• The bonds between H and C represents a shared pair of electrons
• These are high-energy electrons
• This represents chemical potential energy
• Hydro-carbons posses a lot of chemical potential energy
- **C-H** = high-energy bonds
- Represent uphill $e^-$
- Chemical potential energy

During cellular respiration, C-H bonds are broken:
- $e^-$ fall downhill to (electronegative) oxygen
- Loss of potential energy used to recharge ATP
Based on the information above, come up with a definition for: oxidized and reduced
Tip

LEO The Lion Goes GER

Lose Electrons Oxidation

Gain Electrons Reduction
Oxygen is very electronegative. e\textsuperscript{-} are stripped from fuel as it combusts.

\[ \text{Reactants} \quad \begin{array}{c} \text{Methane} \quad \text{Oxygen} \\ \text{becomes oxidized} \quad \text{becomes reduced} \end{array} \quad \text{Products} \quad \begin{array}{c} \text{Carbon dioxide} \quad \text{Water} \\ \text{Energy} \end{array} \]

\[ \text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + \text{Energy} + 2\text{H}_2\text{O} \]

Loose Electrons, Oxidize \quad \quad Gain Electrons, Reduce
For a – d above determine if the molecule is being oxidized or reduced

- Oxygen is very electronegative
- $e^-$ are stripped from fuel molecules as they combust
1. Which reaction is photosynthesis and which is cellular respiration?
2. What is similar between the two reactions, what is different?
3. What is oxidized in cellular respiration?
4. What is oxidized in photosynthesis?
**Glycolysis** 6-C sugar (glucose) is split into two 3-C pyruvate molecules, yielding 2 net ATP

**Evolutionary significance:**
- Does not require oxygen – Early Earth’s atmosphere lacked $O_2$
- Takes place in the cytoplasm (predates organelles such as mitochondria)
- It is the most widespread metabolic pathway among Earth’s organisms
Glycolysis and Cellular Respiration Animation

http://www.sumanasinc.com/webcontent/animations/content/cellularrespiration.html
1. In the preparatory phase, what has happened to the 2 ATP and explain why?
2. What is about to occur with the 2 NAD⁺?
3. What has occurred to the glucose molecule?
1. How many ATP were invested to break glucose?
2. How many ATP result in the payoff phase?
3. How many net ATP result?
4. Name and quantify the three products of glycolysis:
1. What specifically does NAD\(^+\) gain to convert it to NADH?
2. Has NAD\(^+\) been oxidized or reduced?
3. What role (job) does NADH play in cellular respiration?
Dehydrogenase catalyzes the transfer of two electrons and two protons from a substrate to NAD+ to form NADH and water. The reaction can be represented as:

$$2e^- + 2H^+ + 2[H] \xrightleftharpoons{} 2e^- + H^+$$

NAD+ (oxidized form) + 2[H] (from food) \rightarrow NADH (reduced form) + H+
During glycolysis 4 ATP (2 net) are generated

These ATP are generated by substrate-level phosphorylation

An enzyme catalyzes the reaction
Fermentation

• The goal of fermentation is to reduce $\text{NADH} \rightarrow \text{NAD}^+$ so that glycolysis can continue.

• NADH must pass the high energy $e^-$ and $H^+$ to an organic molecule:

  - $\text{Pyruvic acid} + \text{NADH} \rightarrow \text{alcohol} + CO_2 + \text{NAD}^+$
  - $\text{Pyruvic acid} + \text{NADH} \rightarrow \text{lactic acid} + \text{NAD}^+$
1. What determines the route of pyruvate after glycolysis?
2. What are two possible products of fermentation?
3. Where does fermentation occur?
4. Where does respiration occur?
5. How many times more ATP can be formed through cellular respiration?
6. How does fermentation relate to NAD$^+$?

The goal of fermentation is to NADH $\rightarrow$ NAD$^+$ so that glycolysis can continue.

NADH must pass the high energy e$^-$ and H$^+$ to an organic molecule:
1. What effect does the folding of the inner membrane (called the cristae) have on total surface area?

2. Discuss how having a double-membrane compartmentalizes the mitochondrion:

3. Is there an electrochemical gradient present in the mitochondrion? Justify with evidence:
1. **Describe** the electrochemical gradient (using space-specific terms):

2. **Describe** and **explain** the net direction of $H^+$ movement:

3. **Describe** what action is occurring by the enzyme ATP synthase:

4. **Explain** the energy-transformation that is occurring in order to drive this reaction: $\text{ADP} + P_i \rightarrow \text{ATP}$
1. Summarize 3 lines of evidence that suggests that glycolysis is a very ancient and evolutionary-conserved metabolic pathway:

2. What does the word glycolysis mean?

3. Glycolysis starts with an energy investment. How many ATP are invested per glucose and why is this investment required?

4. What is the net ATP generated as a result of glycolysis?

5. In addition to ATP, how many NADH result (per glucose molecule) and what does NADH represent?

6. What is the name of the 2 three-carbon molecules that result from glycolysis?
Describe three ways, that the two 3-C Pyruvate molecules that emerged from glycolysis, have been modified in the link reaction shown below:
1. How many hydrogen atoms do the combined NADH and FADH$_2$ carry?
2. Where did these hydrogen atoms come from?
3. NADH and FADH$_2$ donate electrons to the _____.
1. Where are the ETC proteins found?
2. Where do the e⁻ for the ETC come from?
3. What occurs as the e⁻ are passed down the ETC?
1. Name the final electron acceptor:
2. What does it become after it has accepted the electrons?
3. How would its absence affect the process & why?
1. How was an electrochemical gradient generated?
2. How is the structure of the mitochondrion involved?
3. How is this gradient used to: \( \text{ADP} + P_i \rightarrow \text{ATP} \)?
The Link Reaction

1. What has occurred to the six carbons of glucose?

2. What do NADH and FADH$_2$ carry?

3. What do NADH and FADH$_2$ represent?

4. How much ATP has been generated?
Glucose

1 PREPARATORY PHASE

Net yield: 2 ATP and 2 NADH

2 PAYOFF PHASE

Pyruvate (2 molecules)
Pyruvate oxidation
1. Describe the 4 energy transformations that occur along the pathway below:

2. Why do we need to recharge ATP?

3. In what form is most of the energy in glucose actually lost to the environment?
1. Which bonds represent high-energy bonds?
2. During combustion, is gasoline oxidized or reduced?
3. Which gas is required for gasoline combustion (is it oxidized or reduced)?
4. What are the products of gasoline combustion?
5. From which reactants of the reaction does each of the atom found in the products come from?
6. Describe the energy transformations that occur when gasoline combusts in a car’s engine:
75% of the energy in gasoline is lost as heat
25% is available to move the car

100% of mass of the gasoline comes out the exhaust pipe as, mostly as CO₂ and H₂O
(a) Uncontrolled reaction

(b) Cellular respiration
Catabolic Pathway
1. Which bonds represent high energy $e^-$?

2. Describe the change in potential energy of the $e^-$

3. Name the molecules that carry the $e^-$ to the ETC

4. Which part of the diagram represents oxidative phosphorylation?

5. Has the fuel been oxidized or reduced? Explain:

6. Is oxygen oxidized or reduced? Explain:

7. What happens to the oxygen at the end?
You will measure the rate at which a reactant (oxygen) is consumed.
KOH will remove CO₂ produced from the volume in the system – making changes in volume due to O₂ consumption
1. What will you measure to quantify the rate of cellular respiration?

2. What is the purpose of the KOH?
1. What will you measure to quantify the rate of cellular respiration? **The volume of oxygen consumed over time.**

2. What is the purpose of the KOH? **It combines with CO₂ gas to form a precipitate; therefore a change in volume will be due only to O₂ consumption.**
Bottom of Meniscus
Analysis of Results I

After you have collected data for the amount of oxygen consumed over time by germinating and nongerminating peas at two different temperatures, you can compare the rates of respiration. Let's review how to calculate rate.

Rate = slope of the line, or \( \frac{\Delta y}{\Delta x} \)

In this case, \( \Delta y \) is the change in volume, and \( \Delta x \) is the change in time (10 min).

Initial = 0.07 ml
at 10 minutes = 0.23 ml

\( \Delta Y = 0.23 \text{ ml} - 0.07 \text{ ml} = 0.16 \text{ ml} \)

\( \Delta X = 10 \text{ min} - 0 \text{ min} = 10 \text{ min} \)

\( \frac{\Delta Y}{\Delta X} = 0.016 \text{ ml/min} \)
\[ PV = nRT \]

**Where**
- \( P \) = pressure of the gas
- \( V \) = volume of the gas
- \( n \) = number of moles of the gas
- \( R \) = the gas constant (its value is fixed)
- \( T \) = temperature of the gas

\[ V = \frac{nRT}{P} \]

1. Effect of ↑ and ↓ temperature on volume:
2. Effect of ↑ and ↓ atmospheric pressure on volume
### Control (glass beads)

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1. Based on the graph, what is the respiration rate for 12 degree corn? 
*Show set-up & include units*

2. Based on the data table, what is the respiration rate between 5 and 15 minutes? 
*Show set-up & include units*
1. Based on the graph, what is the respiration rate for 12 degree corn?
   \[0.6 \text{ ml} /15 \text{ min.} = 0.04 \text{ ml} /\text{min}.\]

2. Based on the data table, what is the respiration rate between 5 and 15 minutes?
   \[
   \frac{(1.2 - 0.4)}{(15 - 10)} = 0.8 \text{ ml}/10 \text{ min.} = 0.08 \text{ ml}/\text{min.}
   \]