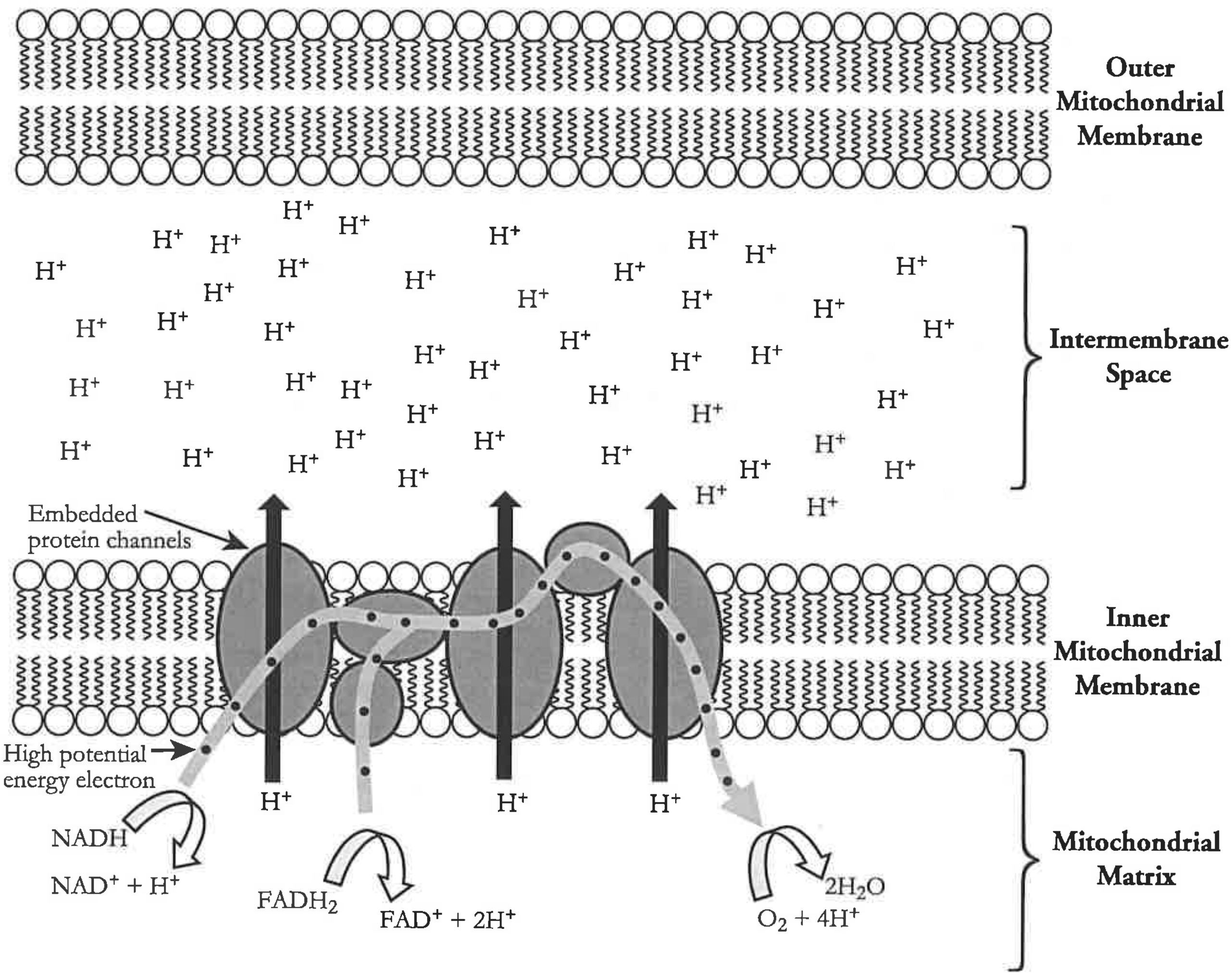
Oxidative Phosphorylation

How are the electrons in NADH and $FADH_2$ used to make ATP during cellular respiration?

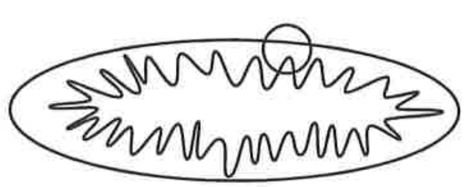
Why?

The final phase of cellular respiration is **oxidative phosphorylation**. Both the electron transport chain and chemiosmosis make up oxidative phosphorylation. During this phase of cellular respiration, all of the NADH and $FADH_2$ that were produced in other phases of cellular respiration (glycolysis, the link reaction, and Krebs cycle) are used to make ATP. The process occurs in the protein complexes embedded in the inner mitochondrial membrane.

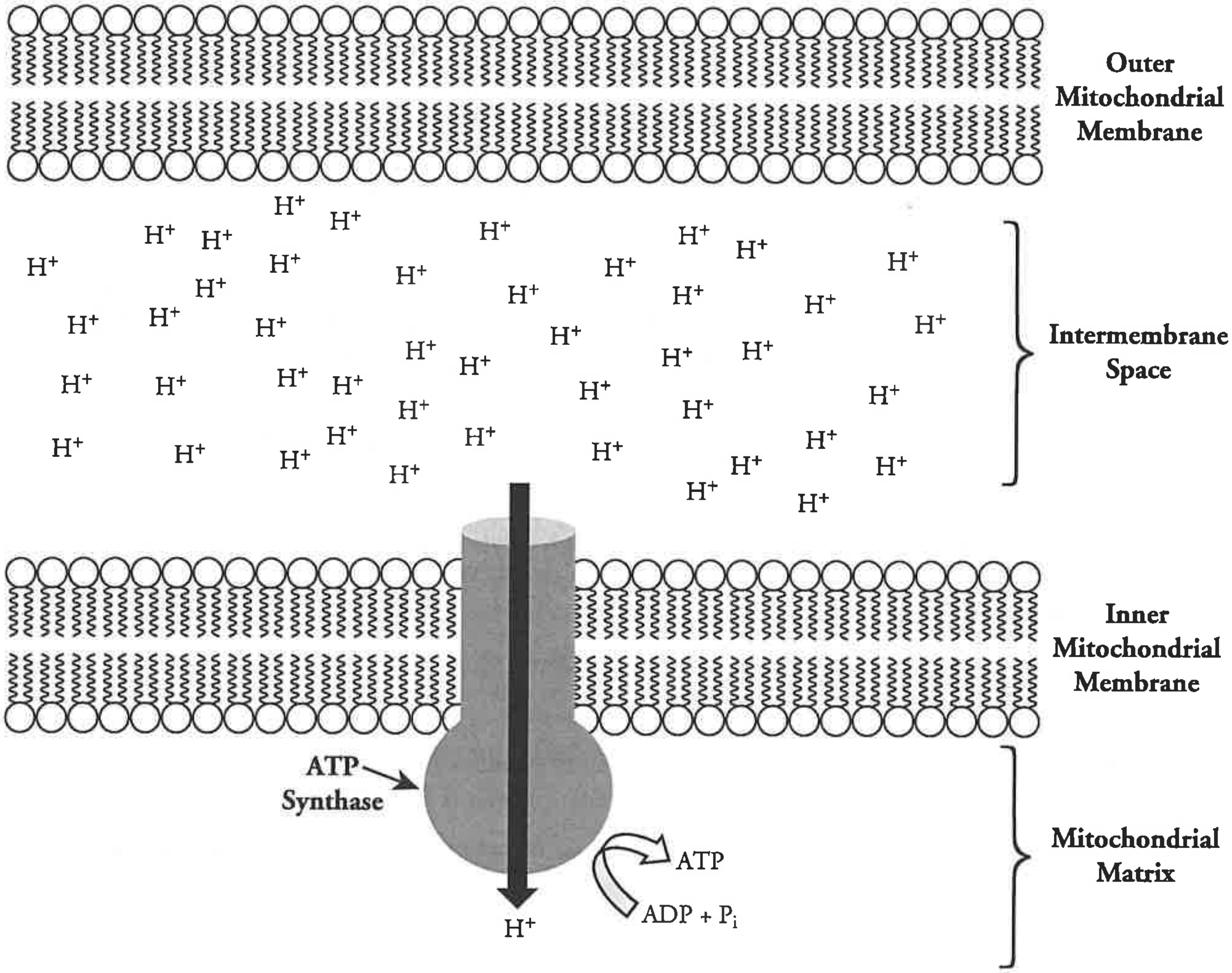
Model 1 – Electron Transport Chain



1. Consider the membranes illustrated in Model 1. Circle a section of the mitochondria below where this site might be located.



Model 2 – Chemiosmosis



8. Describe the movement of hydrogen ions through the membrane illustrated in Model 2.

   Hydrogen ions are moving from the intermembrane space through the inner mitochondrial membrane to the mitochondrial matrix.

9. Would free energy be required for the hydrogen ions to move in the direction shown in Model 2? Explain your reasoning.

   No, it does not require energy as the hydrogen ions are diffusing down the concentration gradient.

10. What is the name of the embedded protein that provides a channel for the hydrogen ions to pass through the membrane?

    ATP synthase.

11. The flow of hydrogen ions through the protein channel provides free energy to do work. What process in Model 2 requires energy?

    The production of ATP from ADP and P_i will require energy.

Read This!

The embedded protein complex, ATP synthase, is more of a machine than a chemical enzyme. Research has shown that a protein "rotor" down the middle of the ATP synthase complex turns as hydrogen ions flow through. This rotates other proteins, which then "squeeze" the ADP and inorganic phosphate groups together to form ATP.

12. During oxidative phosphorylation, what molecule is being phosphorylated?

    ADP adds a phosphate group to make ATP.

13. Under ideal conditions each NADH molecule will result in three ATP molecules, and each $FADH_2$ molecule will result in two ATP molecules during oxidative phosphorylation. Calculate the total number of ATP molecules that might be produced in this phase of cellular respiration from one glucose molecule.

    10 NADH (2 from glycolysis, 2 from link, and 6 from the Krebs cycle) × 3 ATP each = 30 ATP

    2 $FADH_2$ (from the Krebs cycle) × 2 ATP each = 4 ATP

14. Considering all the stages of cellular respiration (glycolysis, link, Krebs cycle, and oxidative phosphorylation) how many ATP molecules are produced from one glucose molecule, assuming ideal circumstances?

    Glycolysis = 2 ATP *Krebs cycle = 2 ATP*

    Link = 0 ATP *Oxidative phosphorylation = 34 ATP* *Total = 38 ATP*

15. Because of its role in aerobic respiration, oxygen is essential for most living things on Earth. In complete sentences, describe the role of molecular oxygen (O_2) in aerobic respiration.

    Molecular oxygen is essential in aerobic respiration as it combines with hydrogen ions and electrons that are carried by NADH and $FADH_2$. Without the oxygen to pick up the electrons as they complete the electron transport chain, the electron transport chain would cease to function.

16. Consider the overall chemical reaction for cellular respiration.

    $$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

    Complete the table below to identify the phase of cellular respiration where each of the reactants are used, the products are produced, and the location in the cell where that phase occurs. You may need to refer back to previous activities on cellular respiration.

	Reactants		**Products**		
	$C_6H_{12}O_6$	$6O_2$	$6CO_2$	$6H_2O$	38ATP
Phase(s) at which it is used or produced	*Glycolysis*	*Oxidative phosphorylation*	*Link, Krebs cycle*	*Oxidative phosphorylation*	*Glycolysis, Krebs cycle, ETC, oxidative phosphorylation*
Location	*Cell cytoplasm*	*Mitochondrial matrix*	*Mitochondrial matrix*	*Mitochondrial matrix and inner membrane*	*Cell cytoplasm, mitochondrial matrix and inner membrane*

STOP

Extension Questions

17. **Substrate level phosphorylation** is the term used for phosphorylation that removes a phosphate from one molecule and joins it to another molecule. Oxidative phosphorylation is the term used for the attachment of free inorganic phosphate to a molecule. Identify the phases of cellular respiration that use substrate level phosphorylation and that use oxidative phosphorylation.

    During glycolysis and the Krebs cycle, ATP is formed from phosphate groups that are attached to carbon chain molecules—substrate level phosphorylation. During the electron transport chain and chemiosmosis, ATP is formed from free inorganic phosphate—oxidative phosphorylation.

18. Which side of the inner mitochondrial membrane would have a higher pH?

    The space between the inner mitochondrial matrix would have less hydrogen ions, so it would have the higher pH value.

19. During glycolysis the enzyme hexokinase uses ATP to transfer a phosphate to glucose to form fructose-diphosphate. Suppose that a cell has only glucose available for energy and that the activity of hexokinase is suddenly stopped. Explain in detail what is most likely to occur in the cell.

    The cell will ultimately be unable to produce ATP. Because energy production requires that glucose first be metabolized in glycolysis, the loss of hexokinase would block ATP production in the cell.

20. Prokaryote cells must have energy for cellular processes just like eukaryote cells do. Yet, they have no mitochondria.

    a. Which phase(s) of cellular respiration would be unaffected by the lack of mitochondria in a cell?

    Glycolysis.

    b. The link reaction and Krebs cycle occur in the cytoplasm of prokaryotes in the same way that they occur in the mitochondria of eukaryotes. However, a concentration gradient across a membrane is a requirement of the electron transport chain. Propose an alternate site for this phase of cellular respiration in prokaryotic cells.

    The cell membrane could be used.