

CELLULAR RESPIRATION

GLYCOLYSIS AND FERMENTATION

All cells break down complex organic compounds into simpler molecules. Cells use some of the energy that is released in this process to make ATP.

OBJECTIVES: Define cellular respiration. Describe the major events in Glycolysis. Compare and contrast lactic acid fermentation and alcoholic fermentation. Calculate the efficiency of glycolysis.

HARVESTING CHEMICAL ENERGY

1. Autotrophs, such as plants, use photosynthesis to convert light energy from the Sun into Chemical energy, which is stored in Carbohydrates and other Organic Compounds.
2. Both Autotrophs and Heterotrophs depend on these Organic Compounds for the energy to Power Cellular Activities.
3. By Breaking Down Organic Molecules into simpler molecules, CELLS RELEASE ENERGY.
4. Some of the energy is used to make ATP from ADP and Phosphate. ATP is the Main Energy Currency of Cells.
5. The Complex Process in which Cells Make ATP by Breaking Down Organic Molecules is known as CELLULAR RESPIRATION. OR THE PROCESS BY WHICH FOOD MOLECULES ARE BROKEN DOWN TO RELEASE ENERGY FOR WORK IS CALLED CELLULAR RESPIRATION.

6. PHOTOSYNTHESIS EQUATION:



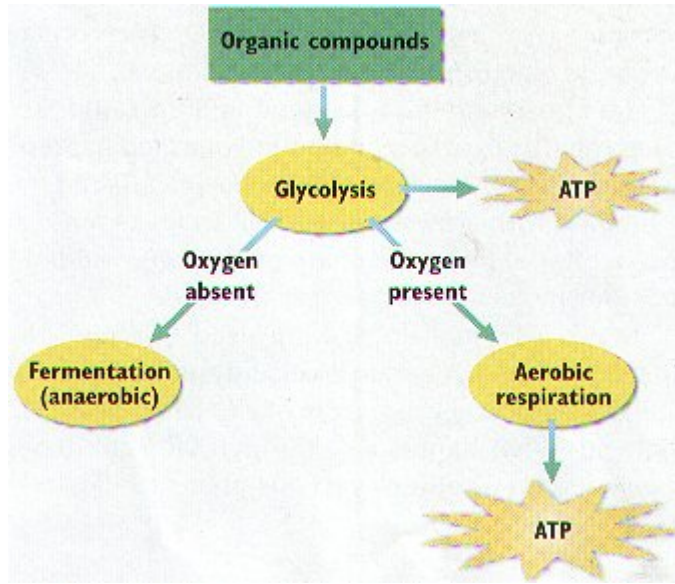
CELLULAR RESPIRATION EQUATION:



7. Cellular Respiration takes place in TWO STAGES.

STAGE 1 - Cellular Respiration BEGINS with a Biochemical Pathway called **GLYCOLYSIS**, that takes place in the **Cells Cytosol**, YIELDS a relatively Small amount of ATP and does not require oxygen.

STAGE 2 - The Second Stage of Cellular Respiration is called **OXIDATIVE RESPIRATION**, and follows Glycolysis. Oxidative Respiration takes place within the Mitochondria. This is far more effective than Glycolysis at recovering energy from food molecules. OXIDATIVE RESPIRATION IS THE METHOD BY WHICH PLANT AND ANIMAL CELLS GET THE MAJORITY OF THEIR ENERGY.



8. **THERE ARE TWO TYPES OF CELLULAR RESPIRATION: AEROBIC (PRESENCE OF OXYGEN) AND ANAEROBIC (ABSENCE OF OXYGEN) RESPIRATION OR FERMENTATION.**

9. Because they operated in the Absence of Oxygen, the FERMENTATION PATHWAYS are said to be **ANAEROBIC PATHWAYS.**

10. If OXYGEN is PRESENT, the products of Glycolysis ENTER the

PATHWAYS of **AEROBIC RESPIRATION.**

11. Aerobic Respiration produces a much Larger Amount of ATP, UP TO 20 TIMES MORE ATP PRODUCED.

GLYCOLYSIS

1. Both types of PATHWAYS BEGIN with Glycolysis.
2. Glycolysis is a pathway in which One Six-Carbon Molecule of GLUCOSE is Oxidized to Produce Two Three-Carbon Molecules of **PYRUVIC ACID OR PYRUVATE.**
3. The word "**GLYCOLYSIS**" means "**The Splitting of Glucose**". In a series of Ten Reactions, a molecule of Glucose is split into Two identical smaller molecules, each called **PYRUVIC ACID or PYRUVATE.**
4. **GLYCOLYSIS** IS THE PROCESS BY WHICH GLUCOSE IS CONVERTED TO PYRUVIC ACID, AND SOME OF ITS ENERGY IS RELEASED.
5. Glycolysis occurs in the **CYTOSOL OF THE CELL.**

6. Whether or not Oxygen is present, Glycolysis SPLITS (BY OXIDATION) GLUCOSE INTO THREE-CARBON MOLECULES OF PGAL. PGAL IS THEN CONVERTED TO THREE-CARBON PYRUVIC ACID.

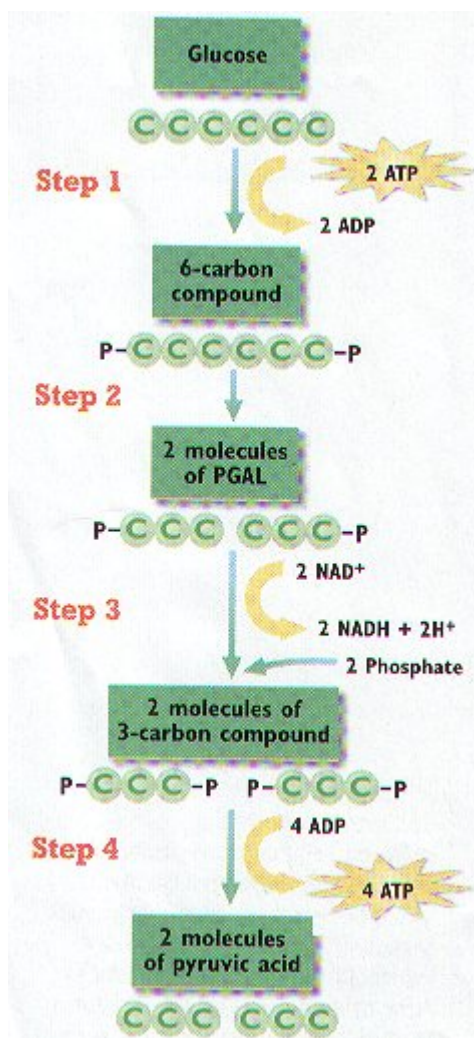
7. Glucose is a Stable molecule that DOES NOT Break down Easily.

8. For a Molecule of Glucose to undergo Glycolysis, a Cell must First "SPEND" ATP to energize the Glucose Molecule. The ATP provides the Activation Energy needed to begin Glycolysis.

9. Although ATP (ENERGY) is used to begin Glycolysis, the reactions that make up the process eventually produce A **NET GAIN OF TWO ATP MOLECULES**.

10. Glycolysis is followed BY THE BREAK DOWN OF PYRUVIC ACID.

11. Like other Biochemical Pathways, Glycolysis consists of a series of Chemical Reactions. These reactions can be condensed into FOUR MAIN STEPS:



STEP 1 - TWO Phosphates are attached to Glucose, forming a NEW Six-Carbon Compound. The Phosphate Groups come From TWO ATP, which are Converted to ADP.

STEP 2 - The Six-Carbon Compound formed in Step 1 is SPLIT into TWO Three-Carbon Molecules of PGAL.

STEP 3 - The TWO PGAL Molecules are Oxidized, and each Receives a Phosphate Group Forming Two NEW Three-Carbon Compounds. The Phosphate Groups are provided by Two molecules of NAD⁺ forming NADH.

STEP 4 - The Phosphate Groups added in Step 1 and Step 3 are Removed from the Three-Carbon Compounds. This reaction produces Two molecules of Pyruvic Acid. Each Phosphate Group is combines with a molecule of ADP to make a molecule of ATP. Because a total of Four Phosphate Groups were Added, **FOUR MOLECULES OF ATP ARE PRODUCED**.

TWO ATP Molecules were used in Step 1, but FOUR are Produced in Step 4. Therefore, Glycolysis has a NET YIELD of TWO ATP Molecules for every Molecule of Glucose that is

converted into Pyruvic Acid. What happens to the Pyruvic Acid depends on the Type of Cell and on whether Oxygen is present.

FERMENTATION

1. In the Absence of Oxygen, Some Cells can Convert Pyruvic Acid into other compounds through Additional Biochemical Pathways that also Occur in the Cytosol.

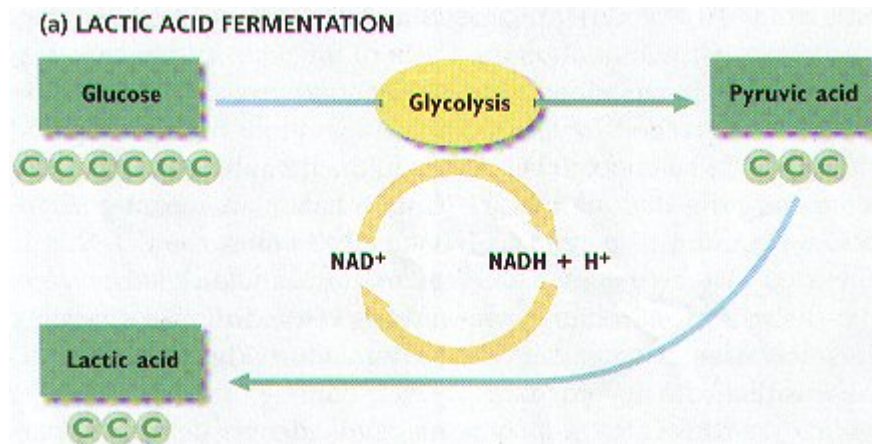
2. The Combination of Glycolysis PLUS these Additional Pathways are known as FERMENTATION.

3. THE CHEMICAL REACTIONS THAT RELEASE ENERGY FROM FOOD MOLECULES IN THE ABSENCE OF OXYGEN ARE ALSO CALLED ANAEROBIC RESPIRATION.

4. There are TWO TYPES of Anaerobic Respiration or Fermentation: LACTIC ACID FERMENTATION AND ALCOHOLIC FERMENTATION.

5. During the processes of Fermentation NO ADDITIONAL ATP IS SYNTHESIZED.

6. LACTIC ACID FERMENTATION IS THE PROCESS THAT PYRUVIC ACID IS CONVERTED TO LACTIC ACID.



7. Lactic Acid involves the Transfer of TWO Hydrogen atoms from NADH and H⁺ to Pyruvic Acid. In the process, NADH is Oxidized to form NAD⁺ which is needed to Keep Glycolysis Operating.

8. Lactic Acid Fermentation by Microorganisms plays an Essential role in the manufacture of Food Products such as YOGURT and CHEESE.

9. **CERTAIN ANIMAL CELLS, INCLUDING OUR MUSCLE CELLS CONVERT PYRUVIC ACID TO LACTIC ACID.**

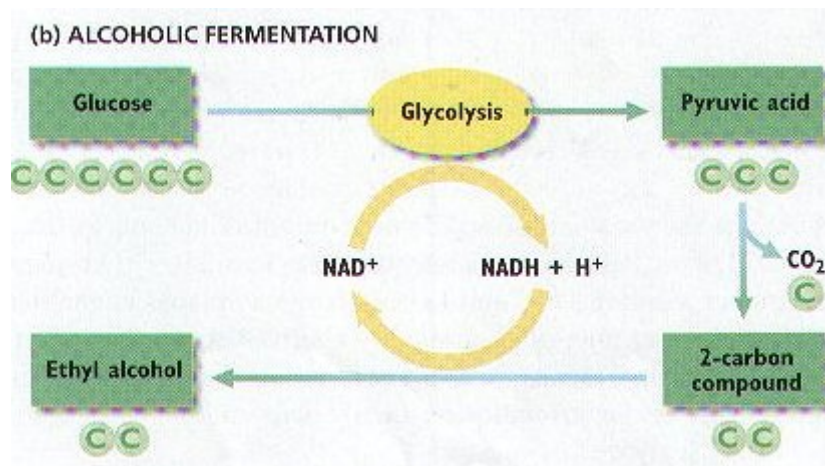
10. **DURING EXERCISE, BREATHING CANNOT PROVIDE YOUR BODY WITH ALL THE OXYGEN IT NEEDS FOR AEROBIC RESPIRATION. WHEN MUSCLES RUN OUT OF OXYGEN, THE CELLS SWITCH TO LACTIC ACID FERMENTATION.**

11. This process provides your muscles with the energy then need during exercise.

12. The side effects of Lactic Acid Fermentation is Muscle Fatigue, Pain, Cramps, and you feel Soreness.

13. Most Lactic Acid made in the muscles diffuse into the bloodstream, then to the LIVER, where it is converted back to PYRUVIC ACID When Oxygen becomes Available.

14. **ALCOHOLIC FERMENTATION CONVERTS PYRUVIC ACID TO CARBON DIOXIDE AND ETHANOL (ETHYL ALCOHOL).**



15. Bakers use Alcoholic Fermentation of YEAST to make Bread.

16. As Yeast Ferments the Carbohydrates in dough, CO₂ is produced and trapped in the dough, causing it to rise.

17. When the dough is baked the Yeast Cells Die, and the Alcohol Evaporates, You cannot get drunk from eating bread!

18. Alcoholic Fermentation is used to make wine, beer, and the ethanol added to gasoline to make gasohol.

19. The fact that alcohol is used to power a car indicated the amount of Energy that remains in the Alcohol Molecules.

ENERGY YIELD

1. Energy is Measured in units of **kilocalories (kcal)**. One kilocalorie EQUALS 1,000 calories (cal).
2. Scientist have calculated that the Complete Oxidation of a Standard Amount of Glucose releases 686 kcal.
3. The kcal released from Glucose during **Glycolysis only has the Efficiency of 3.5%**. (Formula page 131)
4. It's clear that the Anaerobic Pathways are NOT Very Efficient in transferring Energy.
5. The Anaerobic Pathways provide enough Energy for many present-day Organisms. Most of these are **UNICELLULAR**, and those that are **Multicellular are Very Small**. All of them have Limited energy Requirements.
6. Larger Organisms have much Greater Energy Requirements that CANNOT BE satisfied by the Anaerobic Pathways.
7. Large Organisms, including yourself, meet their Energy Requirements with the more Efficient Pathways of Aerobic Respiration.

AEROBIC RESPIRATION

In most cells, the Pyruvic Acid that is produce in glycolysis does not undergo fermentation. Instead, if Oxygen is available, Pyruvic Acid enters the pathway of Aerobic Respiration, or Cellular Respiration that requires Oxygen. Aerobic Respiration produces nearly 20 times as much ATP as is produced by glycolysis alone.

OBJECTIVES: Summarize the events of the Krebs Cycle. Summarize the events of the electron transport chain. Relate aerobic respiration to the structure of a mitochondrion. Calculate the efficiency of aerobic respiration.

OVERVIEW OF AEROBIC RESPIRATION

1. Aerobic Respiration has TWO Major STAGES: **THE KREBS CYCLE and the ELECTRON TRANSPORT CHAIN.**
2. THE BREAK DOWN OF PYRUVIC ACID IN THE PRESENCE OF OXYGEN IS CALLED **AEROBIC RESPIRATION.**



3. AEROBIC RESPIRATION TAKES PLACE INSIDE THE CELL'S MITOCHONDRIA ("POWER HOUSE").

4. DURING AEROBIC RESPIRATION, ATP IS PRODUCED IN TWO PATHWAYS KNOWN AS THE KREBS CYCLE AND THE ELECTRON TRANSPORT CHAIN.

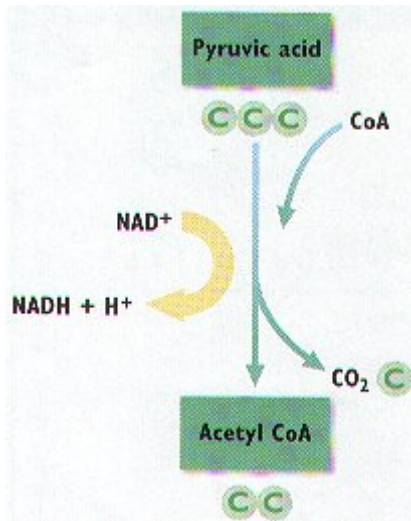
5. THE SERIES OF OXIDATION REACTIONS THAT MAKE UP THE SECOND PHASE OF AEROBIC RESPIRATION IS CALLED THE KREBS CYCLE.

6. THE KREBS CYCLE IS A BIOCHEMICAL PATHWAY THAT BREAKS DOWN acetyl CoA, producing ATP, H, AND CARBON DIOXIDE.

7. In Prokaryotes the reactions of the Krebs cycle take place in the Cytosol of the Cell.

8. In EUKARYOTIC CELLS, these reactions take place in the MITOCHONDRIA.

9. The Pyruvic Acid that is produced in glycolysis Diffuses across the Double Membrane of a Mitochondrion and enters the MITOCHONDRIAL MATRIX, the Space Inside the Inner Membrane of a Mitochondrion.



10. When Pyruvic Acid enters the Mitochondrial Matrix, it Reacts with a molecule called COENZYME A to form ACETYL COENZYME A, abbreviated acetyl CoA. CO₂, NADH, and H⁺ are produced in this reaction.

11. DURING THE PROCESS FROM GLYCOLYSIS THROUGH THE KREBS CYCLE, ONE GLUCOSE MOLECULE YIELDS FOUR ATP, TEN NADH AND TWO FADH₂.

12. THE ENERGETIC ELECTRONS IN THE MOLECULES OF NADH AND FADH₂ THAT ARE FORMED DURING THE KREBS CYCLE ARE USED TO MAKE ATP IN A SERIES OF REACTIONS

KNOWN AS THE ELECTRON TRANSPORT CHAIN.

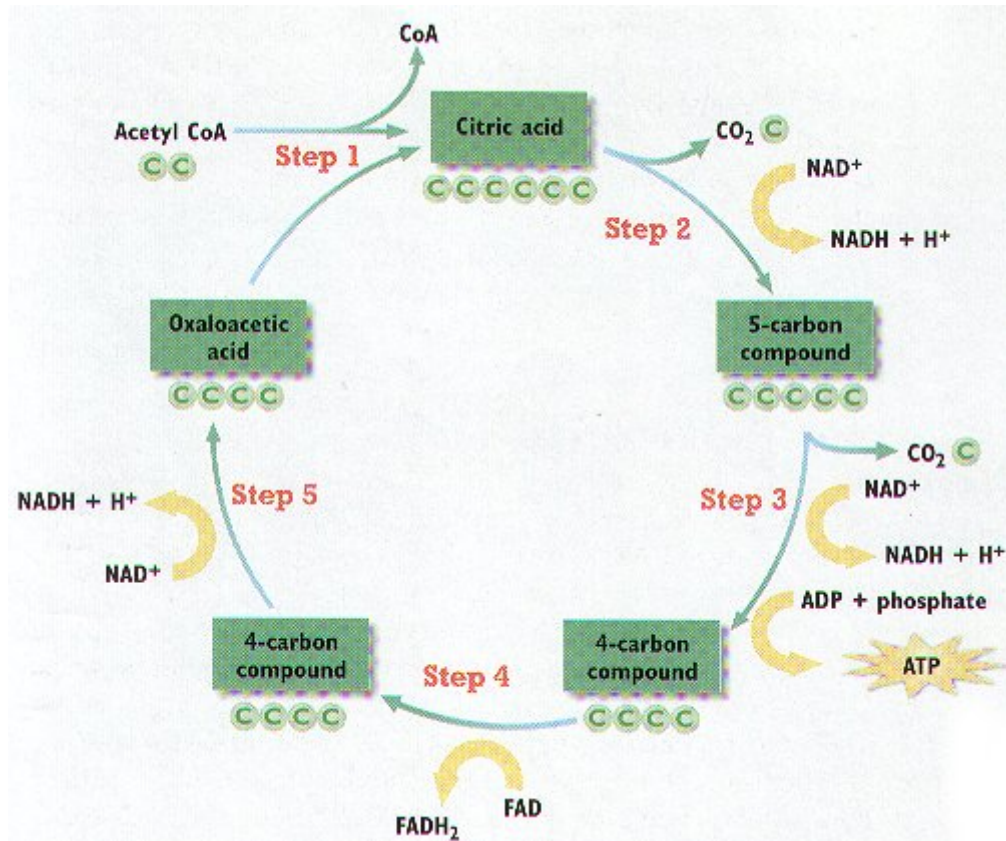
13. MOST of the ATP Produced during Aerobic Respiration is MADE BY the ELECTRON TRANSPORT CHAIN.

THE KREBS CYCLE

1. The Krebs cycle is a biochemical pathway that breaks down Acetyl CoA, producing CO₂, H⁺, NADH, FADH₂, and ATP.

2. The reactions that make up the cycle were identified by Hans Krebs (1900-1980), a German-British biochemist.

3. **The Krebs cycle has FIVE Main Steps -- ALL Five Steps occur in the Mitochondrial Matrix.**
FOLLOW THE STEPS --



STEP 1 - A Two-Carbon Molecule of Acetyl CoA Combines with a Four-Carbon Compound, **OXALOACETIC ACID** (AHKS-uh-loh-SEET-ik), to Produce a Six-Carbon Compound **CITRIC ACID**.

STEP 2 - Citric Acid Releases a CO₂ Molecule and a Hydrogen Atom to Form a Five-Carbon Compound. By LOSING a Hydrogen Atom with its Electron, Citric Acid is OXIDIZED. The Hydrogen atom is transferred to NAD⁺, REDUCING it to NADH.

STEP 3 - The Five-Carbon Compound Releases a CO₂ Molecule and a Hydrogen Atom, forming a Four-Carbon Compound. NAD⁺ is reduced to NADH. A Molecule of ATP is also Synthesized from ADP.

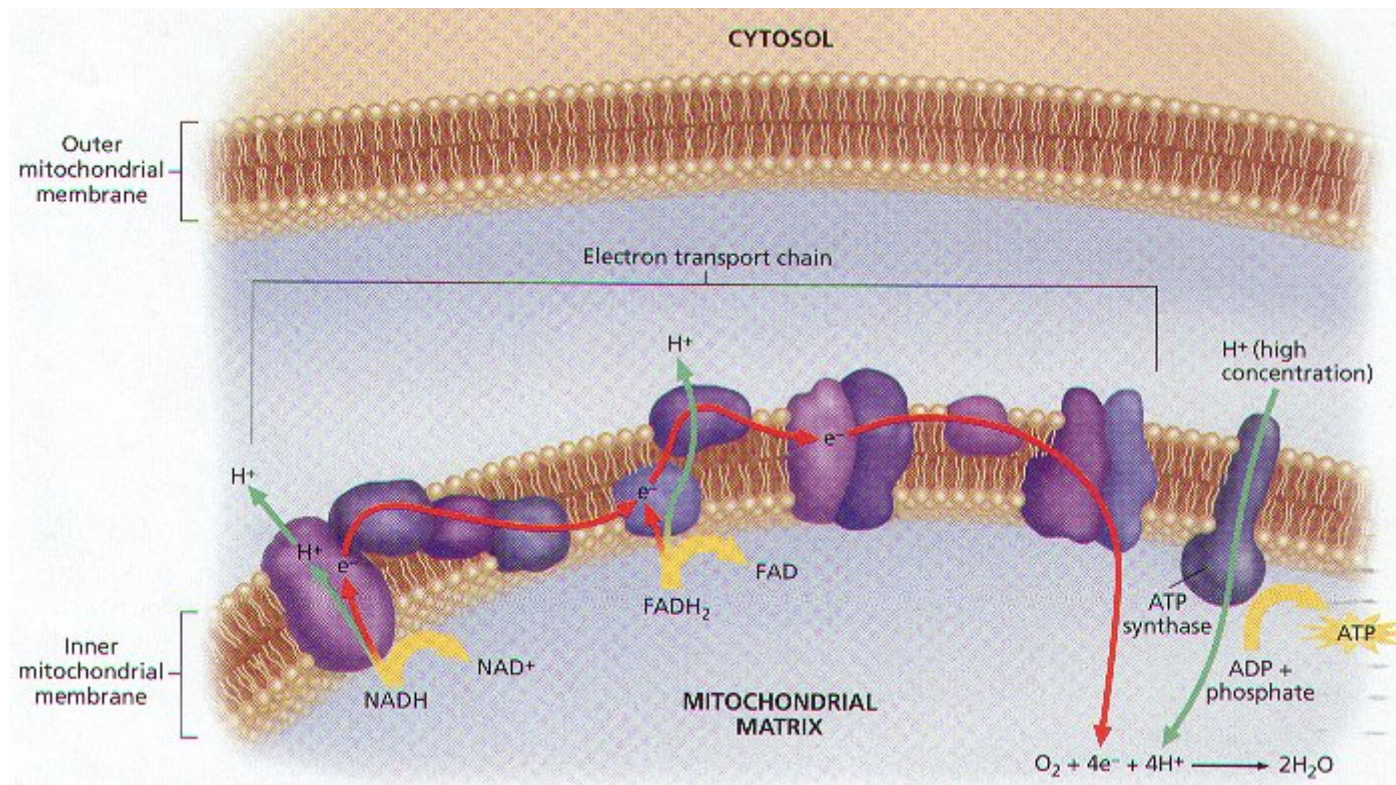
STEP 4 - The Four-Carbon Compound Releases a Hydrogen Atom to form another Four-Carbon Compound. The Hydrogen is used to Reduce FAD (Flavin Adenine

Dinucleotide) to FADH_2 , a Molecule similar to NAD^+ that Accepts Electron during Redox Reactions.

STEP 5 - The Four-Carbon Compound Releases a Hydrogen Atom to REGENERATE OXALOACETIC ACID, which keeps the Krebs cycle operating. The Hydrogen Atom Reduces NAD^+ to NADH .

4. In Glycolysis one Glucose Molecule produces TWO Pyruvic Acid Molecules, which can then form TWO Molecules of Acetyl CoA.
5. One Glucose Molecule causes TWO Turns of the Krebs cycle.
6. The Two Turns produce SIX NADH , TWO FADH_2 , TWO ATP, and FOUR CO_2 Molecules.
7. The **CO_2** is a **WASTE PRODUCT** that Diffuses out of the cells and is given off by the organism.
8. The BULK of the Energy released by the Oxidation of Glucose still has NOT been transferred to ATP. Only FOUR Molecules of ATP - TWO from Glycolysis and TWO From the Krebs cycle.
9. 10 Molecules of NADH and the 2 FADH_2 Molecules from the Krebs cycle DRIVE the Next Stage of Aerobic Respiration - The Electron Transport Chain.
10. That is Where MOST of the Energy Transfer from Glucose to ATP Actually Occurs.

ELECTRON TRANSPORT CHAIN

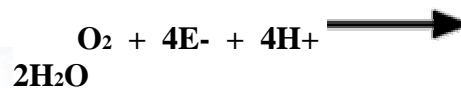


1. The **ELECTRON TRANSPORT CHAIN** makes up the Second Stage of Aerobic Respiration.
2. In **EUKARYOTIC CELLS** the Electron Transport chain **LINES the INNER MEMBRANE of the Mitochondrion**, the inner membrane has many long folds called **CRISTAE**.
3. In **Prokaryotes**, the Electron Transport Chain **LINES the CELL MEMBRANE**.
4. ATP is produced by the Electron Transport Chain when NADH and FADH₂ RELEASES Hydrogen Atoms, REGENERATING NAD⁺ and FAD, which return to the Krebs Cycle to be reused.
5. The electrons in the hydrogen atoms from NADH and FADH₂ are at a High Energy Level.

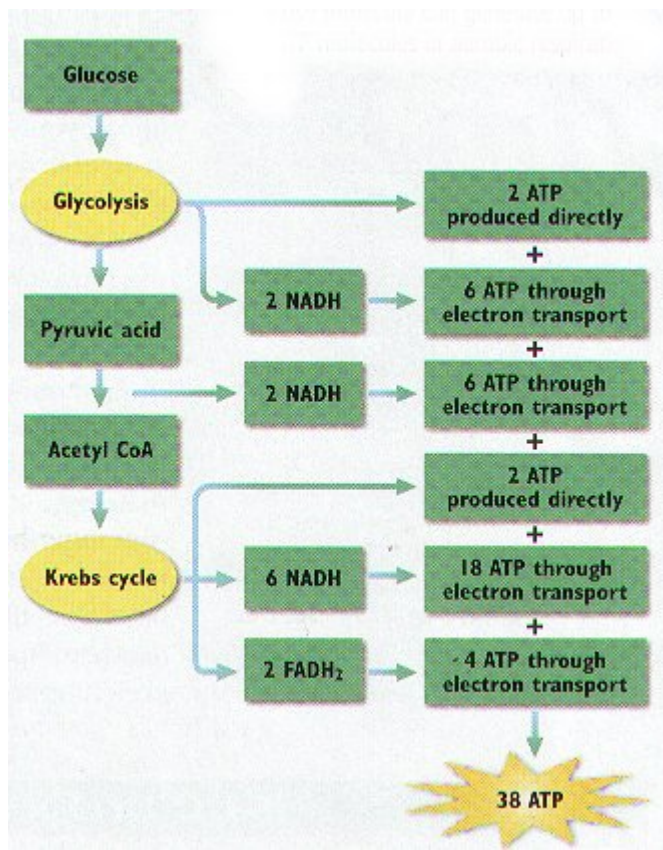
6. These High Energy Electron are PASSED Along a Series of Molecules. As the move from Molecule to Molecule, the Electrons LOSE some of their Energy.
7. The Energy they LOSE is used to PUMP Protons of the Hydrogen Atoms from the Mitochondrial Matrix to the other side of the Inner Mitochondrial Membrane.
8. The Pumping builds up a High Concentration (A Concentration Gradient) of Protons in the space Between the INNER and OUTER Mitochondrial Membranes.
9. The Concentration Gradient of Protons Drives the Synthesis of ATP by Chemiosmosis.
10. ATP Synthase (enzyme) Molecules are located in the Inner Mitochondrial Membrane. The ATP Synthase MAKES ATP from ADP as Protons move down their Concentration Gradient into the Mitochondrial Matrix.

THE ROLE OF OXYGEN

1. ATP can be synthesized by Chemiosmosis only if Electrons continue to move from molecule to molecule in the Electron Transport Chain.
2. Oxygen SERVES as the FINAL Acceptor of Electrons. By Accepting Electrons from the last molecule in the Electron Transport Chain, Oxygen allows additional electrons to pass along the chain. Allowing ATP to continue to be synthesized.
3. Oxygen also accepts Protons that were once part of the Hydrogen Atoms supplied by NADH and FADH₂. By combining with both Electrons and Protons, Oxygen forms WATER:



ENERGY YIELD



1. Through Aerobic Respiration a Maximum Yield of 38 ATP Molecules can be PRODUCED.

- A. 2 - Glycolysis
- B. 2 - Krebs cycle
- C. 34 - Electron Transport Chain

2. The actual number of ATP Molecules generated through Aerobic Respiration varies from Cell to Cell.

3. Most Eukaryotic Cells Produce only about 36 ATP Molecules per Glucose Molecule.

4. If a cell produces 38 ATP Molecules the Efficiency would be 66%.