**Study Plan: Episode 3—Metabolism**

* Read the UNIT OVERVIEW presented in this Study Guide.
* View the video "Metabolism", episode #3. I had trouble getting directly to episode three. I ended up going to episode #4 and then clicking on the previous button, which then took me back to episode #3
* Read Chapter Nine from the text (pgs. 170 – 192)
* Read UNIT OBECTIVES and KEY CONCEPTS sections of this study guide.
* View the video a second time, this time taking notes. Pay particular attention to topics identified by the UNIT OBJECTIVES or KEY CONCEPTS as significant.
* Return to the Unit Objectives and Key Concepts listed in this Study Guide. Review sections of the text or video pertinent to material you don't feel you have mastered.
* Test your mastery of the material by answering the Review Questions at the end of this Study Guide.
* Check your answers against the answer key; review material relating to any questions you missed.
* Explore further! Retrieve from the library the articles listed in Suggested Further Readings that appear interesting.

**Unit Overview**

Metabolism refers to all of the biochemical reactions of a cell – the processes involved in the making and using energy. Metabolism is essential for the survival and growth of all organisms. The instructions for all of the metabolic reactions are contained within the DNA. In **catabolism**, macromolecules are **broken into smaller molecules**; the smaller molecules may be further “catabolized” to yield ATP (adenosine triphosphate), or they may be **assembled into new macromolecules** by ATP-driven **anabolic** processes (anabolism). ATP is the molecule used by all living organisms for energy; the energy for its synthesis is derived from the transfer of electrons. Different organisms have different metabolic strategies; strategies determined by their DNA and selected for by their environment. In ecosystems complex assemblages of organisms with different metabolic strategies function together to cycle energy and matter through the system.

An ecosystem's consumers (pathogenic bacteria, yeast) generate energy by respiration or fermentation. In both processes, ATP is generated by harvesting electrons from an **organic** **compound** (a compound that contains both carbon and hydrogen) and shuttling them to a different compound. In respiration, the terminal electron acceptor (TEA) is usually oxygen; in fermentation it is a simple organic molecule formed by the breakdown of the original compound. In wastewater treatment facilities, nutrients in sewage serves as the electron donor for a community of microorganisms referred to as sludge; oxygen is made available as the TEA. When making beer, brewers provide yeast with sugar to serve as an electron donor; the simple organic compound used as a final electron acceptor reduces to alcohol! In natural systems, primary producers, phototrophs and chemolithotrophs, form the organic compounds required by consumers. Phototrophs (example: algae) convert **light** energy to ATP; chemolithotrophs convert energy stored in the chemical bonds of **inorganic** **compounds** to ATP.

Microorganisms have evolved a multitude of diverse metabolic strategies, enabling them to exploit a variety of different energy sources. Environments change and new energy sources become available. Random mutations change the DNA of microbes, enabling them to fill new niches and earn a living from novel compounds. However, the directions for earlier metabolic strategies remains encoded in the DNA of some of these organisms, ensuring their survival should environmental conditions change again.

**Unit Objectives**

* Explain the function and importance of metabolism.
* Relate the diversity in metabolic abilities to differences in the DNA of different organisms
* List the two nutritional classes and describe how organisms in each obtain energy and carbon
* Provide an example of an organism from each nutritional class.
* Distinguish between:
  + phototrophs and chemolithotrophs
  + anabolic and catabolic reactions
  + anaerobic and aerobic respiration
  + fermentation and respiration
* Explain what ATP is
* Describe the phases of microbial growth in a culture

**Key Words**

* Acidophile
* Anabolism
* ATP
* Barophile
* Catabolism
* Cytochrome
* Death phase
* Electron transport system
* Facultative
* Fermentation
* Glycolysis
* Growth curve
* Halophile
* Krebs cycle
* Lag phase
* Log phase
* Mesophile
* Metabolism
* Microaerophile
* Psychrophile
* Substrate
* Thermophile

**Key Concepts**

**METABOLISM: AN OVERVIEW**

* Metabolism is the sum of all the chemical reactions that channel the flow of energy and matter in the cells.
* Enzymes direct metabolic reactions; the reactions that *can* happen are determined by the enzymes present in the cell.
* DNA carries the directions for enzyme synthesis; it determines the cell's metabolism.
* The principal function of metabolism is for the doubling all cellular components and reproduction
* There are two broad groups of reactions: Catabolism and Anabolism
  + catabolic pathways "break bonds" and produce (1) energy in the form of ATP or (2) subunits to make new organic molecules
  + anabolic pathways make bonds: Biosynthesis and polymerization are anabolic processes
* ATP, the energy molecule, is produced through anaerobic and aerobic respiration and fermentation
* An organism's DNA determines how they obtain their source of energy and their carbon for making their own organic molecules
* Microbial respiration, both aerobic and anaerobic is a useful tool in the bioremediation of environmental pollutants
* Microbial fermentation produces many useful byproducts

**OBTAINING NUTRIENTS: NUTRITIONAL CLASSES OF MICROORGANISMS:**

* Nutrients for metabolism are transported across the cell membrane before they enter into metabolism
* Nutritional classes are defined according to two factors:

1. The energy source used to generate ATP.
2. The source of carbon atoms used to make new molecules.

* Autotrophs or "self-feeders"; have specialized pathways to harvest energy and carbon from light and/or inorganic sources and produce an ecosystem's organic carbon compounds
  1. Phototrophs, such as photosynthetic bacteria and algae, get their energy from light and their carbon from CO2 (and produce O2 and carbon molecules like glucose as part of the carbon cycle)
  2. Chemolithotrophs, such as the Archaea living near the deep sea vents, derive their energy from inorganic compounds and their carbon atoms from CO2.
* Heterotrophs are other feeders
  1. Chemoheterotrophs derive energy and carbon from the breakdown of organic compounds in fermentation and respiration.
  2. Single-celled animals, protozoa and many microbes are chemoheterotrophs
* Autotrophs are the primary producers and heterotrophs are the primary consumers

**CATABOLIC PATHWAYS:**

* Catabolic pathways lead to production of energy (ATP) or subunits to make other molecules so that the cells can grow and reproduce.
* Catabolic reactions are organized into pathways that convert substrates, or starting materials to a series of compounds called metabolic intermediates or metabolites. Each pathway is an ordered sequence of chemical reactions; each reaction is catalyzed by a different enzyme.
* Compounds are oxidized when they lose electrons or hydrogen atoms; they are reduced when they gain electrons or hydrogen atoms.
* In respiration the electrons are "passed" through a series of steps (electron transport chain) to a terminal electron acceptor
  + in **aerobic respiration the acceptor is** **oxygen** (electrons park on oxygen). In the process ATP, water (H2O) and CO2 are made.
  + aerobic respiration occurs in the mitochondria of eukaryotes and in cell membrane of prokaryotes.
  + in **anaerobic respiration oxygen is not used**, the electron can be parked on sulfate, nitrate etc depending upon the microbe (ie. near deep sea vents).
* In **fermentation** the electrons do not go to the electron transport chain but instead are parked on a small organic molecule, an alcohol or a gas.
  + examples include acetic acid (vinegar), lactic acid, ethanol, CO2
  + during the production of beer, yeast ferment the sugars provided in the grains into ethanol (alcohol) and CO2 which is vented off
* **Fermentation is anaerobic metabolism**: occurs in absence of oxygen.
  + in our muscles we produce lactic acid when oxygen is low
* Fermentation occurs in the cytoplasm of both eukaryotes and prokaryotes
* In heterotrophs fermentation and respiration both start with a series of enzymatic steps called glycolysis (means glucose + lysis): 2 ATP and 2 pyruvates (3-carbon molecule) are made per starting glucose (glucose is a 6-carbon sugar molecule).
  + Pyruvate then feeds into the pathways for aerobic respiration if oxygen is present or is converted to alcohol, lactic acid etc in the absence of oxygen via fermentation
* Many microbes are facultative anaerobes: this means they prefer to use oxygen since they make more ATP but they can use fermentation pathways in the absence of oxygen
  + Yeast use aerobic respiration when making bread (the C02) bubbles cause the bread to rise

**ATP IS THE ENERGY MOLECULE OF THE CELL!**

* + Adenosine triphosphate (ATP) is formed by adding a single phosphate group (the yellow balls in the figure) to adenosine diphosphate (ADP) which is a nucleotide.
  + Phosphorylation occurs when a phosphate group is joined to another molecule, so when ADP is phosphorylated, it becomes ATP.
  + ATP's energy is stored in the two high-energy bonds that join the last two of its three phosphate groups.
  + When these high-energy bonds are broken, a phosphate group is readily donated to other compounds. Phosphorylated compounds participate in metabolic reactions that would not occur if a reactant did not have the high energy phosphate group added on.

**ANABOLIC PATHWAYS**

* + The anabolic reactions of the cell are organized into biosynthesis pathways, enzyme-catalyzed reaction sequences that convert precursor metabolites into the cell's small molecules. This includes coenzymes (molecules that assist enzymes) and building blocks for macromolecules.
  + The building blocks are then put together to form macromolecules which are large complex molecules. Since polymers of the subunits are made this is called polymerization
  + Macromolecules include nucleic acids (DNA and RNA), proteins, carbohydrates and lipids
    - nucleotides are subunits for DNA/RNA
    - amino acids are subunits for proteins
    - simple sugars like glucose are subunits for carbohydrates like starch and cellulose
    - fatty acids are subunits for lipids
  + Vitamins are ready-made molecules that act as coenzymes or their precursors.

**THE WAY MICROORGANISMS GROW**

* + Doubling time is the period required for cells in a microbial population to grow, divide and produce two new cells for each one that existed before.
  + Microbial growth is graphed on a logarithmic scale.
  + A microbial culture typically passes through four distinct phases of growth: the lag phase, exponential (or log) phase, stationary phase and the death phase.
  + A **lag phase** usually follows the inoculation of the microbe into fresh culture medium. It is a no-growth period, but there is considerable metabolic activity as cells prepare to grow.
  + During **exponential phase** cells double at a constant rate; exponential phase ends when one or more essential nutrients are depleted or toxic metabolic byproducts accumulate.
  + During **stationary phase** growth cell division is match by cell death.
  + During **death phase**, cells die exponentially, but at a slower rate than they grow during log phase. Death usually occurs when cells deplete their intracellular reserve of ATP.
  + Under most natural conditions, nutrients continuously enter a cell's environment at low concentrations; the growth rate is determined by the concentration of the limiting nutrient.
  + When brewing beer, yeast cells are grown in culture; their growth is limited by the amount of sugar the brewer makes available!
  + Most microbes grow at neutral pH values (approximately 6 – 8). Some grow at acidic pH values (5 or less) and these are the organisms used to ferment food (yogurt, cheese)
  + Most microbes grow in the **mesophilic** range (above refrigeration temperatures; > 4oC) and up to slightly above body temperature (37oC). There are **thermophilic** microbes that grow at high temperatures found in nature (hot springs, volcanic vents). Likewise, there are microorganisms that grow at refrigeration temperatures (4oC and lower). These are called either **psychrophiles** or **cryophilic** organisms.
  + In the lab we cultivate bacteria on nutrient broth or nutrient agar (a solid form as in the Petri dishes used in Lab #4). The individual “dots” that grow on the agar are celled colonies. Each colony arose from a single bacterial cell. Some microorganisms will not grow on agar and we use a living source of growth media, such as fertilized chicken eggs or eukaryotic cells grown in culture. This is the manner in which viruses and some bacteria (e.g. Rickettsiae) are grown). Some bacteria have to be grown in the absence of the air because the O2 can kill them. Examples of these are *Clostridium botulinum* (botulism) and *Clostridium* *tetani* (tetanus).
  + In the lab we use several different methods to get isolated colonies – an important step when analyzing bacteria. These are the pour plate, the streak plate, and the spread plate. Note that we always use solid media (agar plates) to obtain isolated colonies.

**Waste Water Treatment**

* Waste water treatment plants can be thought of as a metabolism-driven ecosystem.
* Waste comes from a variety of sources including sinks and toilets.
* The first stage is to separate large particles from the small particles
* Respiration then takes place in which bacteria convert the various materials in the waste water into a form they can use (energy in the form of electrons); the electron are put onto O2 (oxygen) and ATP is created in the process. Thus, water and ATP are made in these catabolic processes.
* Air is added to the treatment process because the O2 can become the rate-limiting factor.
* The mixed liquor (waste water and microbes) goes to a clarifier where the microbes and any other material settle to the bottom.
* The clarified water is sent to the river while the solid settled material either goes back to the beginning (aeration basin) as a source of the microbes or it is sent to an anaerobic digester.
* The anaerobic digester has another complex population of microbes that carry out fermentation, which further reduces the wastes to organic acids.
* Methanogens in the anaerobic digester utilize the organic acids to produce methane, which can be used as natural gas.
* The residual bacteria from the anaerobic digester can be dried and used in agriculture as a fertilizer.
* Minerals end up in the water from these processes. These minerals are needed by primary producers (algae and plants).

**Volcanic vents**

* The minerals discharged from the vents crystallize rapidly in the cold water. These minerals, especially sulfur, are used as a source of energy since no light penetrates the water to the depths at which we find these vents.
* These microorganisms (chemolithotrophs) then serve as food for larger organisms such as tubeworms, fish, and crabs.
* Chemolithotrophs were responsible for the quick recovery of the area devastated by the eruption of Mount St. Helens.

**Review Questions**

**True/False**

1. Oxidation is the loss of electrons.

2. All autotrophs are photosynthetic.

3. In both eukaryotes and bacteria respiration occurs in the mitochondria.

4. In alcoholic fermentation, pyruvate is converted to C02 and ethanol.

5. Heterotrophs and autotrophs work together to cycle energy and nutrients through ecosystems.

6. In aerobic respiration, electrons are delivered to an electron transport chain.

7. If an exponential culture is moved from a poor to a rich medium, a lag phase does not normally occur.

**Multiple Choice**

1. All organisms in this nutritional class of microorganisms harvest energy (electrons) and carbon from the same source.

A) autotrophs

B) heterotrophs

C) chemotrophs

D) phototrophs

2. Exponential growth of a population occurs in the \_\_\_\_\_\_\_\_\_\_\_\_ phase.

A) death

B) lag

C) log

D) stationary

3. The use of a closed container (such as a brewer's tank) for microbe cultivation means that

A) four stages of population growth do not occur.

B) nutrients are continually supplied.

C) four stages of population growth will occur.

D) metabolic byproducts are continually removed.

4. Macromolecules of the cell are produced by

A) polymerization or anabolism.

B) biosynthesis.

C) catabolism.

D) glycolysis.

5. In the absence of oxygen, \_\_\_\_\_\_\_\_\_\_occurs in the muscle tissue of animals.

A) lactic acid fermentation

B) alcohol fermentation

C) anaerobic respiration

D) metabolism does not proceed; the tissue dies

6. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ are the producers in deep sea ocean vent ecosystems.

A) Phototrophs

B) Chemolithotrophs

C) Organotrophs

D) Heterotrophs

**Fill In**

1. \_\_\_\_\_\_\_\_\_\_ anaerobes are capable of both aerobic and anaerobic metabolism.

2. In anaerobic respiration an inorganic molecule other than \_\_\_\_\_\_\_\_\_\_ is the terminal electron acceptor.

3. During \_\_\_\_\_\_\_\_\_\_ the breakdown products can be used to make ATP or be substrates for anabolic reactions.

4. The cell's \_\_\_\_\_\_\_\_\_\_ determines its metabolic strategy.

5. During the brewing process when the sugar supply runs out the yeast enter the \_\_\_\_\_\_\_\_\_\_\_\_ phase

**Discussion Questions**

1. How does a microbe's DNA determine its metabolic strategy? What role does the environment play in shaping the metabolic strategies of microbial populations?

2. Is the projected size of a bacterial population simply a matter of doubling the cell number over regular time intervals?

**Answers**

**True/False**

1. T 2*.* F 3. F 4. T 5. T 6. T 7. F

**Multiple Choice**

1. B 2. C 3. C 4. A 5. A 6. B

**Fill In**

1. Facultative 2. oxygen 3. Catabolic 4*.* DNA 5. death or decline

**Discussion**

1. DNA codes for the enzymes that drive metabolic reactions, determining what metabolic reactions can happen in a cell. The environment selects for organisms that can competitively fill available niches.

2. Will all of the cells produced continue to live and reproduce? Will the rate of division be affected by environmental factors? Also, consider the effect of limiting factors and nutrients.

**Suggested Readings**

Dawes, E. A. 1986. *Microbial energetics.* New York: Chapman and Hall Gottschalk, G. 1979. *Bacterial Metabolism.* New York: W.H. Freeman.

Ingraham, J.L.; Maaloe, 0.; and Neidhart, F.C. 1983. *Growth of the bacterial cell.* Sunderland, Mass.: Sinauer.

Neidhardt, F.C. 1987. *Escherichia coli and Salmonella typhimurium.* Washington, D.C.: American Society for Microbiology