Chapter 6 Metabolism: Fueling Cell Growth

Summary Outline

6.1 Principles of metabolism

A. **Catabolism** encompasses those processes that transform and release energy.

B. **Anabolism** includes the processes that utilize energy to synthesize and assemble the building blocks of a cell.

C. Harvesting energy

1. **Energy** is the ability to do work.
2. The first law of thermodynamics states that the energy in a system can never be created or destroyed.
3. The second law of thermodynamics states that **entropy** always increases.
4. **Photosynthetic organisms** harvest the energy of sunlight, using it to power the synthesis of organic compounds.
5. **Chemoorganotrophs** transform energy by organic compounds.
6. Free energy is the amount of energy that can be gained by breaking the bonds of a chemical.
   a) **Exergonic** reactions release energy.
   b) **Endergonic** reactions utilize energy.

D. Components of metabolic pathways

1. A **specific enzyme** facilitates each step of a metabolic pathway by **lowering the activation energy** of a reaction that converts a substrate into a product.
2. **ATP** is the energy currency of the cell.
   a) **Substrate level phosphorylation** uses the chemical energy released in an exergonic reaction to add P_i to ADP.
   b) **Oxidative phosphorylation** harvests the energy of proton motive force to do the same thing.
3. The energy source is oxidized to release its energy; this oxidation-reduction reaction **reduces an electron carrier**.
4. **NAD^+, $NADP^+$,** and **FAD** are electron carriers. Their reduced form functions as reducing power. NADH and $FADH_2$ are used to provide electrons for the generation of proton motive force. NADPH is used in biosynthesis.
5. **Precursor metabolites** are building blocks that can be used to make the subunits of macromolecules, but they can also be oxidized to release energy.

E. Scheme of metabolism

1. The central metabolic pathways are:
   a) **Glycolysis**
   b) The **pentose phosphate pathway**
   c) **The tricarboxylic acid cycle (TCA cycle)**
2. **Glycolysis** oxidizes glucose to pyruvate, producing ATP, reducing power and precursor metabolites.
3. The **pentose phosphate pathway** also oxidizes glucose to pyruvate, but its primary role is the production of precursor metabolites and reducing power essential for biosynthesis.
4. The **transition step** forms acetyl CoA, which then enters the tricarboxylic acid cycle (TCA) cycle.
5. **Respiration** uses the reducing power accumulated in the central metabolic pathways to generate ATP by oxidative phosphorylation.

a) **Aerobic respiration** uses O_2 as a terminal electron acceptor.
b) **Anaerobic respiration** uses an inorganic molecule other than O_2 as a terminal electron acceptor.

6. **Fermentation** uses pyruvate or a derivative as a terminal electron acceptor rather than oxidizing it further in the TCA cycle; this recycles the reduced electron carrier NADH.

6.2 Enzymes

A. **Enzymes** function as **biological** catalysts, which are not permanently changed during a reaction.
B. The enzyme **substrate** binds to the active site or catalytic site to form a temporary intermediate called an enzyme-substrate complex.
C. **Cofactors** and **coenzymes** act in conjunction with enzymes.
D. **Environmental factors** that influence enzyme activity include
   1. Temperature
   2. pH
   3. salt concentration
E. **Allosteric regulation** uses an effector that binds to the allosteric site of the enzyme that in turn alters the relative affinity of the enzyme for its substrate.
F. **Enzyme inhibition**
   1. **Competitive inhibition** occurs when the inhibitor competes with the normal substrate for the active binding site.
   2. **Non-competitive inhibition** occurs when the inhibitor and the substrate act as different sites on the enzyme.

6.3 Central metabolic pathways

A. **Glycolysis** is a nine-step pathway that converts one molecule of glucose into two molecules of pyruvate; the theoretical net yield is two ATP, two NADH + H^+ and six different precursor metabolites.
B. **Pentose phosphate pathway** can generate some ATP, but its greatest significance is that it forms NADPH and two different precursor metabolites.
C. **Transition step** results in the decarboxylation and oxidization of pyruvate, and joins the resulting acetyl group to coenzyme A forming acetyl-Co A. This produces NADH + H^+ and one precursor metabolite.
E. **Tricarboxylic acid cycle** completes the oxidation of glucose; the theoretical yield is 6 NADH + $6H^+$, $2FADH_2$, 2ATP and three different precursor metabolites.

6.4 Respiration

A. The **reducing power** accumulated in **glycolysis, the transition step,** and the **TCA cycle** is used to drive the **synthesis of ATP**.
B. **Electron transport chain**
   1. The **electron transport chain** sequentially passes electrons, and, as a result, ejects protons. Most of the carriers are grouped into large complexes that function a proton pumps that generate the **chemiosmotic gradient** called the **proton motive force**.
   2. The mitochondrial electron transport chain has three different complexes (complexes I, II, and IV) that function as proton pumps.
   3. Prokaryotes vary with respect to the types and arrangements of their electron transport components.
   4. Some prokaryotes can use inorganic molecules other than O_2 as a terminal electron acceptor (**anaerobic respiration**). This harvests less energy than aerobic respiration.
C. **ATP synthetase**
   1. ATP synthetase harvests the energy released by the electron transport chain as it allows protons to move back across the membrane, driving the synthesis of ATP.
   2. The theoretical maximum yield of ATP of aerobic respiration is 38 ATP.

6.5 **Fermentation** is used by organisms that cannot respire, either because a suitable inorganic terminal electron acceptor is not available or because they lack an electron transport chain.

6.6. Catabolism of organic compounds other than glucose
- A. Hydrolytic enzymes break down macromolecules into their respective subunits.
- B. **Polysaccharides and disaccharides**
  1. Amylases digest starch, releasing glucose subunits.
  2. Cellulases degrade cellulose.
  3. The sugar subunits can enter glycolysis to be oxidized to pyruvate.
- C. **Lipids**
  1. Fats are hydrolyzed by lipase, releasing glycerol and fatty acids.
  2. Glycerol is converted to the precursor metabolite glyceraldehyde 3-phosphate; fatty acids are degraded by beta-oxidation, generating reducing power and the precursor metabolite acetyl-CoA.
- D. **Proteins**
  1. Proteins are hydrolyzed by proteases.
  2. Deamination removes the amino group; the remaining carbon skeleton is then converted into the appropriate precursor molecule.

6.7 **Chemolithotrophs** are autotrophs; they do not require an external source of organic carbon because they can fix carbon dioxide.

6.8 **Photosynthesis** captures the energy of sunlight and uses it to drive the synthesis of ATP.
- A. The role of photosynthetic pigments
  1. **Chlorophylls** are the primary pigments used to harvest solar energy.
  2. **Carotenoids** are accessory pigments that absorb wavelengths of light not absorbed by the chlorophylls and then transfer that energy to the chlorophylls.
- B. **Photophosphorylation**—light energy excites an electron, which is passed along an electron transport chain, generating proton motive force.
- C. Electron source
  1. **Oxygenic phototrophs** extract electrons from water.
  2. **Anoxygenic phototrophs** extract electrons from reduced compounds other than water.

6.9 Carbon fixation—**Calvin cycle** is used to incorporate CO_2 into organic carbon.

6.10 **Anabolic pathways**—synthesizing subunits from precursor molecules
- A. Lipid synthesis
- B. Amino acid synthesis
- B. Nucleotide synthesis