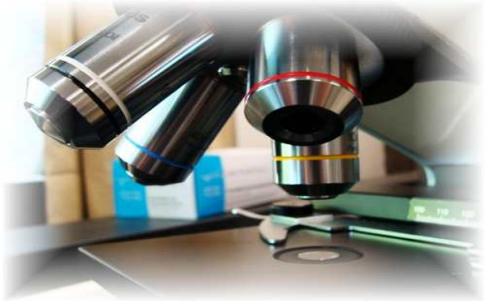

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• The SPO Virtual Classrooms offer many educational resources, including practice test questions, review questions, lecture PowerPoints, video tutorials, sample assignments and course syllabi. New materials are continually being developed, so check back frequently, or follow us on Facebook (Science Prof Online) or Twitter (ScienceProfSPO) for updates.

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• Several helpful links to fun and interactive learning tools are included throughout the PPT and on the Smart Links slide, near the end of each presentation. You must be in *slide show mode* to utilize hyperlinks and animations.

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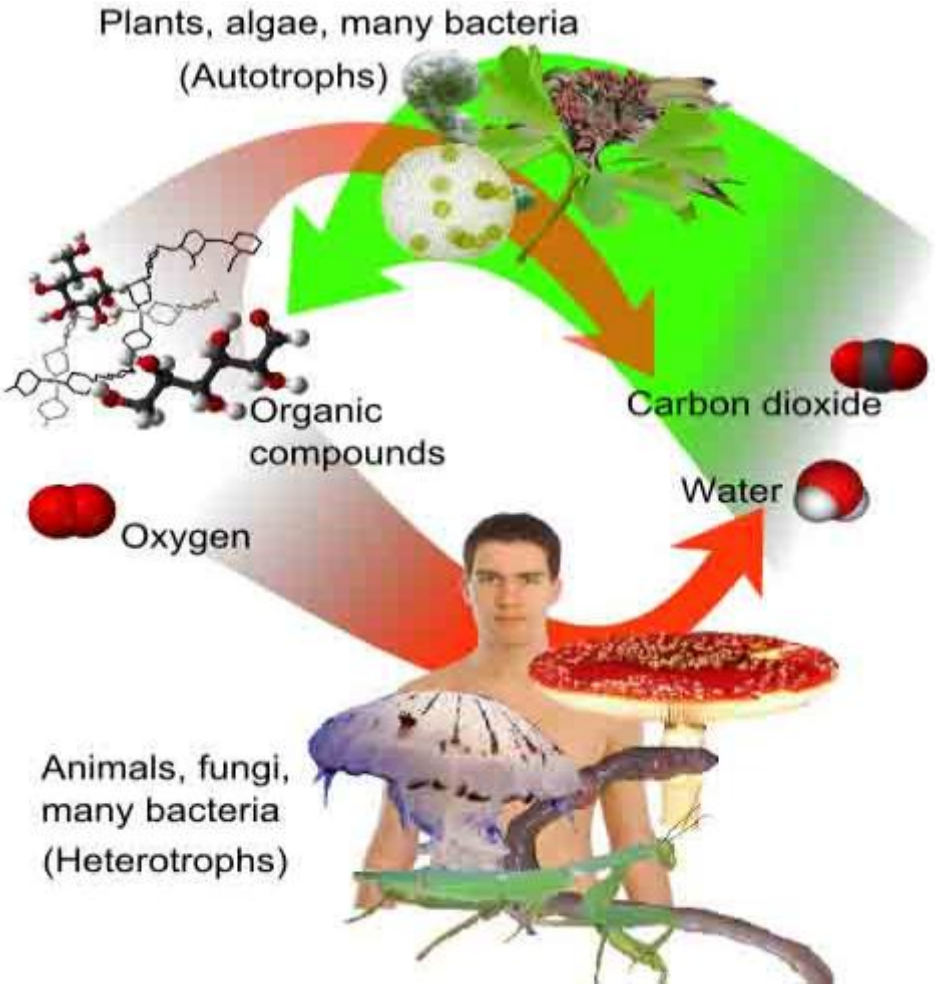
Image: Compound microscope objectives, T. Port

Metabolism

Aerobic Cellular Respiration



From the Virtual Cell Biology Classroom on ScienceProfOnline.com

Image: Autotrophs & Heterotrophs, Mikael Häggström

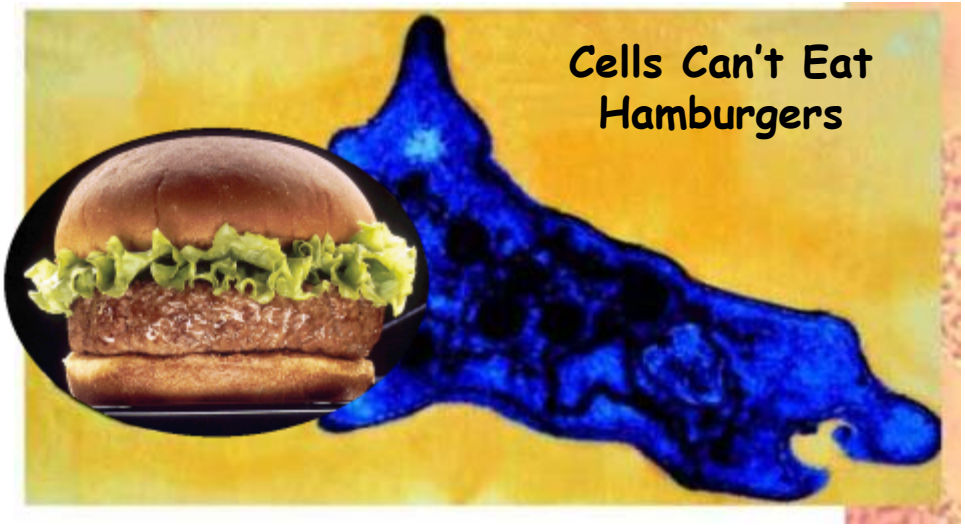
Metabolism

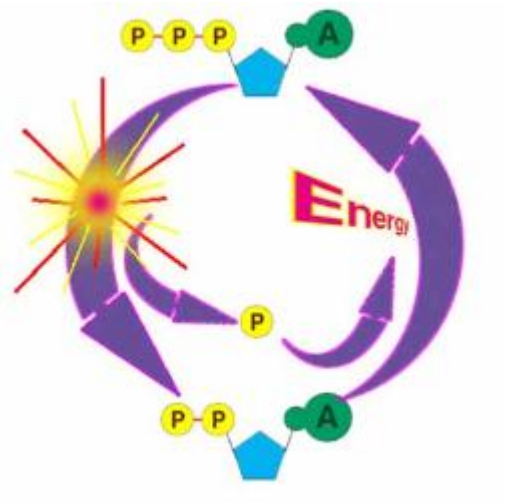
The Transformation of Energy

- Cells either get their energy either by **photosynthesis** or by **eating stuff**.

- But a cell can't just use sunlight or nutrients to run cellular reactions.

Q: What type of fuel is needed to run a cell?

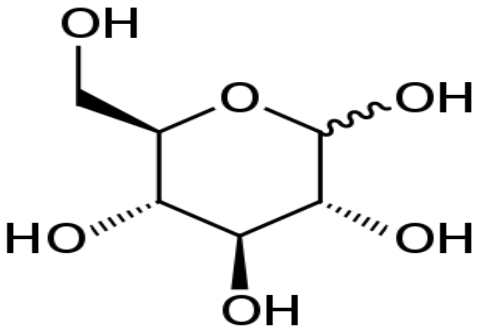




Images: Hamburger, Wiki; ATP-ADP Cycle, CUNY

Metabolism

Energy is obtained by breaking chemical bonds in foods we eat, like *glucose*.

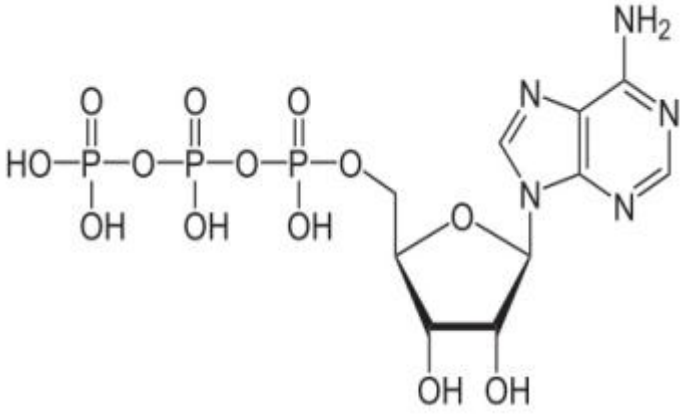


Metabolism transfers food energy into *ATP energy*, the common energy currency of cells.

Image: Leo after pouring baby food on his head ☺, T. Port

ATP Production & Energy Storage

Q: This molecule has a sugar, a base and three phosphate groups. What kind of monomer is it?



- Adenosine 5'-triphosphate
- Multifunctional "molecular currency" of intracellular energy transfer.
- Metabolism releases energy from nutrients.
- That energy can be stored in high-energy phosphate bonds of ATP.
- ATP transports chemical energy within cells.
- ATP can be used to fuel many cellular reactions.

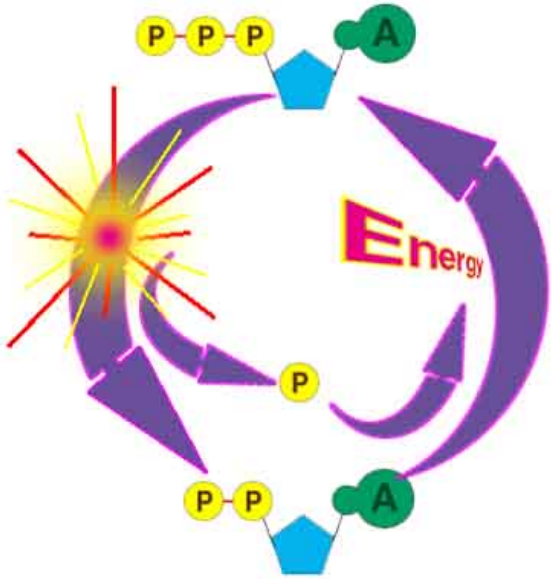


Image: ATP Molecule, NEUROtiker; ATP-ADP Cycle,

Basic Chemical Reactions Underlying Metabolism

1. Anabolism & Catabolism

2. Oxidation and Reduction Reactions

3. ATP Production and Energy Storage

This is stuff that you need to know before we begin discussing cellular respiration.

Building and Breaking Down Molecules

Anabolic Reaction

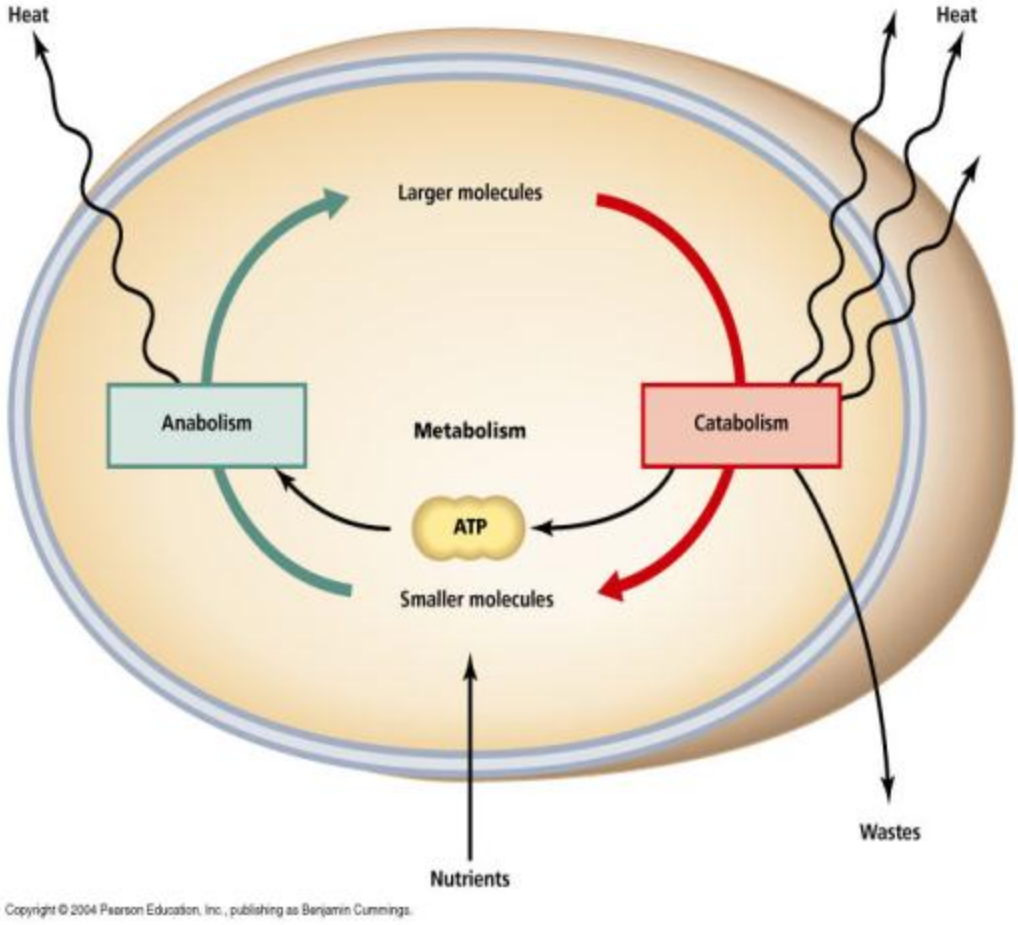
(anabolism)

The phase of metabolism in which simple substances are **synthesized** into the complex materials of living tissue.

Catabolic Reaction

(catabolism)

The metabolic **break down** of complex molecules into simpler ones, often resulting in release of energy.



Basic Chemical Reactions Underlying Metabolism

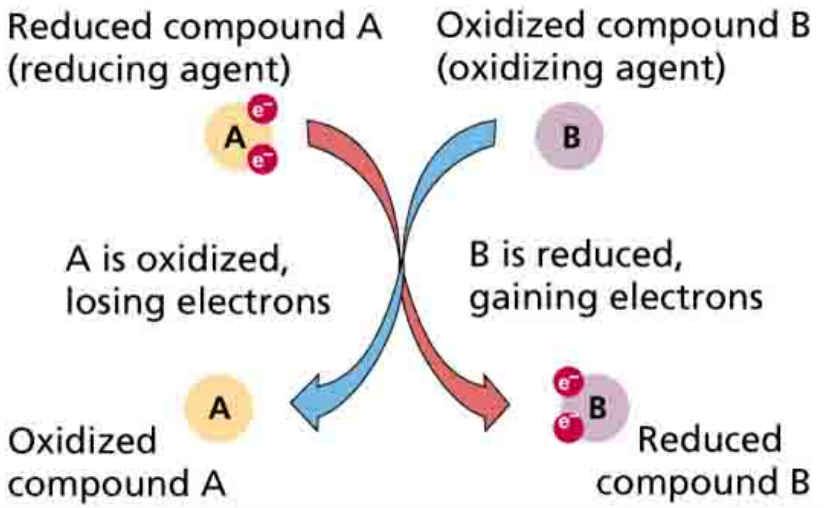
1. Catabolism and Anabolism

2. Oxidation Reduction (Redox) Reactions

3. ATP Production and Energy Storage

This is stuff that you need to know before we begin discussing cellular respiration.

Oxidation-Reduction Reaction



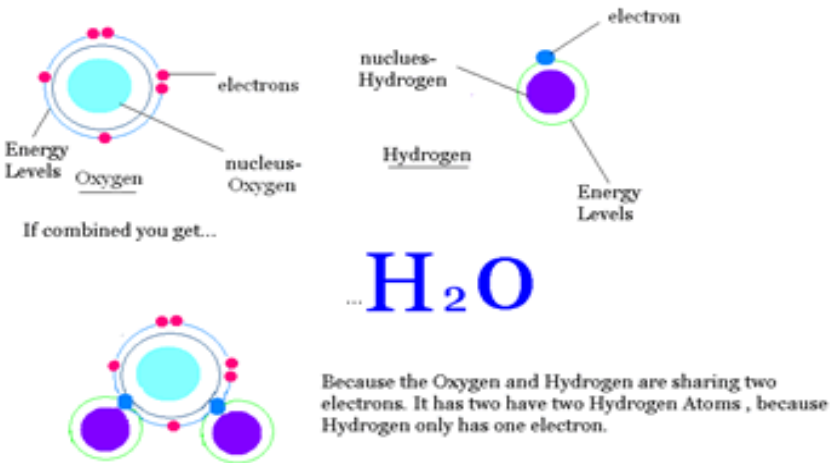


Image: Oil Rig Platform, NASA

From the Virtual Cell Biology Classroom on ScienceProfOnline.com

Oxidation and Reduction Reactions

What do they have to do with metabolism?

- Cells use special molecules to carry electrons *(often in H atoms).*
- This is potential energy.

REVIEW!
Animated lesson on Redox Reactions and How NAD+ Works

- Two important **electron carriers**:
  - Nicotinamide adenine dinucleotide (NAD^+) → **add electrons & hydrogen → NADH**
  - Flavine adenine dinucleotide (FAD) → **add electrons and hydrogen → $FADH_2$**

- Think of these energy carriers as **rechargeable batteries**. (When they have the electrons and hydrogens they are charged up, when they don't, they need charging.)

Basic Chemical Reactions Underlying Metabolism

1. Catabolism and Anabolism

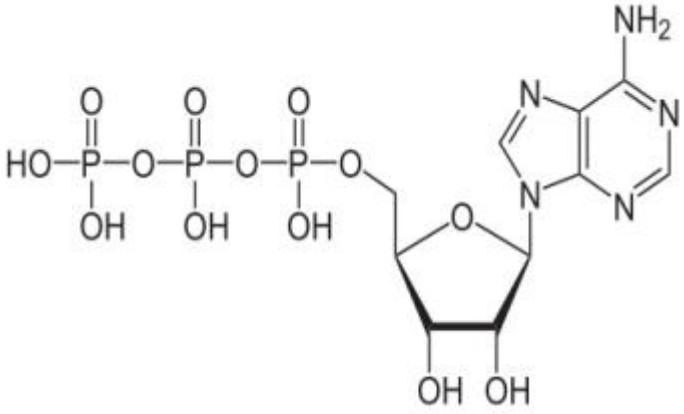
2. Oxidation and Reduction Reactions

3. ATP Production and Energy Storage

This is stuff that you need to know before we begin discussing cellular respiration.

ATP Production & Energy Storage

Q: This molecule has a sugar, a base and three phosphate groups. What kind of monomer is it?



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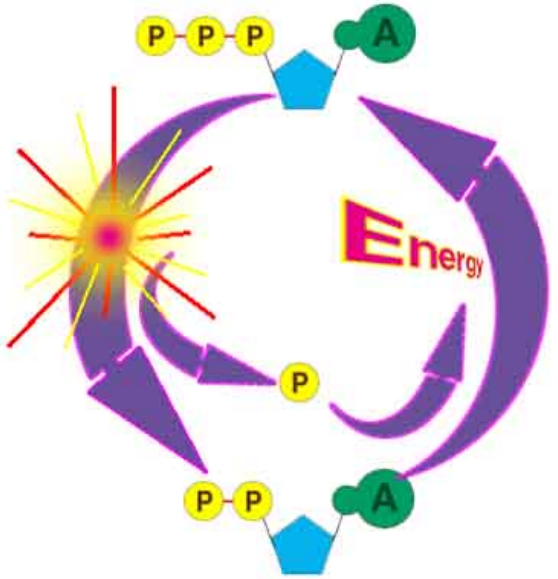
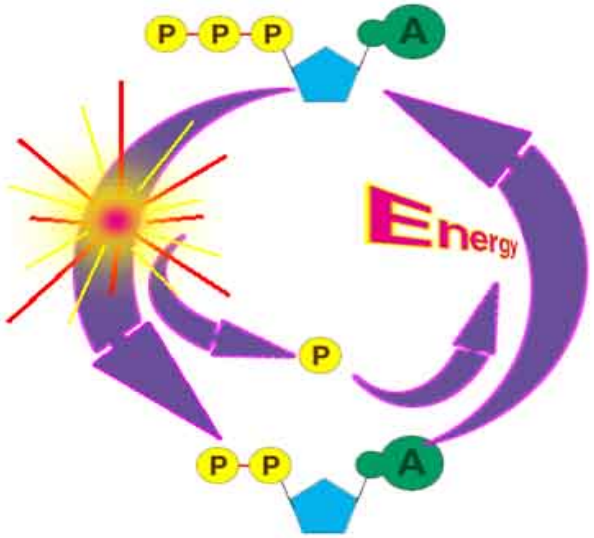
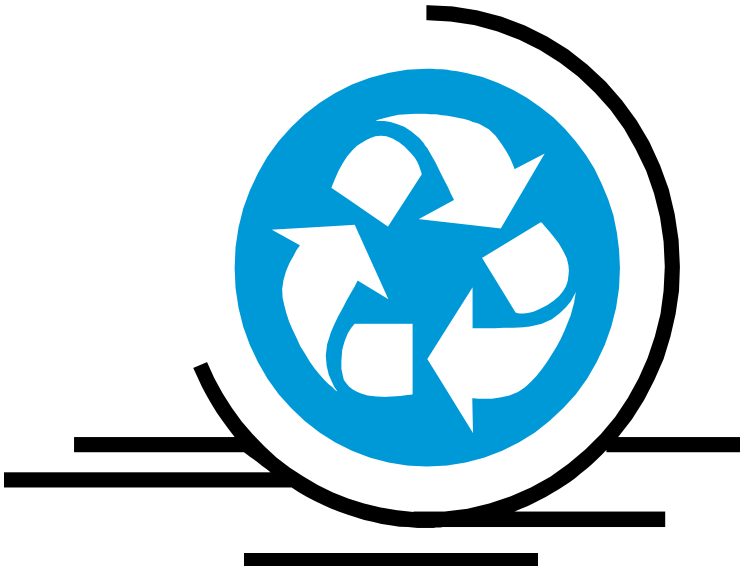


Image: ATP Molecule, NEUROtiker; ATP-ADP Cycle,

ATP Production & Energy Storage





- In a working muscle cell the entire pool of ATP is recycled once each minute.
- Over 10 million ATP per second per cell.
- A biological "rechargeable battery!

Images: ATP molecule, NEUROtiker; ATP-ADP Cycle, CUNY

Aerobic Cellular Respiration *is* Carbohydrate Catabolism

- Organisms **catabolize** (break down) **carbohydrates** as the primary energy source for anabolic reactions.
- The monosaccharide **glucose** is used most commonly.
- Glucose catabolized by:
  - **Aerobic cellular respiration** → Results in complete breakdown of glucose to carbon dioxide, water and a lot of

  - **Anaerobic respiration & Fermentation** → Only partially breaks down glucose, into pyruvic acid and organic waste products and a little

Aerobic Cellular Respiration →

Utilizes four subpathways:

1. glycolysis
2. synthesis of acetyl CoA
3. Krebs cycle
4. electron transport chain

End result is complete breakdown of glucose to carbon dioxide, water and **ATP**.

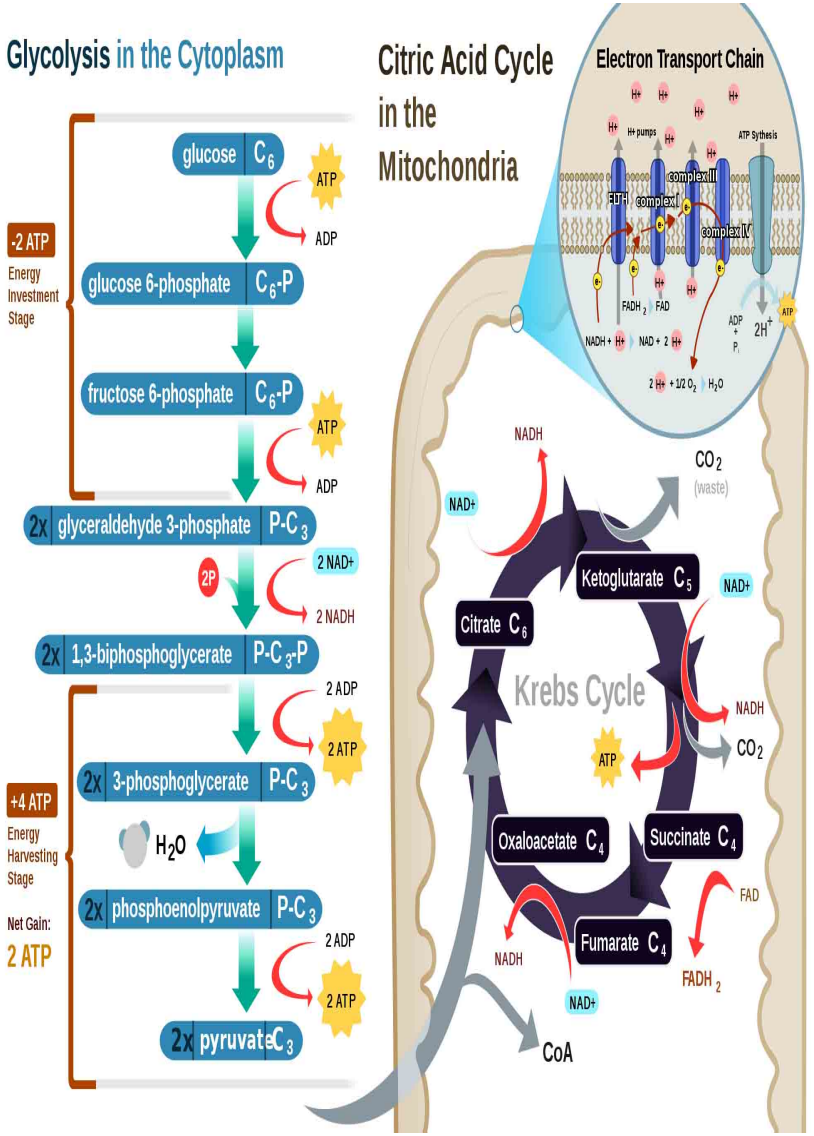


Image: Cellular Respiration, Regis Frey

Glycolysis

- Occurs in **cytoplasm** of most cells.

- Involves splitting of a six-carbon glucose into two three-carbon molecules of **pyruvate**.

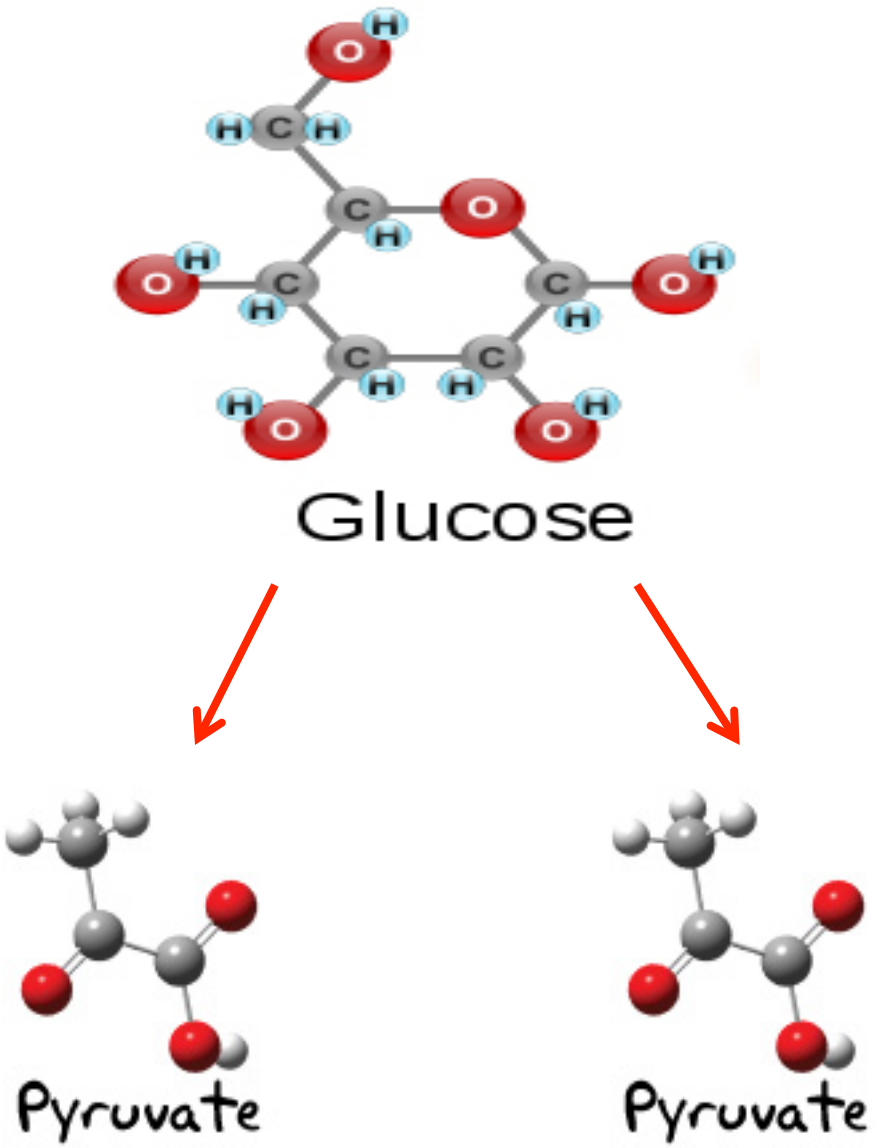
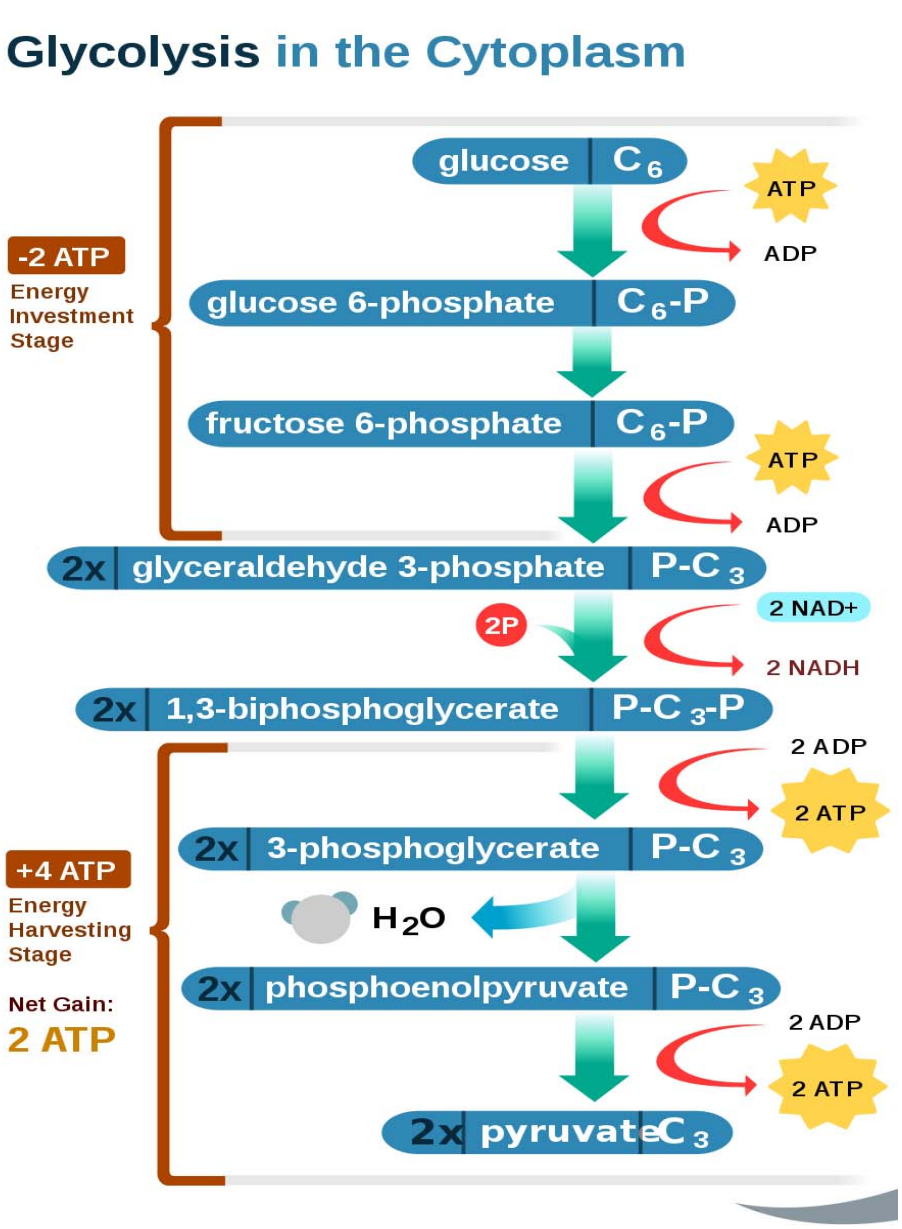


Image: Glucose molecule, YassineMrabet



Q: What goes into this reaction?

Q:What is produced in the end?

- 2 molecules of _____
- 2 molecules of _____
- 2 molecules of _____

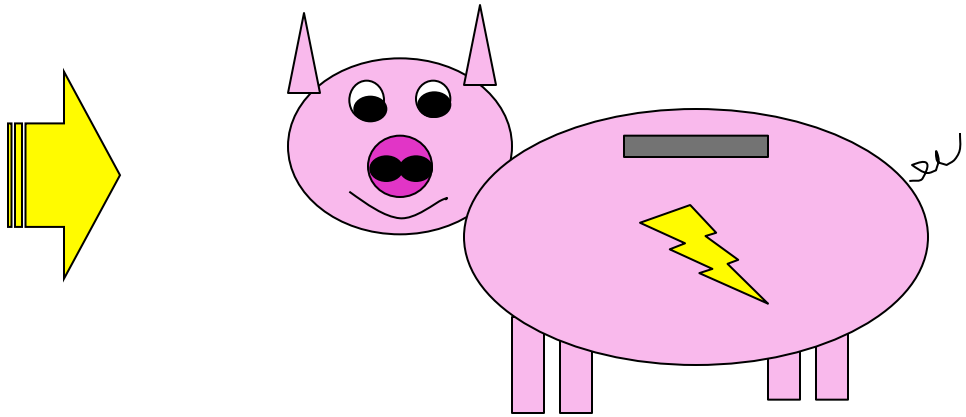
REVIEW!

Animated lesson on [How Glycolysis Works]

Aerobic Cellular Respiration

Subpathway	Molecule In	Molecule Out	Energy Obtained
1. glycolysis			
2. synth acetyl-CoA			
3. Krebs cycle			
4. ETC			

Let's put the energy extracted from glucose into our energy piggy bank.



Aerobic Cellular Respiration →

Utilizes four subpathways:

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End result is complete breakdown of glucose to carbon dioxide, water and **ATP**.

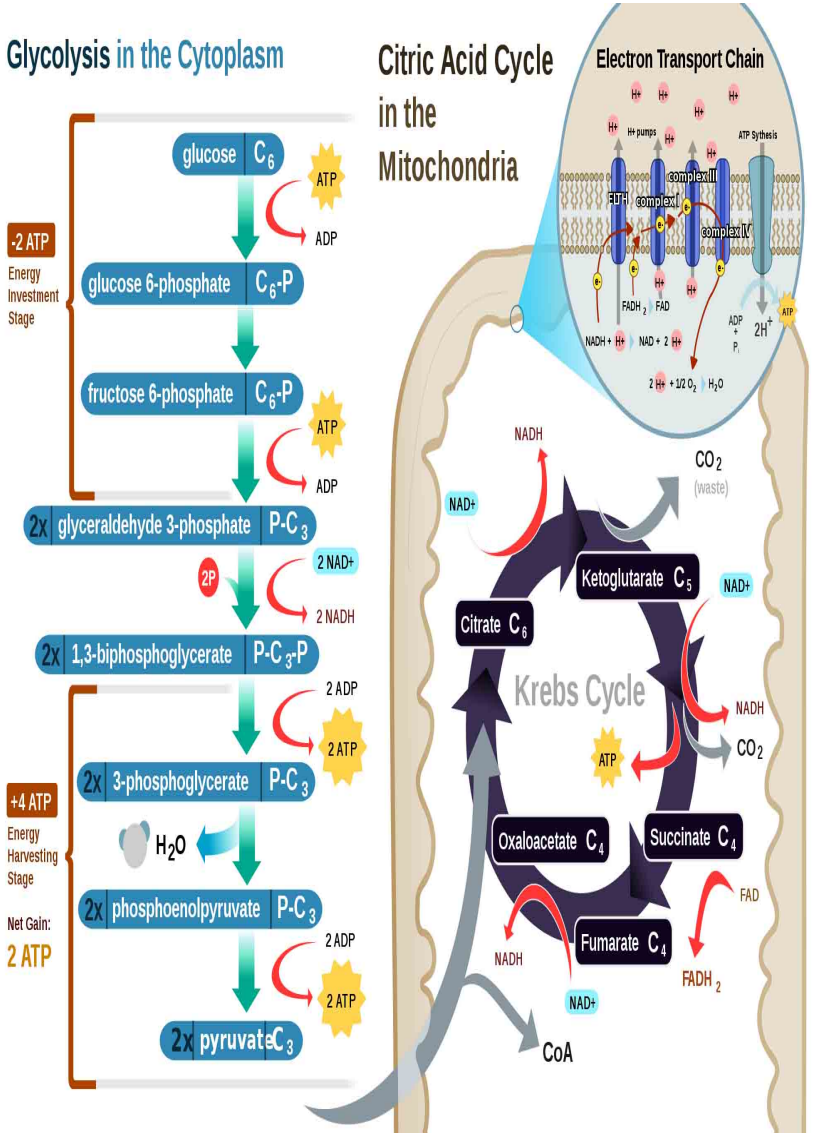
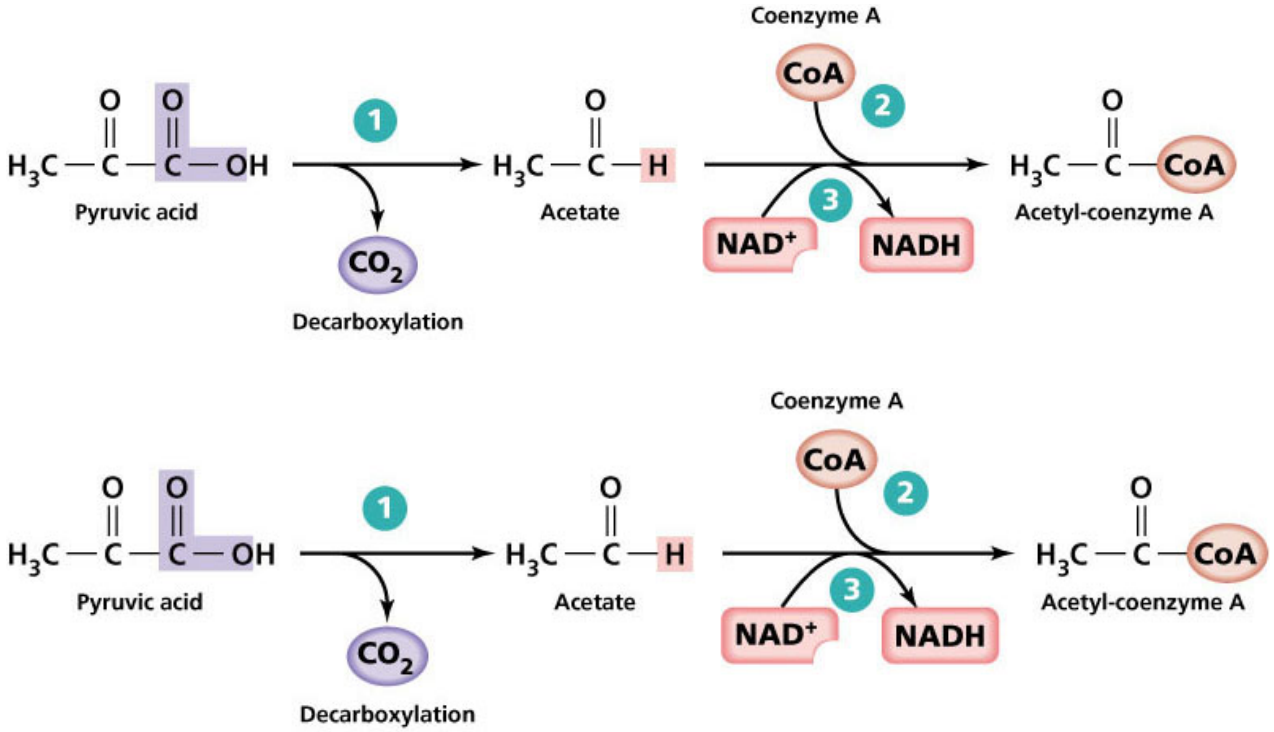


Image: Cellular Respiration, Regis Frey

Synthesis of Acetyl-CoA



The two molecules of pyruvate (pyruvic acid above) **result in:**

- 2 molecules of _____
- 2 molecules of _____ (This is what generates carbon dioxide that you breathe out.)
- 2 molecules of _____ (electron carrier)

Aerobic Cellular Respiration →

Utilizes four subpathways:

1. glycolysis
2. synthesis of acetyl CoA
3. Krebs cycle
4. electron transport chain

End result is complete breakdown of glucose to carbon dioxide, water and **ATP**.

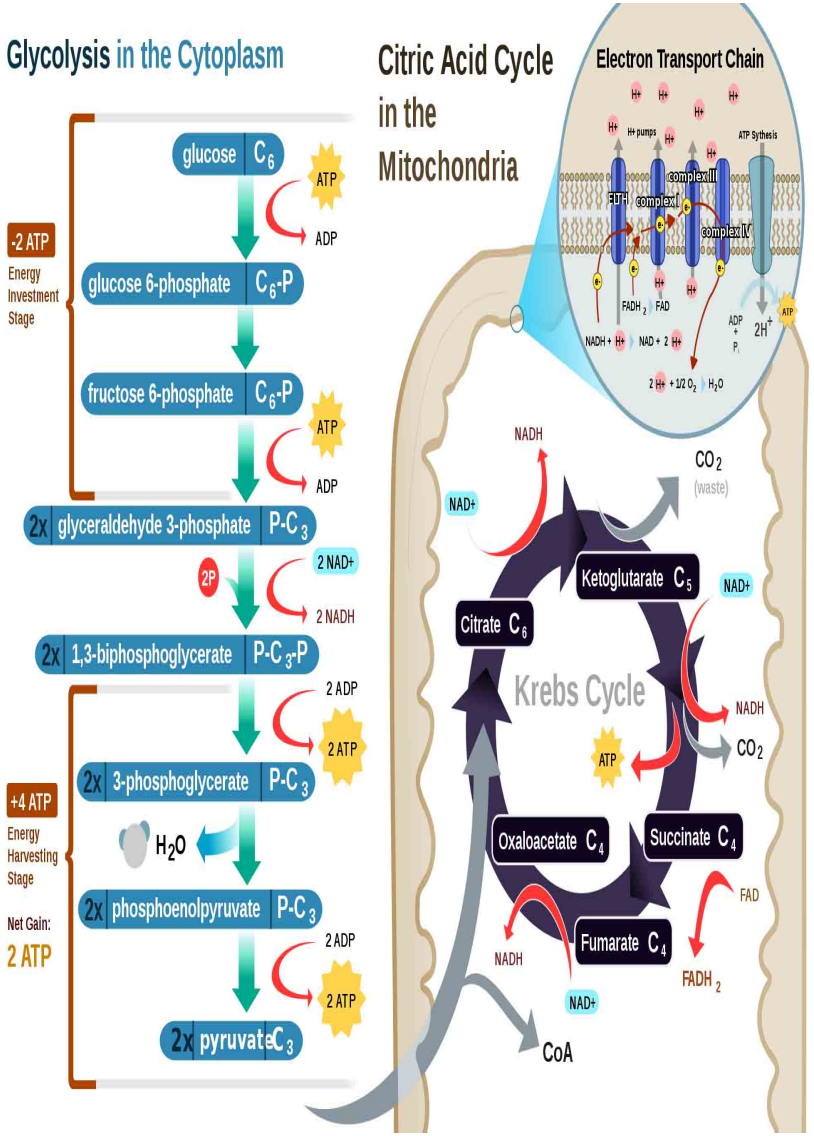
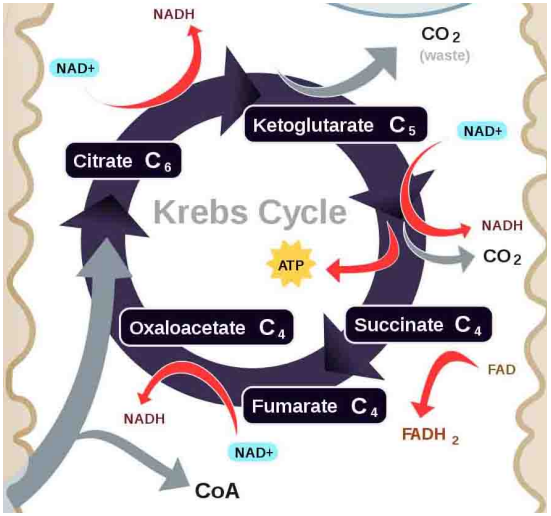


Image: Cellular Respiration, Regis Frey

Krebs Cycle
(Citric Acid Cycle)



- Great amount of energy remains in bonds of acetyl-CoA.

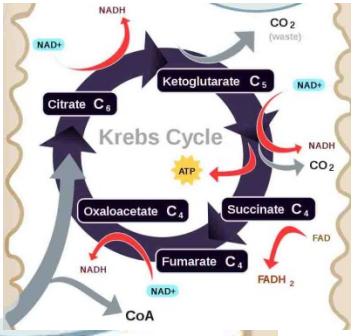
- The Krebs cycle transfers much of this energy to electron carriers NAD^+ and FAD.

- Occurs in **cytoplasm** of prokaryotes and in matrix of **mitochondria** in eukaryotes.

Image:Krebs Cycle of Cellular Respiration, Regis Frey

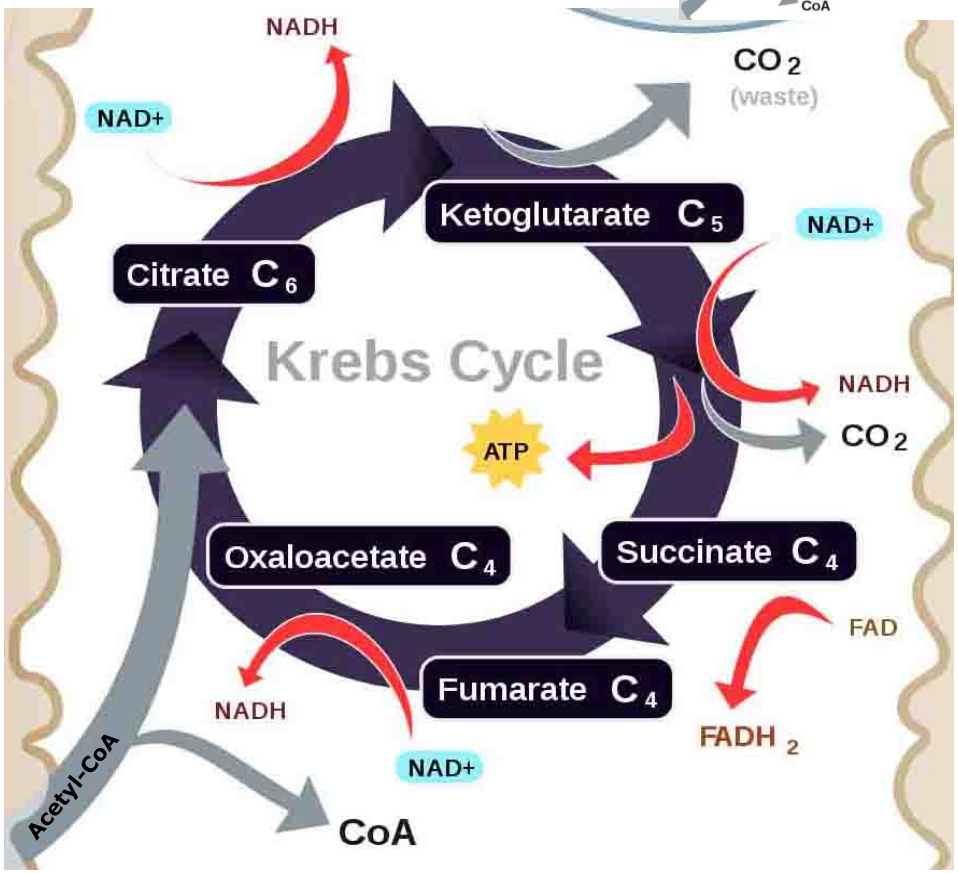
Krebs Cycle

(a.k.a Citric Acid Cycle)



The two molecules of Acetyl Co-A result in:

- Two molecules of ATP ATP
- Two molecules of _____ (electron carrier)
- Six molecules of _____ (electron carrier)
- Four molecules of _____ (This is what generates carbon dioxide you breathe out.)



REVIEW!

Animated lesson and quiz on Krebs Cycle

Image: Krebs Cycle of Cellular Respiration, Regis Frey

Aerobic Cellular Respiration →

Utilizes four subpathways:

1. glycolysis
2. synthesis of acetyl CoA
3. Krebs cycle
4. electron transport chain

End result is complete breakdown of glucose to carbon dioxide, water and **ATP**.

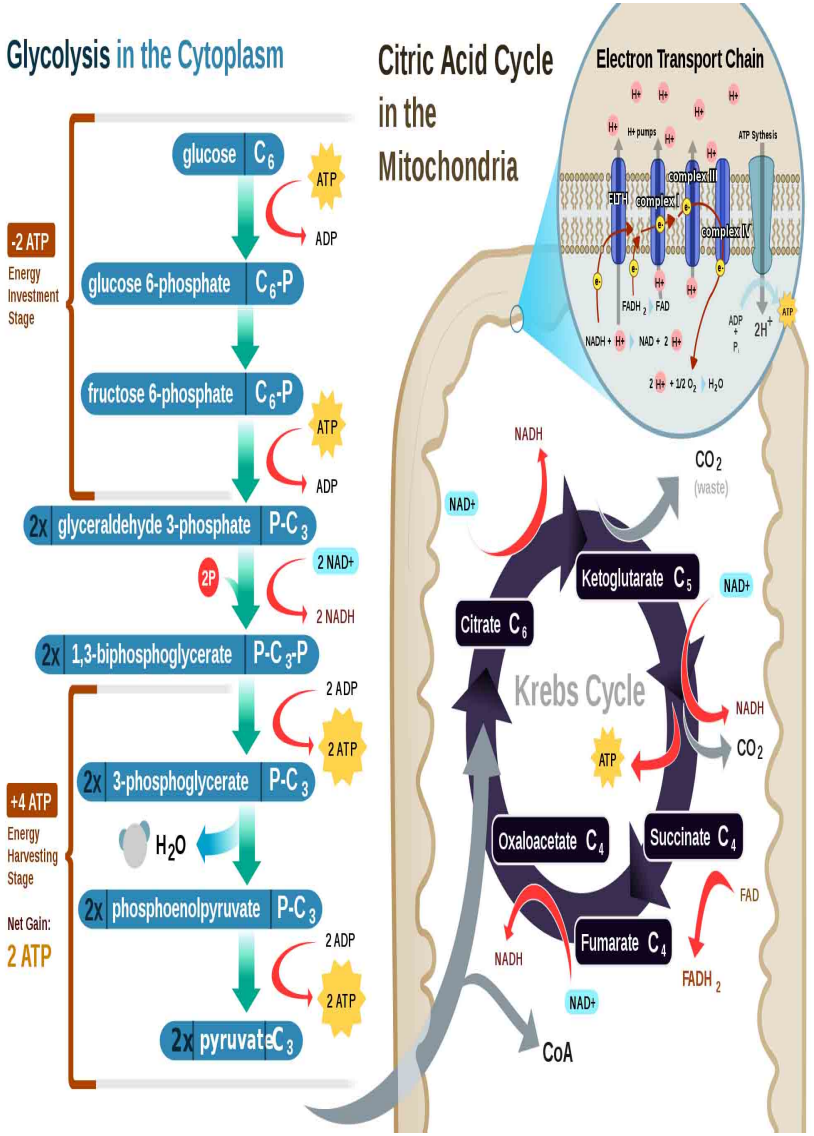
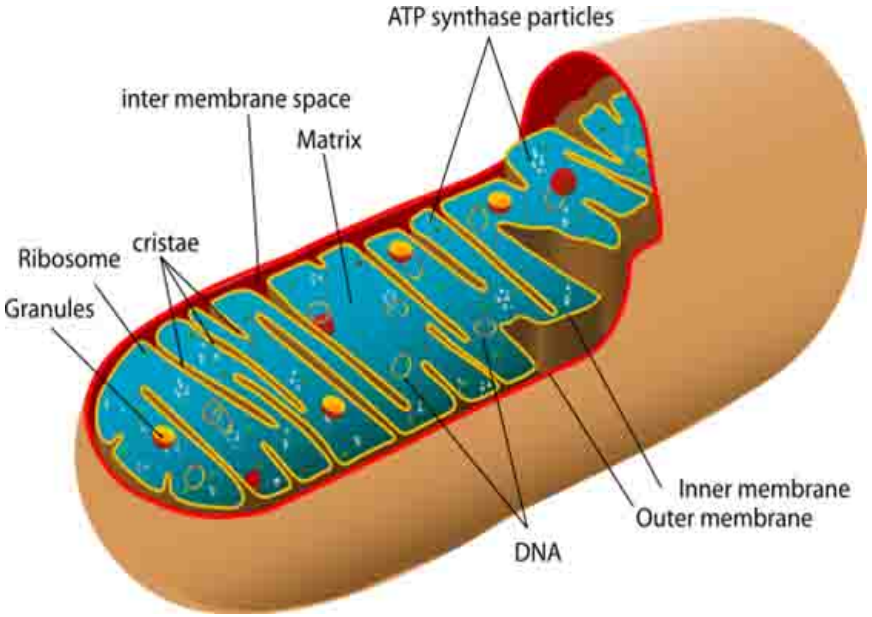


Image: Cellular Respiration, Regis Frey

Electron Transport

- Most of the ATP made in cellular respiration comes from the stepwise release of energy through a series of redox reactions between molecules known as the **electron transport chain** (ETC).



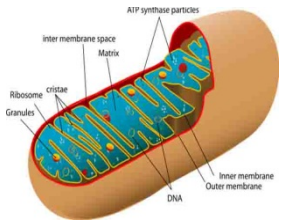
- Must occur in a membrane. The ETC is located in cristae of **mitochondria** in eukaryotes.

- **Q: Where would the ETC of prokaryotes be located?**

Three main events important in the ETCs generation of ATP:

1. _____
2. _____
3. _____

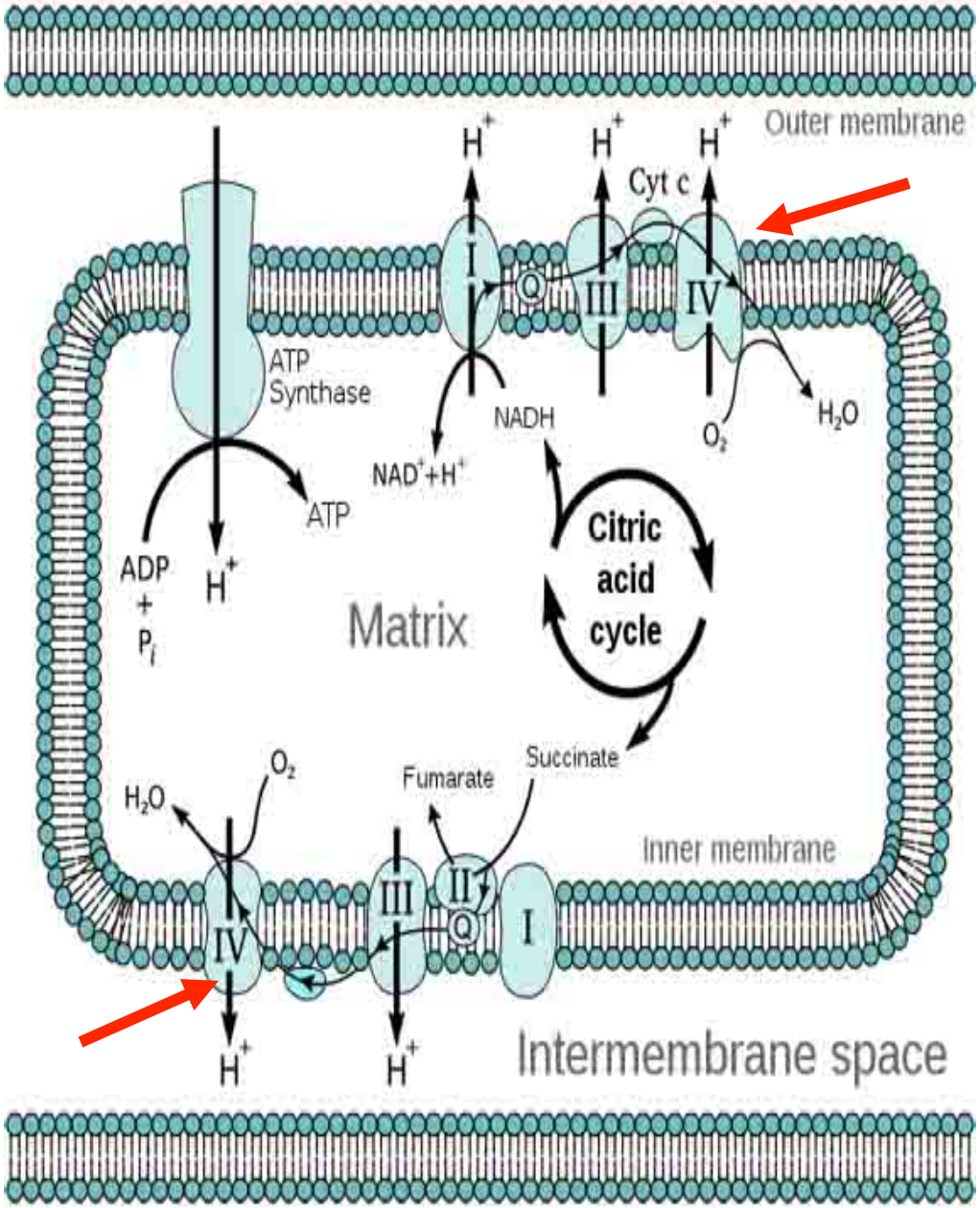
Image: Mitochondrion diagram M. Ruiz



Electron Transport

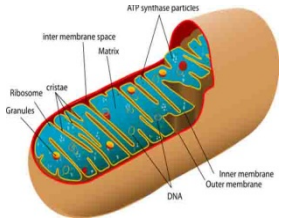
1. Oxidation Reduction Reactions

- The electron carriers (NADH and $FADH_2$) bring electrons and protons (H+) to the ETC.
- Carrier molecules in the membrane of the mitochondria pass electrons from one to another and ultimately to final electron acceptor.



From the Virtual Cell Biology Classroom on ScienceProfOnline.com

Images: Mitochondrion diagram M. Ruiz
Electron transport chain, Tim Vickers

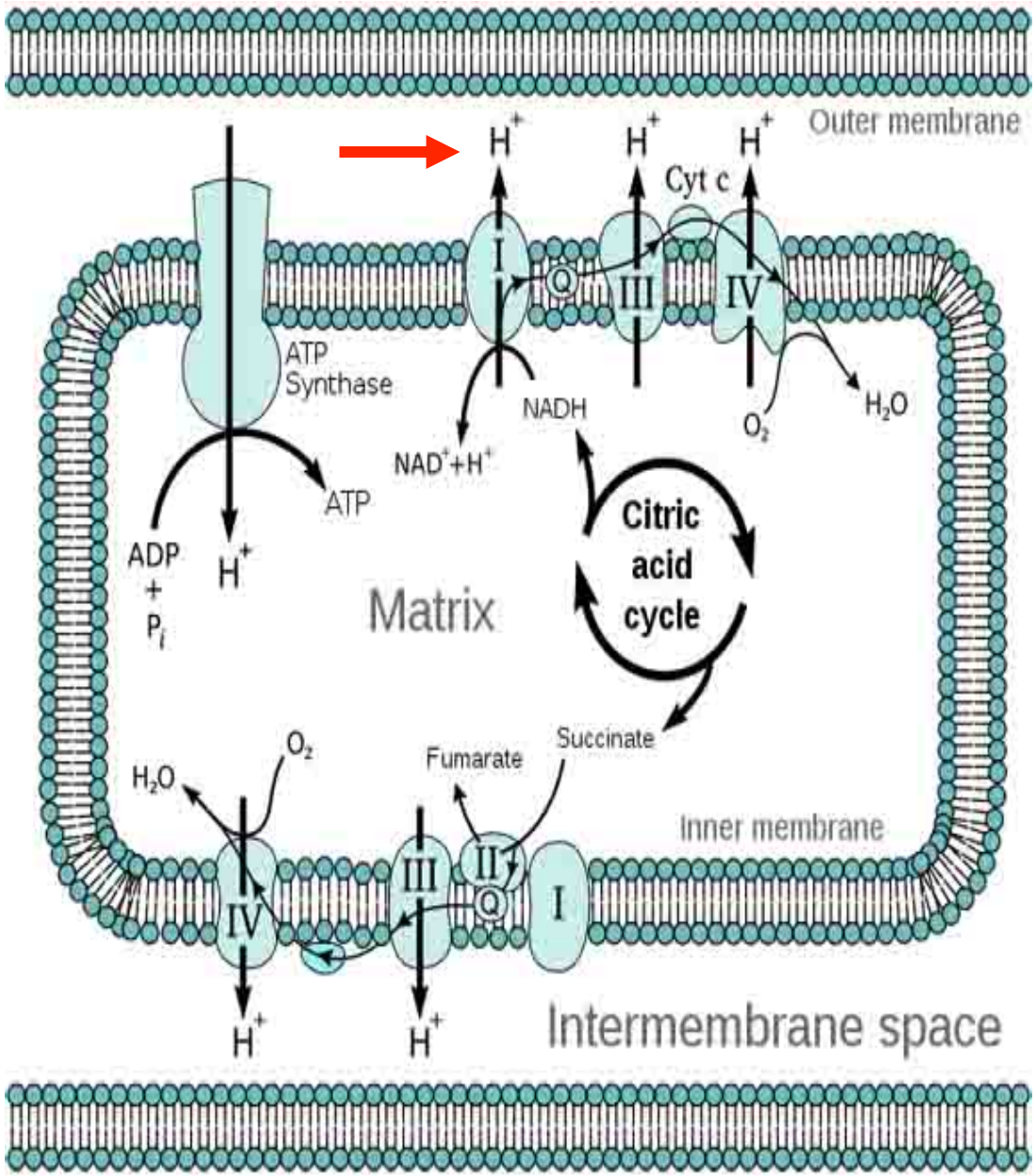


Electron Transport

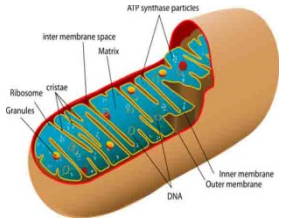
2. Creation of a Proton Gradient

- Energy from each electron being passed down the chain is used to pump protons (H+) from one side of the membrane to the other.

- Proton gradient = type of **ion gradient** *(difference in ion concentration on either side of a membrane)* … potential energy available for work in cell.



Images: Mitochondrion diagram M. Ruiz
Electron transport chain, Tim Vickers



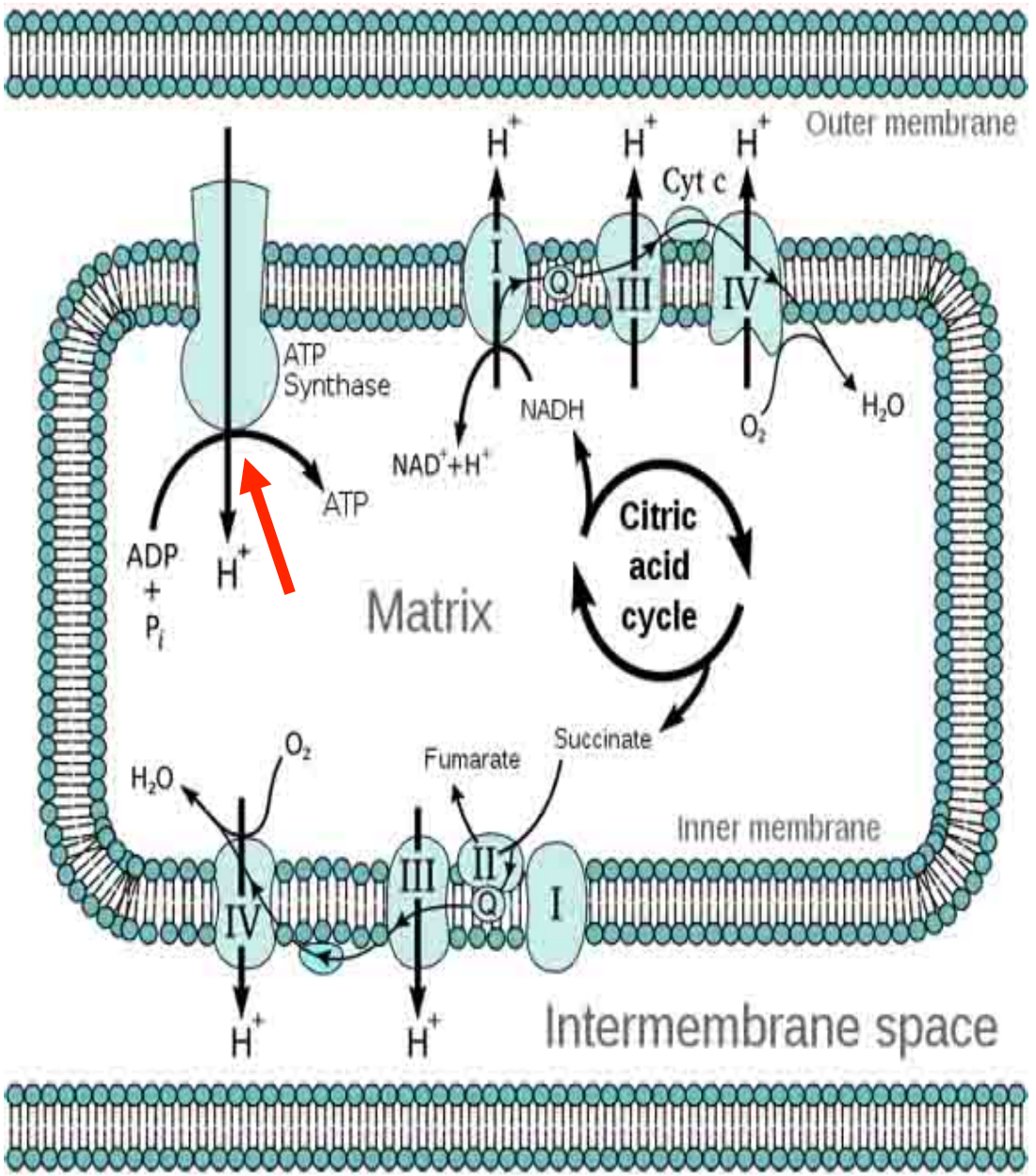
Electron Transport

3. Synthesis of ATP

H^+ ions flow down proton gradient through protein channels (ATP synthase) that phosphorylate ADP to make ATP.

REVIEW!

Animated lesson on Electron Transport Chain



Images: Mitochondrion diagram M. Ruiz
Electron transport chain, Tim Vickers

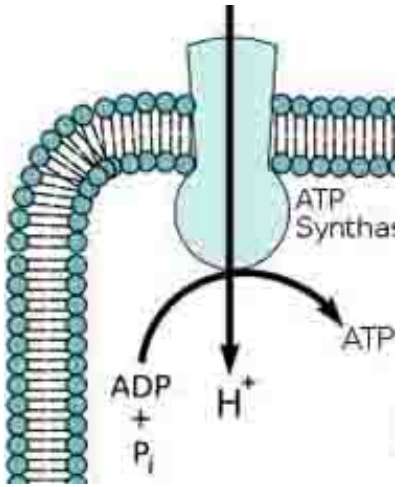
Meet the Enzyme: ATP Synthase

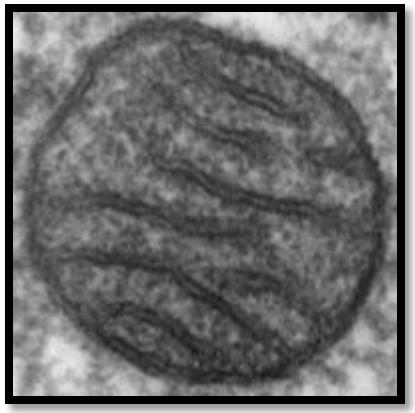
Important metabolic enzyme that harnesses energy for biological cells to use.

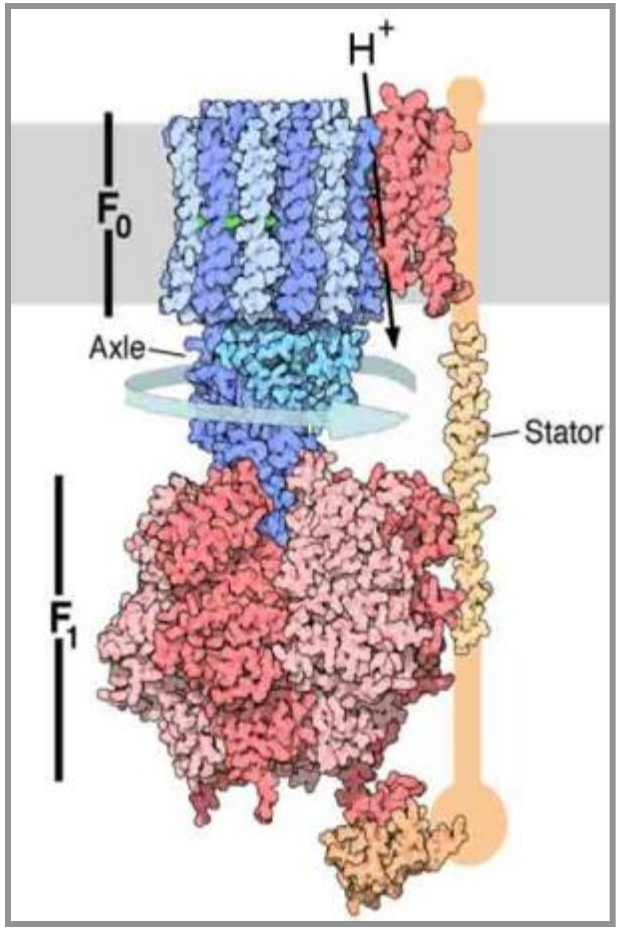
Involved in synthesis of adenosine triphosphate (ATP), from:

- adenosine diphosphate (ADP)
- a phosphate group and
- energy from H+ ion
- gradient

ATP is the most commonly used "energy currency" of cells.







Reaction:

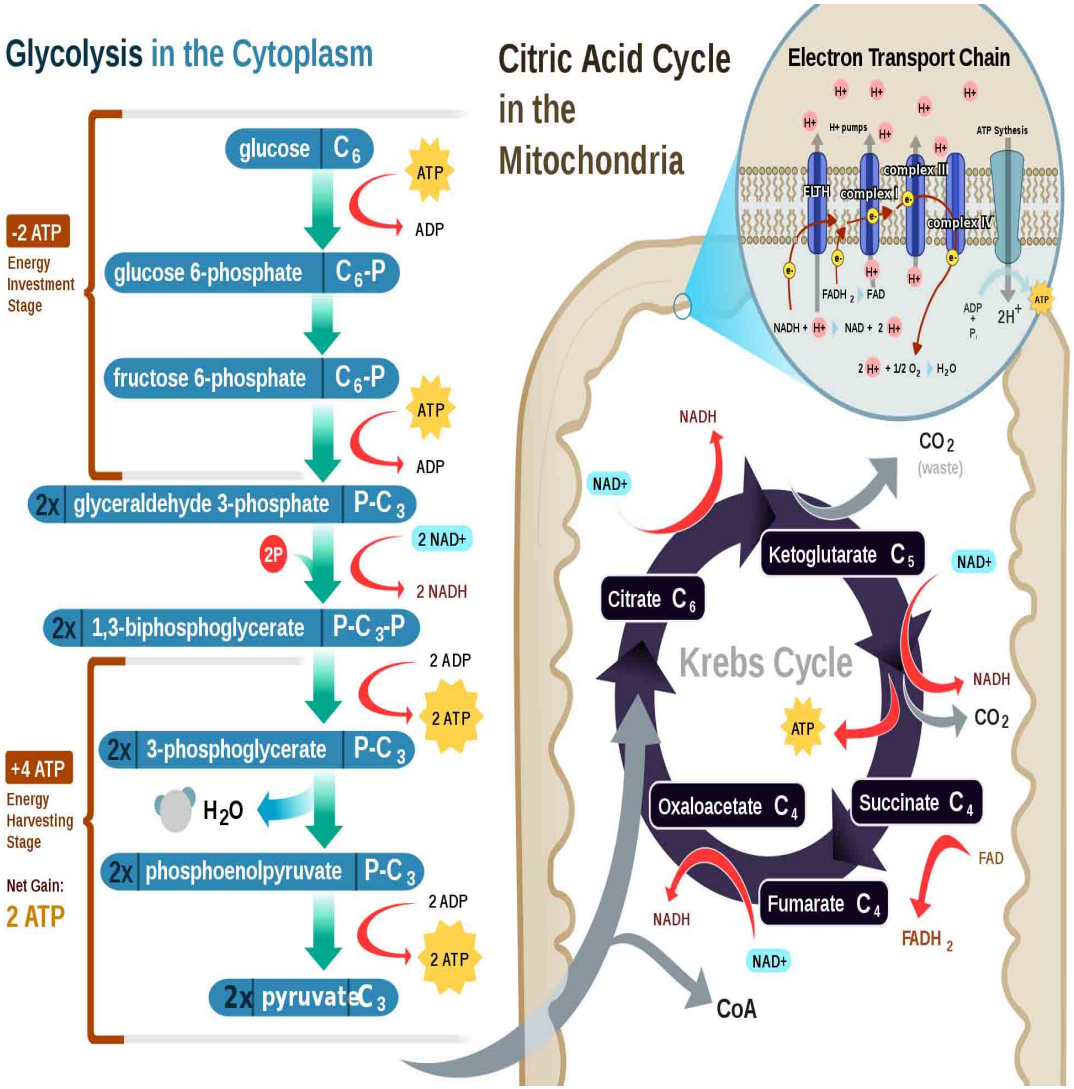
(ATP synthase)

$$ADP + Pi \dashrightarrow ATP$$

substrate substrate product

Images: ATP synthase diagram, Tim Vickers

Aerobic Cellular Respiration



REVIEW!

Animated lesson and quizzes on Cellular Respiration

Image: Cellular Respiration, Regis Frey

Aerobic cellular respiration →

Utilizes glycolysis, synthesis of acetyl-CoA, Krebs cycle, and electron transport chain; results in complete breakdown of _____ to carbon dioxide, water & 

The ultimate objective is to make 

molecules to do cellular work.

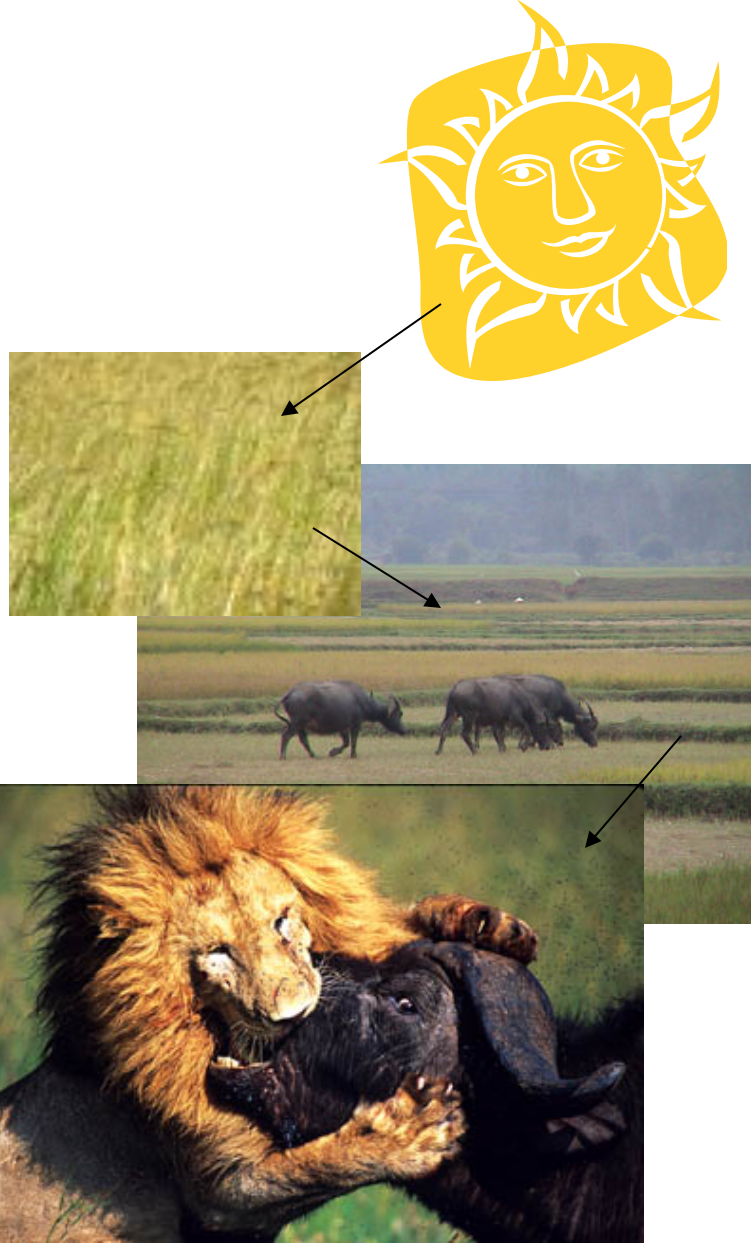
Each NADH results in 3 ATP, Each FADH2 results in 2 ATP.

A total of 38 molecules of ATP are formed from one molecule of glucose.

Lets figure out how we got 38 ATP by the end of aerobic respiration.

Where does the energy come from?

In other words, how do we get glucose to begin with?



Autotroph - organism that makes organic compounds from inorganic sources.

Plants, some bacteria, and some protista make their own food using light energy.

Heterotroph - organism that cannot make organic compounds from inorganic sources.

They obtain their organic compounds by consuming other organisms. Almost all animals, fungi and some Protista and bacteria.

Sun → Autotroph → Heterotroph

Conversion of Energy

- Every food chain begins with **anabolic** pathways in organisms that synthesize their own **organic molecules** from inorganic carbon dioxide.

- Most of these organisms capture light energy from the sun and use it to drive the synthesis of **glucose** from CO_2 and H_2O by a process called photosynthesis.

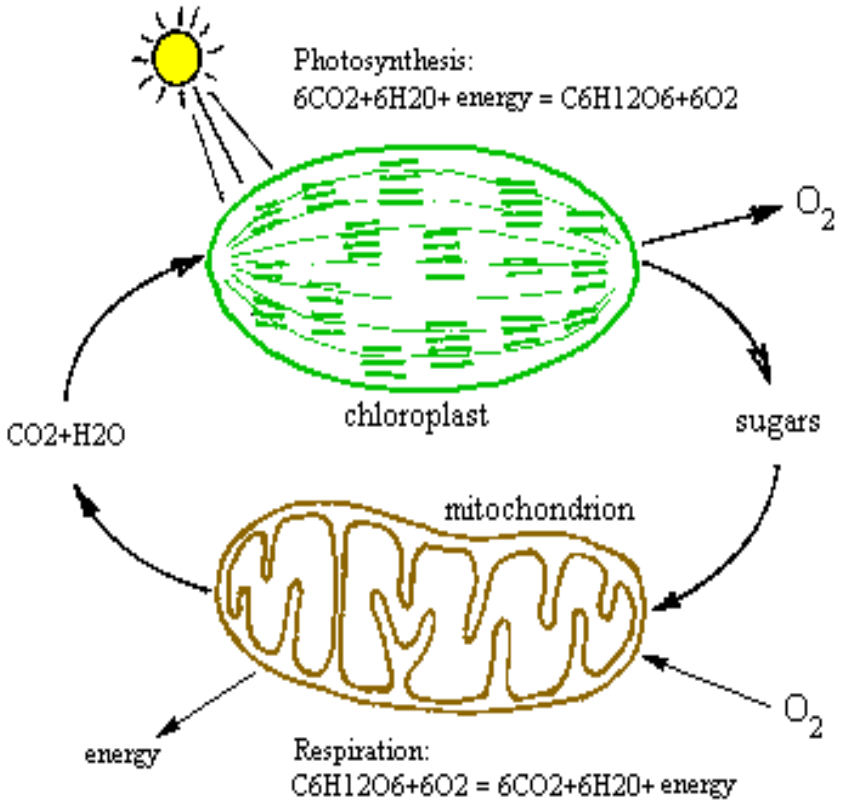
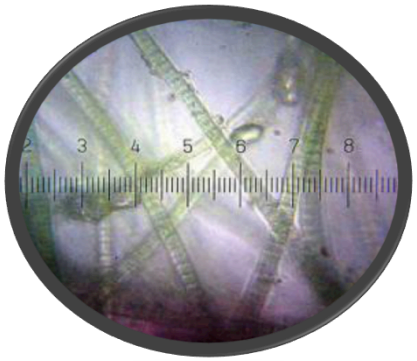
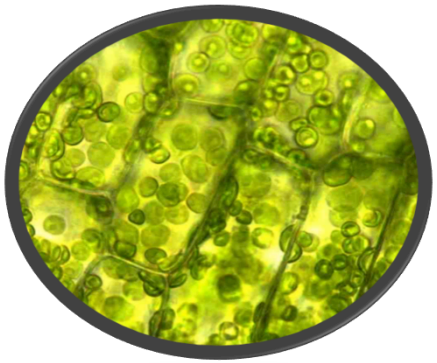


Figure 16 - With the photosynthesis, the solar energy is cumulated by the chloroplasts as sugar molecules. With the glycolysis and the respiration, made by mitochondria, the energy is liberated and supplied to the cell for its biochemical processes.

Cells that Run on Solar Power

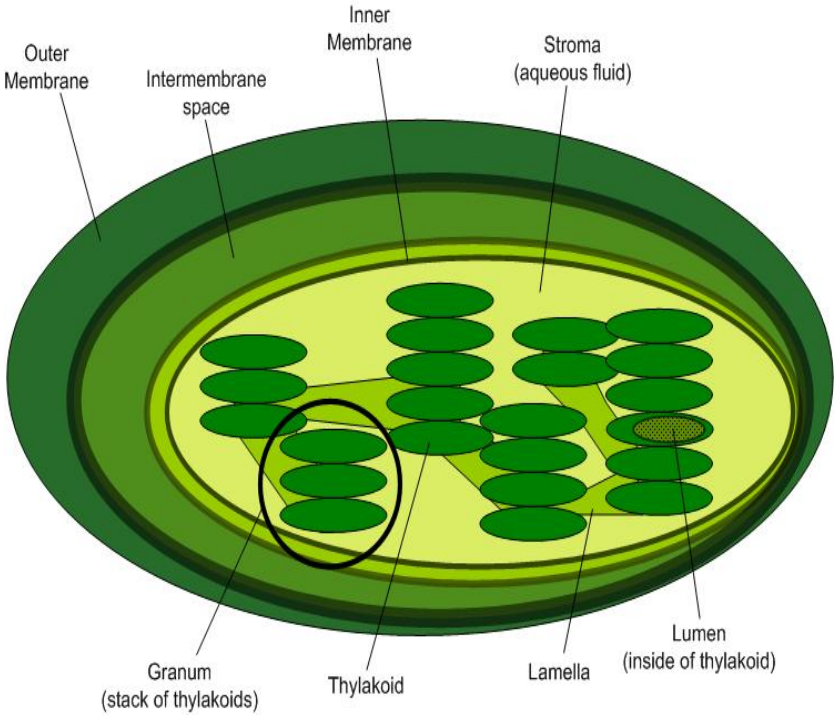


Cyanobacteria are photosynthetic bacteria.



Elodea plant cells with chloroplasts visible.

- Organisms capture light energy with pigment molecules; primarily **chlorophyll**.
- Prokaryotic autotrophs have chlorophyll in their cytoplasm.
- Eukaryotic autotrophs have chlorophyll organized in special photosystems within **chloroplast** organelles.



Images: Cyanobacteria, Bob Baylock; Elodea plant cells, T. Port Chloroplast diagram, Wiki

Metabolic Processes … Bottom Line

Metabolism transforms food energy into energy that our cells can use.

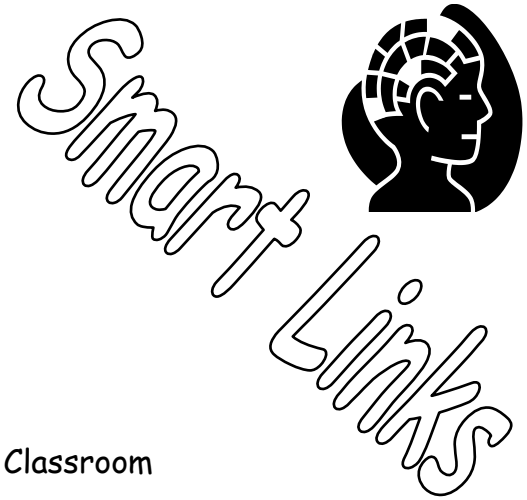
Q: What carbohydrate molecule is the basic component of your food energy?

Q: What is different about how animal cells and plant cells obtain this molecule?

Q:What molecule is the product of metabolism used to do cellular work?

Image: Jumping rope, Meagan E. Klein

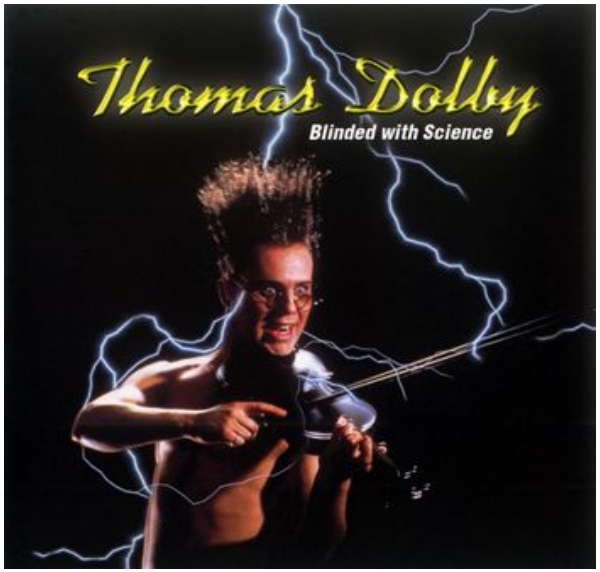
Confused?



Here are links to fun resources that further explain cellular respiration:

- Aerobic Cellular Respiration **Main Page** on the Virtual Cell Biology Classroom of Science Prof Online.
- Cellular Respiration animation by Jay Phelan, "What is Life? A Guide to Biology", W. H. Freeman & Co.
- "The Body Machine" music video by School House Rock.
- How NAD+ Works animation and quiz from McGraw-Hill.
- Glycolysis animation and quiz from McGraw-Hill.
- Krebs Cycle Animation & Quiz from McGraw-Hill.
- Electron Transport Chain animation from Molecular & Cellular Biology Learning Center.
- Electron Transport Chain click through animation by Graham Kent Bio231 Cell Biology Laboratory.
- Food Molecules video from HowStuffWorks, a Discovery company.
- "The Energy" song by Audiovent.

(You must be in PPT slideshow view to click on links.)

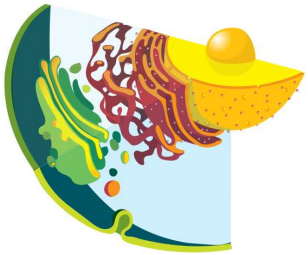


Are you feeling blinded by science?

Do yourself a favor. Use the…

Virtual Cell Biology Classroom *(VCBC)* !

The VCBC is full of resources to help you succeed, including:



- practice test questions
- review questions
- study guides and learning objectives
- PowerPoints on other topics

You can access the VCBC by going to the Science Prof Online website
www.ScienceProfOnline.com

Images: Blinded With Science album, Thomas Dolby; Endomembrane system, Mariana Ruiz, Wiki