May use on final.

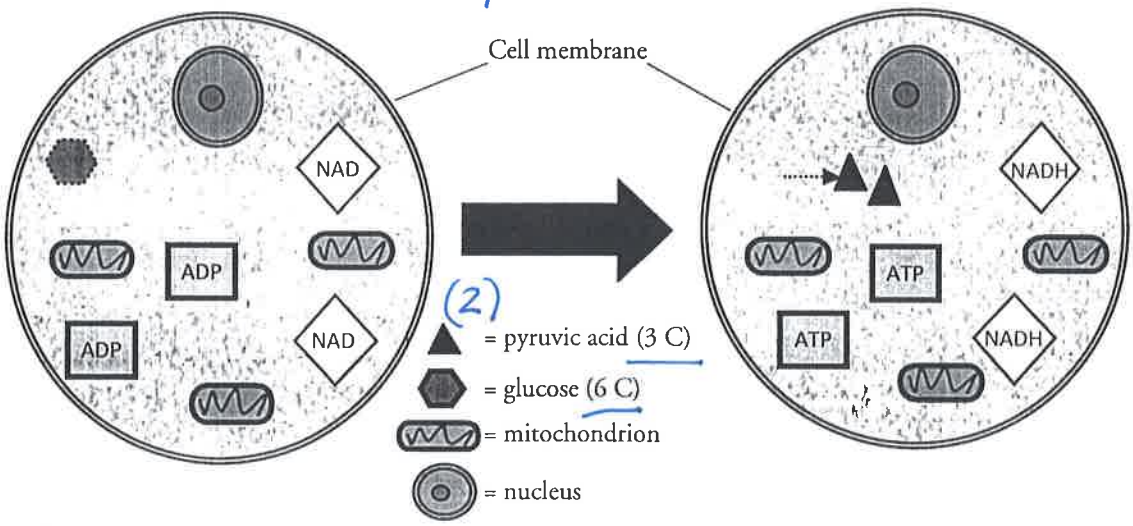
Cellular Respiration

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 (in the cytoplasm of cell)



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?
   6
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?
   3
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 2 pyruvic acid molecules

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.

glucose 6C → 3C pyruvic acid
→ 3C pyruvic acid

5. How many ATP molecules are produced during glycolysis?

2

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

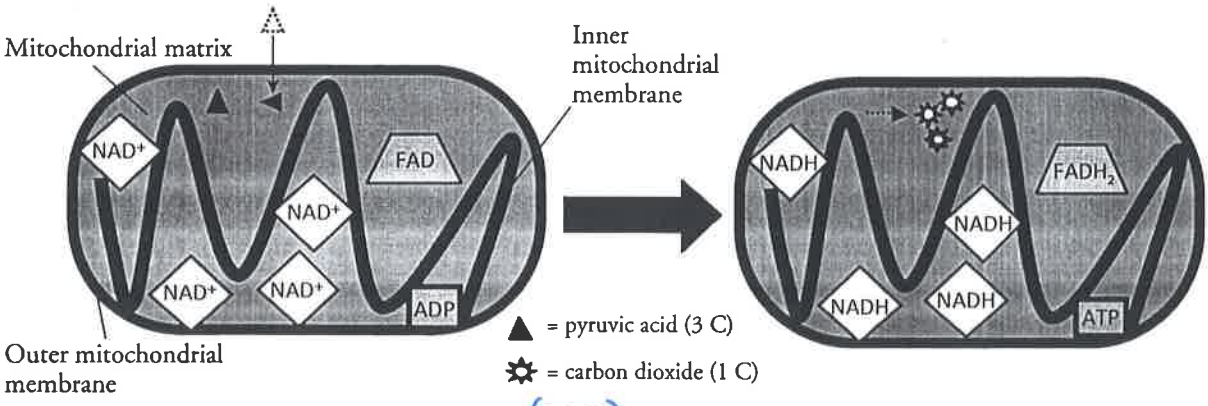
NADH

7. Does glycolysis occur inside or outside the mitochondria?

outside

STOP

Model 2 – Krebs Cycle



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

(one)
1 pyruvic acid → 3CO_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.

3C pyruvic acid → 1C + O_2
3C pyruvic acid → 1C + O_2 = 3CO_2
3C pyruvic acid → 1C + O_2

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.

2(3C) → 6CO_2

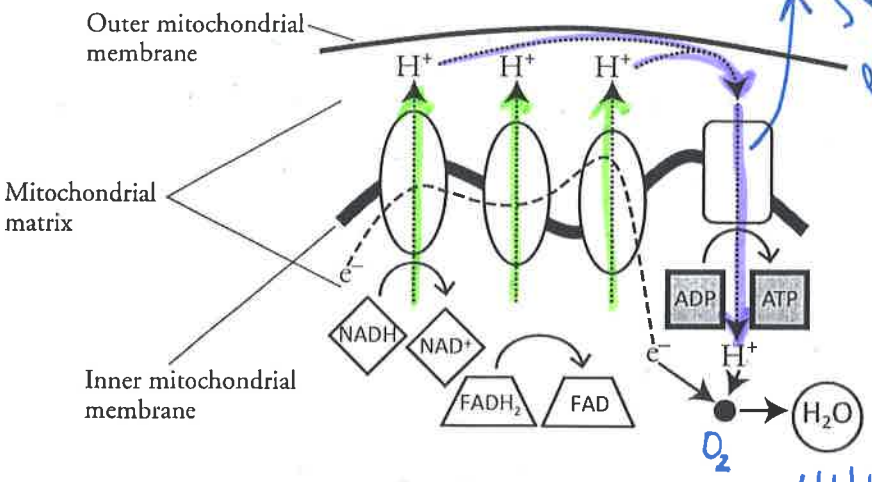
12. What two hydrogen-carrying molecules are formed during the Krebs cycle?

(high energy electrons) 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	∅
Krebs cycle (1st pyruvic acid)	1	4	1
Krebs cycle (2nd pyruvic acid)	1	4	1
Krebs cycle totals	2	8	2

Model 3 – The Electron Transport Chain



ATP synthase enzyme that rotates + turns ADP + P → ATP

= carrier proteins

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

inner mitochondrial membrane

$4H^+ + 4e^- + O_2 \rightarrow 2H_2O$ water

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

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

water

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

electron transport chain requires oxygen so it is aerobic

NAD⁺ = nicotinamide adenine dinucleotide
FAD = flavine adenine dinucleotide

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.

On average NADH ⇒ 3ATP $FADH_2$ ⇒ 2 ATP

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.

	Total ATP	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	2	8	2
Electron Transport Chain	34	→	10 x 3 ATP	2 x 2 ATP
Total ATP Produced	38		30	4
Grand Total ATP produced (add all 3 columns above)			38	

book says 36 ATP

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	electron transport chain	Krebs cycle	electron transport chain	all 3 steps

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?

without enough ATP to fuel the cells, brain + heart cells quickly cease to function