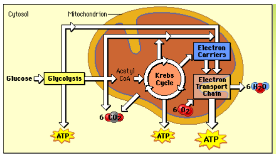
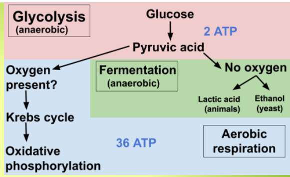
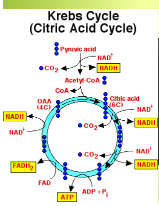
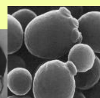
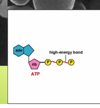


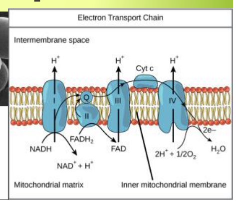


3.6 Cellular Respiration



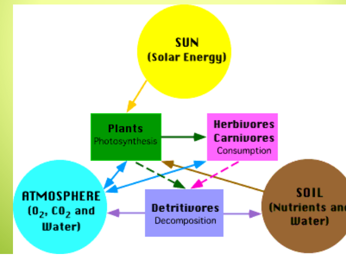






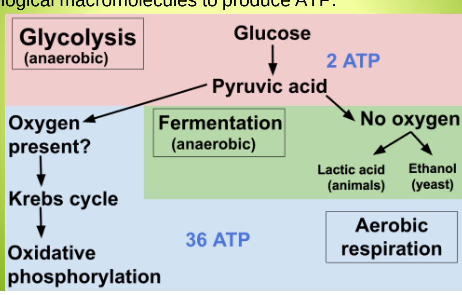
ENDURING UNDERSTANDING

ENE-1 The highly complex organization of living systems requires constant input of energy and the exchange of macromolecules



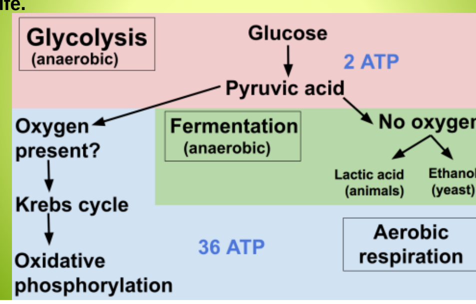
ENE-1.K Describe the processes that allow organisms to use energy stored in biological macromolecules.

- Fermentation and cellular respiration use energy from biological macromolecules to produce ATP.



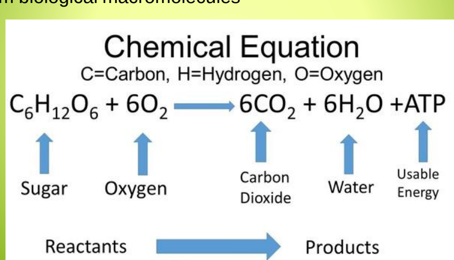
ENE-1.K Describe the processes that allow organisms to use energy stored in biological macromolecules.

- Respiration and fermentation are characteristic of **all forms of life.**



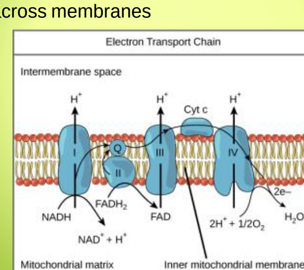
ENE-1.K Describe the processes that allow organisms to use energy stored in biological macromolecules.

- Cellular respiration in eukaryotes involves a series of coordinated enzyme-catalyzed reactions that capture energy from biological macromolecules



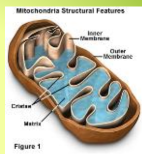
ENE-1.K Describe the processes that allow organisms to use energy stored in biological macromolecules.

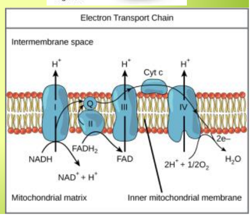
- The electron transport chain transfers energy from electrons in a series of coupled reactions that establish an electrochemical gradient across membranes



Electron Transport Chain

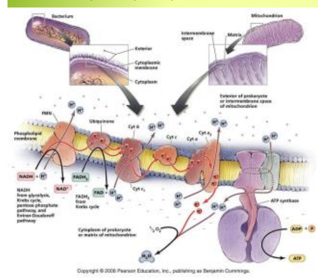
- Series of electron carrier molecules in mitochondrial cristae
- Electrons from NADH pump 3 H^+ into intermembrane space.
- Electrons from $FADH_2$ pump 2 H^+ into intermembrane space
- H^+ ions in this intermembrane space creates an electrochemical gradient. (proton-motive force)





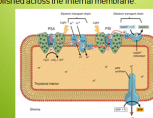
ENE-1.K Describe the processes that allow organisms to use energy stored in biological macromolecules.

- Electron transport chain reactions occur in chloroplasts, mitochondria, and prokaryotic plasma membranes.



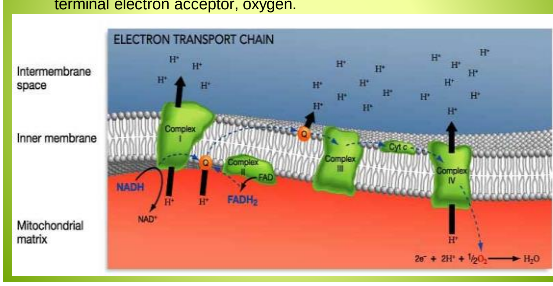
ENE-1.J Explain how cells capture energy from light and transfer it to biological molecules for storage and use

- When electrons are transferred between molecules in a sequence of reactions as they pass through the ETC, an electrochemical gradient of protons (hydrogen ions) is established across the internal membrane.



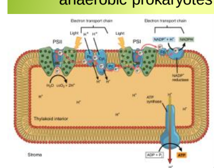
ENE-1.K Describe the processes that allow organisms to use energy stored in biological macromolecules.

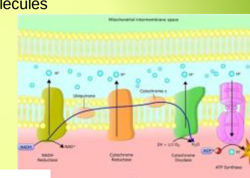
- In cellular respiration, electrons delivered by NADH and $FADH_2$ are passed to a series of electron acceptors as they move toward the terminal electron acceptor, oxygen.



ENE-1.K Describe the processes that allow organisms to use energy stored in biological macromolecules.

- In photosynthesis, the terminal electron acceptor is $NADP^+$. Aerobic prokaryotes use oxygen as a terminal electron acceptor, while anaerobic prokaryotes use other molecules





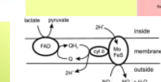
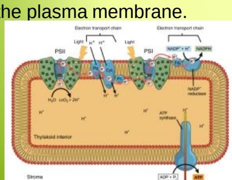
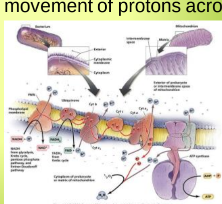


Figure 1.16 The electron transport chain for *Escherichia coli* during anaerobic respiration (based on Smith and Wood [70], Dym et al. [47] and Bertero et al. [46]). FAD is flavin, FeS are iron–sulfur clusters, Q is menaquinone, cyt b is a b-type cytochrome and Mo is molybdopterin-guanosine-dinucleotide.

ENE-1.K Describe the processes that allow organisms to use energy stored in biological macromolecules.

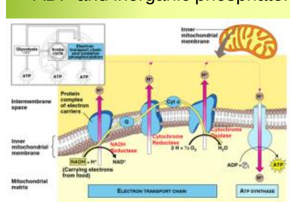
- The transfer of electrons is accompanied by the formation of a proton gradient across the inner mitochondrial membrane or the internal membrane of chloroplasts, with the membrane(s) separating a region of high proton concentration from a region of low proton concentration. In prokaryotes, the passage of electrons is accompanied by the movement of protons across the plasma membrane.

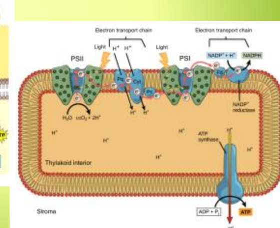




ENE-1.K Describe the processes that allow organisms to use energy stored in biological macromolecules.

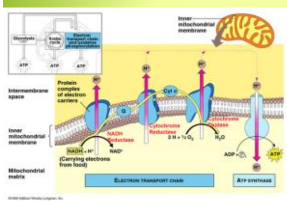
- The flow of protons back through membrane-bound ATP synthase by chemiosmosis drives the formation of ATP from ADP and inorganic phosphate.

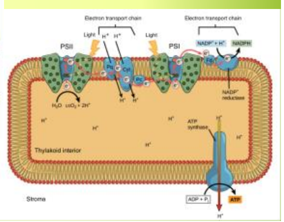




ENE-1.K Describe the processes that allow organisms to use energy stored in biological macromolecules.

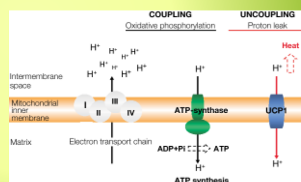
- ❑ This is known as oxidative phosphorylation in cellular respiration, and photophosphorylation in photosynthesis





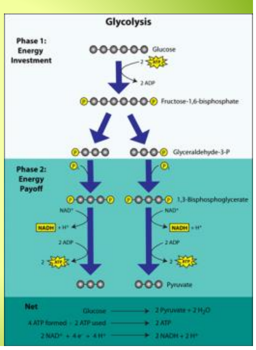
ENE-1.K Describe the processes that allow organisms to use energy stored in biological macromolecules.

- ❑ In cellular respiration, decoupling oxidative phosphorylation from electron transport generates heat. This heat can be used by endothermic organisms to regulate body temperature.
  - – Uncoupling Protein-1 (UCP1)
    - Shown to increase energy expenditure by uncoupling a step in cellular metabolism.
    - Leaks protons across mitochondrial inner membrane.
    - The energy is released the form of heat.



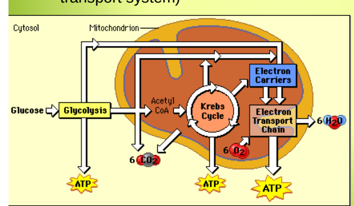
ENE-1.L Explain how cells obtain energy from biological macromolecules in order to power cellular functions

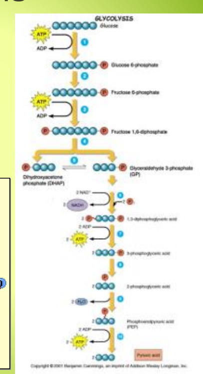
- ❑ Glycolysis is a biochemical pathway that releases energy in glucose to form ATP from ADP and inorganic phosphate, NADH from NAD+, and pyruvate.



Glycolysis

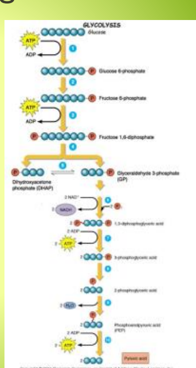
- – The breakdown of glucose to two molecules of pyruvate.
- – Occurs in the cytosol
- – Doesn't require oxygen
- – Universal in organisms (most likely evolved before Krebs cycle and electron transport system)





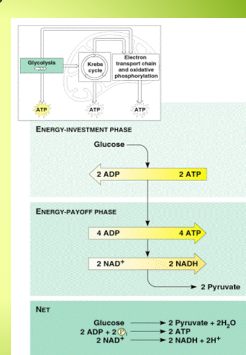
Glycolysis

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



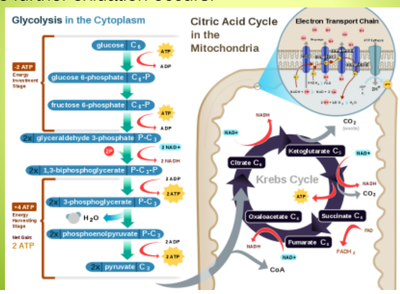
Glycolysis

- – Summary
- – 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
- – Net energy yield per glucose molecule = 2 ATP plus 2 NADH



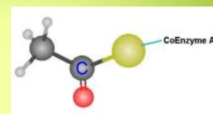
ENE-1.L Explain how cells obtain energy from biological macromolecules in order to power cellular functions

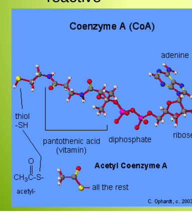
- ❑ Pyruvate is transported from the cytosol to the mitochondrion, where further oxidation occurs.

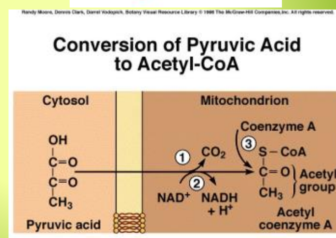


Transition Reaction

– 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

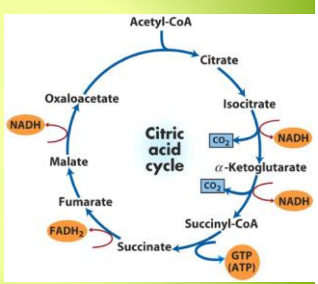






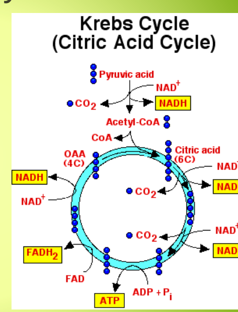
ENE-1.L Explain how cells obtain energy from biological macromolecules in order to power cellular functions

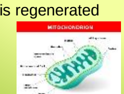
- ❑ In the Krebs cycle, carbon dioxide is released from organic intermediates, ATP is synthesized from ADP and inorganic phosphate, and electrons are transferred to the coenzymes NADH and $FADH_2$



Kreb's Cycle

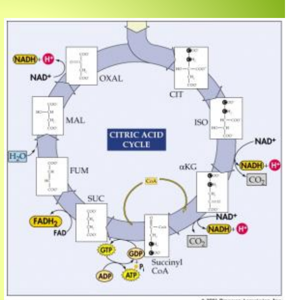
– Sir Hans Krebs (1930's)
– Also called Citric Acid Cycle
– Occurs in mitochondrial matrix if O_2 is present
– Acetyl CoA combines with Oxaloacetate (forming citric acid)
– For each turn of cycle
  - Two CO_2 are released
  - Three 3 NADH produce
  - One FAD is reduced to $FADH_2$
  - GTP accepts a phosphate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





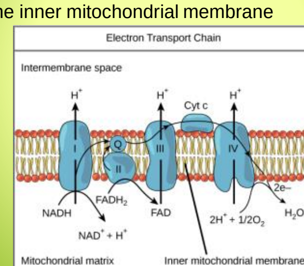
Kreb's Cycle

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



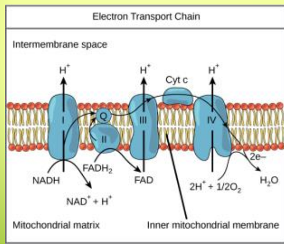
ENE-1.L Explain how cells obtain energy from biological macromolecules in order to power cellular functions

- ❑ Electrons extracted in glycolysis and Krebs cycle reactions are transferred by NADH and $FADH_2$ to the electron transport chain in the inner mitochondrial membrane



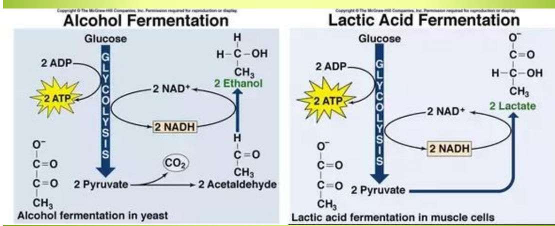
ENE-1.L Explain how cells obtain energy from biological macromolecules in order to power cellular functions

- When electrons are transferred between molecules in a sequence of reactions as they pass through the ETC, an electrochemical gradient of protons (hydrogen ions) across the inner mitochondrial membrane is established.



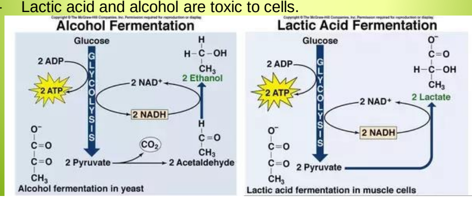
ENE-1.L Explain how cells obtain energy from biological macromolecules in order to power cellular functions

- Fermentation allows glycolysis to proceed in the absence of oxygen and produces organic molecules, including alcohol and lactic acid, as waste products.



Fermentation

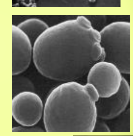
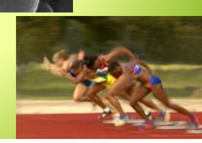
- Consists of glycolysis plus reduction of pyruvate to lactate or alcohol and CO_2.
- NADH passes its electrons to pyruvate
- Regenerates NAD^+ for glycolysis
- Two Types
  - Lactic Acid Fermentation
  - Alcohol Fermentation
- Fermentation results in a net gain of only two ATP per glucose molecule
- Lactic acid and alcohol are toxic to cells.



Fermentation

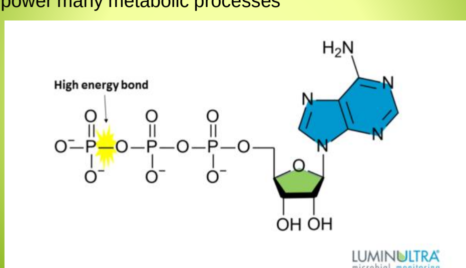
- Examples
  - Anaerobic bacteria produce lactic acid when we manufacture some cheeses.
  - Anaerobic bacteria produce industrial chemicals: isopropanol, butyric acid, propionic acid, and acetic acid.
  - Yeasts use CO_2 to make bread rise, produce alcohol in winemaking
  - Animals reduce pyruvate to lactate when it is produced faster than it can be oxidized by Krebs cycle.



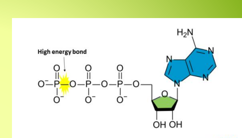
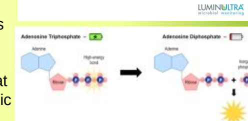
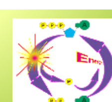
ENE-1.L Explain how cells obtain energy from biological macromolecules in order to power cellular functions

- The conversion of ATP to ADP releases energy, which is used to power many metabolic processes



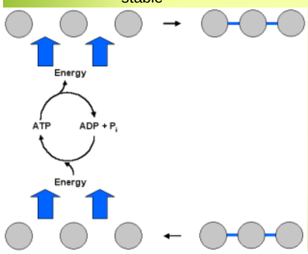
ATP

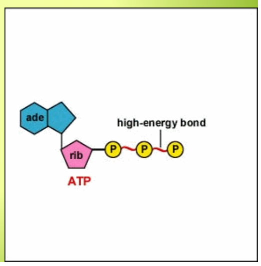
- Structure of ATP
  - **Nucleotides**
    - Nitrogen base adenine
    - Ribose
    - Three phosphates.
  - ATP is called a "high-energy" molecule
    - Three negative phosphates repel
    - ADP is more stable
    - Some energy is lost as heat
    - Overall reaction is exergonic
    - ATP is constantly recycled from ADP + P_i
    - Muscle Cell= 10 million used and recycled per second

ATP

– **Coupling Reactions**
  - Energy released by an exergonic reaction is used to drive an endergonic reaction.
  - Hydrolysis of ATP (**adenosine triphospate**)
    1. Energy from ATP → ADP + P_i is used to fuel reactions.
    2. P_i phosphoraletes an intermediate molecule making it less stable





ATP

– Function of ATP
  - Chemical work
  - Transport work
  - Mechanical work