Cellular Respiration
Chapter 5 Notes
Some Terms to Know

- Aerobic = WITH oxygen
- Anaerobic = withOUT oxygen
- NAD – electron carrier = NADH
- FAD – electron carrier = FADH₂
- Cellular Respiration – a way for cells to make energy when oxygen is present
- Fermentation – a way for cells to make energy when oxygen is not present
Cellular Respiration Overview

- Transformation of chemical energy in food into chemical energy cells can use: ATP

- Overall Reaction:
  \[ C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + ATP \text{ (energy)} \]
Decomposition Reaction...why?

Respiration

\[ \text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{Energy} \]
Hydrolysis

- When water is inserted into a bond to break it!
- Most biological decomposition reactions involve hydrolysis
Cellular Respiration in 3 Stages

- **Glycolysis** – in cytoplasm of cell
- **Krebs Cycle** – if oxygen is present and in the mitochondrial matrix
  - If oxygen is not present, fermentation occurs
- **Electron Transport Chain** – after the Krebs Cycle and in the cristae (membranes) of mitochondria
Cellular Respiration Overview

- Breakdown of glucose begins in the cytoplasm: the liquid matrix inside the cell
- At this point life diverges into two forms and two pathways
  - Anaerobic cellular respiration (aka fermentation)
  - Aerobic cellular respiration
Diagram of the Reaction

- **Glucose** → **Glycolysis** → **Mitochondrion** → **Krebs Cycle** → **Electron Carriers** → **Electron Transport Chain** → **6 H₂O**
- **6 CO₂**
- **ATP**
C.R. Reactions

● Glycolysis
  - Occurs in cytoplasm of all cells
    - Series of reactions which break the 6-carbon glucose molecule down into two 3-carbon molecules called pyruvate
    - Yields 2 ATP molecules for every one glucose molecule broken down
    - Yields 2 NADH per glucose molecule
    - Process is an ancient one—all organisms from simple bacteria to humans perform it the same way
Glycolysis Reaction

1. Phosphorylation of glucose by ATP

2-3. Rearrangement, followed by a second ATP phosphorylation.

4-5. The six-carbon molecule is split into two three-carbon molecules—one G3P, another that is converted into G3P in another reaction.

6. Oxidation followed by phosphorylation produces two NADH molecules and two molecules of BPG, each with one high-energy phosphate bond.
Glycolysis Reaction Cont.

6. Oxidation followed by phosphorylation produces two NADH molecules and two molecules of BPG, each with one high-energy phosphate bond.

7. Removal of high-energy phosphate by two ADP molecules produces two ATP molecules and leaves two 3PG molecules.

8-9. Removal of water yields two PEP molecules, each with a high-energy phosphate bond.

10. Removal of high-energy phosphate by two ADP molecules produces two ATP molecules and two pyruvate molecules.
Anaerobic Cellular Respiration /Fermentation

- Some organisms thrive in environments with little or no oxygen
  - Marshes, bogs, gut of animals, sewage treatment ponds
- No oxygen used = ‘an’aerobic
- Results in no more ATP after glycolysis, final steps in these pathways serve ONLY to regenerate NAD+ so it can return to pick up more electrons and hydrogens in glycolysis.
- Occurs in cytoplasm
- End products such as ethanol and CO₂ (single cell fungi (yeast) in beer/bread) or lactic acid (muscle cells)
Pyruvate Pathways

With oxygen:
- Pyruvate $\rightarrow$ NADH $\rightarrow$ Acetyl-CoA $\rightarrow$ Krebs cycle
- H$_2$O $\rightarrow$ NAD$^+$
- O$_2$

Without oxygen:
- Pyruvate $\rightarrow$ NADH $\rightarrow$ Acetaldehyde $\rightarrow$ Lactate $\rightarrow$ NAD$^+$
- NADH $\rightarrow$ Ethanol $\rightarrow$ CO$_2$
Alcohol Fermentation

Glucose

2 ADP → 2 ATP

Glycolysis

2 NAD^+ → 2 NADH

2 Pyruvate → 2 Acetaldehyde

CO₂

2 Ethanol

Alcohol fermentation in yeast
Lactic Acid Fermentation

Glucose

2 ADP → 2 ATP

2 NAD⁺ → 2 NADH

2 Pyruvate

2 Lactate

Lactic acid fermentation in muscle cells
Aerobic Cellular Respiration

- Oxygen required = aerobic
- 2 more sets of reactions which occur in a specialized structure within the cell called the mitochondria
  - 1. Kreb’s Cycle
  - 2. Electron Transport Chain
Kreb’s Cycle

- Completes the breakdown of glucose
  - Takes the pyruvate (3-carbons) and breaks it down, the carbon and oxygen atoms end up in CO$_2$ and H$_2$O
  - Hydrogens and electrons are stripped and loaded onto NAD$^+$ and FAD to produce NADH and FADH$_2$

- Production of only 2 more ATP but loads NAD and FAD with H$^+$ and electrons which move to the 3$^{rd}$ stage…ETC
Glycolysis

Glycogen → Pyruvate

Cytosol

ATP

Substrate-level phosphorylation

Citric acid cycle

Mitochondrion

ATP

Substrate-level phosphorylation
Krebs Cycle (Citric Acid Cycle)

Pyruvic acid → NAD⁺ → NADH → Acetyl-CoA → CO₂

Acetyl-CoA + OAA (4C) → Citric acid (6C) + NAD⁺

Citric acid (6C) → NAD⁺ + CO₂

NAD⁺ + FADH₂ → NADH + FAD

FAD + ADP + P_i → ATP

http://highered.mcgraw-hill.com/sites/0072507470/student_view0/chapter25/animation_how_the_krebs_cycle_works_quiz_1_.html
Electron Transport Chain

- Electron carriers loaded with electrons and protons from the Kreb’s cycle move to this chain-like a series of steps (staircase).
- As electrons drop down stairs, energy released to form a total of 34 ATP
- Oxygen waits at bottom of staircase, picks up electrons and protons and in doing so becomes water
Electron Carriers

- $\text{NAD} + \text{electrons} = \text{NADH}$
- $\text{FAD} + \text{electrons} = \text{FADH}_2$
- NADH is worth 3 ATP in the ETC
- FADH$_2$ is worth 2 ATP in the ETC
Energy Tally

- 38 ATP for aerobic vs. 2 ATP for anaerobic
  - Glycolysis 2 ATP
  - Kreb’s 2 ATP
  - Electron Transport 34 ATP, 38 ATP

- Anaerobic organisms can’t be too energetic but are important for global recycling of carbon
Glycolysis
Glucose → Pyruvate

Cytoplasm
Electron shuttles span membrane
2 NADH or 2 FADH₂

Mitochondrion
2 NADH
6 NADH
2 FADH₂

Oxidative phosphorylation: electron transport and chemiosmosis

Citric acid cycle
2 Acetyl CoA

+ 2 ATP by substrate-level phosphorylation
+ 2 ATP by substrate-level phosphorylation
+ about 32 or 34 ATP by oxidative phosphorylation, depending on which shuttle transports electrons from NADH in cytosol

Maximum per glucose: About 36 or 38 ATP

Cellular Respiration - heat

- Cell Resp. releases some energy as heat which help keep our internal temps constant.
- Brown fat - more mitochondria so faster CR and more heat = important for hibernating animals and infants
Cellular Resp-heat production in plants

• Some plants produce enough heat energy so that organic compounds break down, causing an odor. Insects flock to the odor – plant gets pollinated
Mitochondrial Disease

- Diseases of the mitochondria appear to cause the most damage to cells of the brain, heart, liver, skeletal muscles, kidney and the endocrine and respiratory systems.

More Mitochondrial Functions

- Non-ATP-related functions are intimately involved with most of the major metabolic pathways used by a cell to build, break down, and recycle its molecular building blocks. Cells cannot even make the RNA and DNA they need to grow and function without mitochondria. The building blocks of RNA and DNA are purines and pyrimidines. Mitochondria contain the rate-limiting enzymes for pyrimidine biosynthesis (dihydroorotate dehydrogenase) and heme synthesis (d-amino levulinic acid synthetase) required to make hemoglobin. In the liver, mitochondria are specialized to detoxify ammonia in the urea cycle. Mitochondria are also required for cholesterol metabolism, for estrogen and testosterone synthesis, for neurotransmitter metabolism, and for free radical production and detoxification. They do all this in addition to breaking down (oxidizing) the fat, protein, and carbohydrates we eat and drink.
Facultative aerobes -

- Can survive for long periods of time with or without oxygen
- They switch back and forth between cell resp & fermentation depending on the availability of oxygen
- Ex: staph/ecoli
Obligate Anaerobes-

- Does not require oxygen and only lives in an anaerobic env.
- Use fermentation/anaerobic respiration to yield energy
- Much less ATP is made this way
- EX: Clostridium bacteria
Obligate Aerobes -

• REQUIRE oxygen for respiration or they won’t live
• Yield much more energy than obligate anaerobes
• EX: plants, animals
Nutrient Cycles – Biogeochemical cycles

- Chemicals are limited, those essential for life must be recycled.
- Elements move through a global cycle (carbon dioxide, oxygen, and nitrogen)
- Phosphorous and sulfur don’t move much – stick around in the soil.
- Carbon Cycle, Nitrogen Cycle, Water cycle
The Carbon Connection…

• Photosynthesis uses it (all photosynthetic organisms)

• CR creates it (so, all living things)
• Cars, factories, appliances emit it
• Decaying organic matter releases it
• Adds to global warming
Ohhhh…Carbon

• Carbon is the backbone of life on Earth. We are made of carbon, we eat carbon, and our civilizations—our economies, our homes, our means of transport—are built on carbon. We need carbon, but that need is also entwined with one of the most serious problems facing us today: global climate change.

• Carbon is the fourth most abundant element in the Universe. Most of Earth’s carbon—about 65,500 billion metric tons—is stored in rocks. The rest is in the ocean, atmosphere, plants, soil, and fossil fuels
Your carbon footprint?

Breakdown of a typical person's Carbon Footprint

- Share of public services: 12%
- Gas, Oil and Coal: 15%
- Electricity: 12%
- Private Transport: 10%
- Public Transport: 5%
- Holiday Flights: 4%
- Food and Drink: 3%
- Clothes and personnel effects: 2%
- Carbon in Car Manufacture: 7%
- Household (buildings and furnishings): 9%
- Recreation and leisure: 14%
Carbon Credits

You

Donate to Carbonfund.org to offset your carbon emissions

Do your part to fight global warming and become carbon neutral.

You (fighting global warming)

Offsets

Your donations fund third-party validated offset projects

Carbonfund.org retires the carbon credits created by the projects

Carbonfund.org

Verified Carbon Offset Projects

Carbon Offset Center

LAWN & GARDEN CENTER