

## I ♥ Energy

### Cellular Respiration (Glycolysis, Krebs' Cycle, etc)

#### Where Is the Energy in Food?

- The energy for living is obtained by breaking down the organic molecules originally produced in plants
  - the ATP energy and reducing power invested in building the organic molecules are stripped away as the chemical bonds are broken and used to make ATP
  - the oxidation of food stuffs to obtain energy is called **cellular respiration**
- The process of aerobic respiration requires oxygen and carbohydrates



- The products are carbon dioxide, water, and energy (heat or ATP)
- Cellular respiration takes place in three stages
  - **Glycolysis**
    - occurs in the cytoplasm
    - does not require oxygen to generate ATP
  - **Krebs cycle**
    - occurs within the mitochondrion
    - harvests energy-rich electrons through a cycle of oxidation reactions
  - **The Electron Transport Chain**
    - the electrons are passed to an electron transport chain in order to power the production of ATP
- Glycolysis is a sequence of reactions that form a **biochemical pathway**
  - in ten enzyme-catalyzed reactions, the six-carbon sugar glucose is broken into two three-carbon pyruvate molecules
  - the breaking of the bond yields energy that is used to phosphorylate ADP to ATP
    - this process is called **substrate-level phosphorylation**
    - in addition, electrons and hydrogen are donated to NAD<sup>+</sup> to form NADH
- Catabolism
  - Embden-Meyerhof-Parnas (EMP) pathway or Glycolysis
  - Tricarboxylic acid cycle (TCA)
  - Respiratory chain
    - Aerobic
    - Anaerobic
  - Alternate pathways
  - Fermentation

- Glycolysis yields only a small amount of ATP
  - only two ATP are made for each molecule of glucose
  - this is the only way organisms can derive energy from food in the absence of oxygen
  - all organisms are capable of carrying out glycolysis
  - this biochemical process was probably one of the earliest to evolve

### **Harvesting Electrons from Chemical Bonds**

- In the presence of oxygen, the first step of oxidative respiration in the mitochondrion is the oxidation of pyruvate
  - pyruvate still contains considerable stored energy at the end of glycolysis
  - the first step is to oxidize pyruvate to form acetyl-CoA
- When pyruvate is oxidized, a single of its three carbons is cleaved off by the enzyme **pyruvate dehydrogenase**
  - this carbon leaves as part of a CO<sub>2</sub> molecule
  - in addition, a hydrogen and electrons are removed from pyruvate and donated to NAD<sup>+</sup> to form NADH
  - the remaining two-carbon fragment of pyruvate is joined to a cofactor called coenzyme A (CoA)
  - the final compound is called **acetyl-CoA**

### **Producing acetyl-CoA**

- The fate of acetyl-CoA depends on the availability of ATP in the cell
  - if there is insufficient ATP, then the acetyl-CoA heads to the Krebs cycle
  - If there is plentiful ATP, then the acetyl-CoA is diverted to fat synthesis for energy storage
- The Krebs cycle is a series of nine reactions that can be broken down into three stages of oxidative respiration
  - Acetyl-CoA enters the cycle and binds to a four-carbon molecule, forming a six-carbon molecule
  - Two carbons are removed as CO<sub>2</sub> and their electrons donated to NAD<sup>+</sup>. In addition, an ATP is produced.
  - The four-carbon molecule is recycled and more electrons are extracted, forming NADH and FADH<sub>2</sub>.

### **The Krebs cycle**

- In the process of cellular respiration, the glucose is entirely consumed
  - the energy from its chemical bonds has been transformed into
    - four ATP molecules
    - 10 NADH electron carriers
    - 2 FADH<sub>2</sub> electron carriers

### Using the Electrons to Make ATP

- Mitochondria use chemiosmosis to make ATP
  - first proton pump use energetic electrons extracted from food molecules to pump protons across the cristae
  - as the concentration of protons builds up in the intermembrane space, the protons re-enter the matrix via ATP synthase channels
  - their passage powers the production of ATP from ADP
- NADH and FADH<sub>2</sub> transfer their electrons to a series of membrane-associated molecules called the **electron transport chain**
  - the transport pass along the electrons to each other and act as proton pumps
  - the last transport protein donates the electrons to hydrogen and oxygen in order to form water

### The electron transport chain

- Chemiosmosis is integrated with electron transport
  - electrons harvested from reduced carriers (NADH and FADH<sub>2</sub>) are used to drive proton pumps and concentrate protons in the intermembrane space
  - the re-entry of the protons into the matrix across ATP synthase drives the synthesis of ATP by chemiosmosis

### Alternatives to Glycolysis

- Pentose phosphate pathway (PPP or HMS):
  - Breaks down pentoses
  - NADPH is produced
  - Operates with glycolysis
  - Produces key intermediates.
- Entner-Doudoroff pathway:
  - Produces NADPH and ATP
  - Generally not found in Gram positive bacteria
  - *Pseudomonas*, *Rhizobium*, *Agrobacterium* are representative organisms that use this pathway.
- Some organisms can still perform, after glycolysis, oxidation reactions to make ATP even in the absence of oxygen
  - these organisms perform **anaerobic respiration**
    - the process involves using an electron acceptor other than oxygen
- Many organisms use sulfur, nitrate, or other inorganic compounds as the electron acceptor in place of oxygen during anaerobic respiration
  - methanogens
    - primitive archaea use CO<sub>2</sub> as the electron acceptor in addition to hydrogens derived from organic molecules

- this process reduces  $\text{CO}_2$  to  $\text{CH}_4$  (methane)
- sulfur bacteria
  - certain primitive bacteria can use inorganic sulfate ( $\text{SO}_4$ ) as an electron acceptor and form hydrogen sulfide ( $\text{H}_2\text{S}$ )
- In the absence of oxygen, animals and plants recycle  $\text{NAD}^+$  add the glycolysis-extracted electron in  $\text{NADH}$  to an organic compound
  - this process is called **fermentation**
    - animals, such as ourselves, add electrons to pyruvate and form **lactate**
    - yeasts (single-celled fungi) first convert pyruvate into acetaldehyde and then add the extracted electron to form **ethanol**