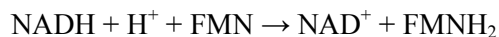1. Regarding the citric acid cycle:
    a. Write a balanced net equation for the catabolism of acetyl-CoA to CO_2
    b. How many ATP equivalents are produced as a result of this catabolism?

2. Given the following reaction:

$$NADH + H^+ + FMN \rightarrow NAD^+ + FMNH_2$$

    a. Which compound becomes reduced?
    b. Which enzyme (that we've studied) catalyzes this reaction?

3. Given the following types of redox centers:

    A. Coenzyme Q   E. Iron-sulfur cluster
    B. Cu ion   F. Heme
    C. FAD   G. NAD^+
    D. FMN

    a. For each protein complex of the electron transport chain, list the redox centers it contains.
       (That is, those that are permanently bound.) You may use the same type of redox center for
       more than one complex.

    b. Starting with succinate and ending with O_2, list *in order* the types of redox centers that carry
       electrons directly through the transport chain. (You may use each type more than once, but if
       the same type is used in several steps that occur in a row, you only need to list that center
       once for that portion of the chain.)

4. True or False?

    a. The ΔG of ATP synthesis via substrate-level phosphorylation isn't the same as that for
       oxidative phosphorylation, because one involves overcoming a barrier to combining ADP and
       P_i, while the other involves overcoming a barrier to releasing the bound ATP.

    b. The proton motive force is caused by a combination of the concentration and charge
       differences that are produced across the inner mitochondrial membrane.

    c. The γ subunit of ATP synthase predominantly binds the T-state (ATP-bound state) of an α-β
       dimer.

    d. The hetero-hexamer (trimer of α-β subunit dimers) of ATP synthase does *not* rotate during
       ATP synthesis.

    e. If the membranes of the mitochondrion are ruptured (broken), oxidative phosphorylation
       cannot occur

    f. Raising the pH of the fluid in the intermembrane space results in ATP synthesis in the matrix.

    g. The correct orientation of the enzyme complexes of electron transport is necessary to the
       formation of the proton gradient.

    h. Exposing a cell to carbon monoxide will affect its ability to produce ATP.

    i. Radioactively labeled P_i is incorporated into cytosolic ATP only in the presence of a proton
       gradient across the inner mitochondrial membrane.

    j. NADH shuttle systems bring NADH into the mitochondrial matrix.

    k. $FADH_2$ formed in the TCA cycle diffuses to Complex II (of the electron transport chain) to
       drop off its electrons.

5. For each cofactor below (a-g), list all matching descriptors (A-L). (The number of answers you should list is given in parentheses.) Each descriptor may be used more than once, and there may be extra (unused) descriptors.

Cofactors	Descriptors
a. NAD (5)	A) Can accept/carry a single electron
b. FMN (3)	B) Can accept/carry two electrons
c. Iron-sulfur cluster (1)	C) Carries (binds) an acyl group
d. Coenzyme A (3)	D) Carries (binds) a carboxyl group
e. Coenzyme Q (2)	E) Is used by pyruvate carboxylase
f. Lipoic acid (3)	F) Is used by pyruvate decarboxylase
g. Biotin (3)	G) Is used by pyruvate dehydrogenase complex
	H) Is used by succinate dehydrogenase
	I) Is used by malate dehydrogenase
	J) Is more likely found in its reduced form
	K) Is more likely found in its oxidized form
	L) Is derived from an essential vitamin

6. What component of electron transport is diffusible in the membrane? Why is it diffusible in the membrane?

7. Which of the following statements are true? There may be more than one correct answer.
   a. The reaction catalyzed by phosphofructokinase is an example of substrate-level phosphorylation.
   b. The reaction catalyzed by succinyl-CoA synthetase is an example of substrate-level phosphorylation.
   c. Generation of ATP through a phosphoryl-transfer reaction is an example of substrate-level phosphorylation.
   d. Respiration-linked phosphorylation requires a proton gradient.
   e. Respiration-linked phosphorylation and fermentation cannot occur in the same organism.

8. The standard reduction potentials for several half reactions of the electron transport chain are provided below:

$$NAD^+ + H^+ + 2e^- \rightarrow NADH \qquad -0.32 \text{ V}$$
$$FMN + 2H^+ + 2e^- \rightarrow FMNH_2 \qquad -0.30 \text{ V}$$
$$FAD + 2H^+ + 2e^- \rightarrow FADH_2 \qquad +0.05 \text{ V}$$
$$CoQ + 2H^+ + 2e^- \rightarrow CoQH_2 \qquad +0.06 \text{ V}$$
$$\text{Cyt. b } (Fe^{3+}) + e^- \rightarrow \text{Cyt. b } (Fe^{2+}) \qquad +0.07 \text{ V}$$
$$\text{Cyt. c } (Fe^{3+}) + e^- \rightarrow \text{Cyt. c } (Fe^{2+}) \qquad +0.25 \text{ V}$$
$$\text{Cyt. } a_3 (Fe^{3+}) + e^- \rightarrow \text{Cyt. } a_3 (Fe^{2+}) \qquad +0.35 \text{ V}$$
$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \qquad +0.82 \text{ V}$$

   a. Calculate the $\Delta E'^\circ$ for the transfer of two electrons from complex II to oxygen in a human muscle cell. Show your work.

   b. Calculate the $\Delta G'^\circ$ for the transfer of two electrons from complex II to oxygen in a human muscle cell. Show your work.

   c. What percentage of this free energy change is lost as heat in the electron transport chain (that is, not stored in the proton gradient)? Assume that the $\Delta G'^\circ$ of electron transfer $\approx \Delta G$ in the cell, and assume that the ΔG of proton transfer across the mitochondrial inner membrane is 20 kJ/mol. Show your work.

9. Given the following oxidation-reduction reaction:

$$A + NAD^+ \rightleftharpoons B + NADH + H^+$$

A starting solution of 100 mM A and 100 mM NAD^+ (buffered at pH 7) is allowed to reach equilibrium. At equilibrium, $[A] = [NAD^+] = 10$ mM.

   a. Calculate the $\Delta E'^\circ$ for this reaction. (Assume the reaction happens at 25°C.)

   b. For a starting solution with $[A] = [B]$ and $[NAD^+] = [NADH]$, in which direction will the reaction proceed? Explain in 20 words or fewer.

   c. For a starting solution with $[A] < [B]$ and $[NAD^+] = [NADH]$, in which direction will the reaction proceed? Explain in 30 words or fewer.

10. If oxygen cannot be properly delivered to cells, how is metabolism affected? For each of the following, choose the sentence (A or B) that best explains the effects of anoxia (O_2 deprivation) on the listed metabolic process.

   a. The electron transport chain (ETC):
       A. is not affected, because electrons can be dissipated by Coenzyme Q.
       B. stops, because electrons cannot be delivered to the final acceptor.

   b. ATP synthase
       A. stops, because there is no proton gradient.
       B. stops, because there's no oxygen to power it.

   c. The citric acid cycle
       A. is not affected, because it doesn't use oxygen.
       B. stops, because of limited NAD^+.

11. You are a blossoming biochemist and wine enthusiast, and you're interested in studying the overlap of your two loves. You decide to try a carbon-tracing experiment with a batch of champagne. After the initial fermentation and bottling, you add yeast and labeled sugar (labeled at carbon 1 of glucose) to the bottle for a second fermentation, which will convert the bottle's contents to champagne. After the ageing period, you open the bottle and measure where the label ended up.

   a. What compound contains the majority of the label? Give its name, draw its structure, and circle the labeled carbon.

   A bit of the label ended up in L-malate, which you find surprising since you know that no aerobic metabolism was occurring. After some reading, you learn that L-malate is responsible for tartness in some wines and can be produced under anaerobic conditions.

   b. Complete the given equation for the net conversion of glucose to malate. (Hint: look at the differences in numbers of C, H, and O elements.)

   glucose + _____ → 2 malate + _____

   c. Briefly explain how glucose would have been converted to L-malate in your champagne, naming the important pathways &/or enzymes (*Hint: there are three of these*). (30 words or fewer.)

   d. Draw the structure of L-malate, and circle the carbon that was labeled in your experiment.

12. In class we discussed the sequence of events in ATP synthesis by ATP synthase. Given the steps below, and starting from the loose conformation (step 'b' below), order them in the proper sequence to describe what happens at *one α/β dimer* of ATP synthase. There are 13 steps, starting and ending with step **b**. (Some steps may be used multiple times; some steps may not be used at all.)

   a. The α/β dimer switches to the open (empty) conformation
   b. The α/β dimer switches to the loose conformation
   c. The α/β dimer switches to the tight conformation
   d. The c-ring, ε, and γ subunits rotate by 120°
   e. The α and β subunits rotate by 120°
   f. ADP and Pi bind
   g. ADP and Pi dissociate
   h. ATP binds
   i. ATP dissociates
   j. ATP is formed
   k. Three protons enter the ring of c-subunits from the matrix
   l. Three protons enter the ring of c-subunits from the intermembrane space