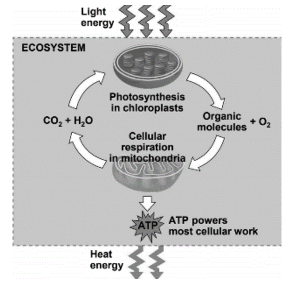
CHAPTER 9: CELLULAR RESPIRATION AND FERMENTATION



- **Integration between respiration and photosynthesis:**
  - ✓ Energy flows into an ecosystem as sunlight and leaves as heat
  - ✓ Photosynthesis generates O_2 and organic molecules, which are used in cellular respiration
  - ✓ Cells use chemical energy stored in organic molecules to regenerate ATP, which powers work

- **Respiration:**
  - ✓ The breakdown of organic molecules is exergonic
  - ✓ Fermentation: is a partial degradation of sugars that occurs without O_2
  - ✓ Aerobic respiration: consumes organic molecules and O_2 and yields ATP
  - ✓ Anaerobic respiration is similar to aerobic respiration but consumes compounds other than O_2
  - ✓ Cellular respiration includes both aerobic and anaerobic respiration but is often used to refer to aerobic respiration
  - ✓ Although carbohydrates, fats, proteins are all consumed as fuel, it is helpful to trace cellular respiration with the sugar glucose: $\mathbf{C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O}$ **+Energy (ATP + heat)**

- **Redox Reactions:**
  - ✓ Chemical reactions that transfer electrons between reactants are called oxidation-reduction reactions, or redox reactions
  - ✓ The transfer of electrons during chemical reactions releases *energy* stored in organic molecules
  - ✓ This released energy is ultimately used to synthesize ATP
  - ✓ In oxidation: a substance **loses** electrons or is oxidized
  - ✓ In reduction: a substance **gains** electrons or is reduced (the amount of positive charge is reduced)
  - ✓ Example:
    becomes oxidized
    $Xe^- + Y \longrightarrow X + Ye^-$
    becomes reduced
  - ✓ The electron donor is called the *reducing agent*
  - ✓ The electron receptor is called the *oxidizing agent*
  - ✓ During cellular respiration, the fuel (such as **glucose**) is **oxidized**, and *O_2* is *reduced*:

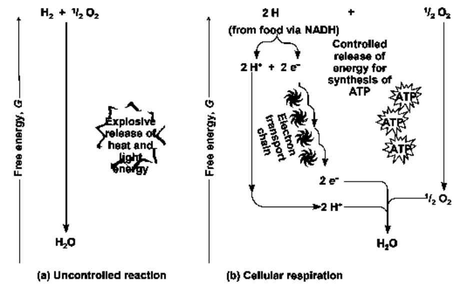
becomes oxidized

$$C_6H_{12}O_6 + 6\,O_2 \longrightarrow 6\,CO_2 + 6\,H_2O + \text{Energy}$$

becomes reduced

- **Stepwise Energy Harvest via NAD+ and the Electron Transport Chain:**
  - ✓ cellular respiration, glucose and organic molecules are broken down in a series of steps
  - ✓ Electrons from organic compounds are usually **first transferred to NAD$^+$**
  - ✓ As an electron acceptor, NAD$^+$ functions as an ***oxidizing agent*** during cellular respiration

- ✓ $NAD^+ + 2e^- + 2H^+ \rightarrow NADH + H^+$
- ✓ Each NADH (the reduced form of NAD^+) represents stored energy that is tapped to synthesize ATP
- ✓ NADH passes the electrons to the electron transport chain
- ✓ Unlike an uncontrolled reaction, the electron transport chain passes electrons in a series of steps instead of one explosive reaction
- ✓ O_2 pulls electrons down the chain in an energy-yielding tumble
- ✓ The energy yielded is used to regenerate ATP



- ➢ <u>**Stages of Cellular Respiration:**</u>
- ✓ **Glycolysis**: breaks down glucose into two molecules of pyruvate
- ✓ **The citric acid cycle**: completes the breakdown of glucose
- ✓ **Oxidative phosphorylation**: accounts for almost **90%** of the ATP generated by cellular respiration
- ✓ **Notes**:

1. smaller amount of ATP is formed in glycolysis and the citric acid cycle by <u>substrate-level phosphorylation</u>
2. For each molecule of glucose degraded to CO_2 and water by respiration, the cell makes up to **32** molecules of ATP

- ✓ **Glycolysis**: ("splitting of sugar") occurs in the <u>cytoplasm</u> and has two major phases:

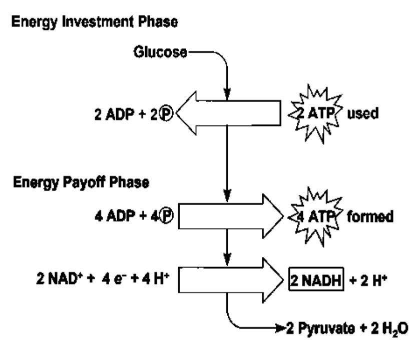
  – Energy investment phase – Energy payoff phase

<u>**Net:**</u>

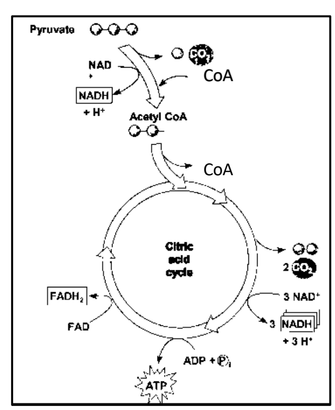
I. Glucose$\rightarrow$ 2 Pyruvate + 2 H_2O

II. 4 ATP formed − 2 ATP used$\rightarrow$2 ATP

III. $2NAD^+ + 4e^- + 4H^+ \rightarrow 2NADH + 2H^+$



- ✓ **The citric acid cycle**: In the presence of $\mathbf{O_2}$, pyruvate enters the <u>mitochondrion</u>
- o Oxidation of Pyruvate to Acetyl CoA:
- * Before the citric acid cycle can begin, pyruvate must be converted to acetyl Coenzyme A (acetyl CoA, abbreviated a SCoAto emphasize it sulfur atom), which links glycolysis to the citric acid cycle
- * This step is carried out by a multienzyme complex (The Pyruvate Dehydrogenase complex) that catalyses three reactions
- o The citric acid cycle, also called the Krebs cycle, takes place within the mitochondrial matrix
- o The citric acid cycle has eight steps, each catalysed by a specific enzyme



- The cycle oxidizes organic fuel derived from pyruvate, generating 1ATP, 3NADH, $2CO_2$ and $1FADH_2$ per turn (Each glucose makes 2 turns)
- In the first step, acetyl group of acetyl CoA joins the cycle by combining with oxaloacetate, forming **citrate**
- The next seven steps **decompose** the citrate back to oxaloacetate, making the process a cycle
- The NADH and $FADH_2$ produced by the cycle relay electrons extracted from food to the electron transport chain

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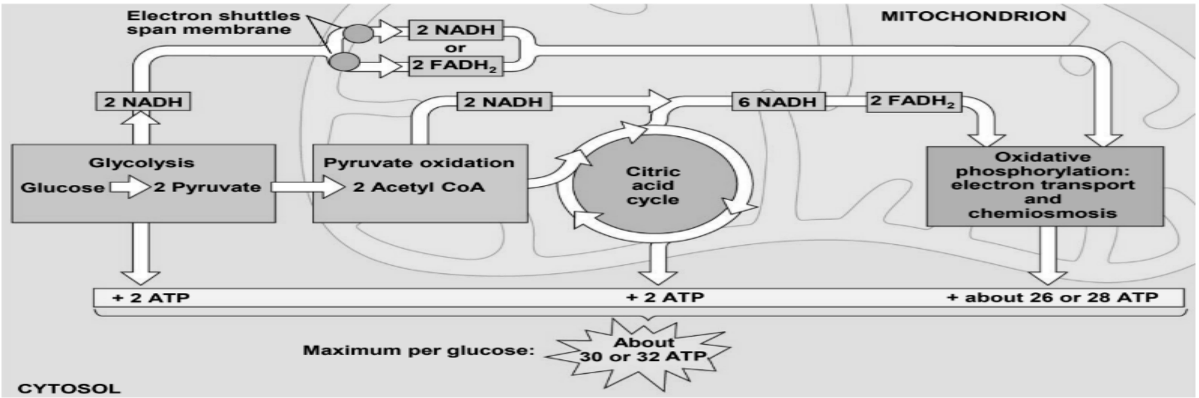
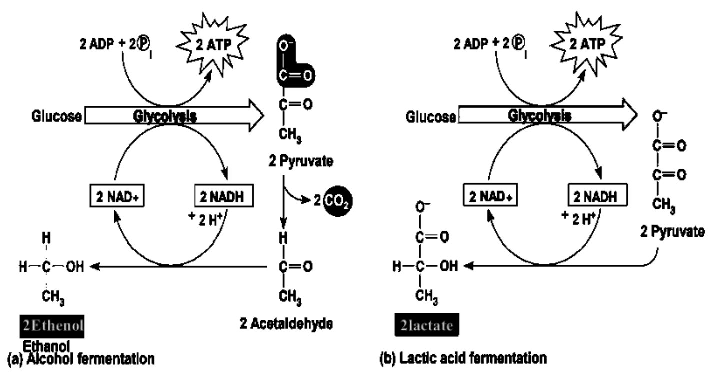
✓ **Oxidative phosphorylation**:

- Following glycolysis and the citric acid cycle, NADH and $FADH_2$ account for most of the energy extracted from food
- These two electron carriers donate electrons to the electron transport chain, which powers ATP synthesis via oxidative phosphorylation
- The electron transport chain is in the cristae of the mitochondrion
- Most of the chain's components are proteins, which exist in multiprotein complexes
- The electron transport chain generates no ATP
- Electrons drop in free energy as they go down the chain and are finally passed to O_2, forming H_2O
- Electrons are transferred from NADH or $FADH_2$ to the electron transport chain
- Electrons are passed through a number of proteins including cytochromes (each with an iron atom) to O_2
- It breaks the large free-energy drop from food to O_2 into smaller steps that release energy in manageable amounts
- Chemiosmosis: (The Energy-Coupling Mechanism)
  - Electron transfer in the electron transport chain causes proteins to pump H^+ from the mitochondrial matrix to the intermembrane space
  - H^+ then moves back across the membrane, passing through channels in ATP synthase
  - ATP synthase uses the exergonic flow of H^+ to drive phosphorylation of ATP
  - This is an example of chemiosmosis, the use of energy in a H^+ gradient to drive cellular work
  - The energy stored in a H+ gradient across a membrane couples the redox reactions of the electron transport chain to ATP synthesis
  - The H+ gradient is referred to as a proton-motive force, emphasizing its capacity to do work
- During cellular respiration, most energy flows in this sequence:
  food → NADH → electron transport chain → proton-motive force → ATP
- About 34% of the energy in a glucose molecule is transferred to ATP during cellular respiration, making about 32 ATP



➢ <u>**Fermentation and anaerobic respiration:**</u>

- <u>Glycolysis</u> can produce ATP with or without O_2 (in aerobic or anaerobic conditions)
- In the absence of O_2, glycolysis couples with fermentation or anaerobic respiration to produce ATP
- Anaerobic respiration uses an electron transport chain with a final electron acceptor other than O_2 (e.g. sulfate)
- Fermentation uses substrate-level phosphorylation instead of an electron transport chain to generate ATP
- Fermentation: Fermentation consists of glycolysis plus reactions that regenerate NAD^+, which can be reused by glycolysis
  - Two common types are alcohol fermentation and lactic acid fermentation:
  - <u>In alcohol fermentation</u>: pyruvate is converted to ethanol in two steps, with the first releasing CO_2 Alcohol fermentation by yeast is used in brewing, winemaking, and baking
  - <u>In lactic acid fermentation</u>: pyruvate is reduced to NADH, forming lactate as an end product, with no release of CO_2, Lactic acid fermentation by some fungi and bacteria is used to make cheese and yogurt and Human muscle cells use lactic acid fermentation to generate ATP when O_2 is scarce



➢ <u>**metabolic pathways:**</u>

- Glycolysis and the citric acid cycle are major intersections to various catabolic and anabolic pathways
- Catabolic pathways funnel electrons from many kinds of organic molecules into cellular respiration
- Glycolysis accepts a wide range of carbohydrates
- Proteins must be digested to amino acids; amino groups can feed glycolysis or the citric acid cycle

- Fats are digested to glycerol (used in glycolysis) and fatty acids (used in generating acetyl CoA)
- Fatty acids are broken down by beta oxidation and yield acetyl CoA
- An oxidized gram of fat produces more than twice as much ATP as an oxidized gram of carbohydrate
- **Anabolic Pathways**
  * The body uses small molecules to build other substances
  * These small molecules may come directly from food, from glycolysis, or from the citric acid cycle
  * Humans can make more than half of the 20 amino acids by modifying compounds siphoned away from citric acid cycle
  * Glucose can be synthesized from pyruvate
  * Fats can be synthesized from Acetyl-CoA

➢ **<u>Regulation of Cellular Respiration via Feedback Mechanisms:</u>**

- Feedback inhibition is the most common mechanism for control
- If ATP concentration begins to drop, respiration speeds up; when there is plenty of ATP, respiration slows down
- Control of catabolism is based mainly on regulating the activity of enzymes at strategic points in the catabolic pathway