

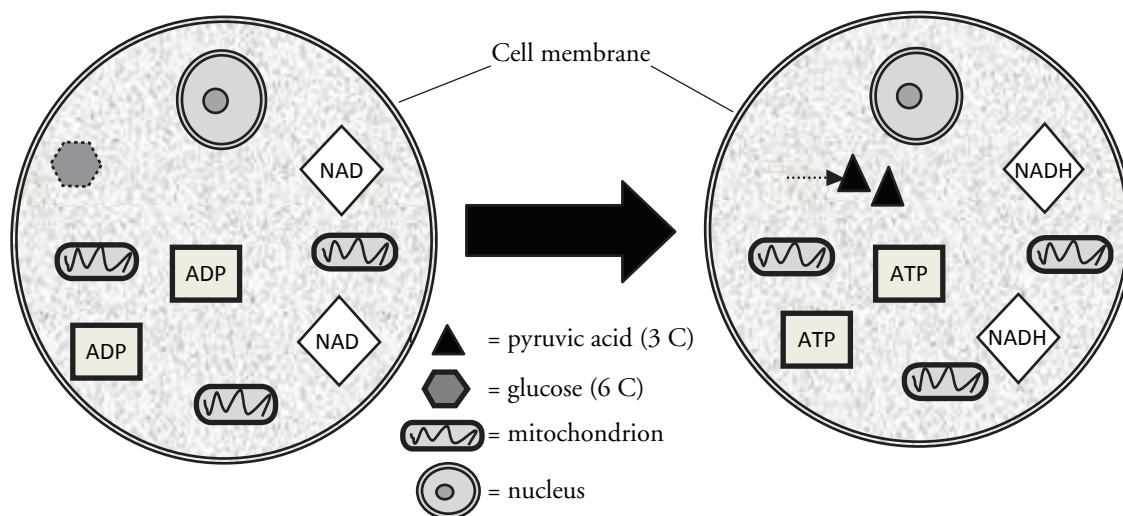
Cellular Respiration

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?
 - b. How many carbon atoms (C) are in one molecule of glucose?
2. Refer to Model 1.
 - a. What is represented by the triangles?
 - b. How many carbon atoms (C) are in one molecule of pyruvic acid?
3. In the process of glycolysis, what happens to glucose after it crosses the cell membrane into the cytoplasm of the cell?

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.

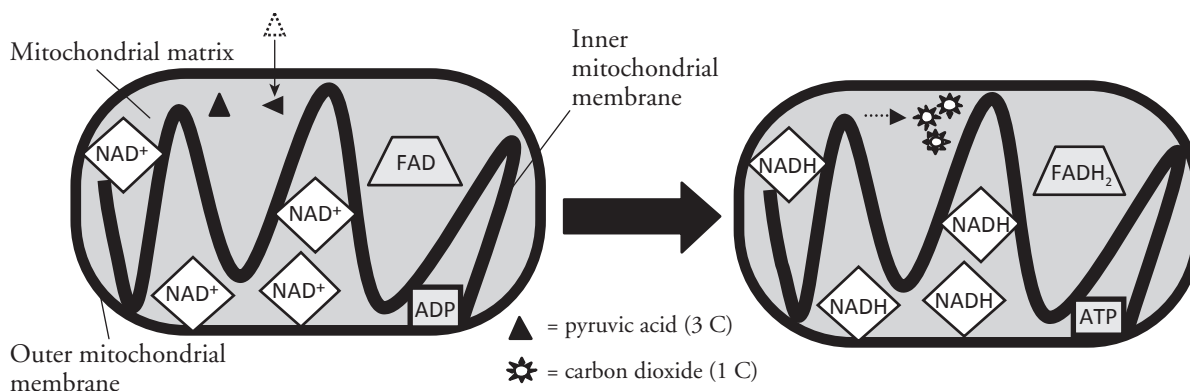
- Thinking about the number of carbon atoms in glucose and in pyruvic acid, explain why there is one molecule of glucose on the left side of the arrow and two molecules of pyruvic acid on the right side of the arrow.



- How many ATP molecules are produced during glycolysis?
- Hydrogen-carrying molecules are also produced during glycolysis. What is the symbol of these hydrogen-carrying molecules?
- Does glycolysis occur inside or outside the mitochondria?



Model 2 – Krebs Cycle



- According to Model 2, what happens to pyruvic acid during the Krebs cycle?
- According to Model 2, where does the change identified in the previous question occur?

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



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.

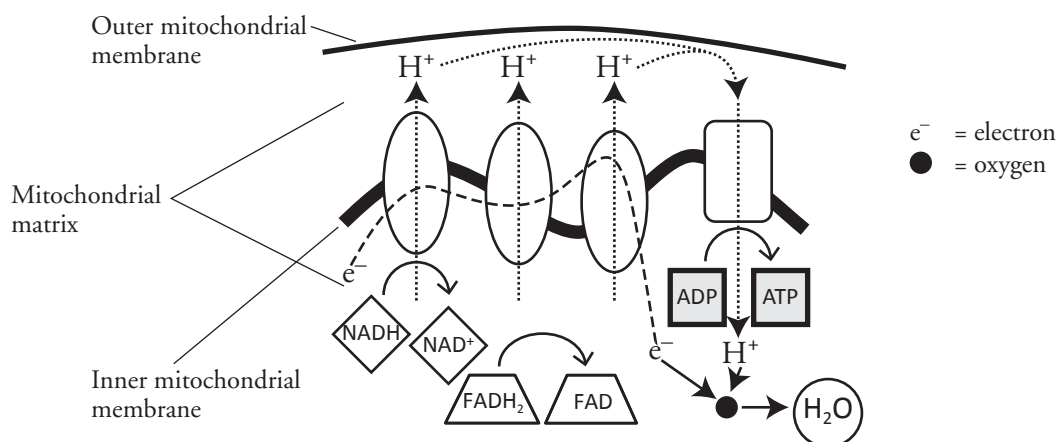
12. What two hydrogen-carrying molecules are formed during the Krebs cycle?

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	FADH₂
Glycolysis			
Krebs cycle (1st pyruvic acid)			
Krebs cycle (2nd pyruvic acid)			



Model 3 – The Electron Transport Chain



14. What cell structure is the site for the electron transport chain?
15. Label the carrier proteins in Model 3.
16. What substance do the carrier proteins transport across the inner mitochondrial membrane?

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?
18. Refer to Model 3.
 - a. What atom accepts the hydrogen ion at the end of the electron transport chain?
 - b. What molecule is formed as a product of that acceptance?
19. Formulate an explanation for why the events of the electron transport chain constitute an aerobic process rather than an anaerobic process (like glycolysis).

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 FADH₂. 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 FADH₂ 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			
Krebs Cycle			
Electron Transport Chain	_____	x 3	x 2
Total ATP Produced			
Grand Total ATP produced (add all 3 columns above)			

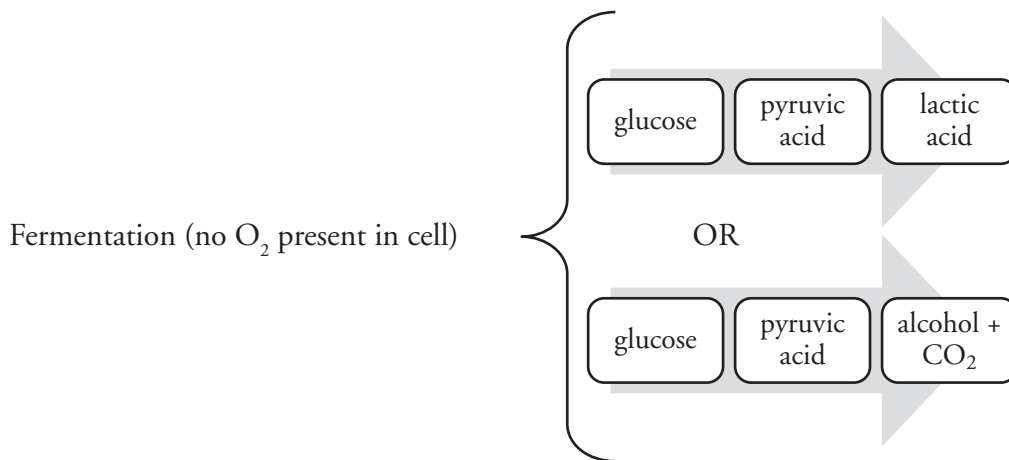
21. Look at the equation for cellular respiration and write in which stage of the process each molecule is either used or produced.

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

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?

Extension Questions

Model 4 – Two Kinds of Anaerobic Respiration



23. What are the two substances that may be formed in anaerobic respiration?
24. Recall that two molecules of ATP are formed during glycolysis. Neither fermentation process shown above creates any more ATP. Knowing this, what would you predict about the cellular energy available to organisms that carry out fermentation?
25. Research the relationship between overexertion of muscles and the formation of lactic acid. How does this relate to “the burn” felt during strenuous activity?
26. What common foods involve the process of fermentation? Use your textbook or other resource to make a list of the foods and the specific organisms used.