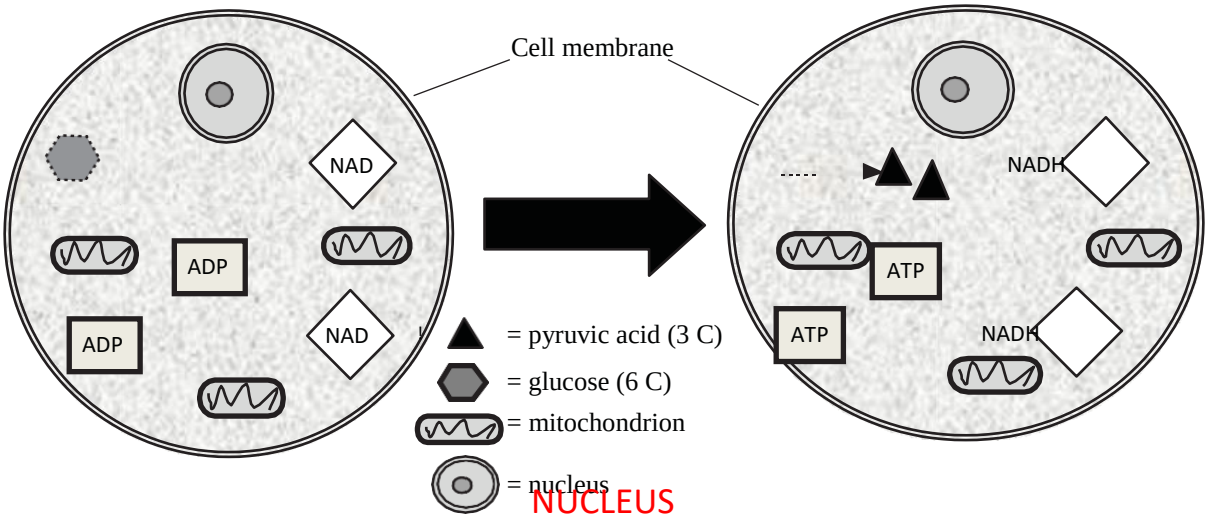
Cellular Respiration

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

   b. How many carbon atoms (C) are in one molecule of glucose?

SIX

2. Refer to Model 1.
   a. What is represented by the triangles?

PYRUVIC ACID

   b. How many carbon atoms (C) are in one molecule of pyruvic acid?

THREE

3. In the process of glycolysis, what happens to glucose after it crosses the cell membrane into the cytoplasm of the cell?

GLUCOSE IS BROKEN DOWN INTO PYRUVIC ACID (2)

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.

ONE GLUCOSE MOLECULE HAS SIX CARBON ATOMS AND EACH PYRUVIC ACID MOLECULE HAS THREE. THEREFORE, THERE HAS TO BE TWO MOLECULES TO CONTAIN ALL SIX CARBON ATOMS.

5. How many ATP molecules are produced during glycolysis?

TWO

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

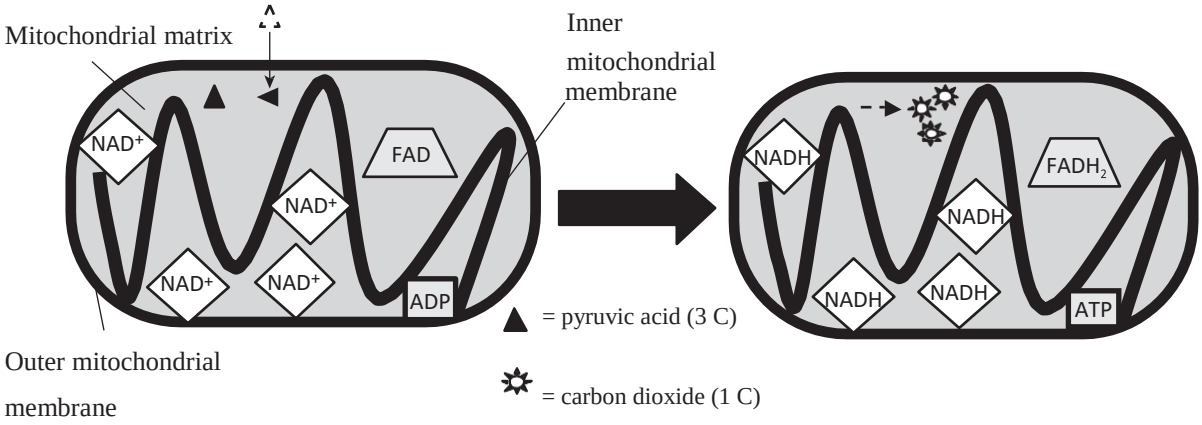
NADH

7. Does glycolysis occur inside or outside the mitochondria?

OUTSIDE (CYTOPLASM)

STOP

Model 2 – Krebs Cycle



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

IT IS BROKEN DOWN INTO THREE MOLECULES OF CO_2

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

IN THE MITOCHONDRIAL MATRIX

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

EACH PYRUVIC ACID MOLECULE CONTAINS THREE CARBON ATOMS AND EACH CARBON DIOXIDE MOLECULE CONTAINS ONLY ONE.

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.

SIX—EACH PYRUVIC ACID HAS THREE CARBONS AND TWO PYRUVIC ACID MOLECULES ARE PRODUCED (3 X 2 = 6)

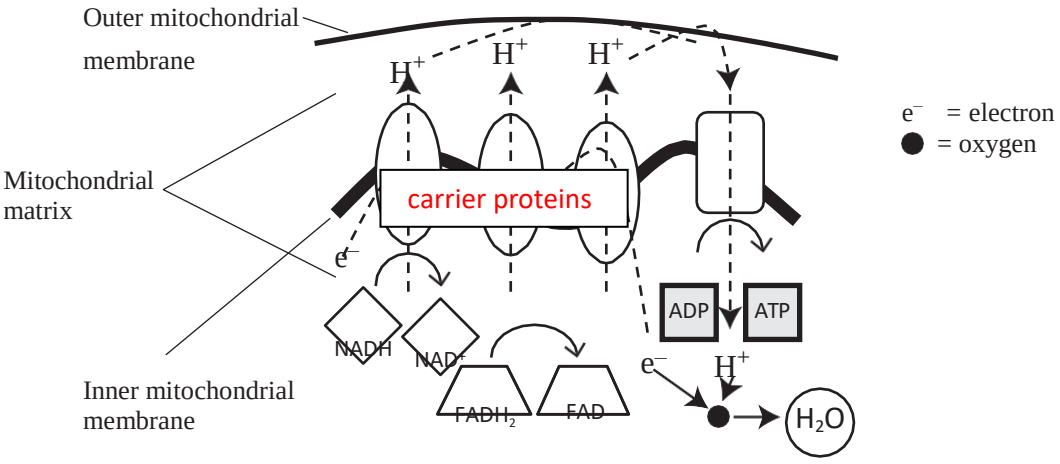
12. What two hydrogen-carrying molecules are formed during the Krebs cycle?

NADH and $FADH_2$

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	0
Krebs cycle (1st pyruvic acid)	1	4	1
Krebs cycle (2nd pyruvic acid)	1	4	1

Model 3 – The Electron Transport Chain



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

THE 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?

HYDROGEN IONS (H+)

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

18. Refer to Model 3.

a. What atom accepts the hydrogen ion at the end of the electron transport chain?

OXYGEN ACCEPTS THE HYDROGEN IONS ("CLEANS UP!" FINAL ELECTRON ACCEPTOR)

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

WATER, H_2O, IS FORMED AS A PRODUCT.

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

THE ELECTRON TRANSPORT CHAIN IS AN AEROBIC PROCESS BECAUSE IT REQUIRES OXYGEN TO COMPLETE THE PROCESS.

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**	**0**
Krebs Cycle	**2**	**8**	**2**
Electron Transport Chain	———————	x 3	x 2
Total ATP Produced	**4**	**30**	**4**
Grand Total ATP produced (add all 3 columns above)		**38**	

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

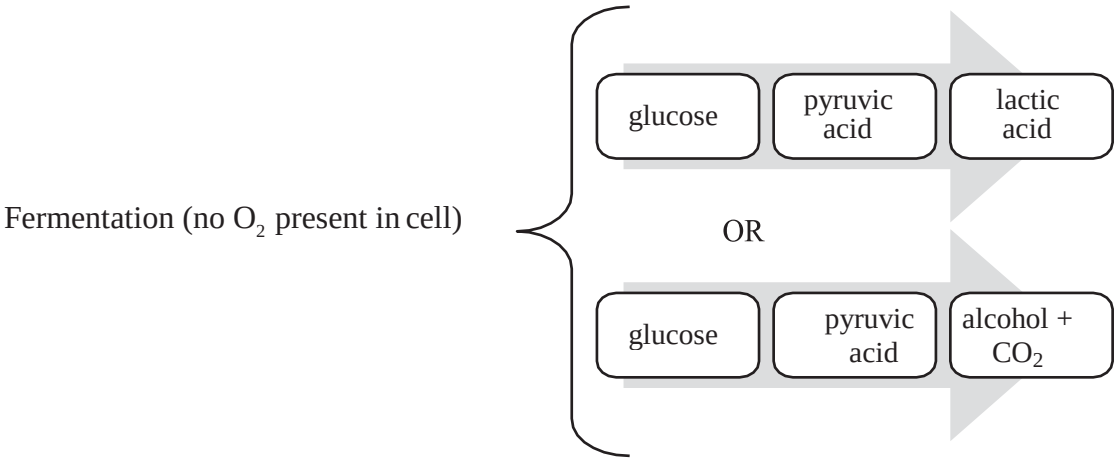
$C_6H_{12}O_6$	+	$6O_2$	→	$6CO_2$	+	$6H_2O$	+	38 ATP
Used in		Used in		Produced in		Produced in		Produced in
GLYCOLYSIS		**ELECTRON TRANSPORT CHAIN**		**KREB'S CYCLE**		**ELECTRON TRANSPORT CHAIN**		**GLYCOLYSIS – 2 KREB'S – 2 E.T.C. - 34**

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?

SINCE THERE WOULD BE SO LITTLE ATP PRODUCED WITHOUT OXYGEN, THE CELLS OF THE BRAIN AND HEART WOULD DIE AND THE FUNCTIONS WOULD STOP.

Extension Questions

Model 4 – Two Kinds of Anaerobic Respiration



23. What are the two substances that may be formed in anaerobic respiration?

LACTIC ACID OR ALCOHOL AND CO_2

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?

THEY MUST REQUIRE VERY LITTLE ENERGY, SINCE GLYCOLYSIS PRODUCES SO LITTLE ATP AND FERMENTATION PRODUCES NO ADDITIONAL ATP.

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?

WHEN MUSCLES REQUIRE MORE ENERGY THAN CAN BE PRODUCED AEROBICALLY, THEY SWITCH TO ANAEROBIC RESPIRATION.

THE LACTIC ACID PRODUCED BUILDS UP AND PRODUCES A BURNING SENSATION IN THE MUSCLES.

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.

BREAD – *Saccharomyces cervisiae* AND OTHER YEASTS

CHEESE – VARIOUS FUNGI

YOGURT – VARIOUS BACTERIA

SAUERKRAUT – VARIOUS BACTERIA

VINEGAR – VARIOUS BACTERIA

WINE - YEASTS