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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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# Metabolism

Anaerobic Cellular  
Respiration

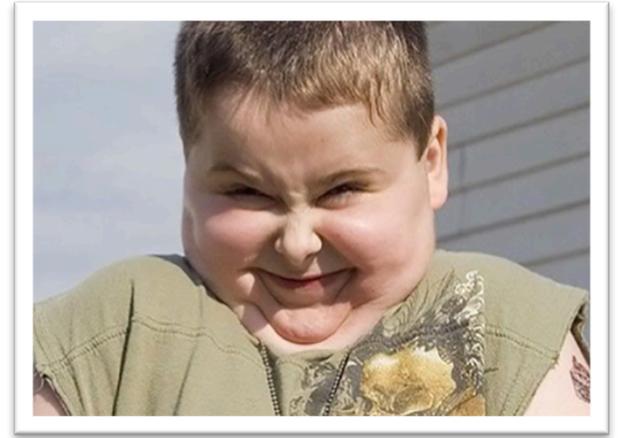
&

Fermentation



# Everyday Biology

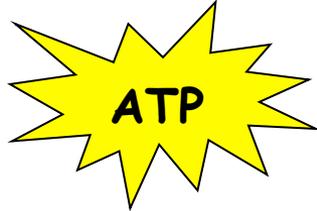
## What causes smelly farts?



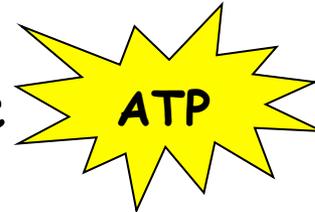
- Most people pass gas at least 10 - 25x a day.
- Farts are mostly a byproduct microbial anaerobic respiration & fermentation in the colon (large intestine).
- Over 99% of fart volume is non-smelly gases, including oxygen, nitrogen, carbon dioxide, hydrogen and methane.
- Smelly farts are caused by microbes 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.

# Aerobic Cellular Respiration →

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



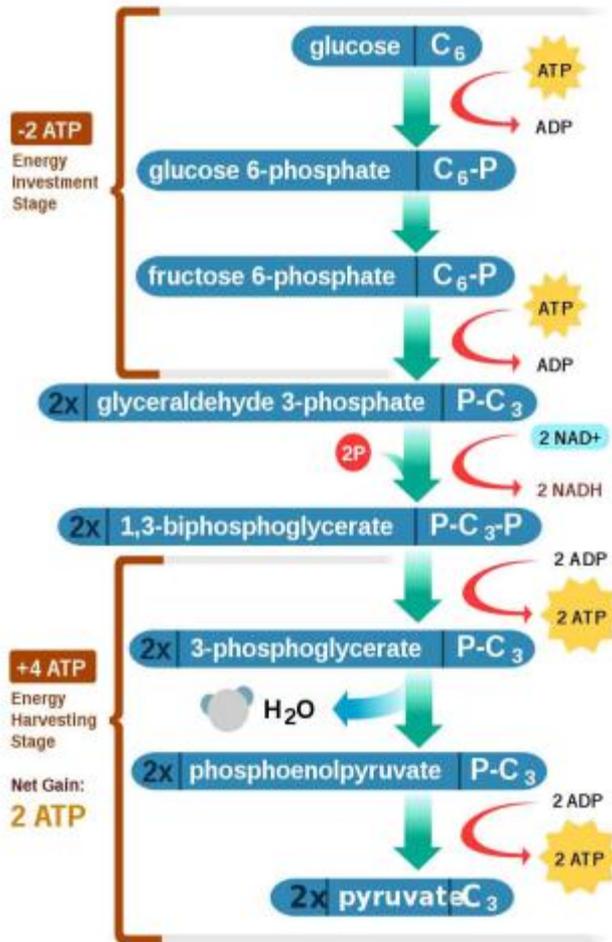
The ultimate objective is to make \_\_\_\_\_ molecules to do cellular work.



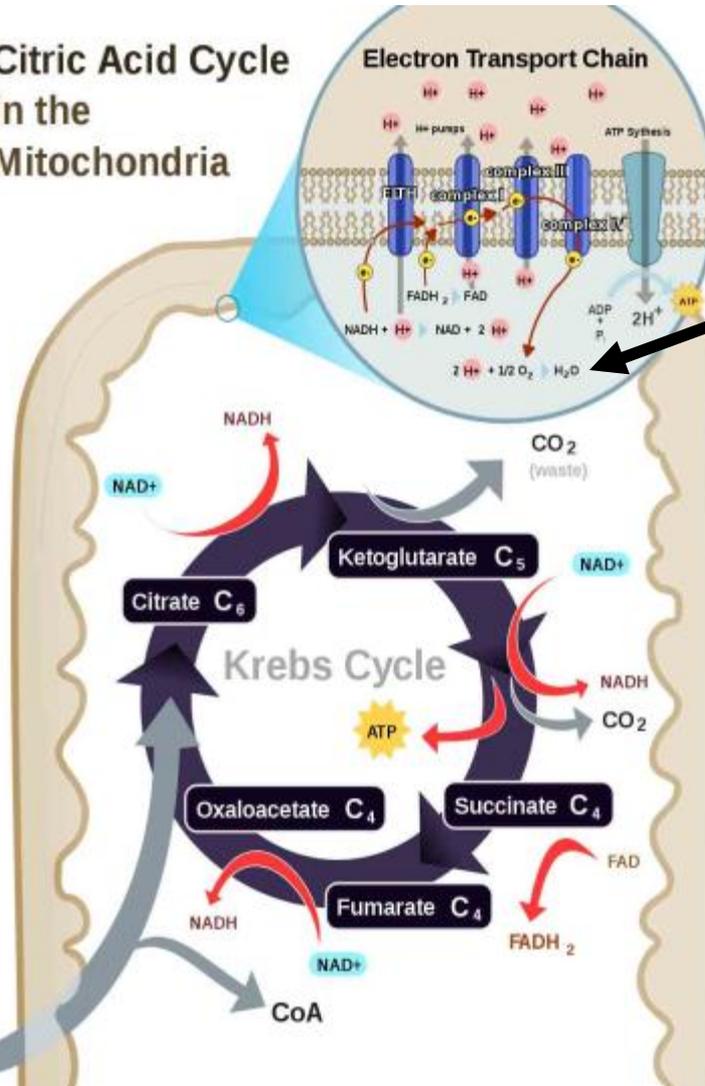
**Q:** How many total ATP can be obtained from one glucose using aerobic cellular respiration?

# Aerobic Cellular Respiration

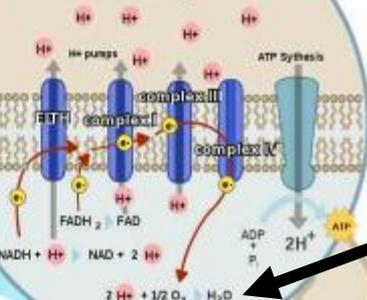
## Glycolysis in the Cytoplasm



## Citric Acid Cycle in the Mitochondria



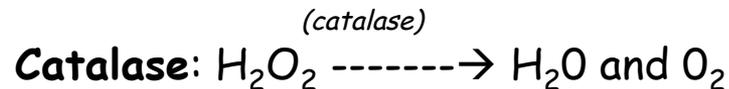
## Electron Transport Chain



**Q: What is the role of O<sub>2</sub> in aerobic cellular respiration?**

# 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:



**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.

# Bacterial Genus: *Clostridium*

## GRAM-POSITIVE

Obligate anaerobe, bacillus-shaped

All species form endospores.

All have a strictly fermentative mode of metabolism (Don't use oxygen).

Vegetative cells are killed by exposure to  $O_2$ , but their endospores are able to survive long periods of exposure to air.

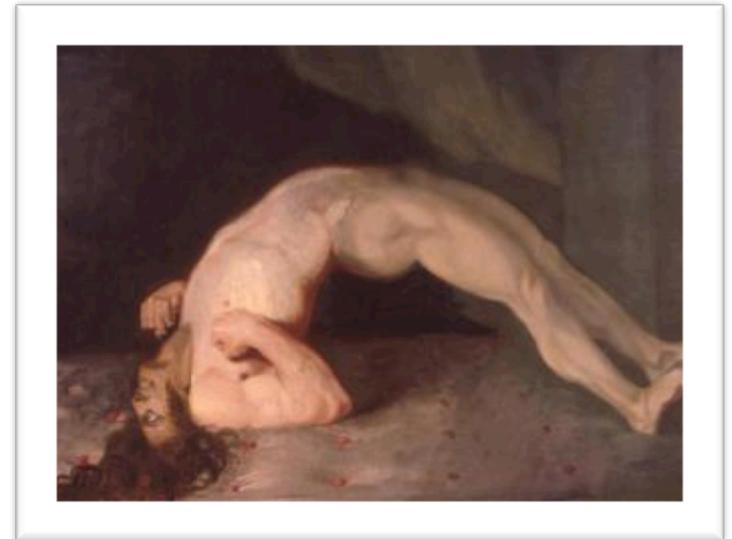
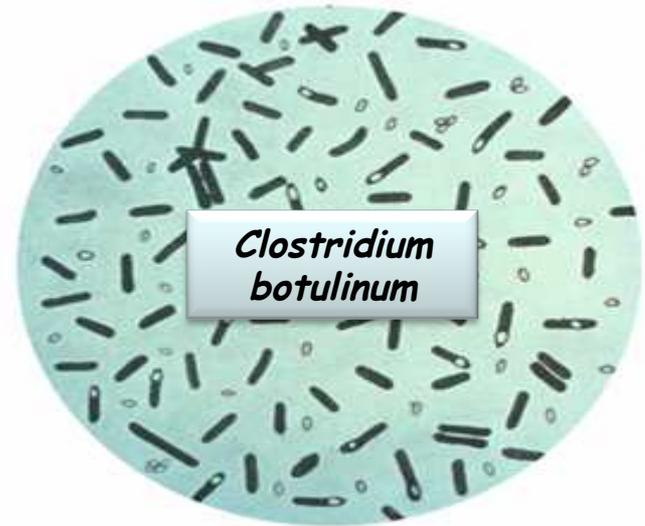
Known to produce a variety of toxins, some of which are fatal.

*Clostridium tetani* = agent of tetanus

*C. botulinum* = agent of botulism

*C. perfringens* = one of the agents of gas gangrene

*C. difficile* = part of natural intestinal flora, but resistant strains can overpopulate and cause pseudomembranous colitis.



Images: *Clostridium botulinum*: stained with Gienian violet. CDC Public Health Image Library. (PHIL #2107), 1979; Charles Bell 1809 painting.

If oxygen is  
required for  
aerobic cellular  
respiration...

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

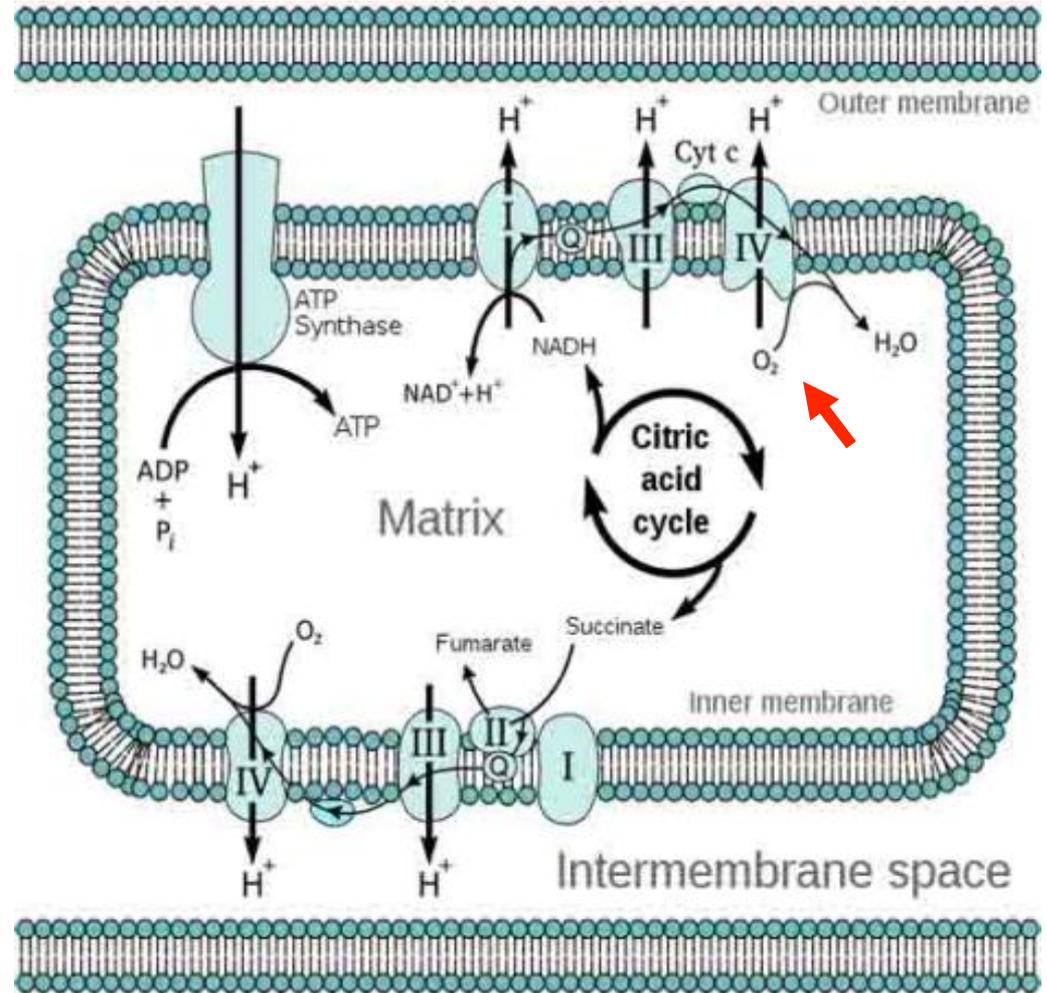
$O_2$ ,

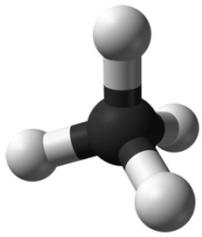
or if they  
can't use oxygen?



# 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.





# More Fun With Farts



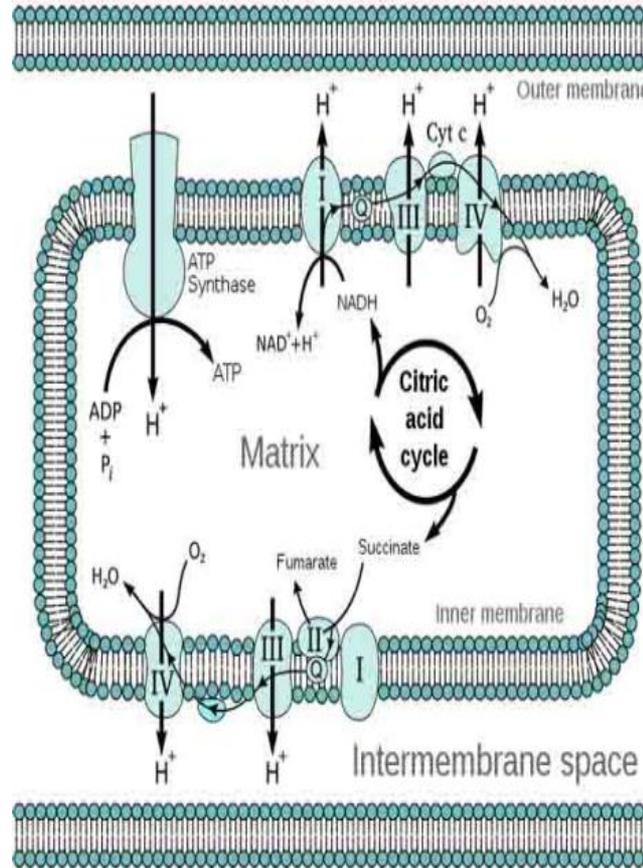
- When  $\text{CO}_2$  is used as an electron acceptor in anaerobic respiration, the product is either **methane** or acetic acid (*depending on the organism*).
- Methane produced in our gut (and released as farts) results from this process.
- [New study of people with GI symptoms](#), found that those with high levels of **hydrogen (H) and methane ( $\text{CH}_4$ ) gases** in their breath also had higher body mass index (BMI) and % body fat.
- Having both  $\text{CH}_4$  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.

# Aerobic vs Anaerobic Respiration

- **Q:** What is the key difference between aerobic and anaerobic respiration?
- **Q:** How does this difference impact the amount of energy that anaerobes can harvest from their food?

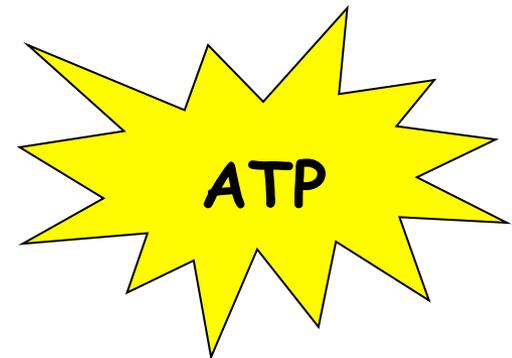
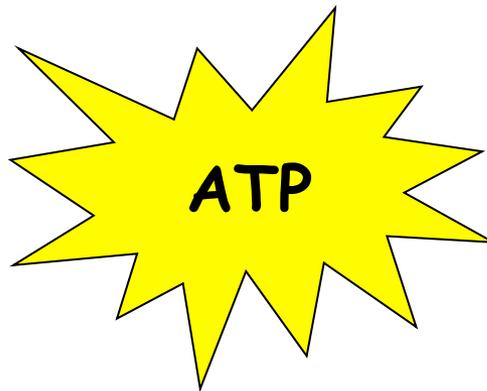


**REVIEW!**

Interactive  
animated lesson  
and comparing  
Anaerobic vs  
Aerobic  
Respiration

# 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.
- Produces only 2 ATP.



# Fermentation

Two different fermentation pathways:

- Yeasts and some bacteria are able to get their ATP from glycolysis by using **alcoholic fermentation**. Converts pyruvate into ethanol and carbon dioxide.
- Animal cells and some bacteria through the process of **lactic acid fermentation**. Here pyruvate results in end product of lactic acid.

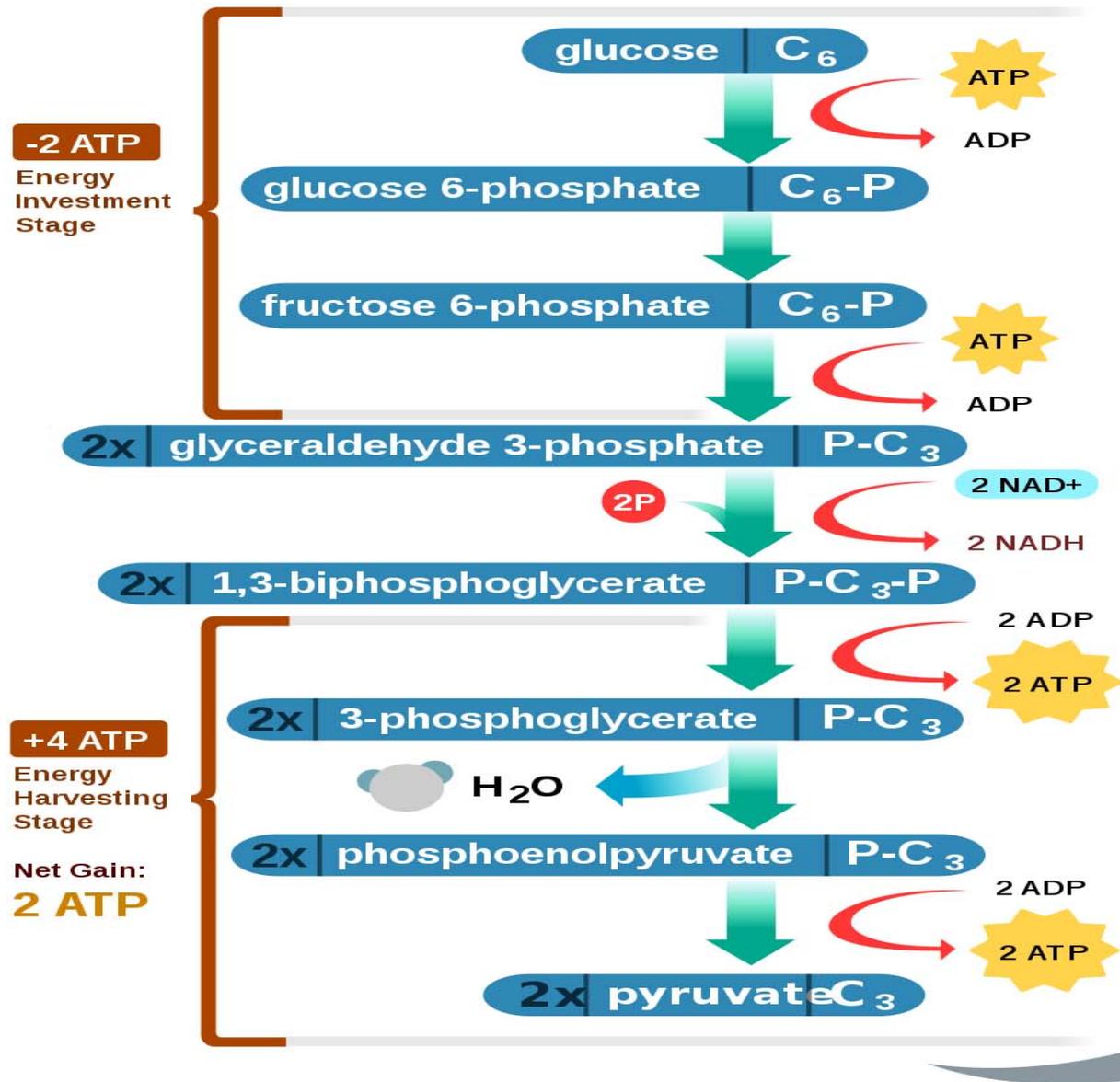


The formation of carbon dioxide, a byproduct of ethanol fermentation, causes bread to rise.

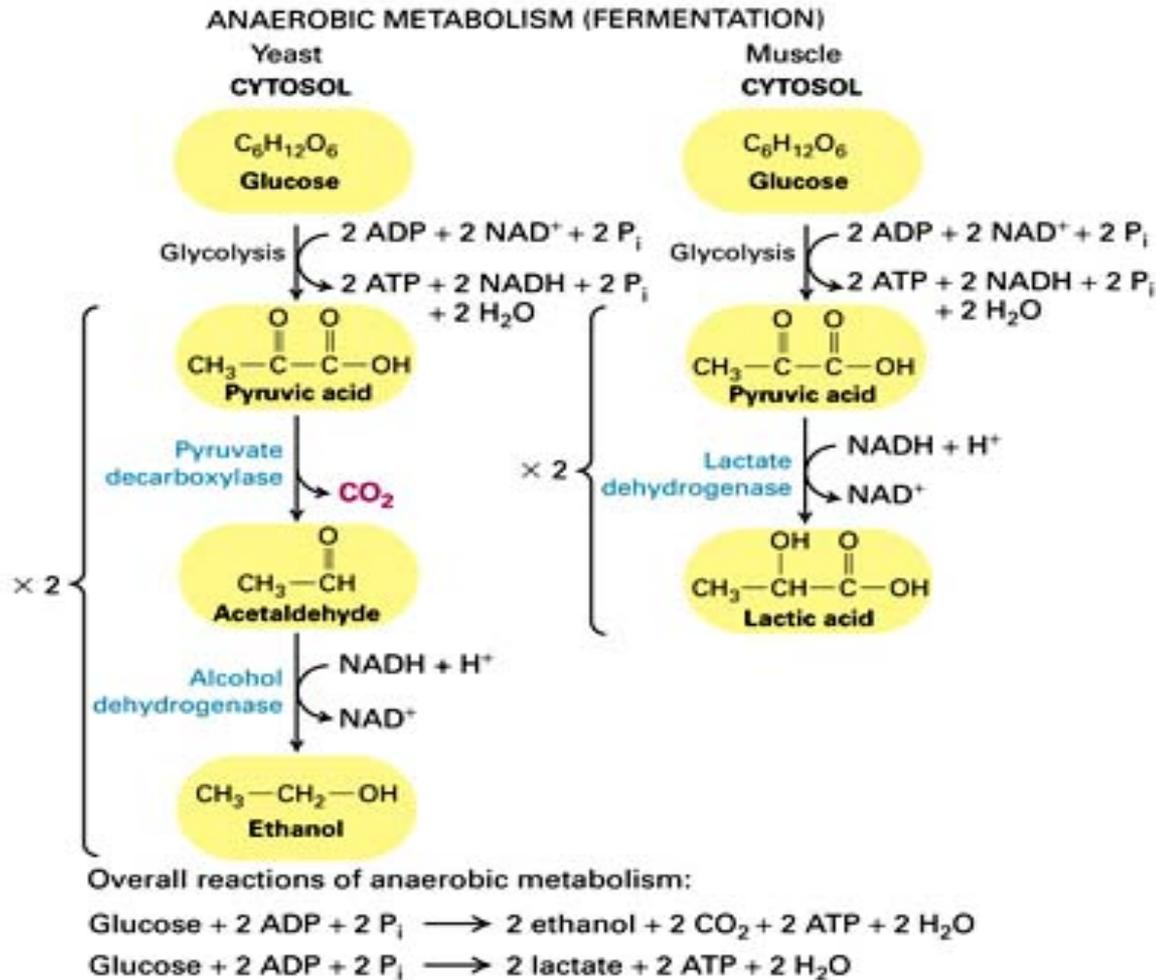


When muscles need energy produced faster than the body can deliver oxygen, such as when lifting heavy weights, the working muscles generate energy anaerobically, through lactic acid fermentation.

# Glycolysis in the Cytoplasm



# Fermentation



**REVIEW!**

Interactive  
animated lesson  
comparing  
Alcoholic  
vs  
Lactic Acid  
Fermentation

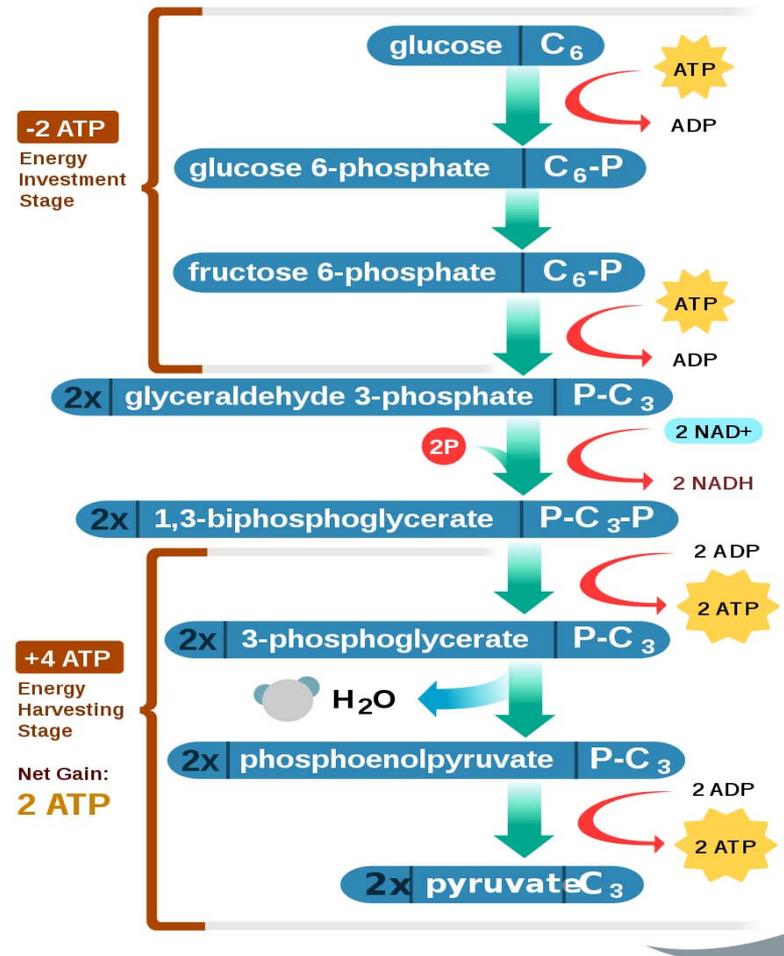
# Why does fermentation require extra steps after glycolysis?

- In fermentation, after glycolysis, there are additional steps to oxidize NADH (into  $\text{NAD}^+$ ).
- 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 =**

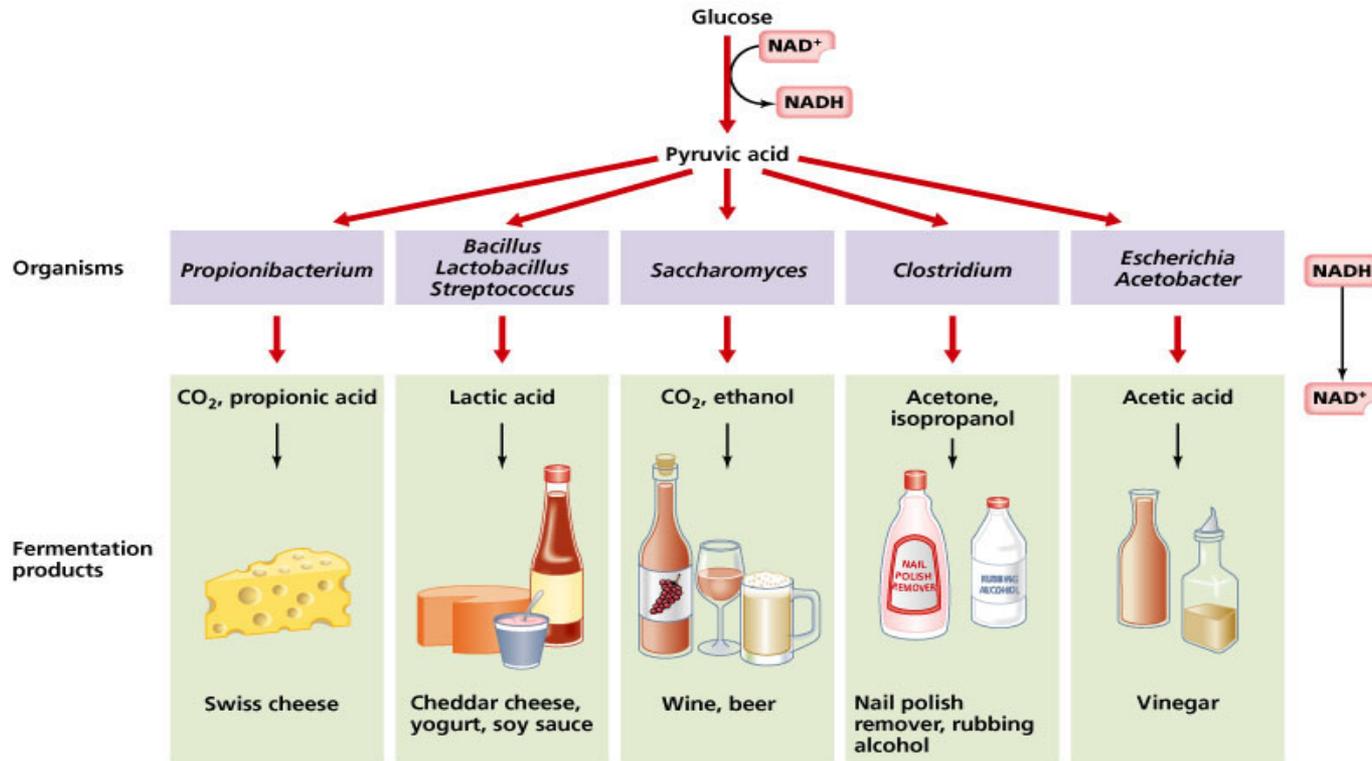
**glycolysis + recycling of  $\text{NAD}^+$**

## Glycolysis in the Cytoplasm



# 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).



# Alcohol Fermentation in Wine

## Louis Pasteur & Industrial Microbiology

- **Q:** *What is fermentation?*

- What causes fermentation?

*Some scientists thought that **air** caused fermentation*

*Others thought that **microbes** caused fermentation.*

- **Q:** *What is pasteurization?*

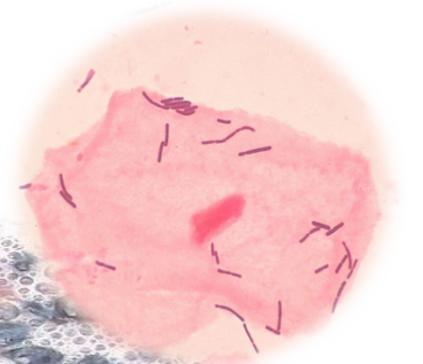
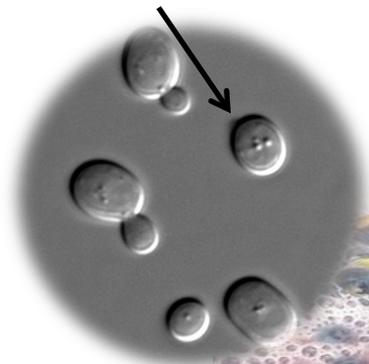
Are these non-living  
blobs or living  
microbes?

< yeast + grapes = yummy wine 😊 (ethanol)

bacteria + grapes = spoiled wine 😞 (lactic acid) >

### Pasteur's Observations:

1. Blobs were alive because they divide and make more of themselves.
2. Put grape juice + yeast in open and in air-tight containers. Fermentation occurred in both. This means that yeast are **facultative anaerobes**.
3. Took two flasks of sterile grape juice and introduced bacteria into one and yeast into another.



# Muscles & Lactic Acid Fermentation

## Slow and Fast Twitch Muscle

- Muscle contains both **slow twitch** fibers and **fast twitch** fibers.
- **Slow twitch fibers** have many mitochondria and use **aerobic respiration** to generate ATP. These fibers contract and fatigue more slowly.
- Slow twitch also contains an oxygen-storing protein, **myoglobin**, which helps provide the oxygen that sustains aerobic respiration.
- **Fast twitch fibers** use **lactate fermentation** to make most of their ATP, so can provide only short bursts of energy.
- Most of us have about 50% slow twitch fibers and 50% fast twitch fibers.
- Long-distance runners often have more **slow twitch** fibers while sprinters or bodybuilders often have more **fast twitch** fibers.

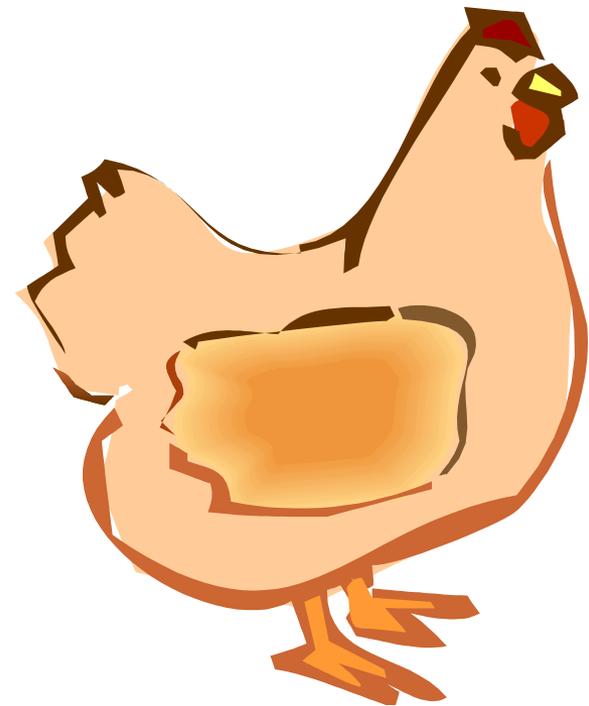




# Slow and Fast Twitch Muscle

**Poultry:** White Meat & Dark Meat

- White meat = **fast twitch**  
Dark meat = **slow twitch**
- Slow twitch is dark because it contains the oxygen-storing protein **myoglobin**.
- In poultry **slow twitch** muscles tend to be prominent in **leg muscles** where long term endurance is required.
- **Fast twitch** muscles are predominant in the wing and breast where quick response, rather than endurance, is needed.
- Wild game birds tend to have more slow twitch muscle than their domestic counterparts. **Q:** Why?



# Souring & Spoilage

## Different Results of Anaerobic Metabolism

- **Souring:** Fermentation of carbohydrates generates organic acids.
- Sour cream, cheese, and yogurt are produced by the action of bacteria doing fermentation.
- Lactic-acid bacteria of the genus *Lactobacillus* are one type of microbe used in the fermentation process.
- These bacteria convert lactose to lactic acid, which causes milk to change from liquid to solid curd and produces a sour flavor.
- **Spoilage:** When microbes use anaerobic respiration to break down proteins, releasing nitrogen and sulfur-containing organic compounds.
- Also known as putrefication.
- Anaerobic respiration of protein often produces foul smelling chemicals such as putrescine, cadaverine & hydrogen sulfide.



# 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 cells use anaerobic respiration extract energy from their food (compared to those that use aerobic respiration)?

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



# Confused?

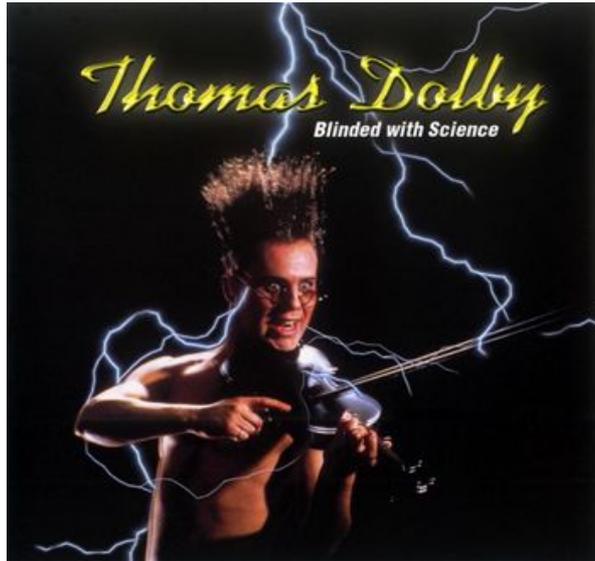
Here are links to fun resources that further explain cellular respiration:

- [Anaerobic Cellular Respiration Main Page](#) on the Virtual Cell Biology Classroom of [Science Prof Online](#).
- [Anaerobic Respiration Page](#) by Timothy Paustain, University of Wisconsin, Madison.
- ["Alphabutt"](#) song by Kimya Dawson
- [How NAD+ Works](#) animation and quiz from McGraw-Hill.
- [Glycolysis](#) animation and quiz from McGraw-Hill.
- [Krebs Cycle Animation & Quiz 1](#) from McGraw-Hill.
- [Krebs Cycle Animation & Quiz 2](#) from McGraw-Hill.
- [Electron Transport Chain](#) animation from Molecular & Cellular Biology Learning Center.
- [Food Molecules](#) video from HowStuffWorks, a Discovery company.
- ["Tiny Bubbles"](#) song by Don Ho.

## Smart Links



(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](http://www.ScienceProfOnline.com)