

Chapter 17 Answers  
Electron Transport and Oxidative Phosphorylation

- 1) Book Study exercises 2, 4, 7
- 2 - The two electrons carried by NADH are transferred together to FMN, which is a two electron acceptor group in Complex I. FMN<sub>H2</sub> then transfers one electron at a time to the first of a series of iron-sulfur clusters. Each electron is then passed through the iron-sulfur center to the mobile electron carrier coenzyme Q, which is a two-electron carrier. Reduced CoQ then transfers its two electrons to complex III. The flow of electrons follows a bifurcated cyclic pathway (the Q cycle) in which the first electron reduces the Rieske iron sulfur protein and then Cytochrome c<sub>1</sub>, which in turn reduces Cytochrome c. Simultaneously, the second electron passes from CoQ<sub>-</sub> to Cytochrome b<sub>L</sub> and then to Cytochrome b<sub>H</sub> and back to CoQ<sub>-</sub>. A second round of the cycle involving a second reduced CoQ results in the reduction of a second Cytochrome c<sub>1</sub> and the reduction of the CoQ<sub>-</sub> back to reduced CoQ. In this way, the electrons of the two carrier NAD<sup>+</sup> are transferred to two molecules of the one-electron carrier Cytochrome c
  - 4 - According to the chemiosmotic theory, the free energy of electron transport is conserved in the formation of a transmembrane proton concentration gradient that is established when protons are pumped from the mito to the inner mito membrane space by the action of the ETS. The free energy of the gradient is harnessed to drive the phosphorylation of ADP to produce ATP.
  - 7 - Oxidative phosphorylation is linked to electron transport by the arrangement of protein complexes in the inner mitochondrial membrane such that electron transport through complexes I, III and IV generates a transmembrane proton concentration gradient whose dissipation through the F<sub>0</sub> channel drives ADP phosphorylation by F<sub>1</sub>F<sub>0</sub>-ATPase. This coupling depends on the impermeability of the membrane, which allows the electron transport complexes to increase the concentration of protons on the cytoplasmic side of the membrane, and which prevents the protons from re-entering the matrix except through F<sub>1</sub>F<sub>0</sub>-ATPase. Electron transport and oxidative phosphorylation can be uncoupled by an agent that dissipates the proton gradient. The result is that electron transport proceeds without the build up of the proton gradient, and hence no ATP is synthesized.
- 2) Which of the following electron transfer system complexes contains a non-heme copper
- a) Site I
  - b) Site II
  - c) Site III
  - d) Site IV \*\*
  - e) Outasite
- 3) Naturally occurring uncoupled mitochondria
- a) is found in non-hibernating animals
  - b) occurs in hot conditions where ATP synthesis is required
  - c) is likely to happen in the backs of some women \*\*\*
  - d) is very dangerous to infants
  - e) occurs in muscle where it can hydrolyze ATP for movement
- 4) Which of the following portion of the electron transport chain is soluble in the cytosol?
- a) ubiquinone
  - b) cytochrome c \*\*\*
  - c) cytochrome C oxidase
  - d) Fe-S centers
  - e) site II of the ETS

5) The target in the respiratory chain for cyanide is

- a) Site I
- b) Site II
- c) Site III
- d) Site IV \*\*\*

6) Which of the following enzymes does not directly link to the electron transport system?

- a) malate dehydrogenase (MDH) \*\*\*\* All of the others are FADH<sub>2</sub> linked enzymes and are therefore a part of complex II
- b) succinate dehydrogenase
- c) the first reductase in  $\beta$  oxidation
- d) Site II

7) Which of the following complexes does not pump protons during electron transfer

- a) Site I
- b) Site II \*\*\*
- c) Site III
- d) Site IV

8) Why are there so many similar components of the electron transport system and how can there be more than one of the same kind and still have a transfer of electrons? The components are the various iron-sulfur centers or the cytochromes that are at first inspection very similar. That is cytochromes to cytochromes and Fe-S centers to other Fe-S centers. The local bonding and proximity to amino acids and their topical location in the protein / membrane alters the reduction potential of two otherwise very similar elements. Think of how very different the environment is for a redox cytochrome is when it is near the matrix than the outer membrane.

9) Explain why the glycerol-3-phosphate shuttle results in only two ATP's per cytosolic NADH, whereas the malate-aspartate shuttle results in three ATP's per cytosolic NADH. You do not have to draw out the structures in the shuttles. This is a direct difference between the manner in which the two shuttles get their reducing equivalents inside the mitochondria matrix. One method moves as NADH which can then donate its electrons to site one and the other pathway utilizes an FADH<sub>2</sub> linked system and thus its electrons are transferred through site two and results in two less electrons transferred.

10) The target for the respiratory chain poison by carbon monoxide is?

- a) Cytochrome a
- b) Cytochrome b
- c) Cytochrome Oxidase \*\*\* Otherwise known as cytochrome C oxidase
- d) UQH<sub>2</sub> Reductase

11) Which is not an electron carrier in the electron transport system?

- a) Lipoate \*\*\* This is the flexible arm used in the PDH complex
- b) Quinone
- c) Cytochrome c
- d) Flavin

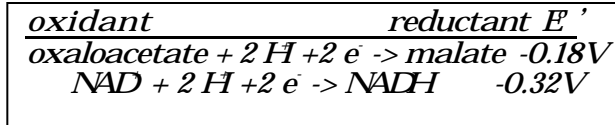
12) Which of the following enzymes is responsible for detoxification of the intermediates produced during of O<sub>2</sub> reduction to H<sub>2</sub>O.

- a) Oxygen reductase
- b) Catalase \*\*\* We may have not covered this much and is not covered on the test
- c) Cytochrome c
- d) Gitoutaherease

13) Which electron system complex does NOT cause the release of protons into the inner mitochondrial space?

- a) Complex I
- b) Complex II \*\*\*
- c) Complex III
- d) Complex IV

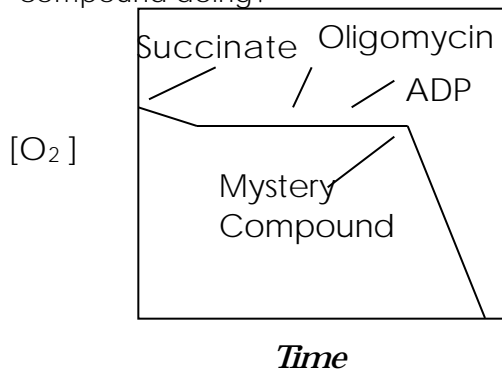
14) The standard reduction potentials at pH 7.0 ( $E^{\circ}$ '), for oxaloacetate and  $NAD^+$  are given below. Which of the spontaneous reactions described will occur when  $NADH$ ,  $NAD^+$ , malate and oxaloacetate are mixed at standard state conditions?



To work this problem one needs to simply add up the change in reduction potential and determine which direction is spontaneous. Then the redox reaction can be chosen.

- a) Oxidation of malate by  $NAD^+$
- b) Oxidation of  $NADH$  by oxaloacetate
- c) Reduction of  $NAD^+$  by malate
- d) Reduction of oxaloacetate by  $NAD^+$
- e) Oxidation of  $NADH$  by malate

15) Describe the what is happening in the following graph, and what is the mystery compound doing?



This is a measure of the P/O ratio of a respiring mitochondria. When succinate is added electrons can enter into the ETS/OxPhos system at site II although at a slow rate because there is little ADP to allow the F0F1-ATPase to continue. Once the endogenous levels of ADP are used up all  $O_2$  reduction stops. Oligomycin blocks at this site and then when ADP is finally added no additional respiration ( $O_2$  use) is permitted. The mystery compound must be an uncoupler such as DNP which will allow the transfer of electrons. For this to happen the oligomycin must have been removed from the ATPase.

16) Explain why oxygen is the ultimate electron acceptor? This is mostly due to the ability of  $O_2$  to accept electrons. The reduction potential for the acceptance of electrons is better than most other biological molecules.

17) Explain the discrepancy in ATP formation in muscle vs. liver. Assume proton's pumped, membrane efficiency are the same for these tissues. At first attempt this seems like a very difficult question, but if you look at it one thing must come to mind –

the shuttling mechanism. Many muscles use the glycerophosphate shuttle. This produces less ATP than the liver's primary shuttle of the Asp-Malate shuttle.

18) In a chemistry handbook, the redox potential for purified Heme B<sub>L</sub> and B<sub>H</sub> are the same, yet electron transfer can take place. How? Again it is local environment (amino acids and pH) that causes the difference.

19) T/F The ATP formation is coupled to the energetically favorable influx of H<sup>+</sup> catalyzed by a proton translocating ATPase. T

20) Which of the following components of the electron transport system is unlike the others in terms of the number of electrons transferred

- a) cytochrome B \*\*\*
- b) FADH<sub>2</sub>
- c) NADH
- d) Ubiquinone

21) T /F concerning heme proteins: The heme is covalently bound for each of the cytochromes and does not effect the redox reactions F

22) Identify which of the ETS complexes that do not contain (an) Fe-S center(s) Only complex IV and V

23) Identify the only mitochondrial ETS complex that contains a bound FAD. Site II

24) If succinate dehydrogenase directly donates its electrons to the ETS, why doesn't malate dehydrogenase. The MDH is comprised of several isozymes. One is cytosolic and another is mitochondrial. Neither of these forms of the enzyme is found in the inner mitochondrial space and is NOT able to directly donate electrons into the ETS as does succinate dehydrogenase.

25) What is the difference in reducing equivalents shuttled by the aspartate malate shuttle and the glycerol 3- phosphate dihydroxyacetone phosphate transfer? Bla Bla Bla – I didn't realize there were so many of these questions. This is more than I wanted

26) What part of the ETS is responsible by the mitochondrial genome. Why are these types of diseases maternally linked? Complex I has a few subunits that are produced from the DNA in the mito itself. The mitochondrial genes are maternally linked and therefore any disease from this source would be linked to mamma.