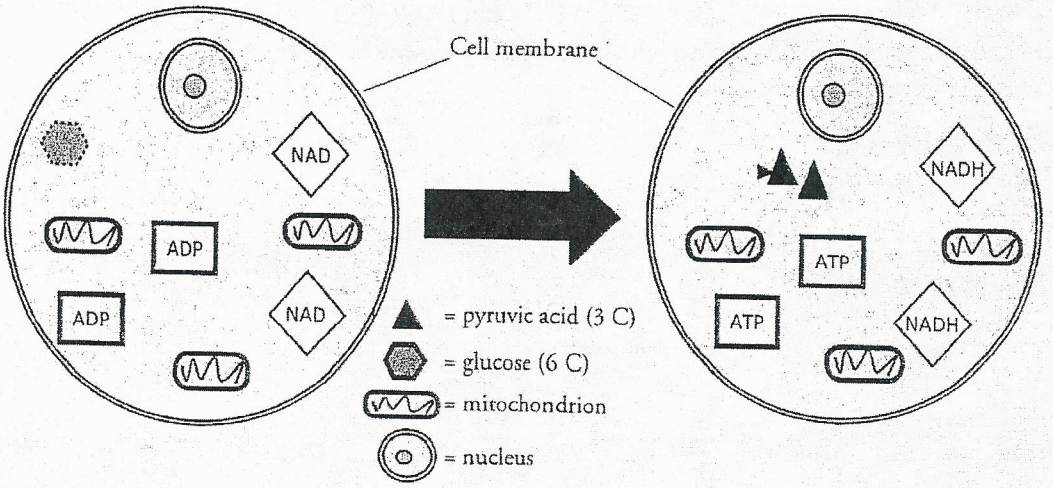
Cellular Respiration

How is energy transferred and transformed in living systems?

Why?

Living organisms display the property of **metabolism**, which is a general term to describe the processes carried out to acquire and use energy. We know that people need to eat, and in our foods are various kinds of nutrients that our cells use. One large group of nutrients in our foods is carbohydrates, which supply our cells with glucose ($C_6H_{12}O_6$). So the question is: How does the food we chew and swallow fuel our cells?

Model 1 – Glycolysis



1. Refer to Model 1.
   a. What is represented by the hexagon?
   Glucose (6C)
   b. How many carbon atoms (C) are in one molecule of glucose?
   6 carbons
2. Refer to Model 1.
   a. What is represented by the triangles?
   Pyruvic Acid (Pyruvate)
   b. How many carbon atoms (C) are in one molecule of pyruvic acid?
   3 carbons
3. In the process of glycolysis, what happens to glucose after it crosses the cell membrane into the cytoplasm of the cell?
   Glucose → (10 enzyme catalyzed reactions) → 2 pyruvate molecules, NADH, 2 ATP (+2 ATP during Pyruvate Oxidation)

Read This!

Glycolysis occurs in the cytoplasm of cells and does not require the presence of oxygen. Therefore, the process is **anaerobic**. It is the first step used by cells to extract energy from glucose in the form of ATP. ATP can be directly used by cells.

4. Thinking about the number of carbon atoms in glucose and in pyruvic acid, explain why there is one molecule of glucose on the left side of the arrow and two molecules of pyruvic acid on the right side of the arrow.

6C → 3C + 3C The 6C molecule is broken down to 2- 3C molecules.

5. How many ATP molecules are produced during glycolysis?

2 ATP net (4 ATP produced, 2 used).

6. Hydrogen-carrying molecules are also produced during glycolysis. What is the symbol of these hydrogen-carrying molecules?

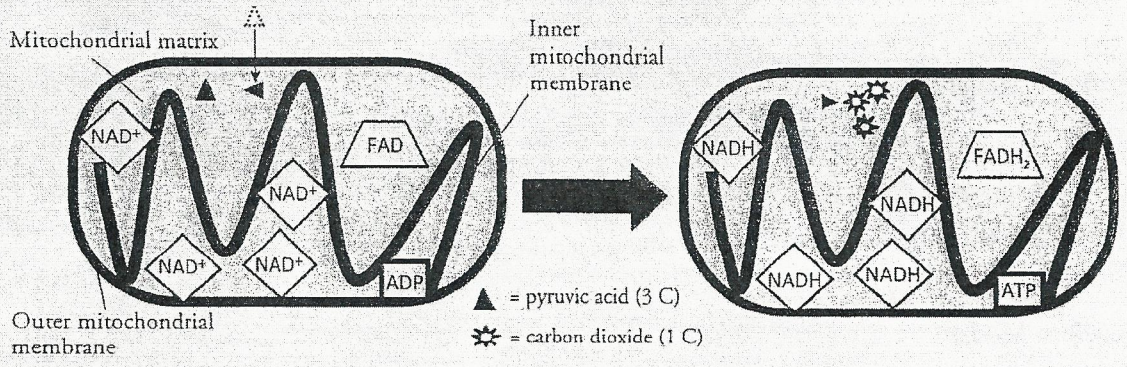
NADH ◇

7. Does glycolysis occur inside or outside the mitochondria?

Outside (in the cytoplasm).

STOP

Model 2 – Krebs Cycle



8. According to Model 2, what happens to pyruvic acid during the Krebs cycle?

Carbons used up to produce CO_2.

9. According to Model 2, where does the change identified in the previous question occur?

mitochondrial matrix.

10. Note the number of atoms of carbon in pyruvic acid and explain why three molecules of carbon dioxide are produced.

- 3 carbon in Pyruvate
- CO_2 has 1 carbon
- each time a CO_2 is produced, 1 carbon is lost from the molecule

11. Considering that glycolysis produces two pyruvic acid molecules per glucose molecule, how many total CO_2 molecules will be produced from the complete breakdown of each glucose molecule? Show a mathematical equation to support your answer.

$6CO_2$

2 from pyruvate oxidation
4 from Kreb's cycle

$C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2 + \text{energy}$

12. What two hydrogen-carrying molecules are formed during the Krebs cycle?

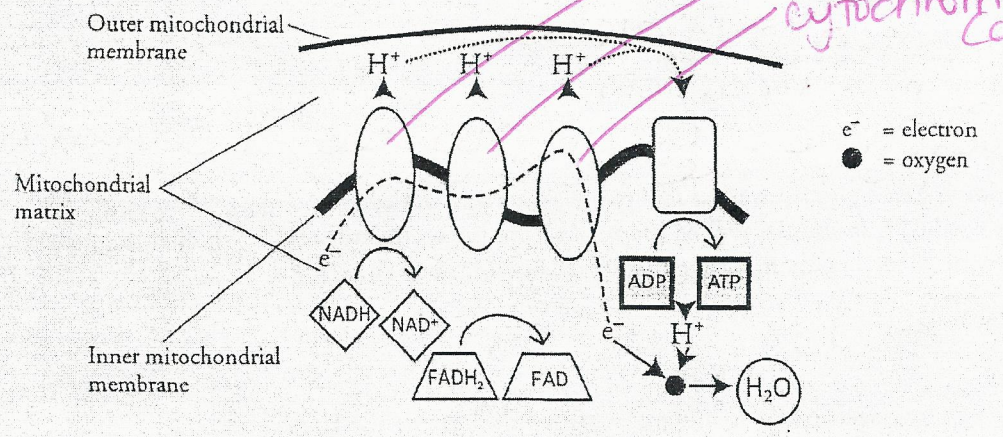
NADH, $FADH_2$

13. Fill out the chart by looking back at the entire process of glycolysis and the Krebs cycle to list the total number of ATPs and hydrogen-carrying molecules produced.

Process	ATP	NADH	$FADH_2$
Glycolysis	2	2 Glycolysis 2 Pyruvic Ox.	/
Krebs cycle (1st pyruvic acid)	1	3	1
Krebs cycle (2nd pyruvic acid)	1	3	1

Model 3 – The Electron Transport Chain

NADP dehydrogenase complex
cytochrome b-c1 complex
cytochrome oxidase complex



14. What cell structure is the site for the electron transport chain?

Inner Mitochondrial Membrane (Cristae)

15. Label the carrier proteins in Model 3.

16. What substance do the carrier proteins transport across the inner mitochondrial membrane?

electrons

Read This!

NADH and $FADH_2$ molecules release hydrogen ions that are transported across the inner mitochondrial membrane with the help of electrons. The result of these multiple processes is the production of large amounts of ATP.

17. What high energy molecules are formed by the electron transport chain?

ATP. (and chemiosmosis)

18. Refer to Model 3.

a. What atom accepts the hydrogen ion at the end of the electron transport chain? (and electrons)

Oxygen.

b. What molecule is formed as a product of that acceptance?

Water. (H_2O)

19. Formulate an explanation for why the events of the electron transport chain constitute an aerobic process rather than an anaerobic process (like glycolysis).

Aerobic processes require oxygen
Anaerobic processes do not require oxygen.
The final electron acceptor in the ETC is oxygen which combines with H^+ ions and electrons to form water. Without the final e^- acceptor, the electron transport chain would not be complete. Therefore it requires oxygen (i.e. aerobic).

Read This!

Remember that glycolysis produces two pyruvic acid molecules per glucose molecule along with two of the hydrogen-carrying NADH molecules. Remember also that the Krebs cycle produces NADH as well as another hydrogen carrier called $FADH_2$. It is important to know that during the electron transport chain, when each NADH gives up electrons and hydrogen ions, there is enough of a potential energy change to make three ATP molecules. When each $FADH_2$ gives up electrons and hydrogen ions, there is enough of a potential energy change to make two ATP molecules.

20. Fill in the chart below to calculate the total amount of ATP produced from the breakdown of each glucose molecule during the three steps of cellular respiration.

	Number of ATP produced from one glucose molecule	Number of H-carriers produced from one glucose molecule	
		NADH	$FADH_2$
Glycolysis	2	2+2	
Krebs Cycle	2	6	2
Electron Transport Chain	———	x 3	x 2
Total ATP Produced	4	30	4
Grand Total ATP produced (add all 3 columns above)		36-38	

Note
36 - Eukaryotes
38 - Prokaryotes
Why?
→ 2x2 in Euk.
2x3 in Prok.

21. Look at the equation for cellular respiration and write in which stage of the process each molecule is either used or produced.

$C_6H_{12}O_6$ + $6O_2$ → $6CO_2$ + $6H_2O$ + 38 ATP

Used in	Used in	Produced in	Produced in	Produced in
Glycolysis	ETC *Pyruvic Ox. and Krebs will only proceed in presence of O_2	Pyruvic Oxidation Krebs Cycle	ETC	Glycolysis Krebs Cycle ETC

22. Compare the ATP available to cells when oxygen is present versus when it is absent. How might this help explain why brain and heart functions are so quickly affected when a person cannot breathe?

Oxygen Present
- More ATP produced - available for work.
- When Oxygen is present, glucose is oxidized through cellular respiration - will enter Pyr. Ox / Krebs Cycle / ETC where the majority of ATP is produced.

Oxygen Absent
- Less ATP produced - less energy for work
- Without oxygen ATP will not be produced through cellular respiration → will not enter Krebs/ETC
- Brain and heart require a constant supply of energy - so no oxygen = less ATP = heart/brain dysfunction.

majority of ATP produced in ETC