

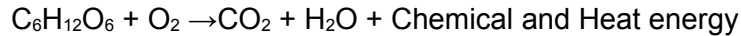
## Review Questions

### Cellular Respiration

**1. What is the purpose of aerobic cellular respiration?**

Aerobic cellular respiration is the harvesting of energy (for ATP synthesis) from the degradation of food molecules (carbohydrates, lipids, and proteins).

**2. Starting with glucose (C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>), write the overall reaction for aerobic cellular respiration.**



**3. List the five stages of aerobic cellular respiration.**

Glycolysis

Transition reaction

Krebs Cycle

Electron Transport System

Chemiosmosis

**4. Describe glycolysis.**

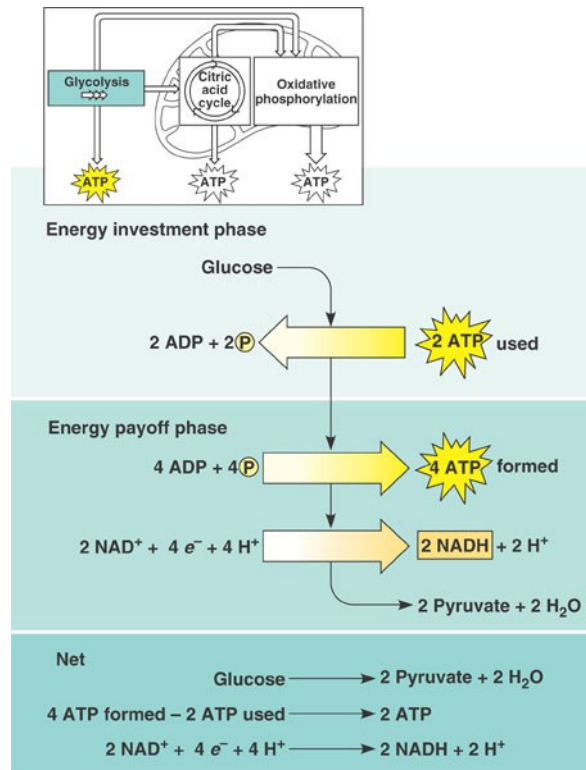
Glycolysis is the oldest energy-harvesting process and is universal to all of life. Glycolysis occurs with or without oxygen. If oxygen is present, the sugar molecule will move through the rest of the stages of aerobic cellular respiration. If not, the process stops at glycolysis.

Glycolysis occurs in the cytosol of the cytoplasm. The rest of the stages occur inside the mitochondrion.

Glycolysis starts with a glucose molecule. The cell has to provide some energy during glycolysis so it spends two ATP molecules. From this investment, glycolysis returns four ATP for a net gain of two ATP.

The glucose molecule is eventually broken into two. The end products of glycolysis are two three-carbon molecules called pyruvate or pyruvic acid.

An electron carrier molecule called nicotinamide adenine dinucleotide (NAD<sup>+</sup>) strips two electrons and a H<sup>+</sup> from the glucose molecule during glycolysis. NAD<sup>+</sup> is reduced to NADH. If oxygen is present, NADH will move to the cristae of the mitochondrion and be oxidized. If there is no oxygen NADH will stay in the cytosol and be oxidized during fermentation.



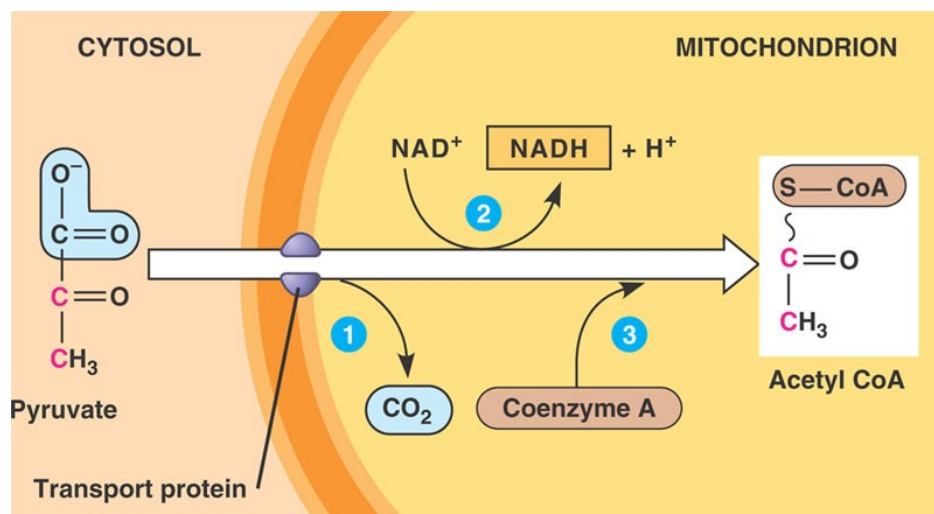
5. **Describe the transition reaction.**

If oxygen is present, the two pyruvate molecules enter the transition reaction. The pyruvates move from the cytosol to the matrix of the mitochondrion.

In the matrix, a carbon dioxide molecule is broken off from each pyruvate.

NAD<sup>+</sup> strips off some more electrons and H<sup>+</sup>.

The end product of the transition reaction is a two-carbon molecule called Acetyl-CoA.



## 6. Describe the Krebs cycle.

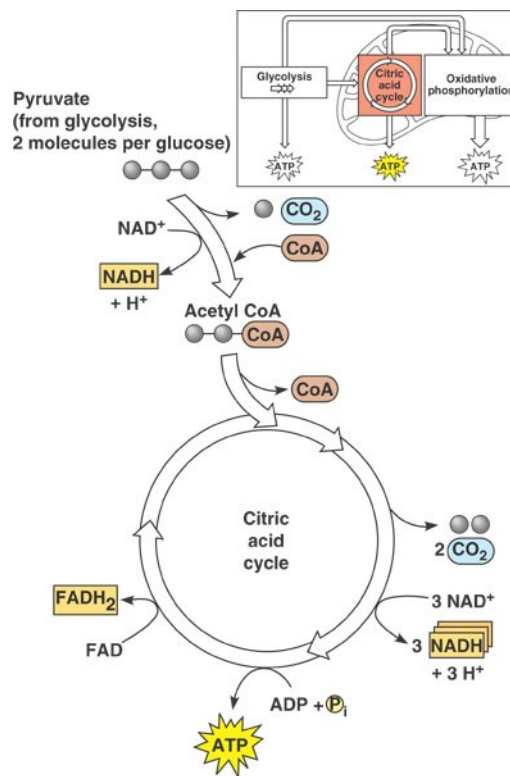
The Krebs cycle (also known as the Citric Acid Cycle) occurs inside the matrix of the mitochondrion.

The two-carbon Acetyl-CoA molecule from the transition reaction enters the cycle.

$\text{NAD}^+$  strips some electrons and  $\text{H}^+$ . A new electron carrier molecule called flavin adenine dinucleotide ( $\text{FAD}^+$ ) removes 3 electrons and two  $\text{H}^+$  from each of the Acetyl-CoA molecules and is reduced to  $\text{FADH}_2$ . Just like  $\text{NADH}$ ,  $\text{FADH}_2$  will then move to the cristae.

A single ATP is generated from the breakdown of each Acetyl-CoA.

The Acetyl-CoA is completely dismantled during the Krebs Cycle and the two remaining carbons leave as carbon dioxide.



## 7. Describe the electron transport chain.

The electron transport chain or electron transport system is located within the cristae of the mitochondrion. A series of transmembrane proteins that transfer electrons are embedded in sequence within the cristae.

$\text{NADH}$  from glycolysis, the transition reaction, and Krebs cycle are oxidized at the start of the chain. So is  $\text{FADH}_2$  from the Krebs cycle.

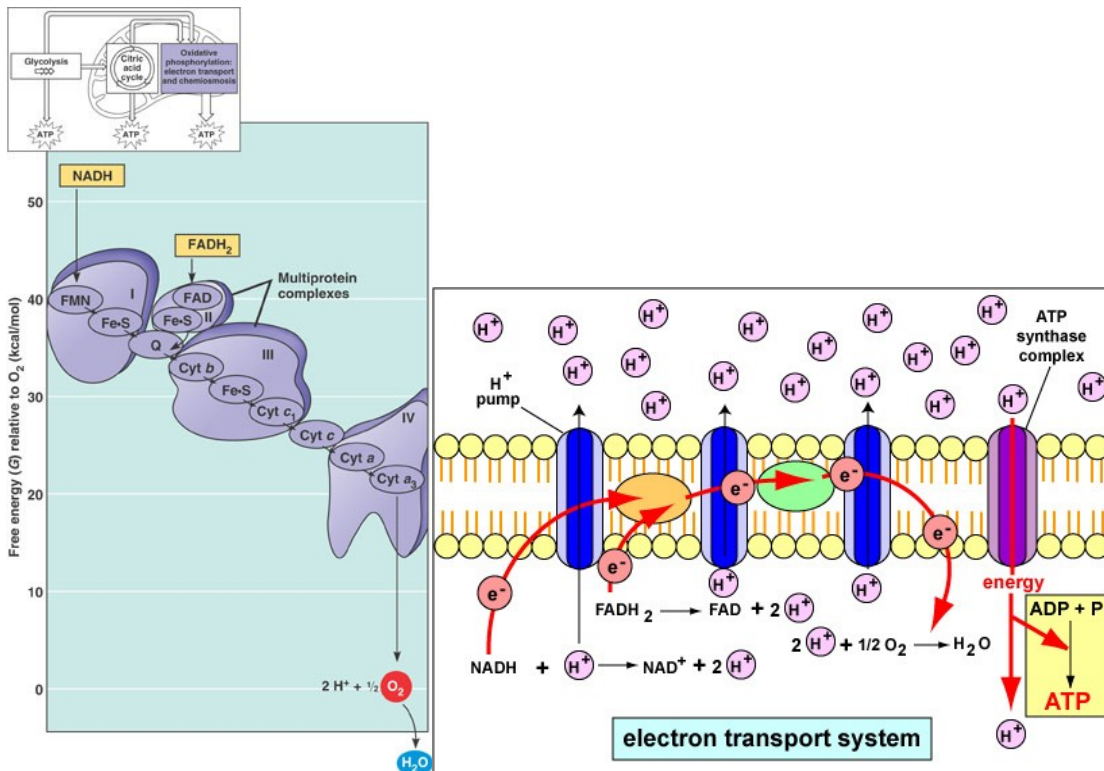
The chain proteins pass the electrons one to another. Each succeeding protein is more electronegative than the previous and so is more attractive to electrons.

This drives the electrons down the chain. The electrons that enter the chain are energized (from the light reaction in photosynthesis) and as they are passed, the proteins extract the energy and return them to their ground state.

The final electron acceptor that bonds to the spent electrons in the chain is oxygen. After being reduced, the oxygen quickly bonds to some hydrogen and the result is water. If you look at the general chemical formula for aerobic cellular respiration you will see water is one of the products. In fact, we call it metabolic water. Some desert-dwelling organisms rely on it completely for their water needs.

The chain proteins use the energy to actively transport  $H^+$  from the matrix into the intermembrane compartment located between the outer membrane of the mitochondrion and the cristae.

A concentration gradient is established between the intermembrane compartment and the matrix. The high concentration of  $H^+$  inside the intermembrane compartment makes the  $H^+$  want to flow back into the matrix where there is a low concentration, but they can't because of the plasma membrane.



## 8. Describe chemiosmosis.

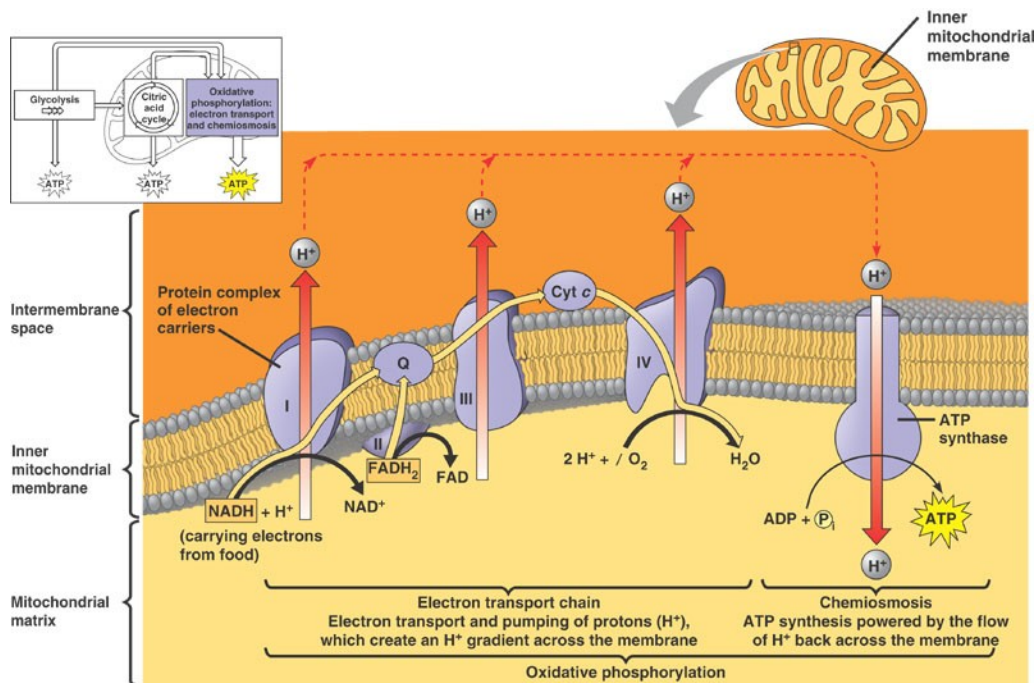
The intermembrane compartment has a high concentration of  $H^+$  from the action of the electron transport chain. Also embedded within the cristae is a  $H^+$  channel protein.

The  $H^+$  follow their concentration gradient and flow through the channel protein and into the matrix.

On the matrix side of the channel there is an ATP synthesizing enzymatic protein. The energy created by the flow of  $H^+$  is used by the enzyme to attach a phosphate group to ADP to make ATP.

From one glucose molecule, chemiosmosis generates 34 ATP. Chemiosmosis is the big payoff in aerobic cellular respiration.

If you remember from the light reaction in photosynthesis, there is also an electron transport chain in the membrane of the thylakoid. Chemiosmosis generates ATP in much the same way in chloroplasts.



### 9. How many ATP molecules are produced from all five stages?

Stage	Number of ATP molecules generated
Glycolysis	2
Transition reaction	0
Krebs Cycle	2
Electron Transport Chain	0
Chemiosmosis	34
Total	38

### 10. List five foods made using lactic acid fermentation.

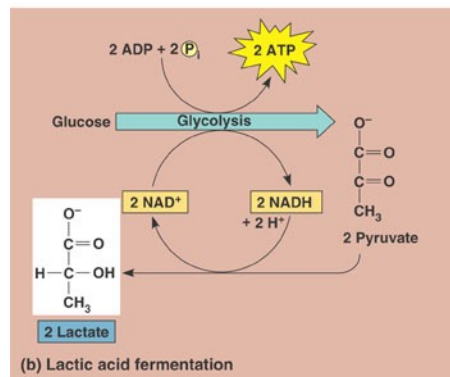
Cheese, yogurt, buttermilk, soy sauce, and sauerkraut

### 11. What is fermentation?

Only two ATP are produced when a glucose molecule ferments. Fermentation takes place in the cytosol. Fermentation ends with one or two steps beyond glycolysis. Fermentation, like cellular respiration, is the harvesting of energy from food. But fermentation takes place in an anaerobic condition (no oxygen) with an organic molecule as the final electron acceptor. There are a variety of different fermentation pathways employed by living organisms.

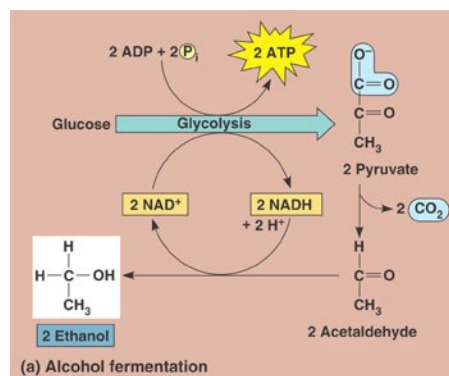
### 12. How does fermentation produce lactic acid?

The lactic acid pathway is fairly common. Some bacteria make lactic acid. We make lactic acid in our muscles when we exercise above our anaerobic threshold. After glycolysis, the pyruvate molecule is reduced by NADH and gains electrons and  $H^+$  creating lactate or lactic acid. You will notice in the figure below that the NADH reduced in glycolysis and then oxidized in step from pyruvate to lactic acid. Since lactic acid receives electrons from NADH, it is the final electron acceptor.



### 13. How does fermentation produce alcohol?

Yeasts make alcohol and carbon dioxide during fermentation. Their pathway is a two step process after glycolysis. A carbon dioxide breaks off of pyruvate creating a two carbon molecule called acetaldehyde. NADH reduces acetaldehyde to ethyl alcohol (ethanol). Ethanol is the final electron acceptor.



Baker's yeast and Brewer's yeast are both *Saccharomyces cerevisiae*. This lovely domesticated yeast makes our beer and makes our bread rise. The carbon

dioxide given off carbonates the beer and makes our bread nice and fluffy. The other fermentation product, alcohol, gives beer its kick and burns off in baking when we make bread.

Wine is made using a slightly different *Saccharomyces* species. Grapes are crushed, inoculated and left to ferment. A foam cap indicates that fermentation has begun. The fermented grape juice is then placed in oak casks to add flavor and continue the fermentation process. Wine has an alcohol content of ~12%. This is the level at which yeast start to be killed off by their own alcohol waste product. Any spirit with higher alcohol content has been distilled. Dry wines are wines where all the sugar has been eaten and broken down by the yeast. Sweet wines still retain some sugar. Red wines are made by keeping the pulp and skins in the fermentation tank to add tannins, color, and flavor. White wines come from just the juice.

#### 14. What is the Pasteur effect?

Louis Pasteur started with two yeast cultures. They both began with the same amount of sugar but one was oxygenated and the other was kept anaerobic. After incubating the cultures for 5 days at 37° C, the anaerobic culture had much less sugar than the aerobic culture. Why? Fermentation only produces 2 ATP per glucose molecule while aerobic cellular respiration makes 38. In order to maintain the same level of metabolism, the anaerobic yeast have to eat a lot more glucose. Pasteur had discovered the difference in energy production between fermentation and aerobic cellular respiration.

#### 15. How are fats and proteins metabolized?

Triglycerides and amino acids share the same aerobic cellular respiration pathway as glucose. However, they enter at different locations. A triglyceride is first broken down into a glycerol and three separate fatty acids. Glycerol enters about halfway into glycolysis. The fatty acids are broken into two-carbon bits by a process called beta oxidation and then enter into the Krebs cycle.

Proteins are first deaminated (have their amino group excised) and depending on the amino acid may enter in at the transition reaction or the Krebs cycle.

