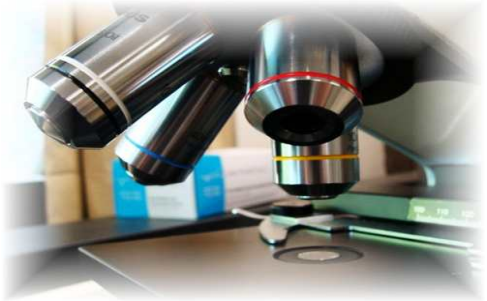


About Science Prof Online PowerPoint Resources

• Science Prof Online (SPO) is a free science education website that provides fully-developed Virtual Science Classrooms, science-related PowerPoints, articles and images. The site is designed to be a helpful resource for students, educators, and anyone interested in learning about science.

• 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.

• Many SPO PowerPoints are available in a variety of formats, such as fully editable PowerPoint files, as well as uneditable versions in smaller file sizes, such as PowerPoint Shows and Portable Document Format (.pdf), for ease of printing.

• Images used on this resource, and on the SPO website are, wherever possible, credited and linked to their source. Any words underlined and appearing in blue are links that can be clicked on for more information. PowerPoints must be viewed in *slide show mode* to use the hyperlinks directly.

• 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.

Alicia Cepaitis, MS
Chief Creative Nerd
Science Prof Online
Online Education Resources, LLC
alicia@scienceprofonline.com

Tami Port, MS
Creator of Science Prof Online
Chief Executive Nerd
Science Prof Online
Online Education Resources, LLC
info@scienceprofonline.com

Image: Compound microscope objectives, T. Port

Metabolism:

Cellular Respiration & Fermentation

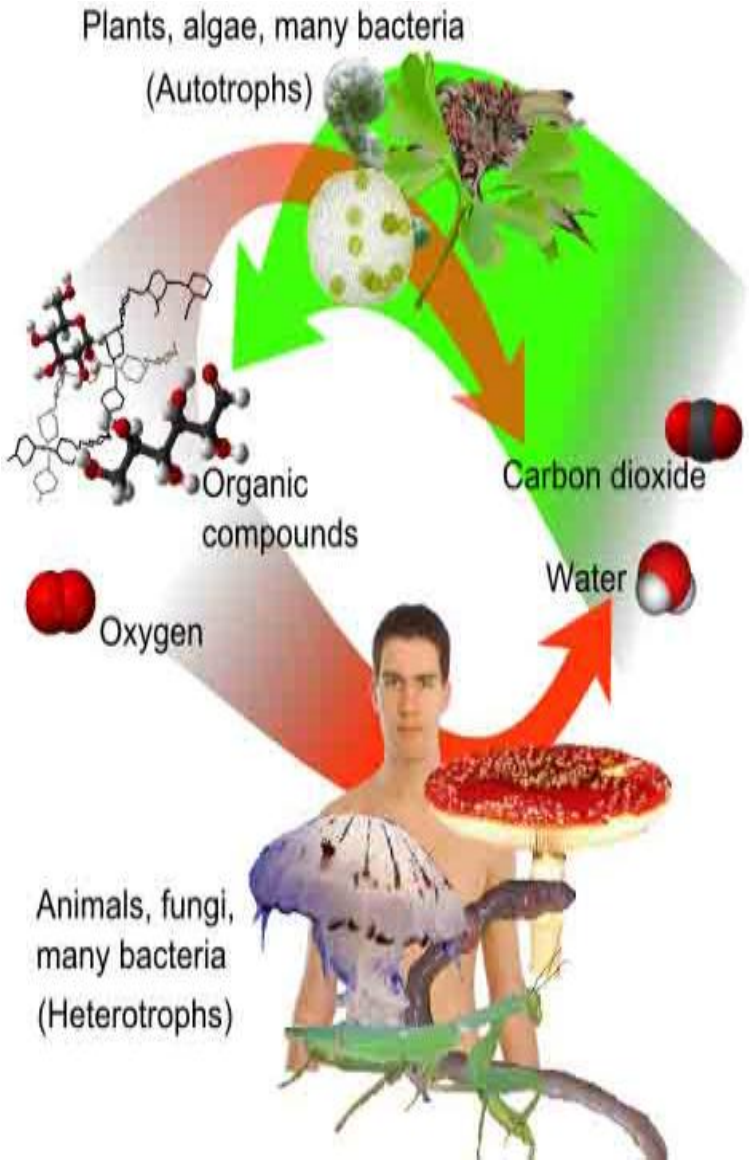


Image: Autotrophs & Heterotrophs, Mikael Häggström

Everyday Biology

What causes smelly farts?

- Most people pass gas at least 10 – 25x a day.
- Farts are mostly a byproduct microbial anaerobic respiration & fermentation in the colon (large intestine).
- Over 99% of fart volume is non-smelly gases, including oxygen, nitrogen, carbon dioxide, hydrogen and methane.
- Smelly farts are caused by microbes that generate volatile sulfur compounds and/or by feces in the rectum.
- Diets high in healthy sulfur containing veggies *(ex. broccoli, cabbage, brussel sprouts)* and protein with sulfur-containing amino acids significantly increase the smell of farts.

Metabolism
The Transformation of Energy

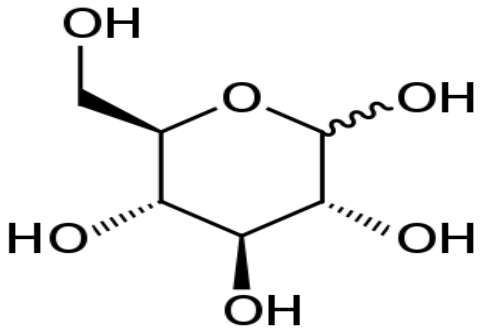
- Cells either get their energy either by _____ or _____ _____.
- But a cell can't just use sunlight or nutrients to run cellular reactions.
- What type of fuel is needed to run a cell? _____

Cells Can't Eat Hamburgers

Image: Hamburger, Wiki

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

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

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

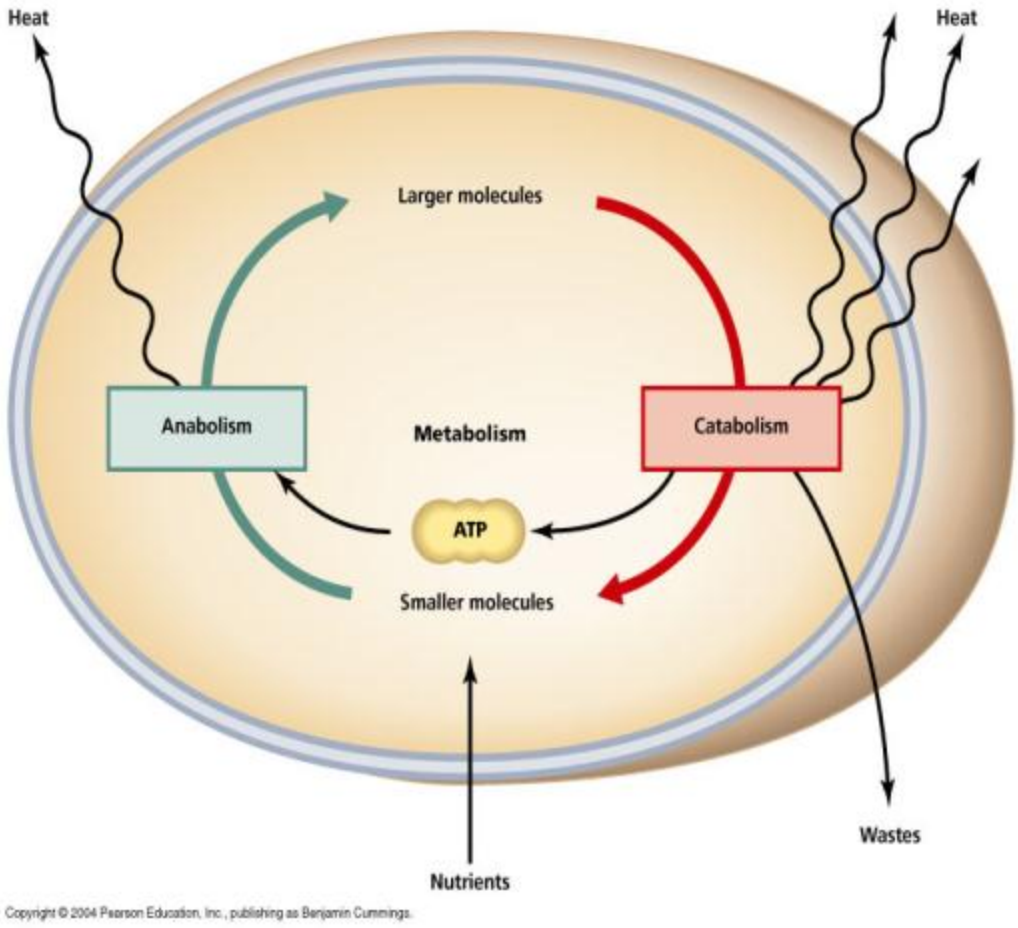
(anabolism)

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

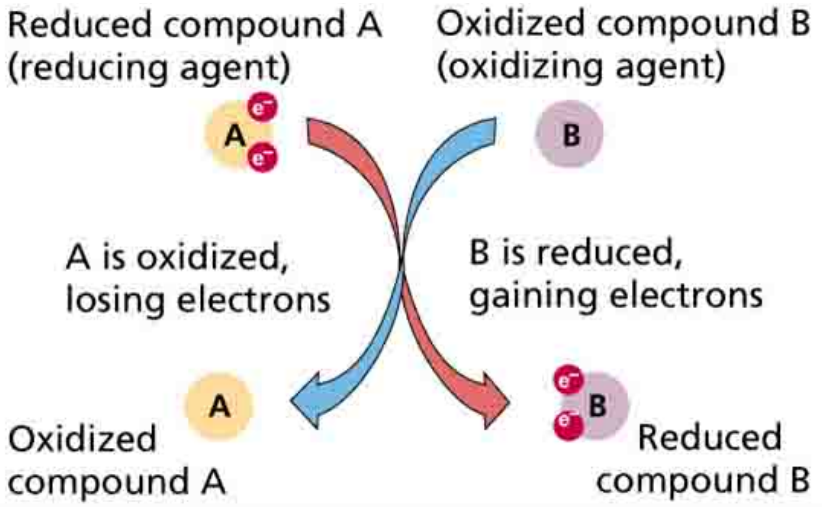
1. Catabolism and Anabolism

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



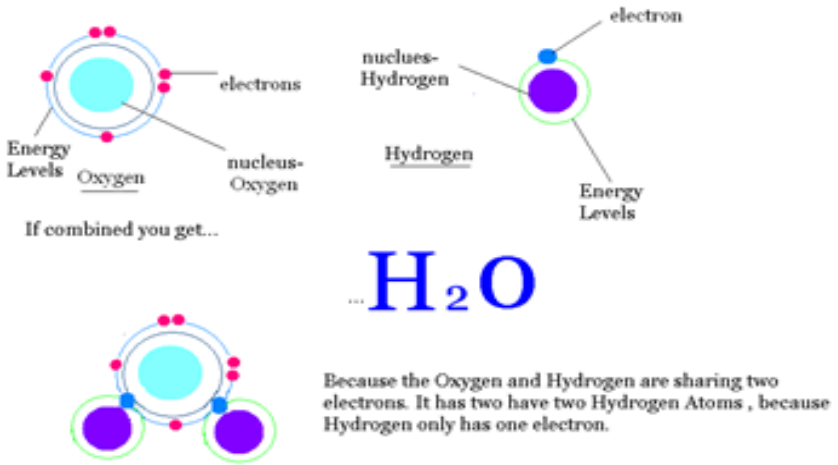


Image: Oil Rig Platform, NASA

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

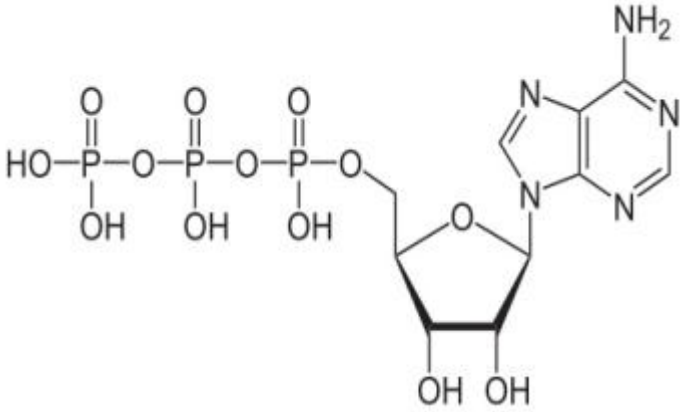
3. ATP Production and Energy Storage

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?



- 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.

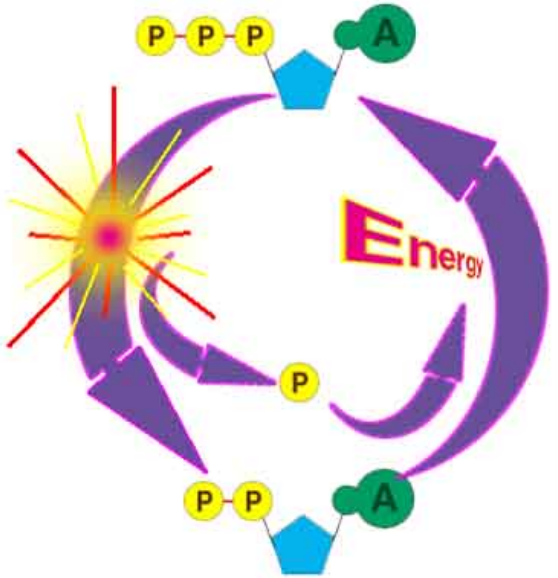
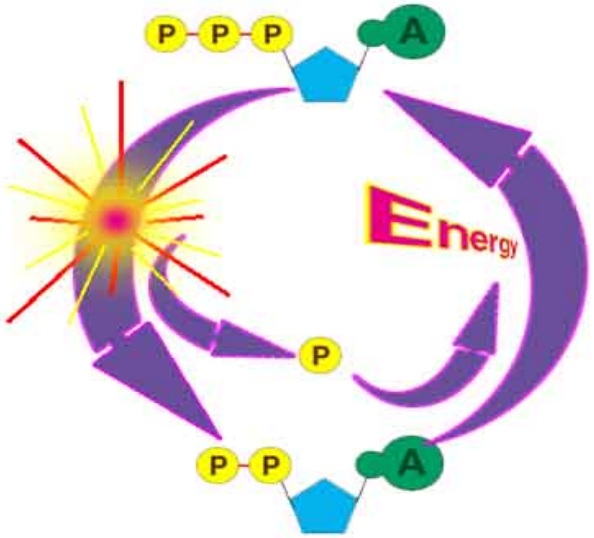
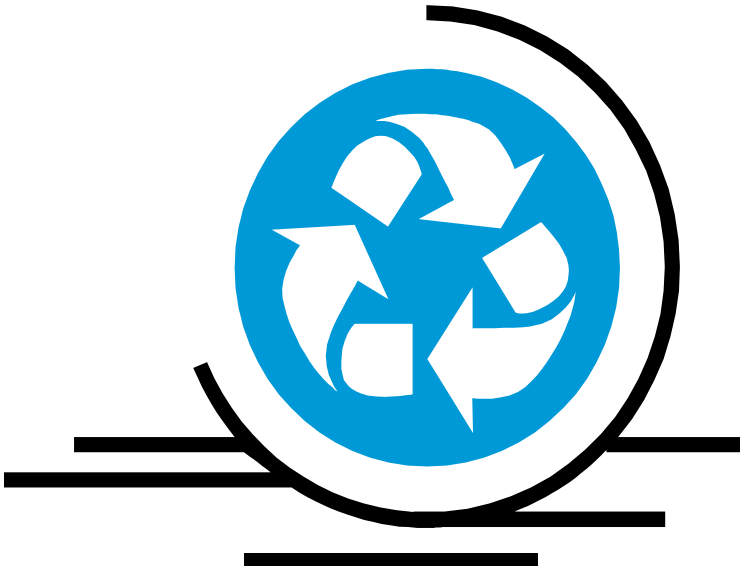


Image: ATP Molecule, NEUROtiker; ATP-ADP Cycle,

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!

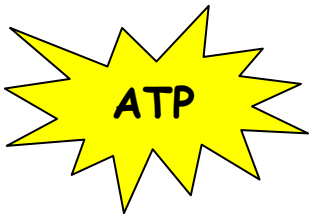
Images: ATP molecule, NEUROtiker; ATP-ADP Cycle, CUNY

Aerobic Cellular Respiration →

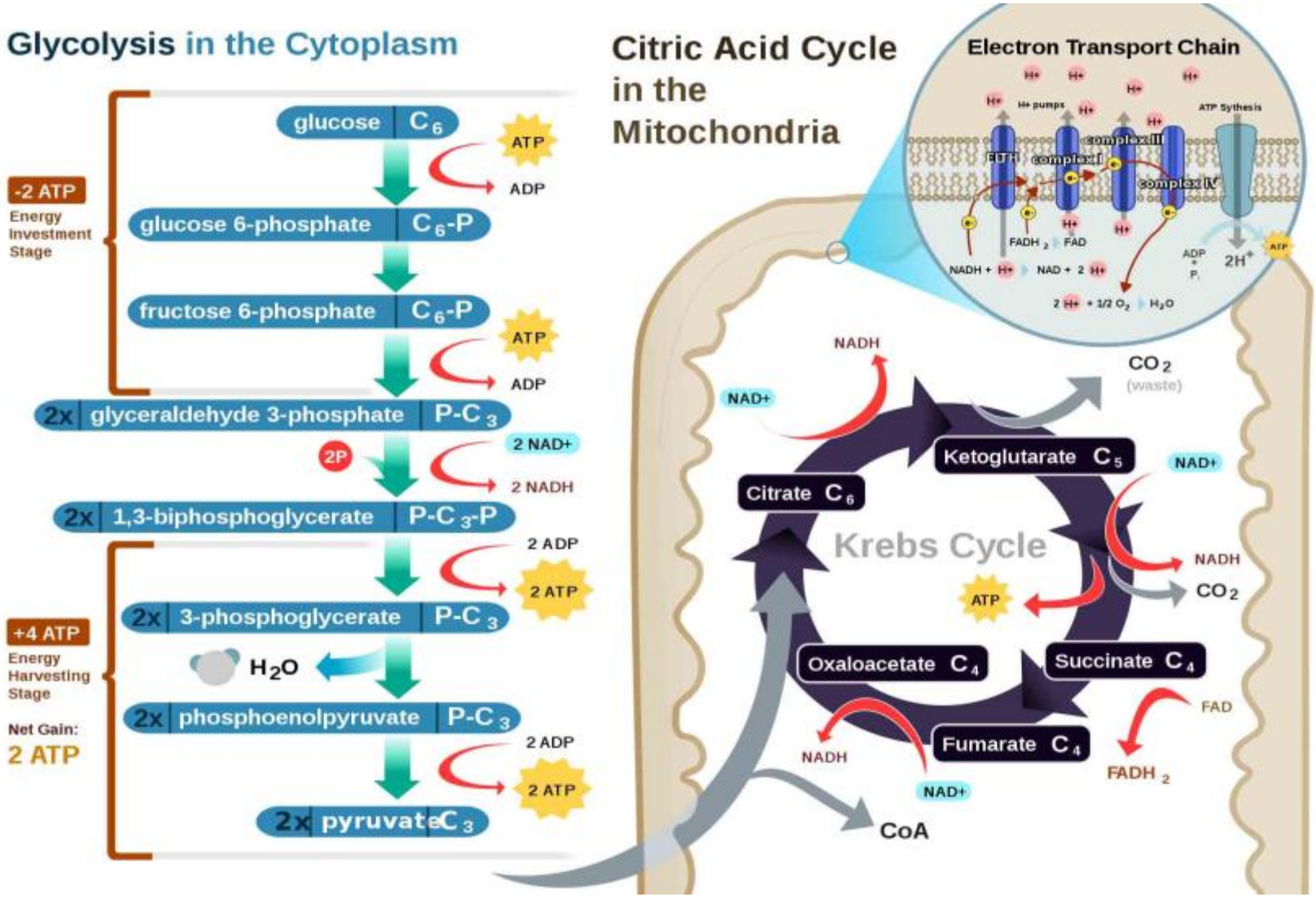
Utilizes four subpathways:

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



Aerobic Cellular Respiration



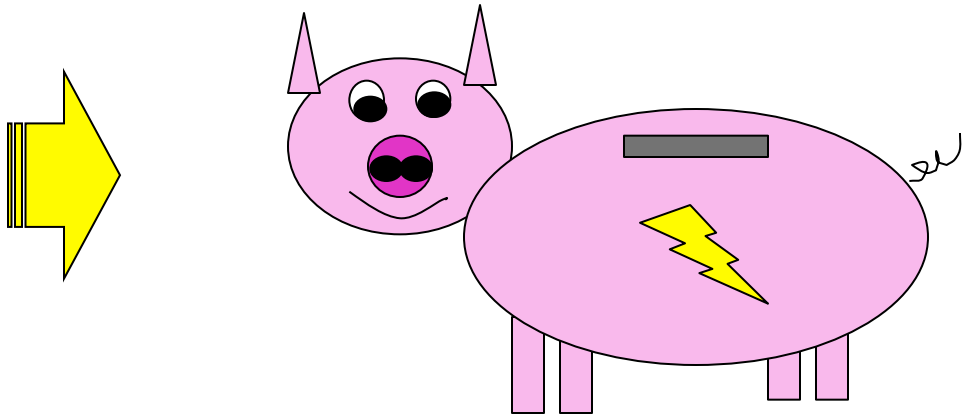
From the Virtual Biology Classroom on ScienceProfOnline.com

Images: Cellular Respiration, Regis Frey

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.



Glycolysis

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

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

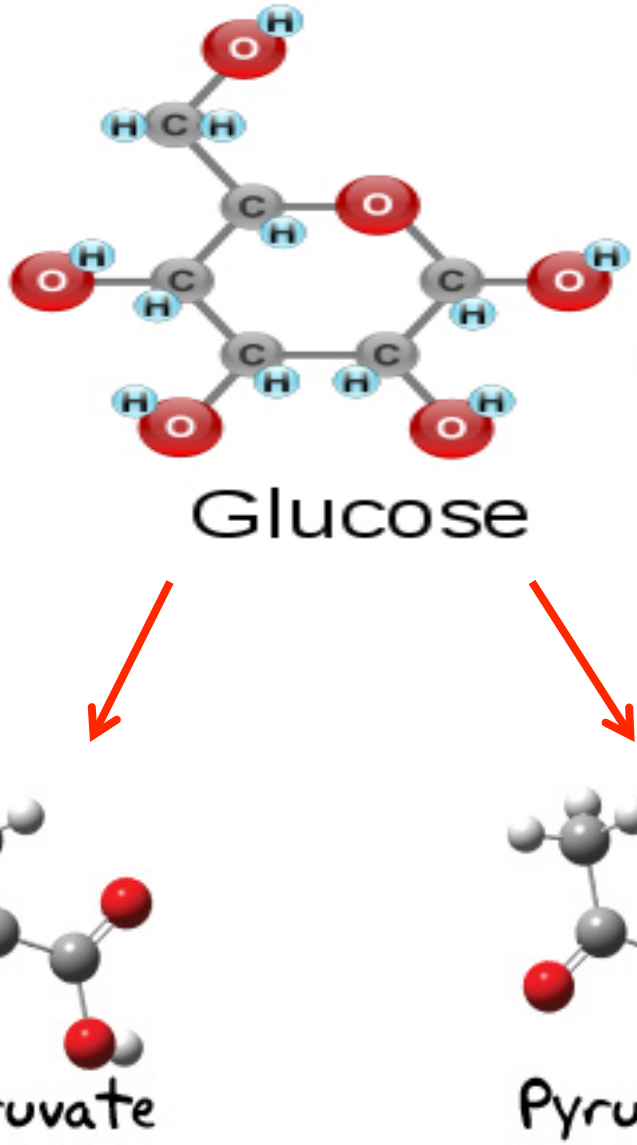
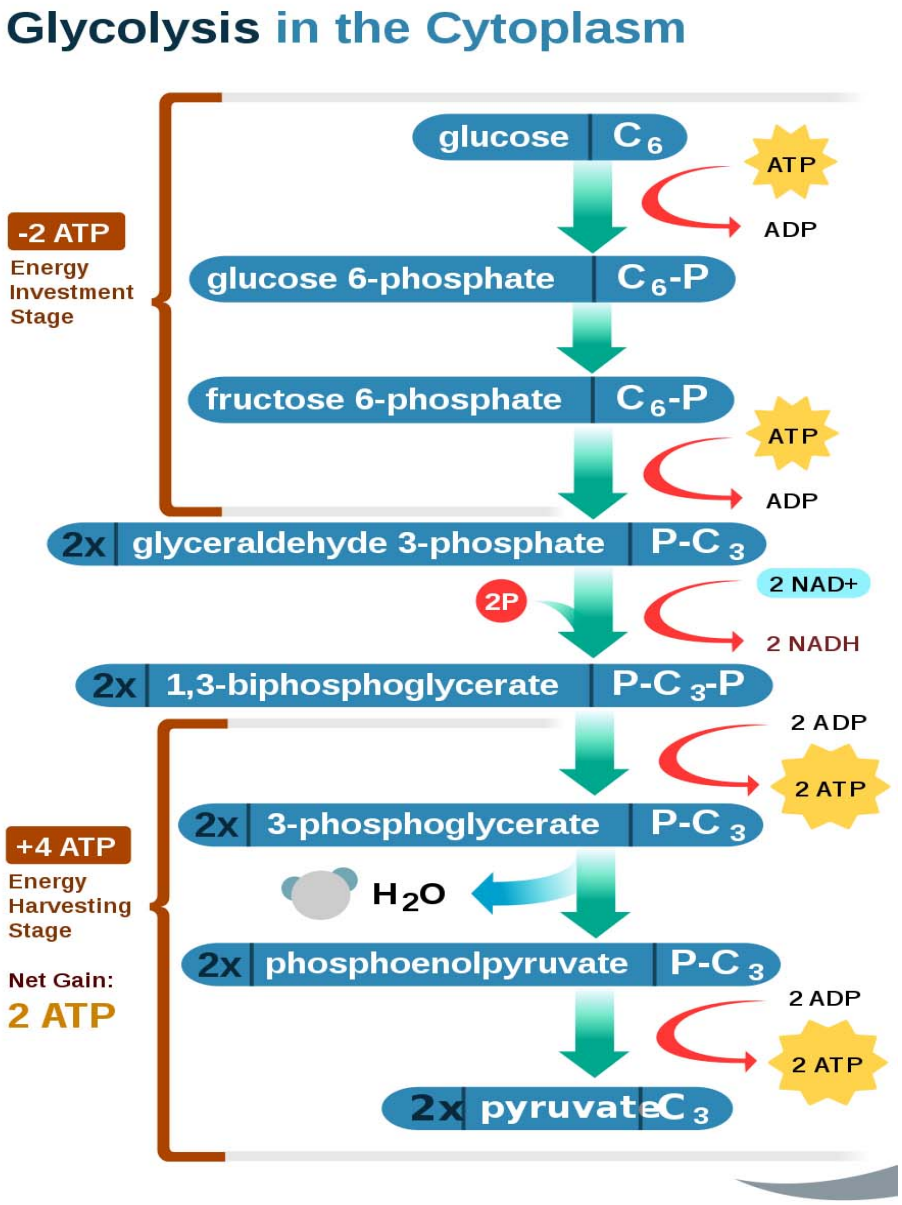


Image: Glucose molecule, YassineMrabet

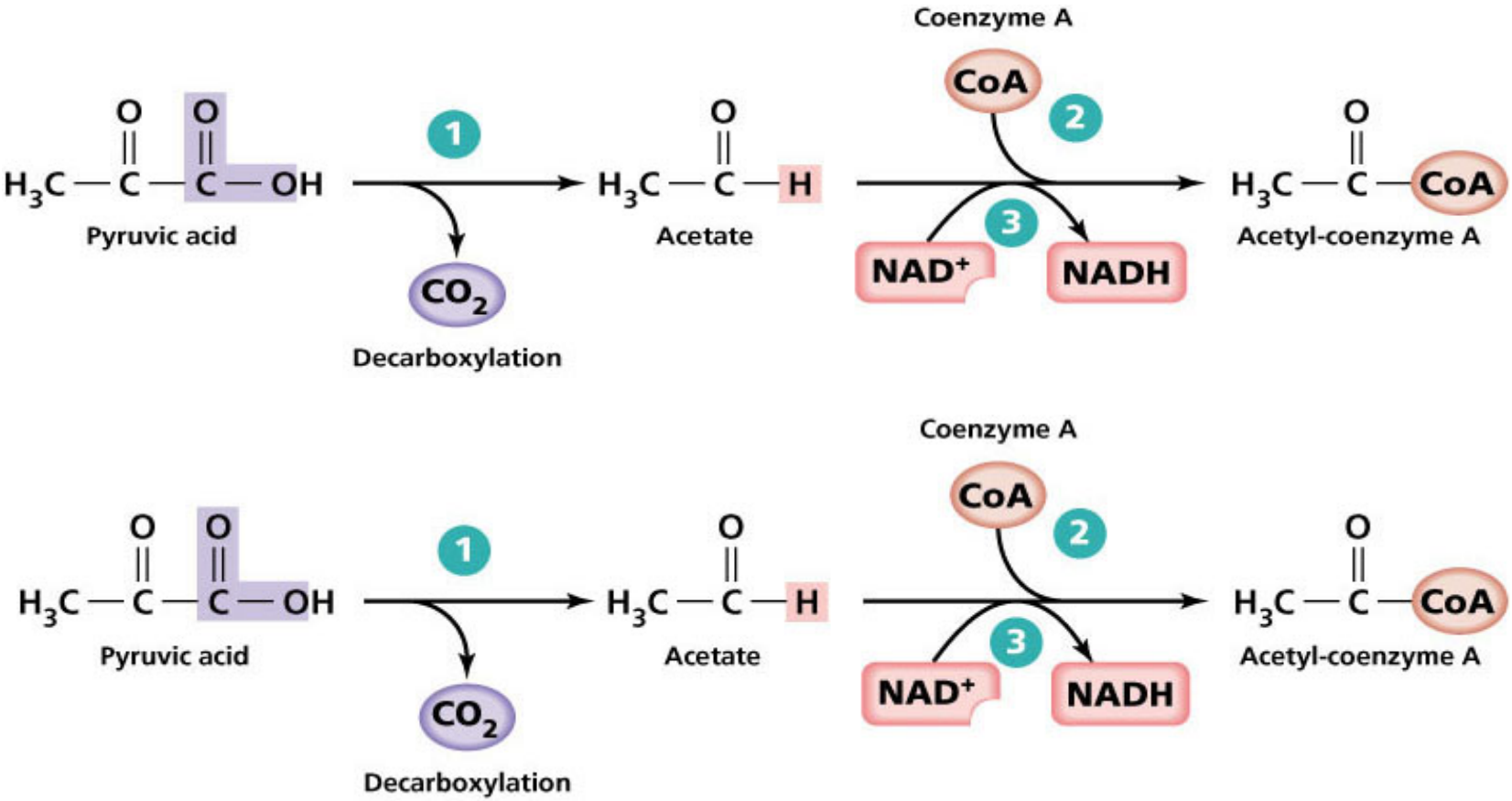


REVIEW!

Animated lesson on [How Glycolysis Works]

Image: Glycolysis, Regis Frey

Synthesis of Acetyl-CoA



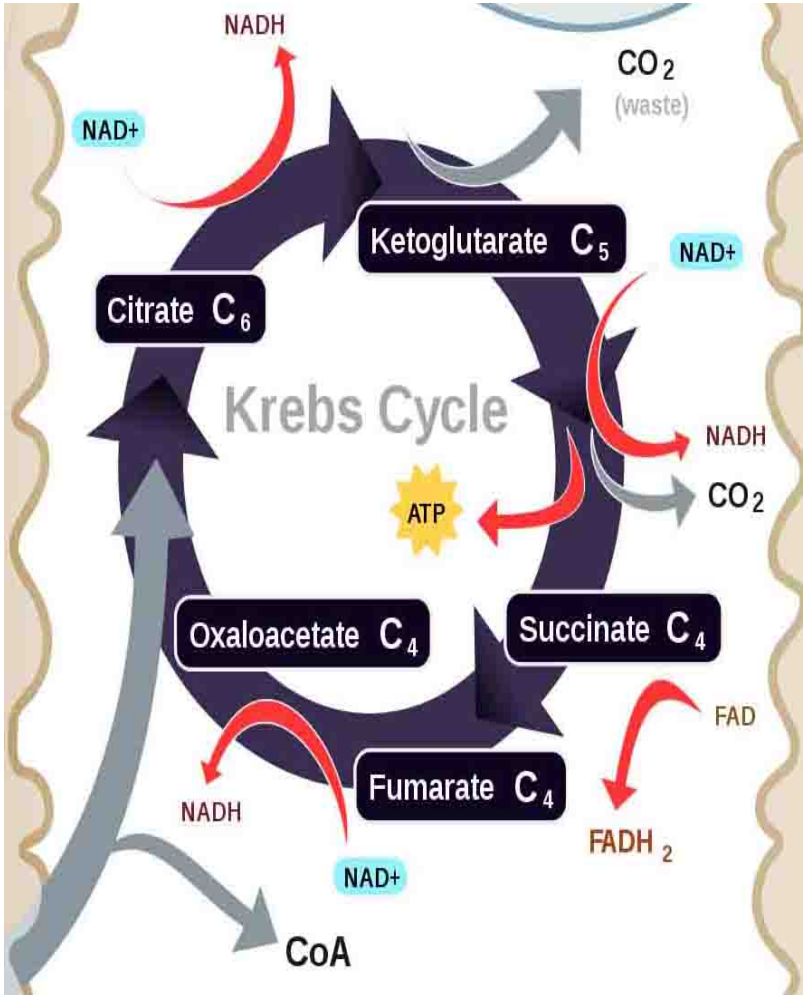
Krebs Cycle

(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.

REVIEW!

Animated lesson and quiz on Krebs Cycle

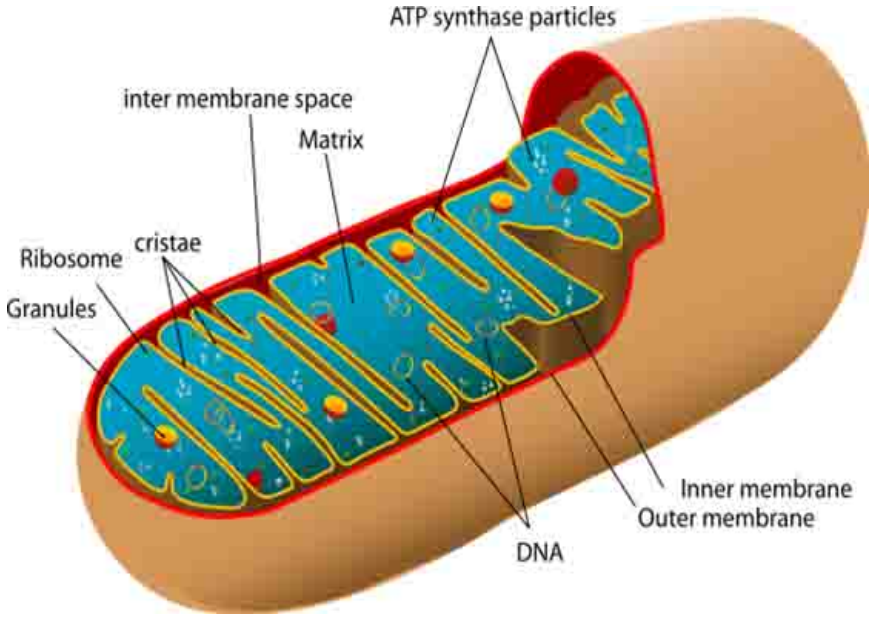


x 2: 1 cycle for each acetyl CoA molecule

Image:Krebs Cycle of 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).



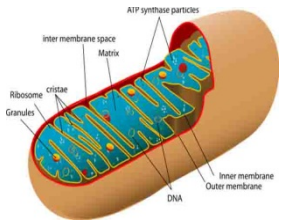
- Must occur in a membrane. The ETC is located in cristae of **mitochondria** in eukaryotes.

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

Three main events important in the ETCs generation of ATP:

1. _____
2. _____
3. _____

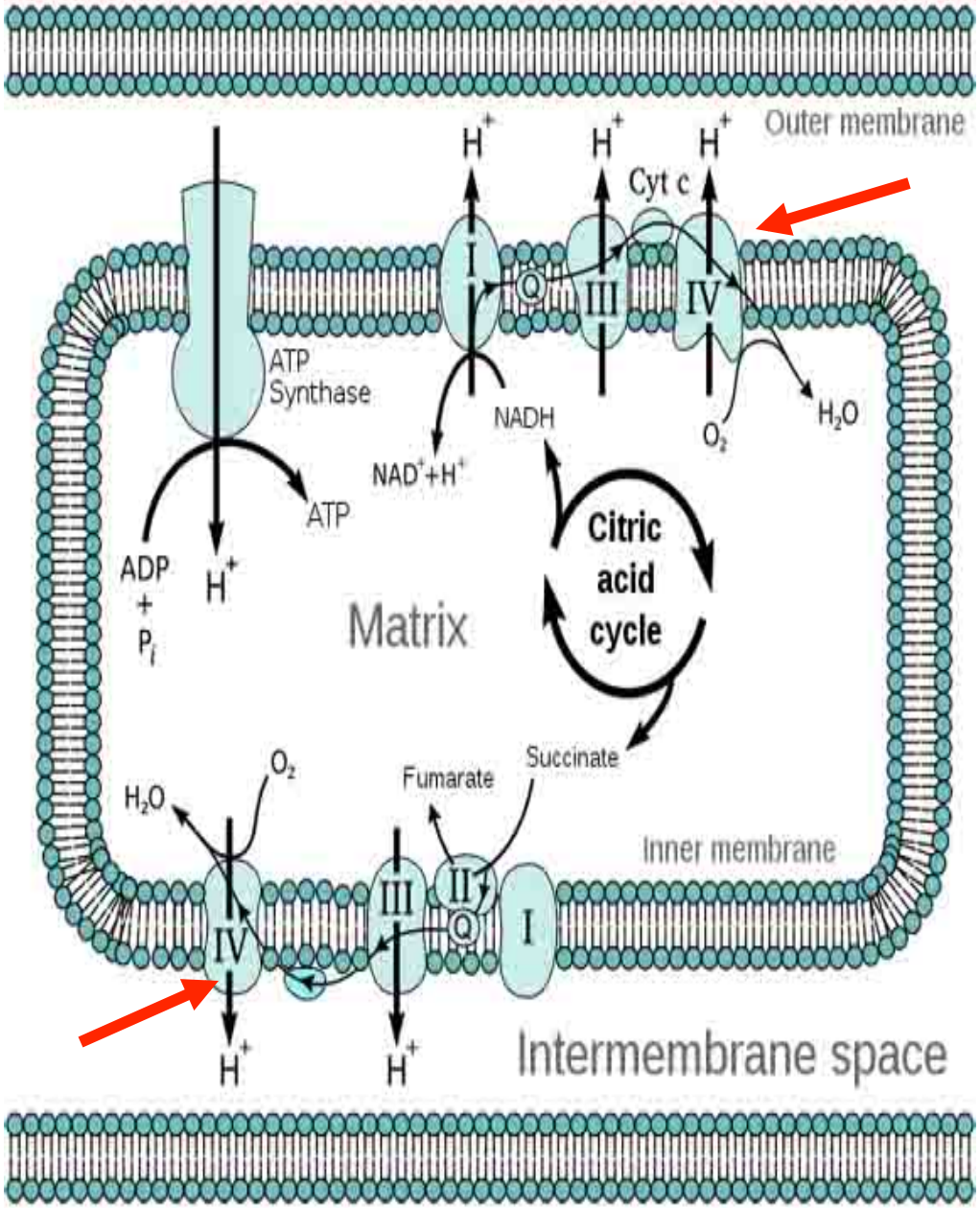
Image: Mitochondrion diagram M. Ruiz



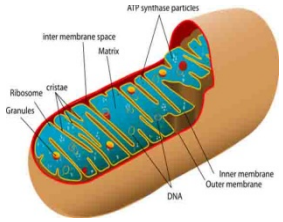
Electron Transport

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.



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

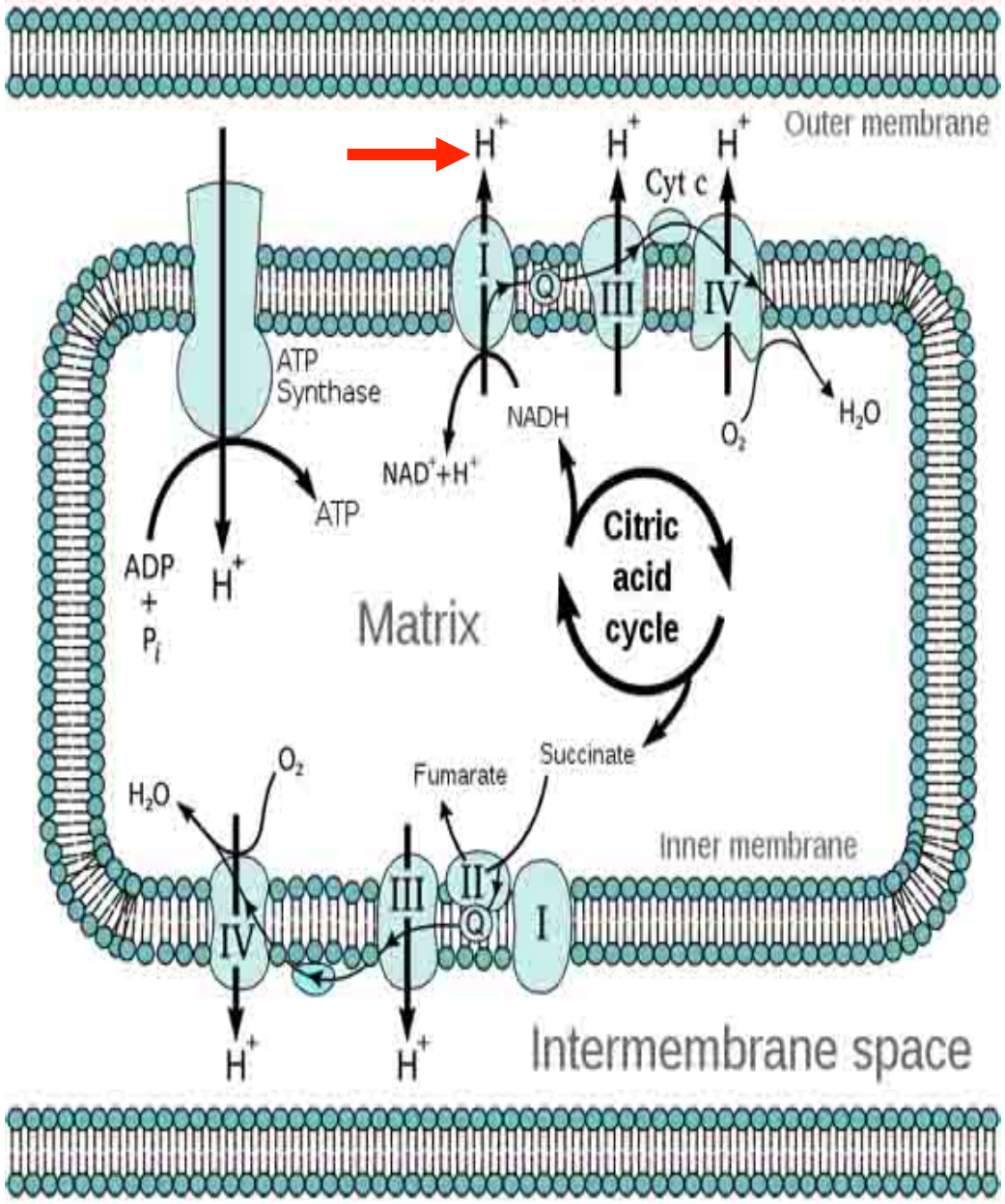


Electron Transport

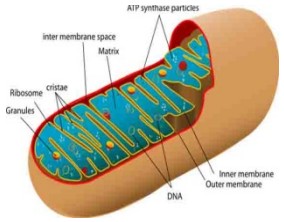
2. Creation of a Proton Gradient

- 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



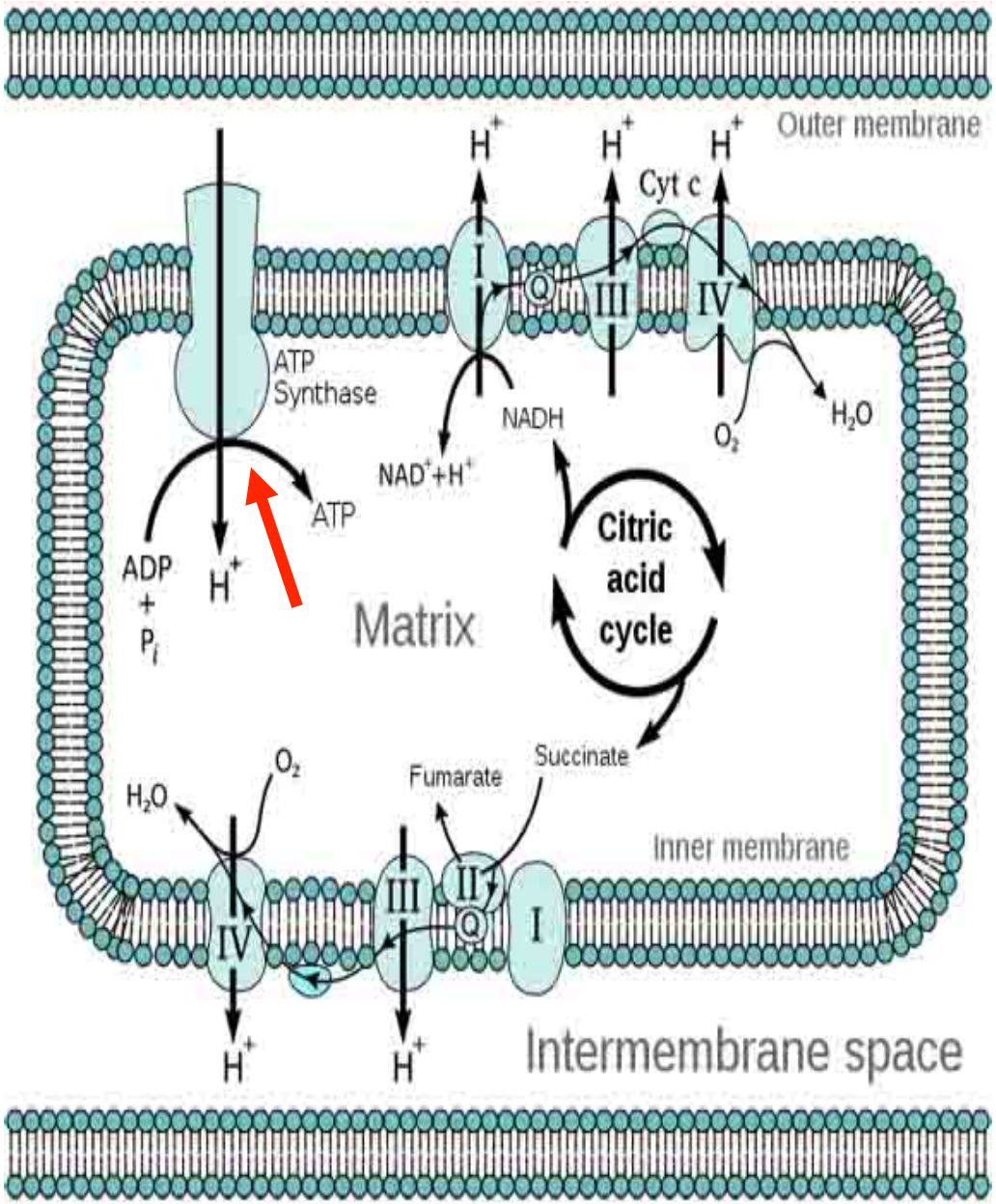
Electron Transport

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

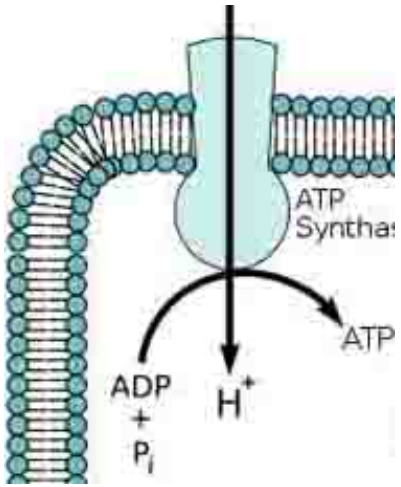
Meet the Enzyme: ATP Synthase

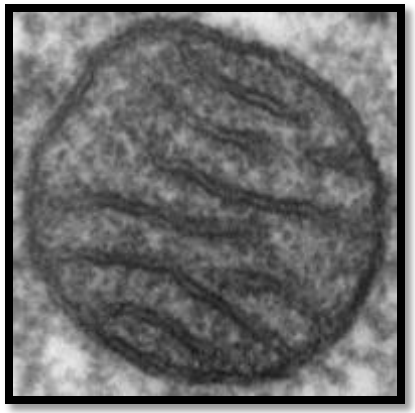
Important metabolic enzyme that harnesses energy for biological cells to use.

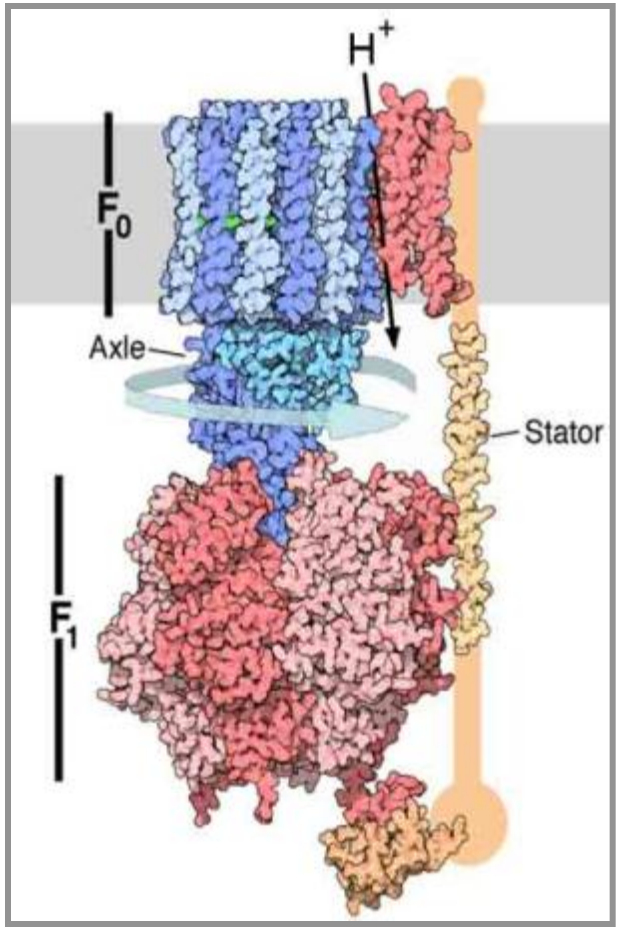
Involved in synthesis of adenosine triphosphate (ATP), from:

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

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







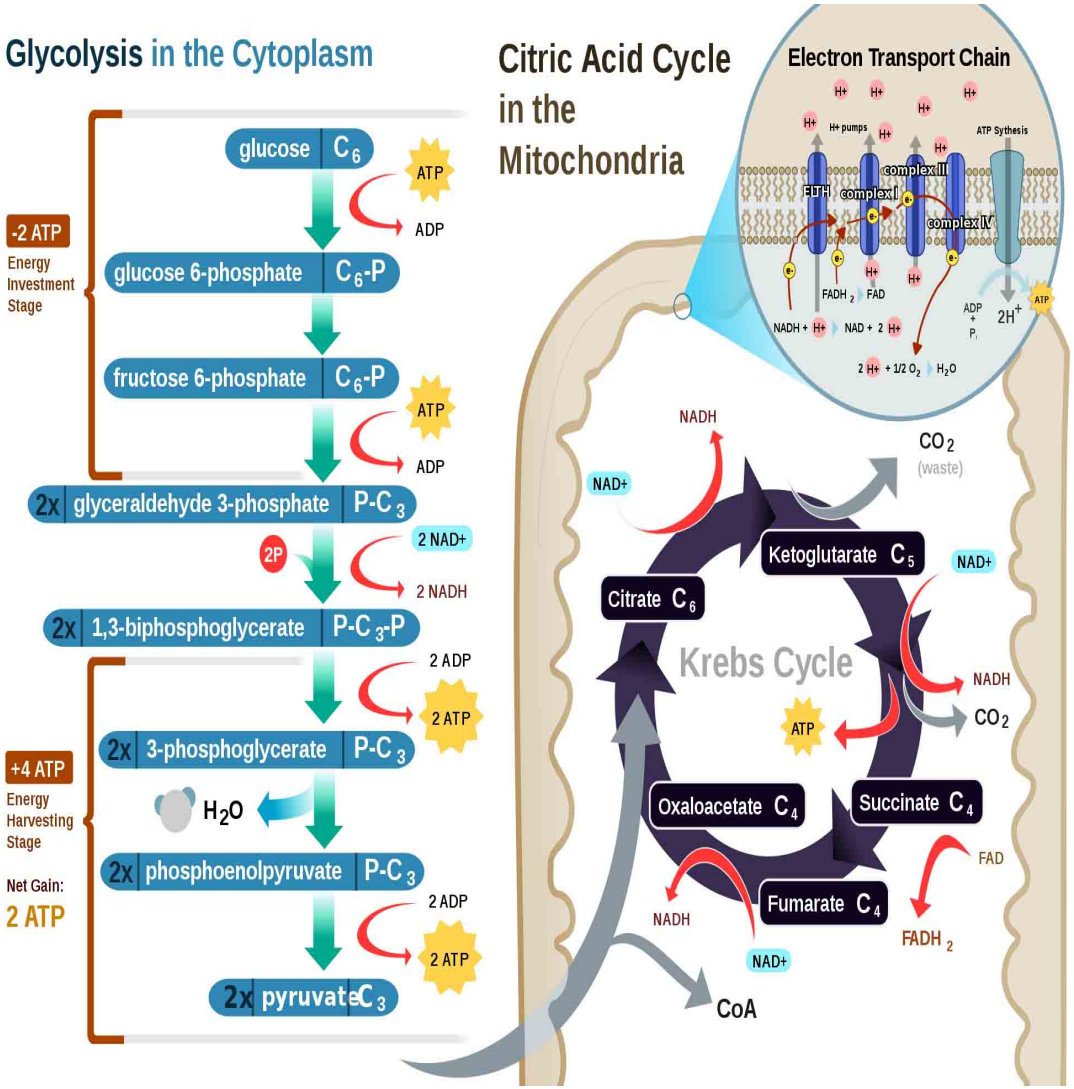
Reaction:

$$ADP + Pi \xrightarrow{\text{(ATP synthase)}} ATP$$

ADP: substrate; Pi: substrate; ATP: 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 & ATP

The ultimate objective is to make ATP molecules to do cellular work.

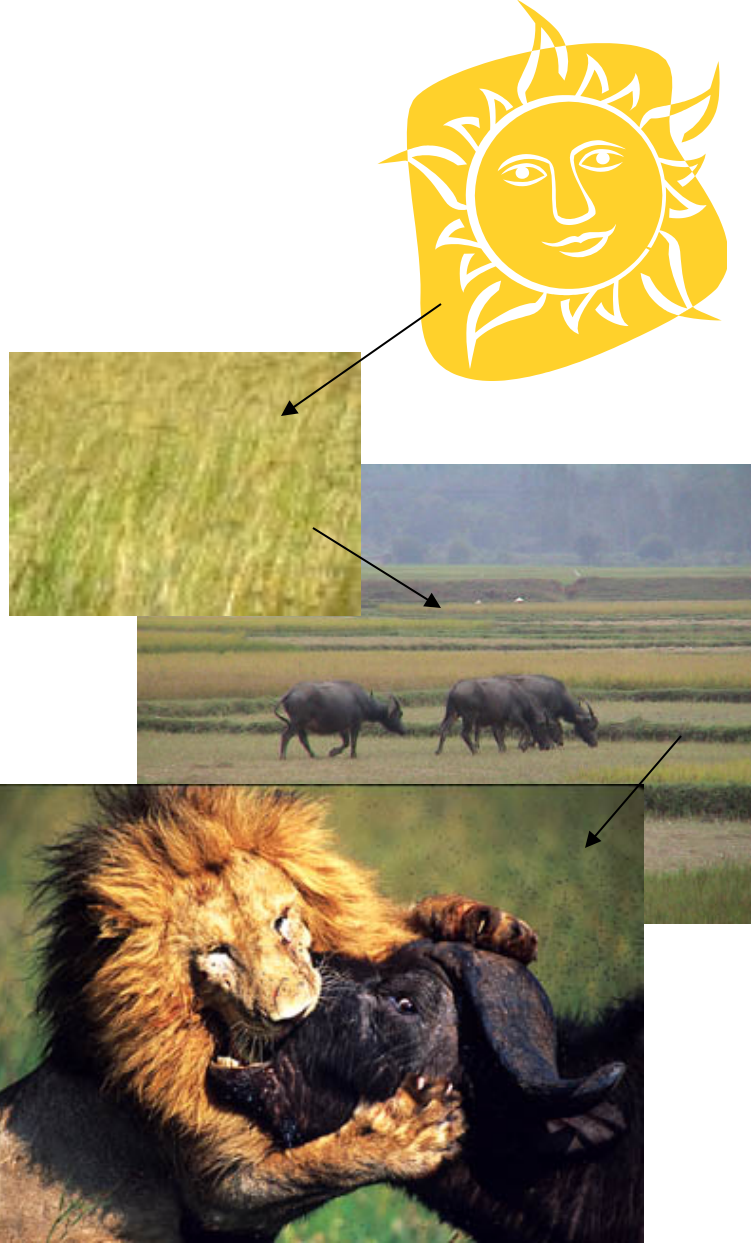
Each NADH results in 3 ATP, Each FADH2 results in 2 ATP.

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.

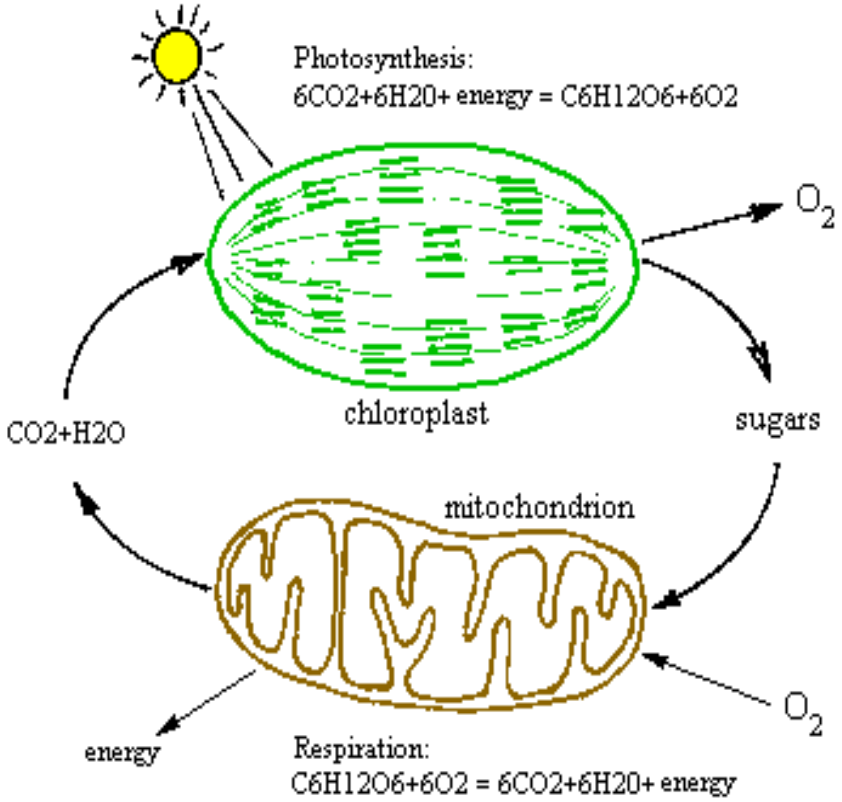


Figure 16 - With the photosynthesis, the solar energy is cumulated by the chloroplasts as sugar molecules. With the glycolysis and the respiration, made by mitochondria, the energy is liberated and supplied to the cell for its biochemical processes.

Using oxygen (1/2 O_2) in metabolism creates toxic waste.

Cells that are able to use aerobic respiration produce special molecules that detoxify oxygen:

Catalase: $H_2O_2 \xrightarrow{\text{(catalase)}} H_2O$ and O_2

Superoxide dismutase (SOD): oxygen radical $\xrightarrow{\text{(SOD)}} H_2O$ and O_2

Q: What kind of molecules are catalase and SOD?

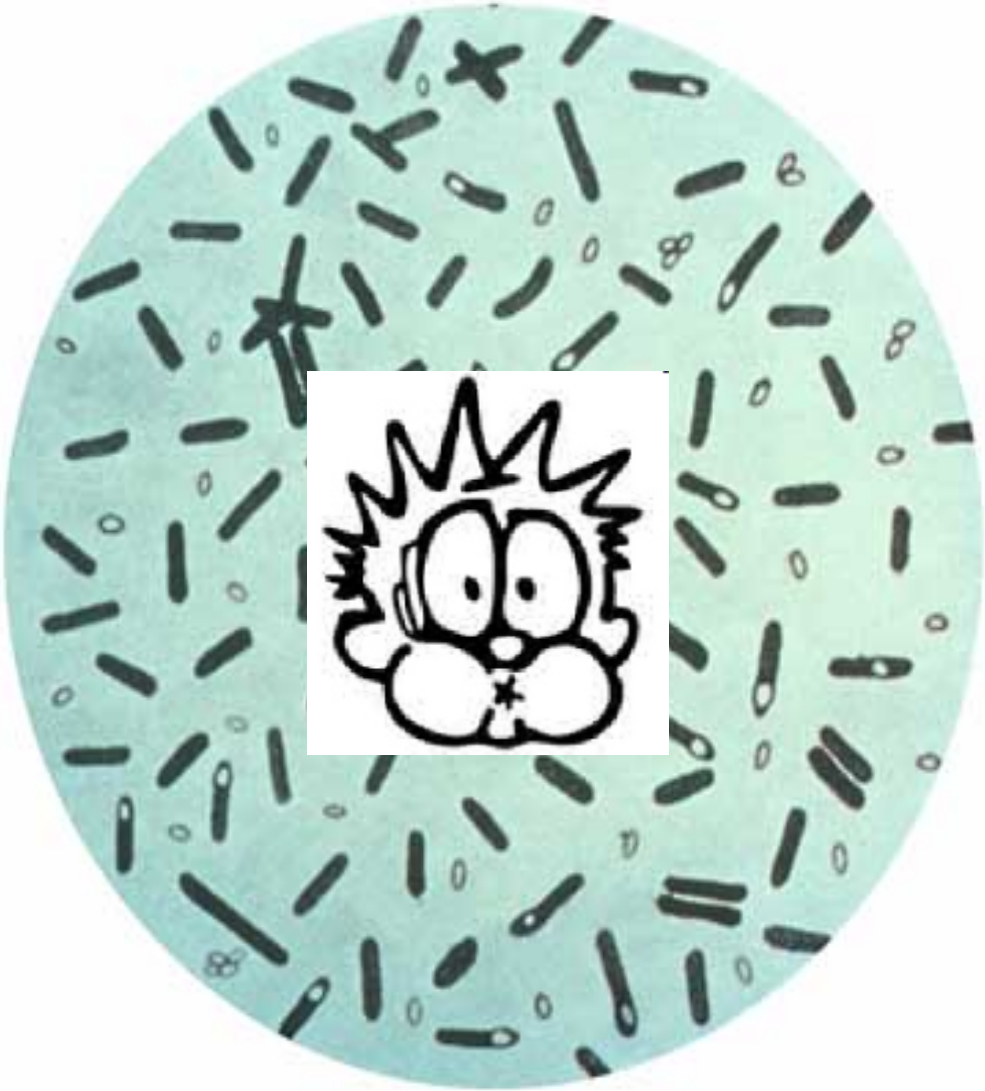
Cells that don't make one or both of these cannot exist in the presence of oxygen.

If oxygen is required for aerobic cellular respiration…

how do cells get **energy** if there is no

O_2,

or if they can't use oxygen?



Images: Clostridium botulinum, CDC; Calvin holding breath, Bill Watterson

Anaerobic Cellular Respiration

- Many anaerobic bacteria, and muscle cells that run out of O^2, can make ATP by using something other than oxygen as an electron acceptor *(nitrate, sulfate & carbon dioxide).*

- In anaerobic respiration, not all the ETC is used, so less ATP is produced.

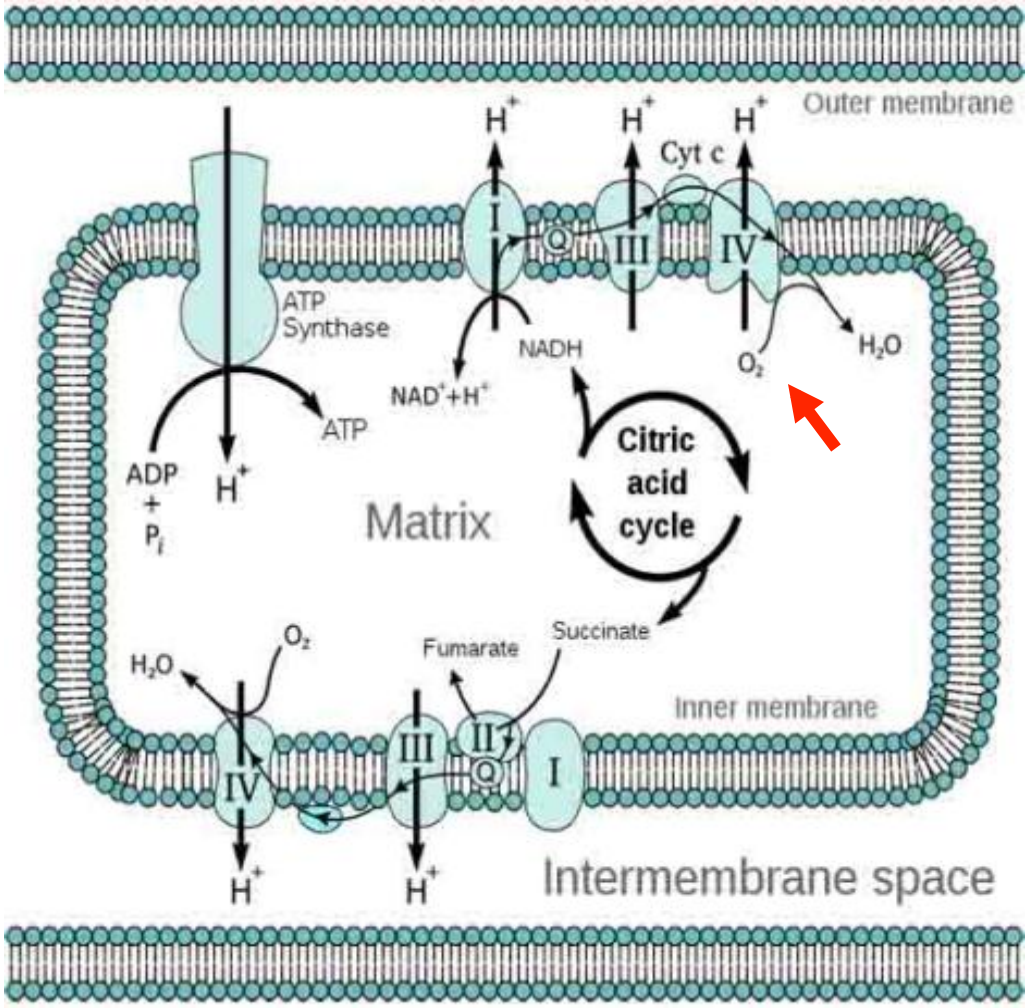
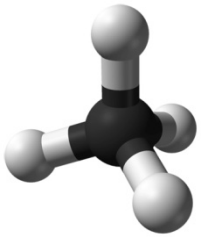


Image: Electron transport chain, Tim Vickers



More Fun With Farts

- When CO_2 is used as an electron acceptor in anaerobic respiration, the product is either **methane** or acetic acid *(depending on organism).*

- **Methane produced in our gut (and released as farts) results from this process.**

- **New study of people with GI symptoms, found that those with high levels of hydrogen (H) and methane (CH_4) gases in their breath also had higher body mass index (BMI) and % body fat.**

- **Having both CH_4 and H in breath indicates presence of *Methanobrevibacter smithii*, a key methane-producing microbe (Archaea) in the human gut.**

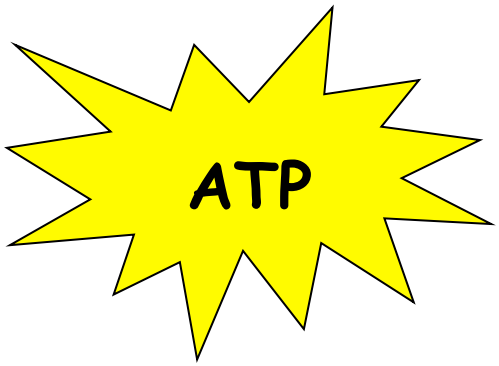
- **In addition to making methane, *M. smithii* scavenges hydrogen from other microbes, and these 2 actions appear to increase nutrient absorption and promote weight gain.**

Image: Methane 3D, Ben Mills

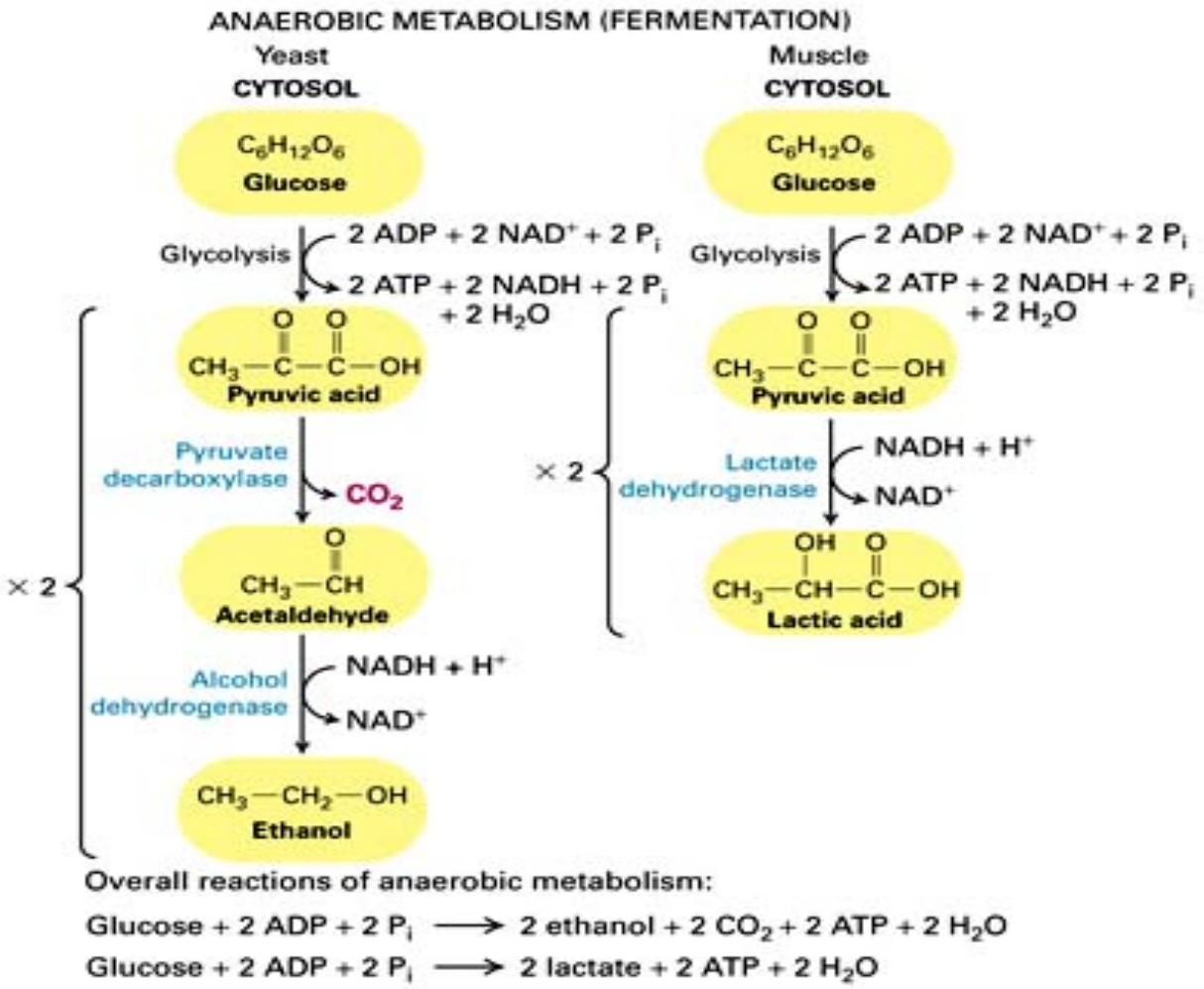
Methane producing Gut Organisms May Promote Weight Gain" Medscape.

Fermentation

- When there is no final **electron acceptor** for the ETC, then electron transport can't happen.
- Fermentation is an alternative system that allows glycolysis to continue without the other steps of cellular respiration.
- Not as energetically efficient as respiration.
- **Q**: How many ATP are gained in glycolysis?



Fermentation



REVIEW!

Interactive animated lesson comparing Alcoholic vs Lactic Acid Fermentation

Why does fermentation require extra steps after glycolysis?

- In fermentation, after glycolysis, there are additional steps to oxidize NADH (into NAD^+).
- Electrons and hydrogen ions from the NADH that was produced by glycolysis are donated to another organic molecule.
- No more ATP is created through these additional steps.
- So essentially…

FERMENTATION =

glycolysis + recycling of NAD^+

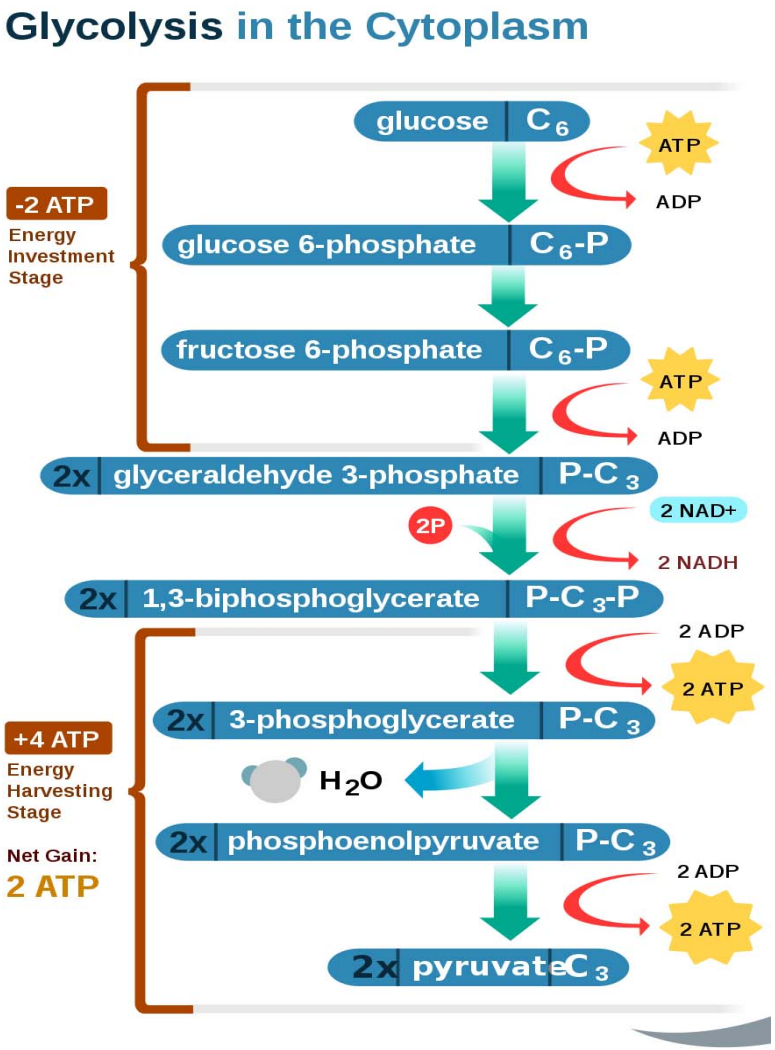
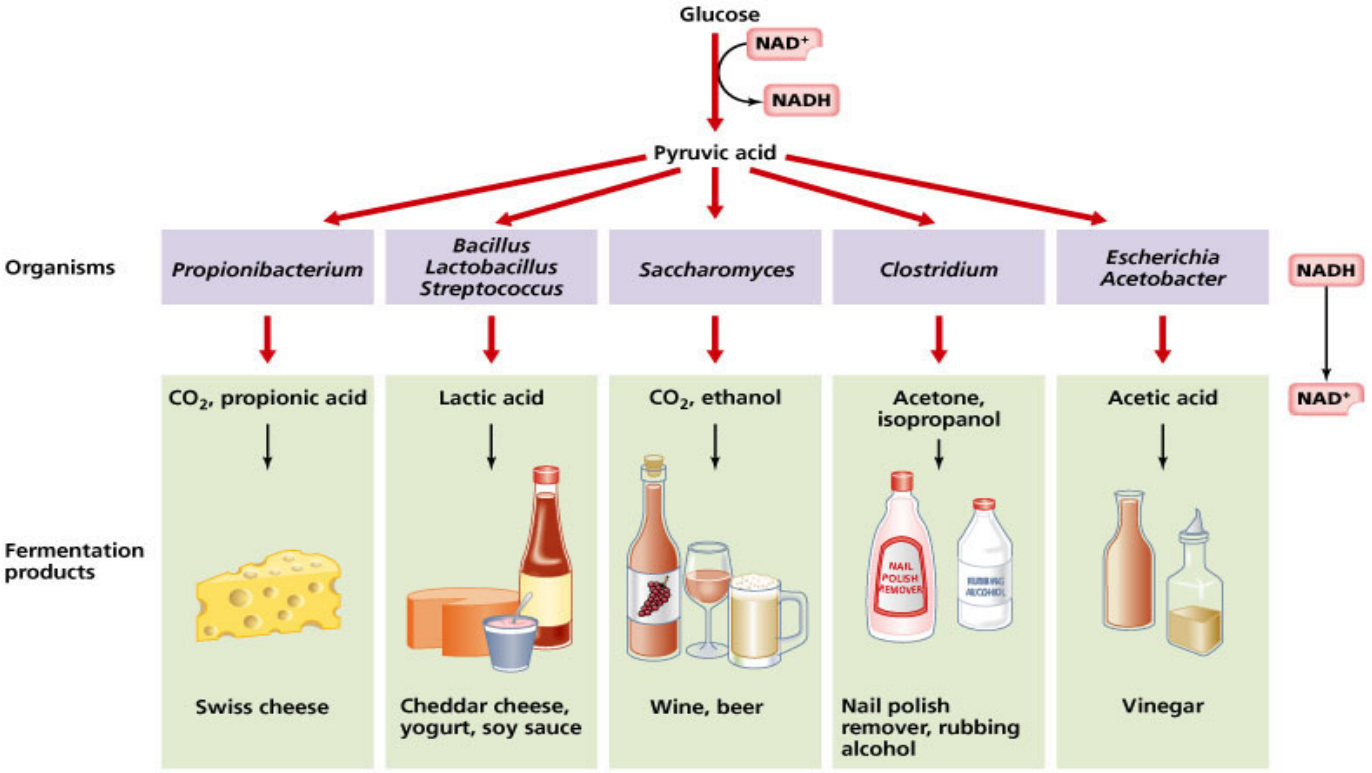


Image: Glycolysis, Regis Frey

Fermentation

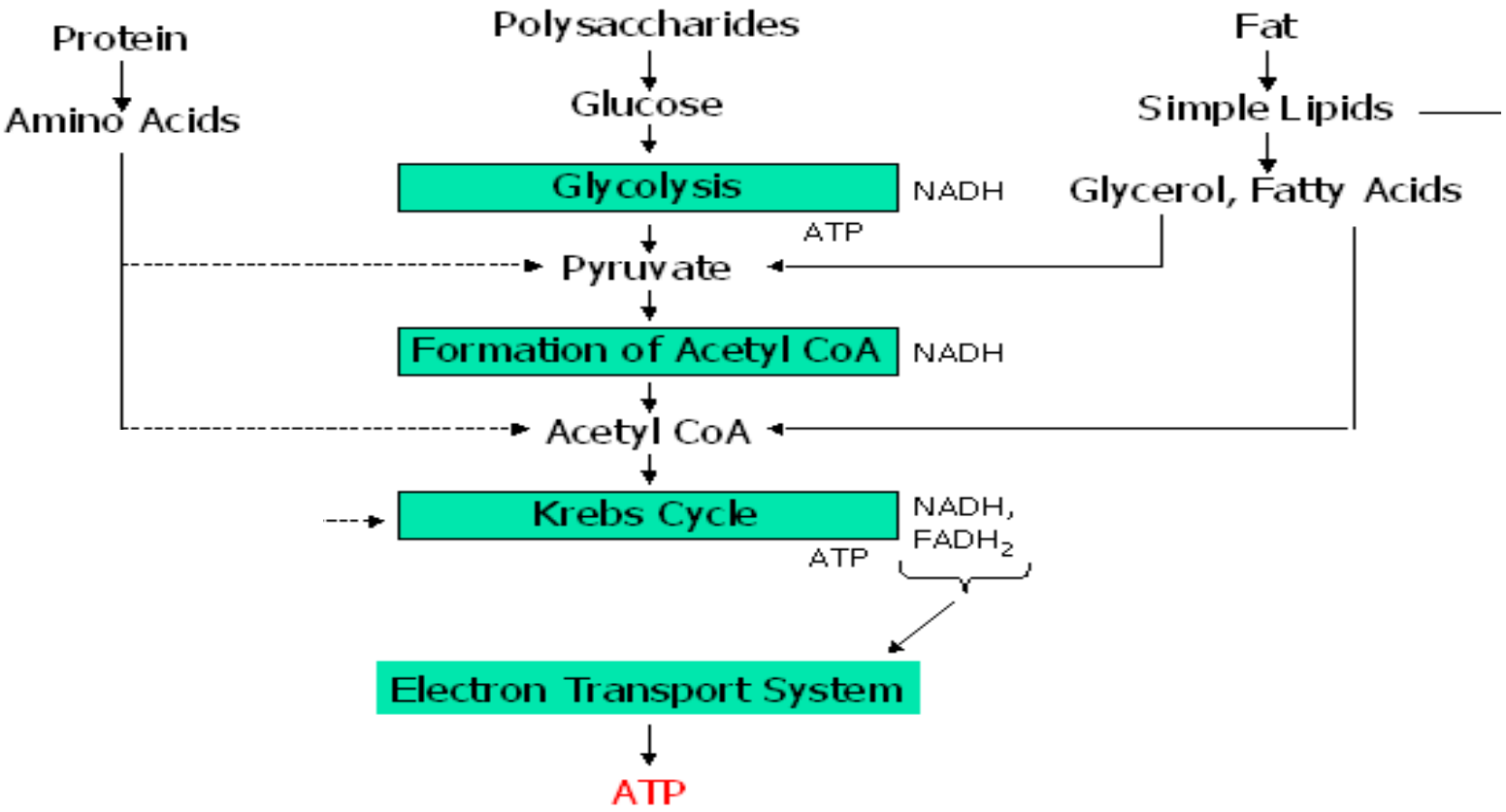
- Most of the potential energy remains in the bonds of fermentation products.
- Fermentation products are wastes to cells that make them, many are useful to humans (ethanol, acetic acid, and lactic acid).



How do we metabolize proteins & fats?

Excess amino acids can be used to synthesize **pyruvate**, **acetyl CoA**, and **alpha ketogluterate**, which enters the Krebs cycle.

The glycerol & fatty acids of fats can also be converted to **pyruvate** and **acetyl CoA** and then enter cellular respiration.



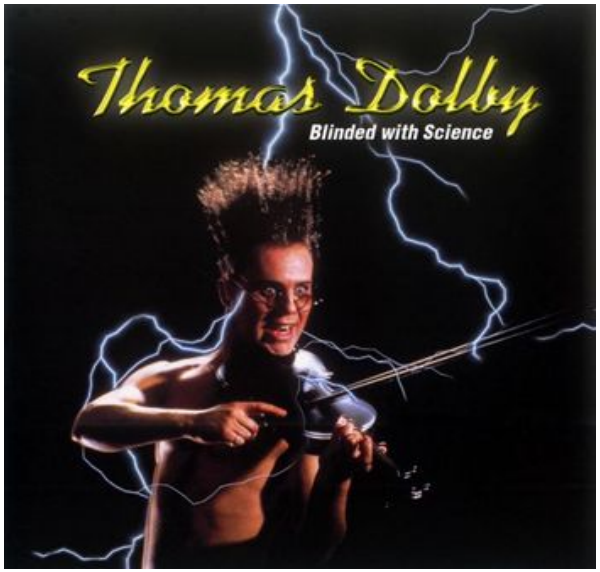
Confused?

Here are links to fun resources that further explain nutrition:

Smart Links

- 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.
- Electron Transport Chain: The Movie from the Virtual Cell Animation Collection.
- Cellular Respiration animation by Jay Phelan, "What is Life? A Guide to Biology", W. H. Freeman & Co.

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

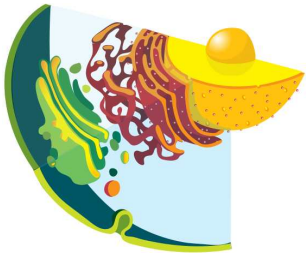


Are you feeling blinded by science?

Do yourself a favor. Use the…

Virtual Biology Classroom *(VBC)* !

The VBC 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 VBC by going to the Science Prof Online website
www.ScienceProfOnline.com

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