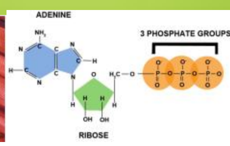
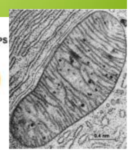
$$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O + ATP$$

Glucose + Oxygen → Carbon dioxide + Water + Energy

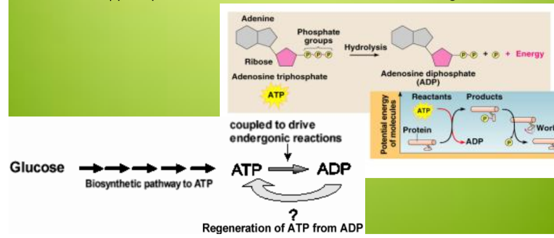
# *Molecular Biology*
# *2.8- Cell Respiration*



## Essential idea:

- Cell respiration supplies energy for the functions of life.
  - **Coupling Reactions**
    - When energy released by an exergonic reaction is used to drive an endergonic reaction.
  - Hydrolysis of ATP (**adenosine triphospate**)
    - Energy from ATP → ADP + $P_i$ is used to fuel reactions.
    - $P_i$ phosphoraletes an intermediate molecule making it less stable




## Nature of science:

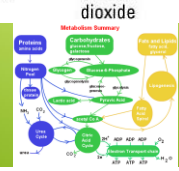
- Assessing the ethics of scientific research
  - The use of invertebrates in respirometer experiments has ethical implications. (4.5)
    - Is it acceptable to remove animals from their natural habitat for use in an experiment?
    - Can the animals be safely returned to their habitat?
    - Will the animals suffer pain or any other harm during the experiment?
    - Can the risk of accidents that cause pain or suffering to the animals be minimized during the experiment? In particular, can contact with the alkali be prevented?
    - Is the use of animals in the experiment essential or is there an alternative method that avoids using animals?

## Equation

- Cell respiration is the controlled release of energy from organic compounds to produce ATP.
  - Mainly carbohydrates (glucose!!!)
  - Also lipids and proteins

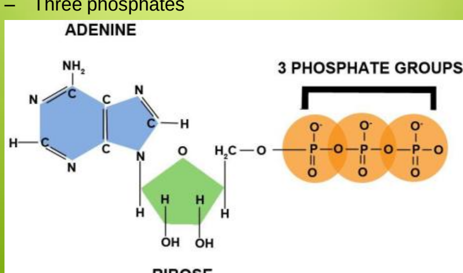
$$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O + ATP$$

Glucose + Oxygen → Carbon dioxide + Water + Energy



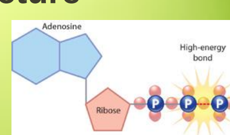
## ATP Structure

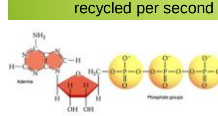
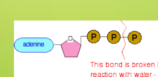
- **Nucleotide**
  - Nitrogen base adenine
  - Ribose
  - Three phosphates

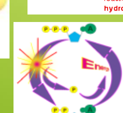
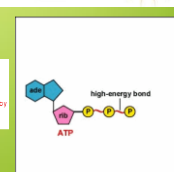



## ATP Structure

- ATP is called a "high-energy" molecule
  - Three negative phosphates repel
  - ADP is more stable
  - Overall reaction is exergonic
  - ATP is constantly recycled from ADP + $P_i$
  - Muscle Cell= 10 million used and recycled per second

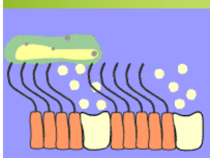


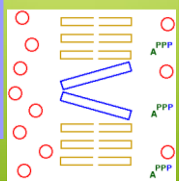



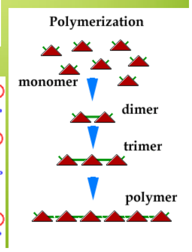



# Function of ATP

- ATP from cell respiration is immediately available as a source of energy in the cell.
  - Chemical work
  - Transport work
  - Mechanical work

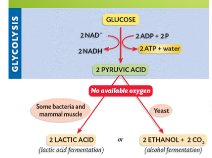



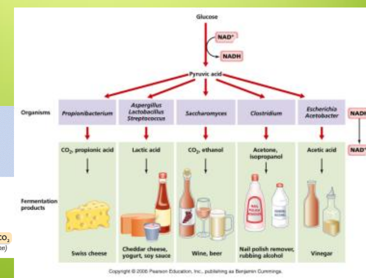



# Anaerobic Respiration

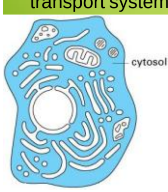
- Anaerobic cell respiration gives a small yield of ATP from glucose.
- Two Pathways
  - Glycolysis
  - Fermentation



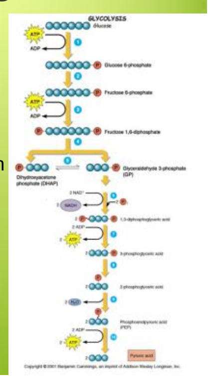




# Glycolysis

- The breakdown of glucose to two molecules of pyruvate.
- Occurs in the cytosol
- Doesn't require oxygen
- Universal in organisms (most likely evolved before Krebs cycle and electron transport system)

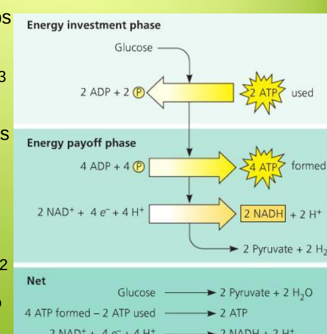






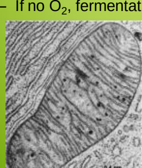

# Glycolysis

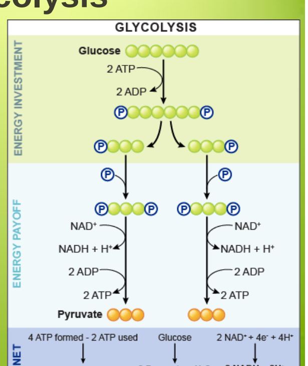
- Energy Investment Steps
  - Two ATP molecules phosphorylate Glucose
  - Glucose splits into two C3 molecules (PGAL), each with a phosphate group.
- Energy Harvesting Steps
  - Further steps generate 4 ATP molecules by substrate-level phosphorylation
  - Reduction of 2NAD$^+$ produces 2 NADH.
  - Two $H_2O$ molecules and 2 pyruvates are produced
  - There is a net gain of two ATP from glycolysis.




# Glycolysis

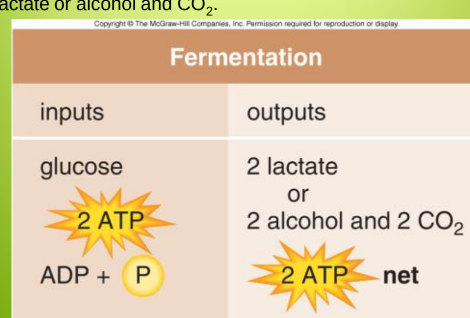
- Summary
  - Net energy yield is 2 ATP (+2 NADH)
  - Two Pyruvate molecules are the final products
  - No $CO_2$ is released
  - If $O_2$ is present, pyruvate enters mitochondria.
  - If no $O_2$, fermentation follows





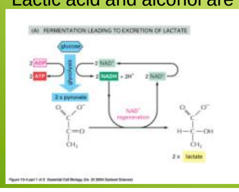

# Fermentation

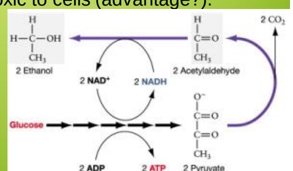
- Consists of glycolysis plus reduction of pyruvate to either lactate or alcohol and $CO_2$.



## Fermentation Pathways

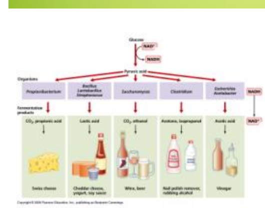
- NADH passes its electrons to pyruvate
- Regenerates $NAD^+$ for glycolysis
- Two Types
  - Lactic Acid Fermentation
  - Alcohol Fermentation
- Fermentation results in a net gain of only two ATP per glucose molecule
- Lactic acid and alcohol are toxic to cells (advantage?).

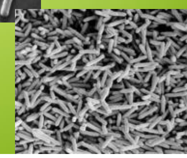





## Fermentation in Organisms

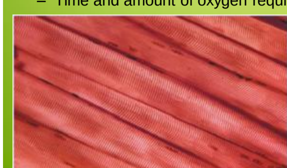
- Anaerobic bacteria produce lactic acid when we manufacture some cheeses.
- Anaerobic bacteria produce industrial chemicals: isopropanol, butyric acid, propionic acid, and acetic acid.

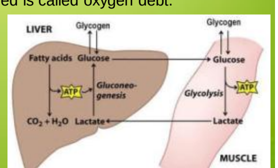




## Fermentation in Organisms

- Lactate production in humans when anaerobic respiration is used to maximize the power of muscle contractions.(IB application)
  - Animals reduce pyruvate to lactate when it is produced faster than it can be oxidized by Krebs cycle.
  - Quick production of small amount of ATP allows contractions to continue.
  - Lactate must be broken down by oxygen in the liver.
  - Time and amount of oxygen required is called oxygen debt.






## Fermentation in Organisms

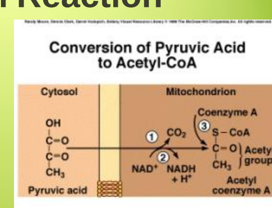
- Anaerobic cell respiration in yeasts produce ethanol and carbon dioxide in baking. (IB application)
  - Yeast can respire aerobically or anaerobically
    - Oxygen in the dough is soon used up so the yeast is forced to respire anaerobically.
    - The carbon dioxide produced by anaerobic cell respiration cannot escape from the dough and forms bubbles causing the dough to swell and rise.
    - Ethanol evaporates during baking.

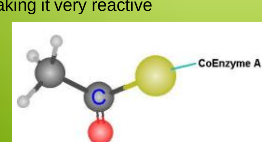
## Fermentation in Organisms

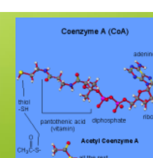
- Bioethanol (ethanol produced by organisms) is a renewable energy source.
  - Most bioethanol is produced from sugar cane and maize, using yeast.
  - Fermenters keep the yeast in optimum conditions.
  - Starch and cellulose in the plant material are broken down by enzymes into sugars.
  - Anaerobic respiration converts sugars in the plant material into ethanol and carbon dioxide.
  - The ethanol is purified by distillation and water is removed to improve combustion.
  - What are the ethical implications of large-scale use of food plants for biofuels and the resulting impact on food prices?

## Transition Reaction

- Pyruvate is transported from the cytoplasm to the mitochondrion, where further oxidation occurs.
- Each pyruvate loses a $CO_2$ (becoming acetate)
- $NAD^+$ is reduced to NADH
- Coenzyme A( B vitamin derivative) attaches to acetate making it very reactive

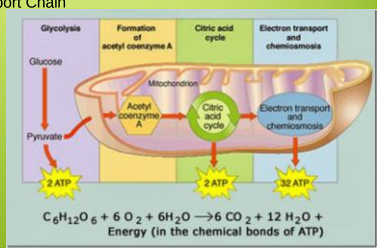


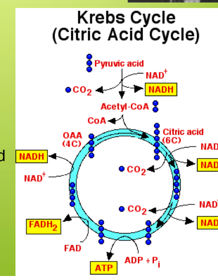
# Aerobic Respiration

- Aerobic cell respiration requires oxygen and gives a large yield of ATP from glucose.
- Three pathways involved
  - Krebs cycle
  - Electron Transport Chain
  - Chemiosmosis



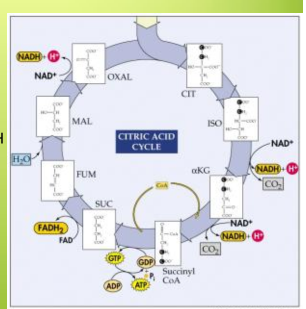

# Kreb's Cycle

- Sir Hans Krebs (1930's)
- Also called Citric Acid Cycle
- Occurs in mitochondrial matrix if $O_2$ is present
- Acetyl CoA combines with Oxaloacetate (forming citric acid)
- For each turn of cycle
  - Two $CO_2$ are released
  - Three 3 NADH produce
  - One FAD is reduced to $FADH_2$
  - GTP accepts a phosphate group and passes it on to convert ADP to ATP.
  - Oxaloacetate is regenerated



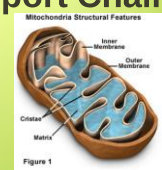

# Kreb's Cycle

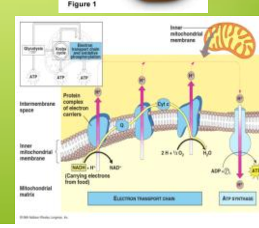
- Summary
  - Krebs cycle turns twice for each original glucose molecule
  - Products of the Krebs cycle per glucose molecule include $4CO_2$, 2ATP, 6NADH and $2FADH_2$
  - NADH and $FADH_2$ carry electrons to electron transport system




# Electron Transport Chain

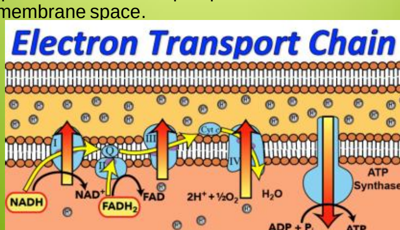
- Series of electron carrier molecules in mitochondrial cristae (inner mitochondrial membrane)
- Carrier Molecules
  - Most are proteins (heme and cytochromes)
  - Ubiquinone is a lipid
  - Electrons pass from higher to lower energy states



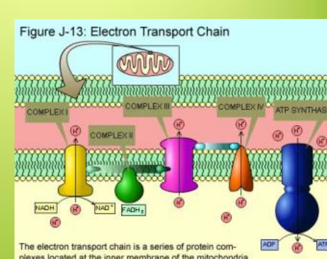
# Electron Transport Chain

- NADH and $FADH_2$ give electrons to carriers
- Oxygen is final acceptor and combines with hydrogen ions to form $H_2O$
- Energy released from flow of electrons down electron transport chain is used to pump $H^+$ ions into the mitochondrial intermembrane space.



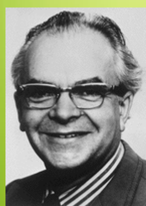

# Electron Transport Chain

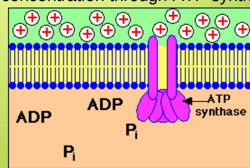
- Electrons from NADH pump 3 $H^+$ into intermembrane space.
- Electrons from $FADH_2$ pump 2 $H^+$ into intermembrane space
- $H^+$ ions in this intermembrane space creates an electrochemical gradient.
- Chemiosmosis follows

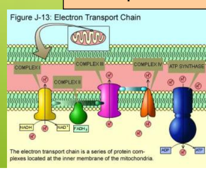


# Chemiosmosis

- Proposed by Peter Mitchell(1961)
- $H^+$ ions flow from high to low concentration through ATP synthase

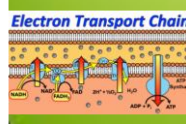


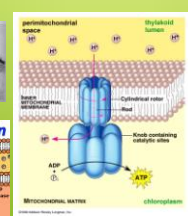


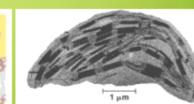



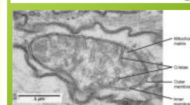

# Chemiosmosis

- ATP Synthase Complexes
  - Channel proteins that also serve as enzymes for ATP synthesis
  - Found in mitochondrial and chloroplast membranes.
  - Found in Prokaryote cell membranes
- Because $O_2$ must be present for system to work, it is also called oxidative phosphorylation. (summary video)

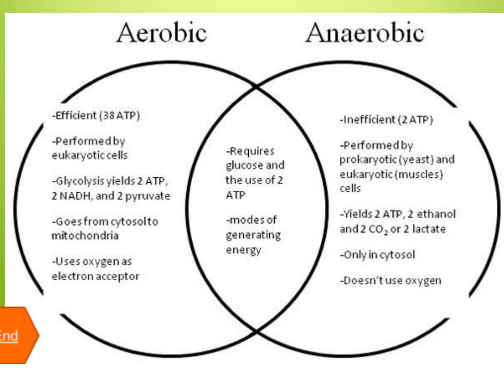




# Aerobic vs Anaerobic Respiration

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