂   d. lactate + CO₂ + H₂

23. (2 pts) Why does fermentation of milk products by *Lactobacillus* prevent spoilage by other organisms?
   Fermentation of milk products by *Lactobacillus* produces acids, lowering the pH to a level that other organisms cannot tolerate.

24. (2 pts) Fill in the blanks to indicate ATP synthesis

25. (2 pts) Fill in the blanks to indicate where oxidation of the substrate is coupled to reduction of NAD

26. (2 pts) Fill in the blanks to indicate where reduction is coupled to oxidation of NADH

27. (1 pt) \(O_2^–, OH^–,\) and \(H_2O_2\) are:
   a) essential to the growth of obligate aerobes   b) high energy intermediates
   c) toxic \(O_2\) byproducts   d) fixed electron carriers

28. (1 pt) Organisms that use \(SO_4\) as a terminal electron acceptor are most likely to use which of the following as an energy source?
   a) \(NO_3\)   b) fermentation products such as acetate   c) NADH   d) NH₄
29. (8 pts) Match the organism with its most likely energy source (one answer each)

__G__ Beggiatoa  
a. sugars
__C__ Thiobacillus ferroxidans  
b. methane (CH₄)
__E__ Nitrosomonas  
c. Fe²⁺
__D__ Nitrobacter  
d. NO₂
__B__ Methylococcus  
e. NH₄⁺
__A__ Lactobacillus  
f. amino acids
__F__ Clostridium  
g. H₂S
__H__ Rhodopsuedomonas  
h. sun

30. (4 pts) Draw the paths of electrons from glucose all the way to O₂ in the diagram below.

31. (4 ½ pts) Label the diagram with each of the following:

a. NADH  
g. flavoprotein
b. NAD  
h. cytochrome
c. ADP  
i. ATP synthase
d. ATP  
j. H₂O
e. O₂

32. (1 pt) What is the energy source for the organism with the following membrane system?

H₂
33. (1 pt) What membrane-bound molecule is responsible for the oxidation of Fe^{2+} by \textit{Thiobacillus ferrooxidans}?
   a) ATP synthase   \textbf{b) Rusticyanin}   c) Hydrogenase   d) Nitrate reductase

34. (1 pt) Light-mediated ATP synthesis in \textit{Halobacterium}:
   a. produces oxygen
   b. uses oxygen
   \textbf{c. occurs in the absence of oxygen}
   d. uses non-cyclic electron flow

35. (1 pt) Cyanobacteria use what as an electron donor?
   a. Rubisco   b. H_2S   c. NO_3^-   \textbf{d. H_2O}

36. (1 pt) Purple and green bacteria use what as an electron donor?
   a. Rubisco   b. H_2S   c. NO_3^-   \textbf{d. H_2O}

37. (1 pt) In anoxygenic photosynthesis, the electrons in chlorophyll that are energized by light
   \textbf{a. pass through an electron transport chain and return to the chlorophyll}
   b. pass through an electron transport chain and reduce NADP
   c. reduce NADP and then return to the chlorophyll
   d. are used to reduce SO_4^{2-} to H_2S

38. (1 pt) Production of propionate from lactate is an example of:
   a. the Stickland reaction   \textbf{b. secondary fermentation}
   c. mixed acid fermentation   d. heterofermentation

39. (1 pt) The storage of huge amounts of organic C that we now use as a source of fossil fuels resulted because:
   a. global temperatures were far lower than normal
   b. consumers (dinosaurs) became extinct and so ceased consuming plant matter
   \textbf{c. reduction of C far exceeded oxidation}
   d. oxidation of C far exceeded reduction

40. (1 pt) The enzyme complex nitrogenase transforms:
   a. NH_4^+ \rightarrow NO_3^-   \textbf{b. NO_3^- \rightarrow N_2O}
   c. NH_4^+ \rightarrow \text{amino acids}   \textbf{d. N}_2 \rightarrow \text{NH}_4^+

41. (1 pt) The enzyme complex nitrogenase functions best under which two conditions?
   a. oxic   \textbf{b. anoxic}   c. high energy supply   d. low energy supply

42. (1 1/2 pts) Match the terms with the appropriate environment
   3. a. halophile   1. cold   4. anaerobic
   1. b. psychrophile   2. acidic   5. hot
   5 c. thermophile   3. salty
43. (3 pts) In a sewage treatment plant, the carbon from organic matter in wastewater is eventually transformed into what three final products?

a. suspended solids  

b. CO$_2$  
c. ATP  
d. CH$_4$  
e. acetate  
f. ethanol  
g. biosolids  
h. propionate

44. (1 pt) In syntrophic associations known as interspecies H transfer, fermentation of one substrate is dependent upon the________________ by another organism's metabolism.

a. consumption of H$^+$  
b. production of O$_2$  
c. production of CO$_2$  
d. consumption of O$_2$

45. (1 pt) Biological oxygen demand refers to:

a. the requirement by aerobic organisms for O$_2$  
b. oxygen tolerance of prokaryotes  
c. the quantity of O$_2$ used by metabolism of organic substrates  
d. the quantity of O$_2$ required for biosynthesis

46. (1 pt) Which of the following includes organisms that can ferment a variety of different carbon sources, such as amino acids, cellulose, and pectin?

a. Bacillus  
b. Cytophaga  
c. Lactobacillus  
d. Clostridium

47. (4 pts) Explain why, following the addition of fresh kitchen or garden waste to a compost pile, temperature: a) rises, and then b) falls. Be specific about the reasons underlying the changes in temperature!

Temperature first rises because of heat generated by metabolism of lots of labile carbon sources. Temperature later falls as the labile carbons sources are used up and metabolism slows.

48. (6 pts) How would you enrich for nitrifying organisms? Provide at least 3 culturing conditions that you would use and explain why they would select for nitrifiers.

Enrichment for nitrifiers requires sources of 1) NH$_4$ for energy, 2) CO$_2$ for C, and 3) O$_2$. Enrichment will be most successful if the medium contains NO organic C on which other organisms can grow.

49. (4 pts) Why do nitrifiers have folded membranes? Be sure to explain: a) the significance of folded membranes and b) why this benefits the nitrifiers in particular.

Metabolic processes, essential for transformation of energy to useable forms, take place in membranes. Therefore, more membrane surface area allows for more potential for the organism to gain energy. The process of nitrification yields relatively little energy. Folded membranes maximize the amount of nitrification an organism can carry out and therefore increase the chance that nitrifiers will be able to get enough energy for growth.
50. Nitrification produces NO$_3^-$, which can in turn be used as an electron acceptor in the process of denitrification.

a. (4 pts) Outline both processes (nitrification and denitrification), in terms of electron donors, electron acceptors, and final products.

b. (2 pts) Draw a picture of where you might find these two processes (in relation to one another) on the landscape.

c. (2 pts) Explain why these two processes do not typically occur side-by-side in the same environment.

a. nitrification: NH$_4^+$ (e- donor) + O$_2$ (e- acceptor) $\rightarrow$ NO$_2^-$, NO$_3^-$, H$_2$O (products)

denitrification: sugars (e- donor) + NO$_3^-$ (e- acceptor) $\rightarrow$ NO, N$_2$O, N$_2$ (products)

b.

c. nitrification requires an oxic environment, whereas denitrification only occurs when oxygen is absent

51. (10 pts) Explain the two most important requirements for fixation of N$_2$ by prokaryotes. Describe how these requirements are met in a) Cyanobacteria, and b) Rhizobium in symbiotic association with leguminous plants. The two most important requirements for N2 fixation are: 1) an anoxic environment, to prevent inactivation of the enzyme nitrogenase, and 2) lots of energy, because substantial amounts of energy are required to transform N$_2$ to NH$_3$.

a. Cyanobacteria meet the energy requirements for N$_2$ fixation by the process of oxygenic photosynthesis. This produces oxygen and so must be separated from nitrogenase. Some Cyanobacteria separate photosynthesis from nitrogenase spatially. They have specialized cells (heterocysts) in which N$_2$ fixation occurs but no photosynthesis takes place. NH$_3$ is transported to other cells, and sugars are received from other cells. Other Cyanobacteria separate the processes temporally, photosynthesizing during the day and fixing N at night. Still others make use of specialized proteins that prevent O$_2$ from binding to nitrogenase. When O$_2$ is not present, the proteins are released from nitrogenase and it can function in N fixation.

b. In the Rhizobium/legume symbiosis, photosynthesis from the plant provides the energy needed for N fixation. A molecule called Leghemoglobin is made in this symbiosis. Leghemoglobin binds O$_2$ so that it cannot interfere with nitrogenase, but so that it can still be used as an electron acceptor for metabolism.