CELLULAR METABOLISM

4

Unit One

Chapter 4

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URLs

http://biology.clc.uc.edu/courses/bio104/cellresp.htm

http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/C/CellularRespiration.html

http://tidepool.st.usm.edu/crswr/110respiration.html

Metabolic Processes
How chemistry becomes Biology!

A. In every cell, thousands of reactions occur daily; these constitute metabolism.
B. Each reaction has an enzyme that controls the speed of the reaction.
C. Metabolic pathways are of two types: in anabolic pathways, larger molecules are constructed from smaller ones; in catabolic pathways, larger molecules are broken down.

D. Anabolism - requires Energy

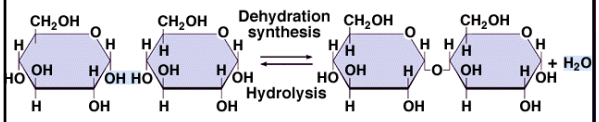
- *provides all substances for growth and repair to body
- *dehydration synthesis – allows monomers to form polymers by removal of H2O molecules
- *peptide bond – formed when amino acids link up; dipeptides and polypeptides
- *proteins are very large and consist of about 100 or more polypeptides

E. Catabolism – produces Energy

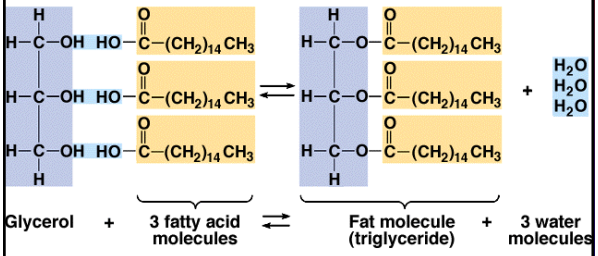
- *physiological process that breaks down large molecules into smaller ones – (large ones into small ones)
- *hydrolysis – addition of water molecules to break down carbohydrates, lipids, proteins, and nucleic acids into their building blocks

ANABOLIC AND CATABOLIC REACTIONS REQUIRE THE HELP OF SPECIFIC ENZYMES

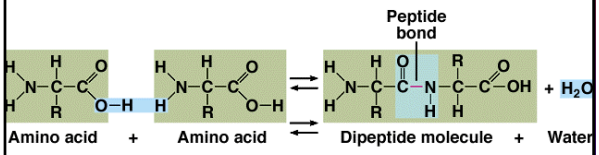
Dehydration Synthesis—Sugar Molecule



Dehydration Synthesis—Fat Molecule



Dehydration Synthesis—Protein Molecule



Control of Metabolic Reactions

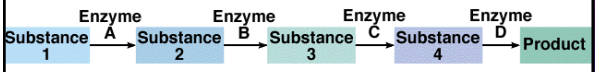
All cells perform certain basic reactions such as the buildup & breakdown of macromolecules. These include 100's of very specific changes that must occur in a particular sequence.

Enzymes control the rates of all the metabolic reactions of the cell.

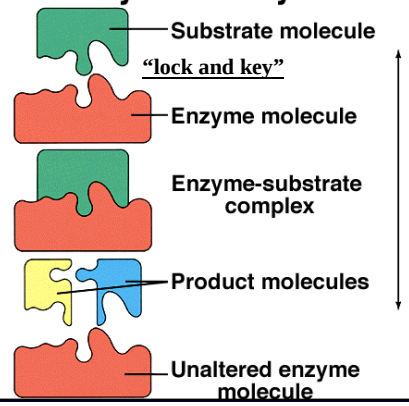
- *activation energy is required to start metabolic reactions
- *enzymes make reactions possible; temperature in cells is too mild to start chemical reactions
- *globular proteins (enzymes) lower activation energy required to start these reactions

- *enzymes have specificity & will act only on a specific substrate (ex. catalase, found in peroxisomes of liver & kidney cells, will only act on H2O2)
- *metabolic pathways – sequences of enzyme-controlled reactions that lead to the synthesis or hydrolysis of biochemicals (product)
- *each enzyme must be able to recognize its substrate;
- *each enzyme's polypeptide chain conforms to the special shape of its substrate molecule
- *active sites – regions of the enzyme that combine with the substrate = enzyme-substrate complex
- *speed of an enzyme-catalyzed reaction depends partly on the # of enzyme & substrate molecules in the cell
- *enzyme names are derived from their substrate's name with a suffix "-ase"

Metabolic Pathway



Enzyme Catalysis



Cofactors and Coenzymes

- *cofactor – enzymes often need help to become active & nonprotein ions (Cu, Fe, Zn & coenzymes) allow the active site to bind the enzyme to its substrate
- *coenzyme – a small organic molecule that will activate a specific enzyme; found in vitamins (coenzyme A)
- *vitamins – organic compounds needed by the cell that the body cannot synthesize in adequate amounts

Factors That Alter Enzymes

*proteins (which are enzymes)
can be denatured by exposure to heat, radiation, electricity, & chemicals with extreme pH levels

45 degrees C = inactive
55 degrees C = denatured
cyanide = can destroy enzymes

Energy for Metabolic Reactions

Energy is the capacity to do work.

Common forms of energy include heat, light, and sound, and electrical, mechanical, and chemical energy.

Release of Chemical Energy

*The energy to drive metabolism is contained in the chemical bonds that build macromolecules.

*This energy is released when these bonds are broken. (burning releases chemical energy)

*oxidation – the process of burning glucose to release energy

BOTH HETEROTROPHS AND AUTOTROPHS obtain Energy by breaking down organic molecules using CELLULAR RESPIRATION.

Ultimately, nearly all the energy that powers living organisms comes from sunlight.

Cellular respiration is the oxygen-dependent process by which cells extract energy from food molecules.

Animals obtain almost all of their energy through cellular respiration.

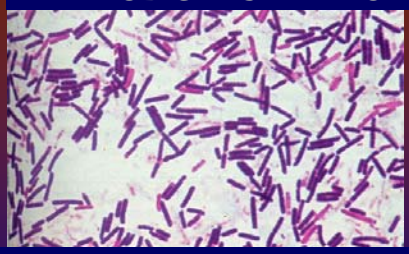
Plants also depend on cellular respiration for ATP at night or at other times when they cannot photosynthesize.

Most living things that carry on photosynthesis make more glucose than they use for their life processes. The extra glucose is stored as starch. This starch can be used by the plant at a later time. It may also be used by animals that eat the plant.

AEROBIC ACTIVITY

The arctic tern nests each summer near the Arctic Circle in North America, then migrates across the Atlantic Ocean to Europe, then south to South Africa, then across the South Atlantic to Antarctica, a distance of 11,000 miles. In the spring, the bird flies all the way back around the world to the Arctic Circle to nest once more.

ANAEROBIC RESPIRATION



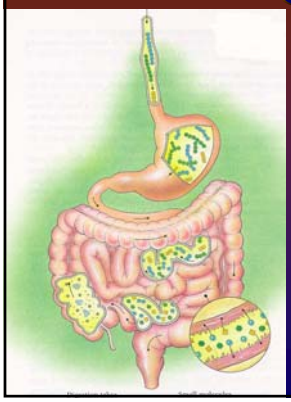
The obligate anaerobe Clostridium botulinum, which causes the serious form of bacterial food poisoning, "botulism," cannot reproduce in the presence of oxygen. It is known, however, for its ability to multiply inside of sealed canned goods.

ANAEROBIC RESPIRATION

Among vertebrates, the red-eared turtle, Chrysemys scripta elegans, is unusual in its ability to live without oxygen. It can stay under water for 2 weeks at a time, relying on glycolysis for energy production.

HOW DO HETEROTROPHS EXTRACT ENERGY FROM MACROMOLECULES?

Cells cannot extract energy directly from complex carbohydrates, proteins, or fats. Large molecules must undergo DIGESTION into smaller units (ie) proteins to amino acids, polysaccharides to glucose and other simple sugars, and fats to fatty acids and glycerol. Digestion occurs through the process of HYDROLYSIS - breaking each link in a polymer through the addition of a molecule of water.



Digestion occurs either outside the cells altogether in some kind of stomach like cavity, or in lysosomes, separated from the cytosol. Complex molecules are broken down.

Small molecules enter cytosol of cells.

Cellular Respiration

Cellular Respiration

3 distinct and interconnected series of reactions

Cellular respiration consists of:

(1) glycolysis

(2) the citric acid cycle

(3) oxidative phosphorylation (electron transport chain).

The end-products of these reactions are heat, carbon dioxide, water, & energy stored in ATP. Some of the energy is lost as heat but half is used to produce ATP.

ATP Molecules

*ATP = adenine, ribose, & 3 phosphates (chain)

*the 3rd phosphate has a high E bond & can be transferred to other molecules; when E is released it is used when cells have to do work (when muscle cells contract); Energy from breakdown of ATP powers cellular work (muscle contraction, active transport, or secretion)

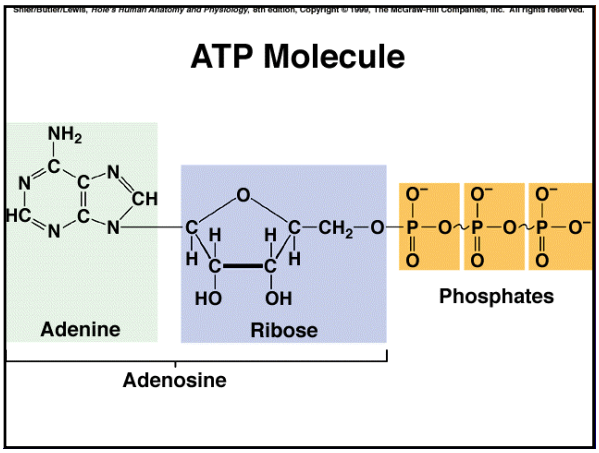
*ATP > < ADP (this is reversible)

*phosphorylation – the process in which a 3rd phosphate is attached to ADP & >s ATP

*without ATP cells die

*oxidative phosphorylation

*glucose can be oxidized & > 38 ATP molecules



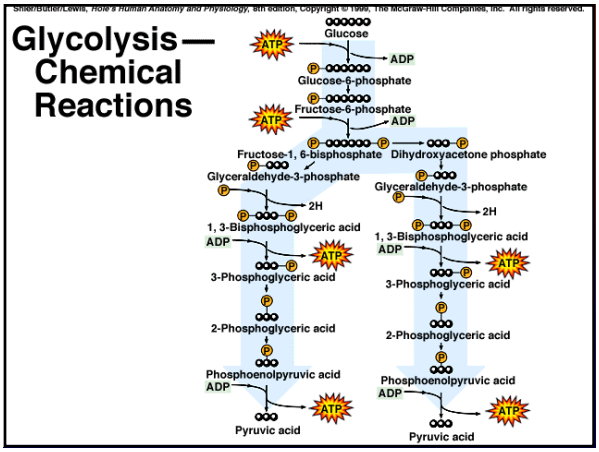
Glycolysis "breaking of glucose"

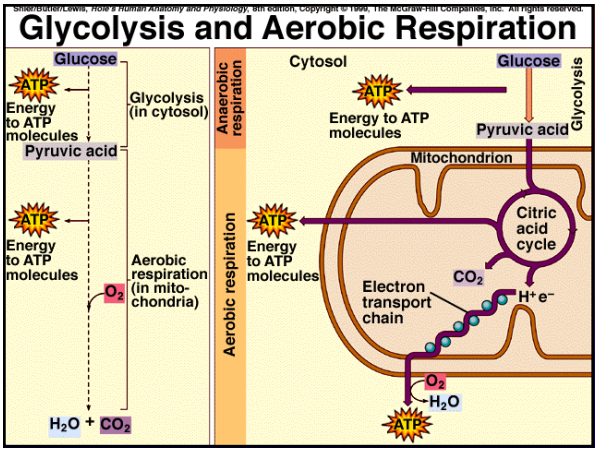
- *occurs in the cell's cytosol
- *anaerobic respiration – occurs without O2
- *ATP must be available to activate glycolysis
- *more energy is released than is used

*10 enzyme catalyzed reactions that break down C6H12O6 into:

- two 3-carbon pyruvic acid molecules
  - high e' H2 atoms are released; electron carrier NADH is produced & delivers H2 to electron transport chain

*glycolysis = net gain of 2 ATP's





GLYCOLYSIS = 3 main events

1. Glucose is phosphorylated (2 P groups are added)
2. Glucose is split into two 3 carbon atoms
3. NADH (H_2 electron carrier) is produced. ATP is synthesized & two 3-carbon pyruvic acid molecules result. NADH contains much of the energy associated with the original glucose molecule.

Anaerobic Reactions Can Occur after Glycolysis

Oxygen is the final electron acceptor in the glycolysis (aerobic reactions). If oxygen is not available the electrons will attach to the pyruvic acid molecules forming lactic acid.

Lactic acid can build up inhibiting glycolysis & ATP formation. (oxygen debt)

When oxygen becomes available again, liver cells convert lactic acid to pyruvic acid.

Aerobic Respiration (Krebs cycle or citric acid cycle & oxidative phosphorylation or electron transport chain)

*reactions are aerobic & require O_2

*sequence of reactions begins with pyruvic acid moving into the mitochondria

*enzymes remove 2 H_2 atoms, a C atom, & 2 O_2 atoms, generating NADH & a CO_2 & leaving a 2-carbon acetic acid → acetyl CoA

Citric Acid Cycle

*begins when acetyl CoA is combined with oxaloacetic acid to form the 6-carbon citric acid & CoA; this cycle occurs as long as O_2 & pyruvic acid are supplied to the mitochondria

*net gain of 2 ATP molecules are produced; the CO_2 produced is excreted from the body

Electron Transport Chain or (oxidative phosphorylation)

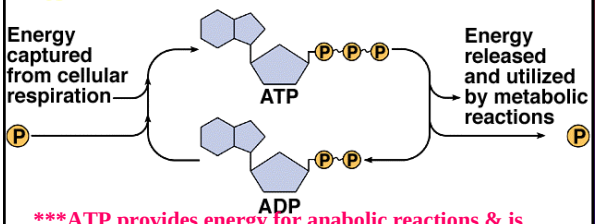
*The hydrogen & high-energy electron carriers (NADH & $FADH_2$) produced at the end of glycolysis & citric acid cycle hold most of the energy contained in the original glucose molecule.

*The high energy electrons are handed off to the electron transport chain with the help of enzymes that use this energy to phosphorylate ADP to form ATP ***net gain of 32-34 molecules of ATP

Adenosine triphosphate

ATP Regeneration

ATP = adenine + ribose + 3 phosphates



***ATP provides energy for anabolic reactions & is regenerated by catabolic reactions. The wavy lines connecting the last 2 P's represent high-energy chemical bonds that provide energy when broken.

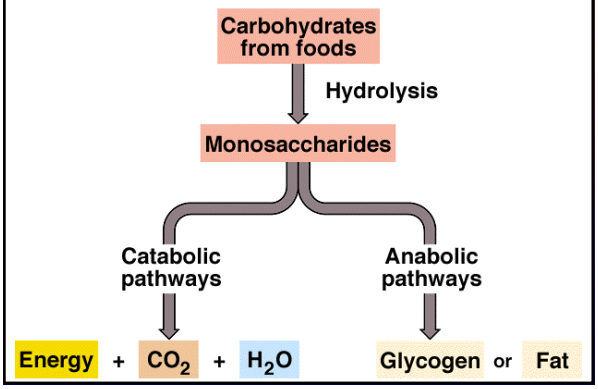
A Closer Look at Cellular Respiration

A. The enzymes controlling these reactions must act in a specific order. They are positioned in stalked particles on the cristae within the mitochondria in the exact sequence as that of the reactions they control.

B. Anabolic and catabolic pathways are interconnected; excessive calories in the diet can enter anabolic as well as catabolic pathways.

The next slides will show the 4 different pathways that the food we eat can take.

Metabolic Pathways



C. Carbohydrate Pathways

OVERVIEW:

*Carbohydrates are used for cellular energy & enter the catabolic pathways of cellular respiration

1. Glucose is broken down to pyruvic acid (as usual)
   *this > 2 ATPs
2. Pyruvic acid is broken down to > 2-3 carbon acetyl groups
3. Coenzyme A is added to the 2-carbon acetyl groups to > acetyl coenzyme A (the important stuff!)
4. Goes into citric acid cycle and E is released
5. Products are CO2 and H2O plus E

Steps in Carbohydrate Pathway:

Glycolysis:

*P groups are added to glucose with help of ATP > fructose
*more P groups are added releasing H2 to be used in synthesis of more ATP
*E is transferred from a P group > ADP
*another high energy P group is transferred > ATP
*Glycolysis > acetyl coenzyme A and 2 ATP molecules

Citric Acid Cycle:

*acetyl coenzyme A becomes citric acid & acetyl coenzyme A is released
*products are CO2 and H2 plus 2 ATPs

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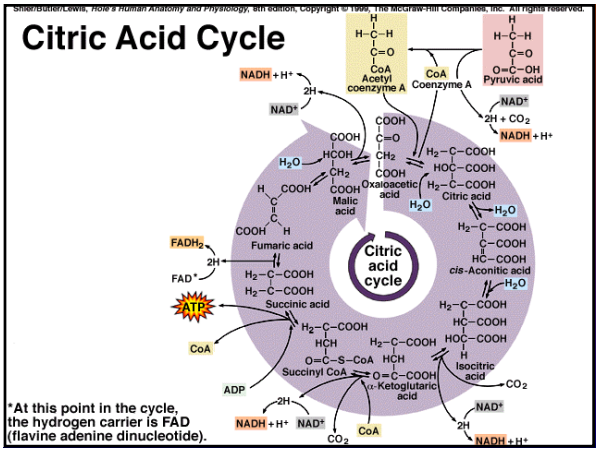
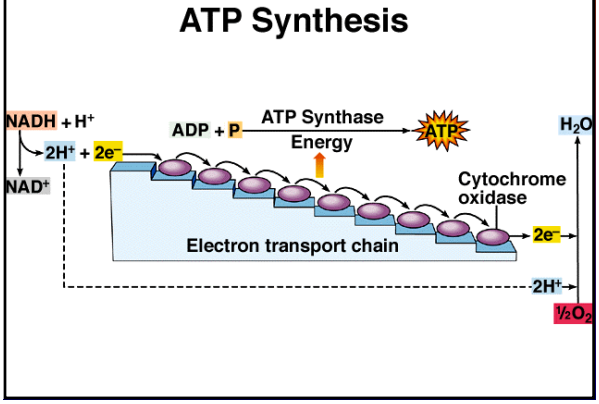


ATP Synthesis: "Electron Transport Chain"

*hydrogen carriers - NAD+ accepts H atoms & > NADH (vitamin niacin supplies NAD+)
*reduction - when NAD+ combines with energized electrons of H > NADH (same with FAD > FADH2)
*oxidation - results when electrons are removed > NAD+ (this process is then recycled)
***The molecules that act as electron carriers comprise an electron transport chain. As electrons pass through the chain E is released.
*cytochromes – iron containing proteins that can also be electron carriers, found in the cristae of the mitochondria (in muscle cells)
*38 molecules of ATP metabolized from 1 glucose molecule
*lactic acid – formed from pyruvic acid when O2 is absent

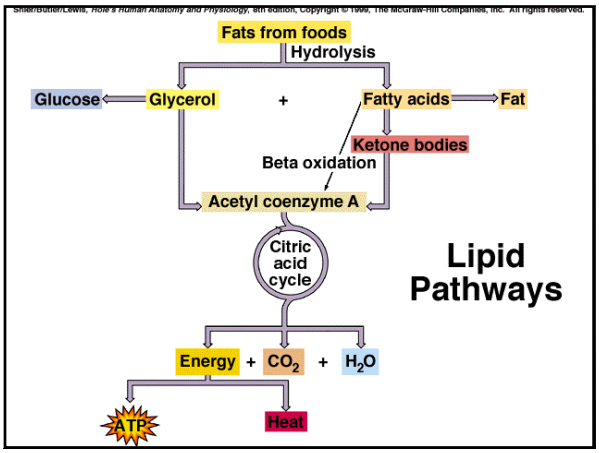


*Excess dietary glucose can enter anabolic pathways, stored as glycogen, or converted to fat (overeating)

D. Lipid Pathways

*most dietary fats are lipids
*liver controls lipid metabolism
*fats supply long term E; (2 times more)

1. Fats have to be broken down (hydrolysis) into glycerol & fatty acids
2. beta oxidation - fatty acids to > acetyl coenzyme A; this occurs in mitochondria
3. acetyl coenzyme A can be oxidized into the citric acid cycle
4. Fats form from glycerol & fatty acids as well as excess glucose or amino acids



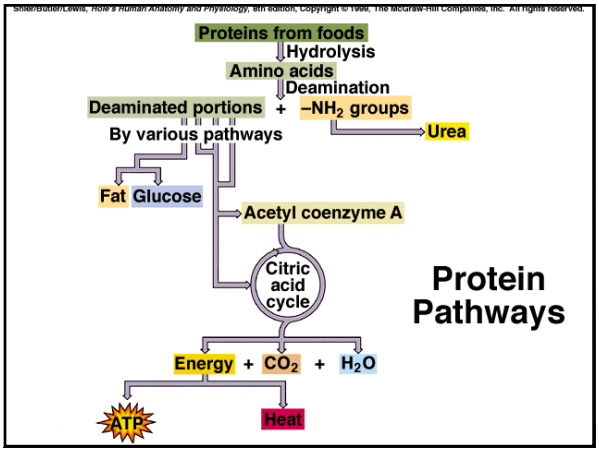
E. Protein Pathways

*proteins - hydrolyzed into amino acids, absorbed & transported by the blood to cells; many are used to form new proteins

*amino acids go into deamination – process occurs in liver & removes –NH2 groups from amino acids; later NH2 groups are converted into urea – a waste

*acetyl coenzyme is formed & E is released or deaminated portion is changed into glucose or fat, CO2 & H2O

*essential amino acids – must be in diet, body cannot adequately synthesize; 8 of them



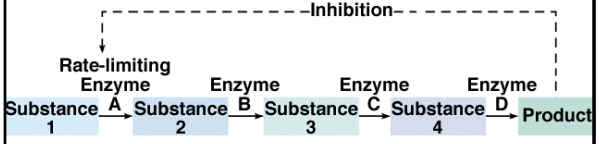
F. Regulation of Metabolic Pathways

*influenced by enzymes that are responsible for a certain step in a pathway

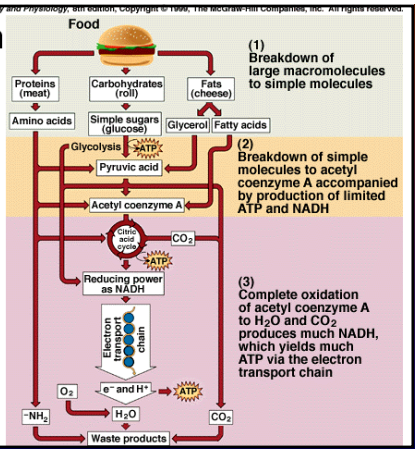
*rate-limiting enzyme – first enzyme in a series that can regulate metabolic pathways

BE SURE TO LOOK AT THE DIAGRAMS THAT SUMMARIZE THE METABOLIC PATHWAYS

Negative Feedback Mechanism



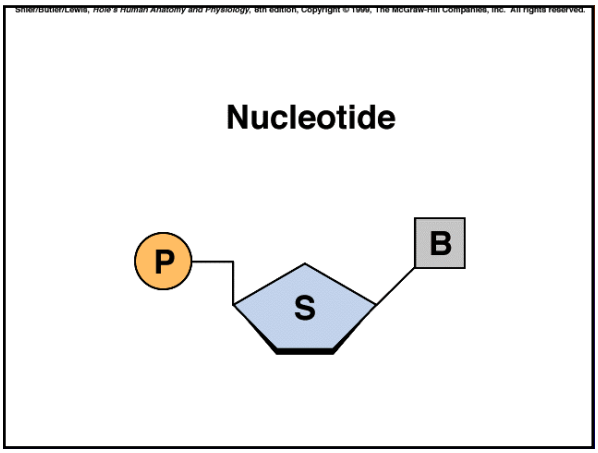
Catabolism Summary

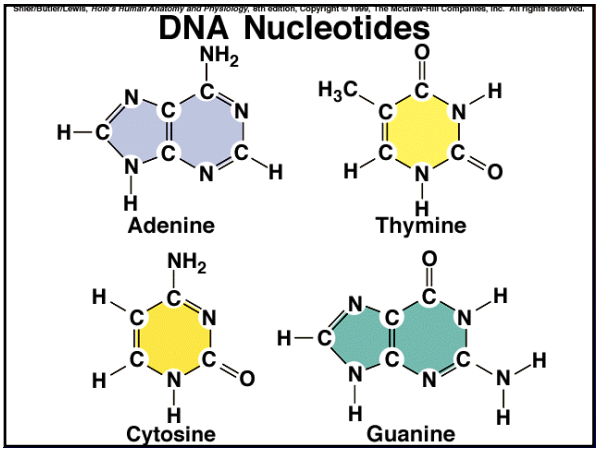


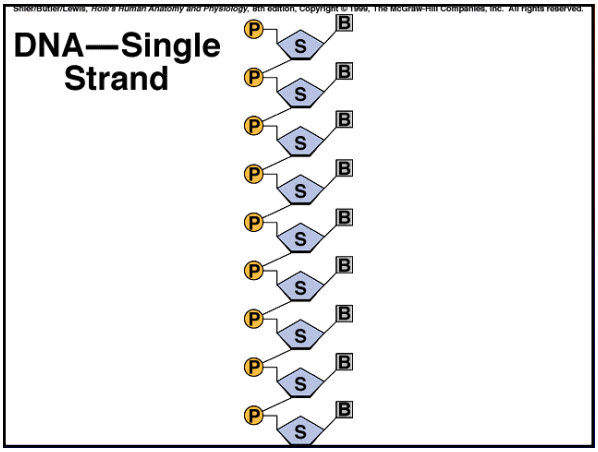
VI. Nucleic Acids and Protein Synthesis

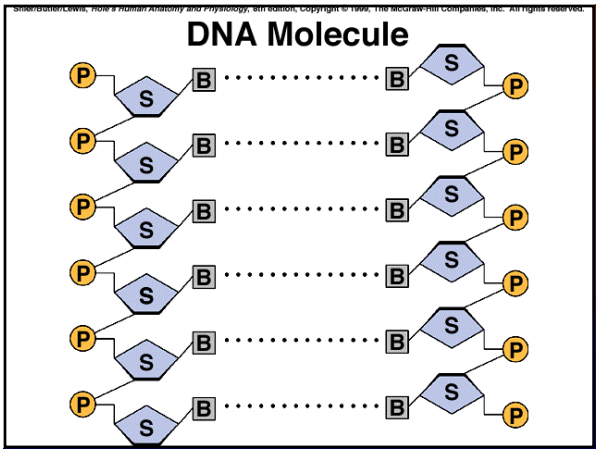
A. Deoxyribonucleic acid (DNA) contains the information needed for the synthesis of each protein (enzyme) required by the cell.

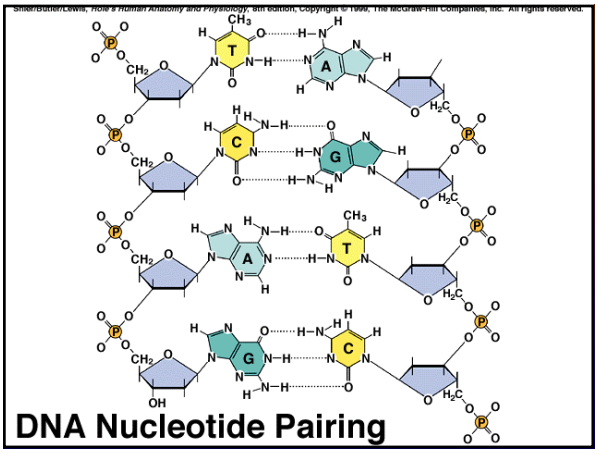
B. Genetic Information
- *gene – the portion of a DNA molecule that contains the information for making a particular protein
- *sequence of nucleotides in a DNA molecules dictates the sequence of amino acids in a protein and how to start/stop the protein's synthesis; DNA is double-stranded; thymine
- *genetic code – method of storing information for protein synthesis
- *DNA – in the nucleus
- *protein synthesis – in the cytoplasm
- *RNA – helps get the information to the cytoplasm



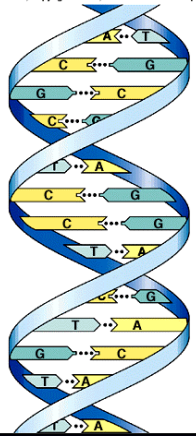








DNA Double Helix



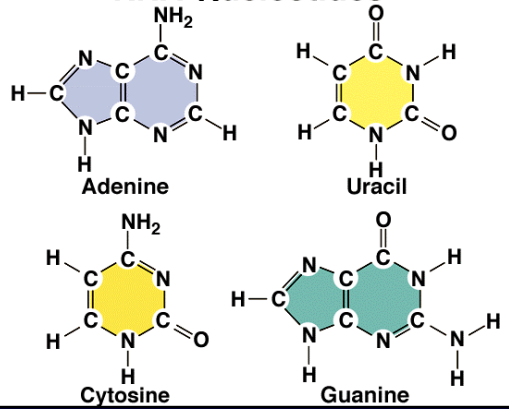
D. RNA Molecules

* RNA – single-stranded, ribose sugar, uracil not thymine

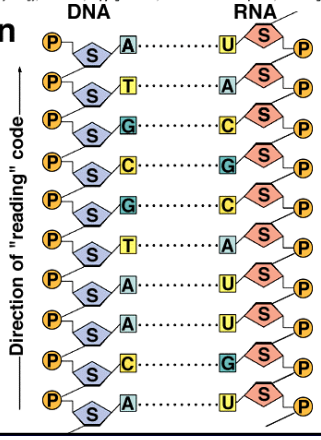
STEPS in delivering information from nucleus to cytoplasm:

1. synthesis of messenger RNA is directed by RNA polymerase
2. RNA polymerase binds to a promotor which is a DNA base sequence that begins a gene causing the double-stranded DNA molecule to unwind and pull apart
3. mRNA contain a nucleotide sequence that is complementary to that of the exposed strand of DNA
4. transcription – process of copying DNA information into the structure of an mRNA molecule
5. mRNA molecules move into the cytoplasm, find the ribosomes, and are templates for the synthesis of protein molecules - translation

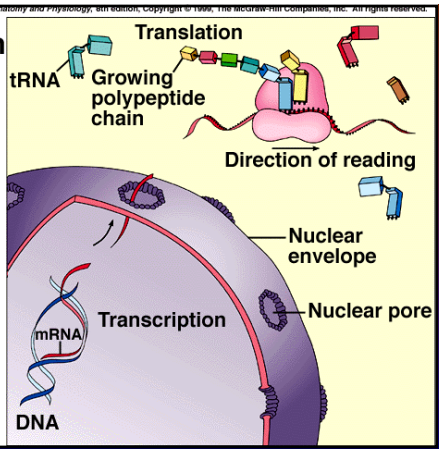
RNA Nucleotides



Transcription



Translation



E. Protein Synthesis

*transfer RNAs (synthesized in nucleus) position amino acids along mRNAs

*one end of tRNAs has binding site for particular amino acid; certain enzymes activate the amino acids ; ATP helps form the bond between the amino acid and the tRNA

*other end has anticodon – 3 nucleotides of tRNA that are complementary to a specific mRNA

*ribosome binds to mRNA and allows transfer to tRNA to recognize its correct position on the mRNA

*ribosomal RNA is a type of RNA that helps form ribosomes

*ribosome has enzymes and ribozymes that help in the synthesis of the protein

*the protein is held until it reaches its correct conformation (shape)

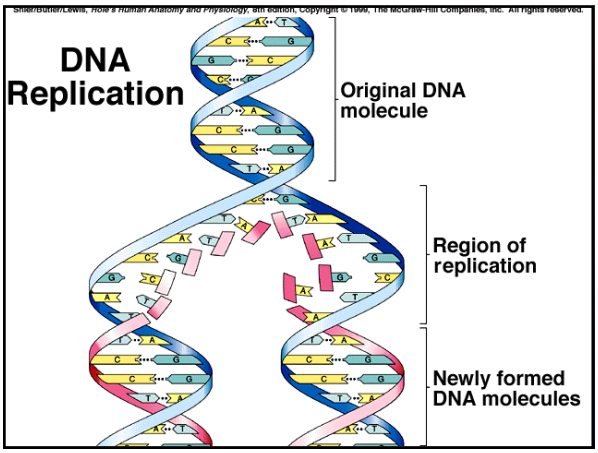
*ATP = E source for protein synthesis

F. DNA Replication
occurs during interphase

*replication - production of an exact copy of DNA a sequence

*new cells must have a copy of the parent cell's genetic code

*each new DNA molecule then contains one old strand and one new strand

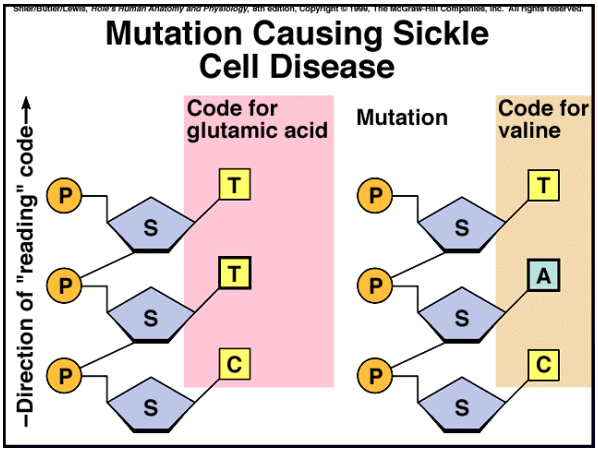


Changes in Genetic Information

A. A change in DNA is called a mutation.

B. Nature of Mutations
*caused by changes in DNA
*proteins can be synthesized by an altered DNA sequence
*repair enzymes can sometimes correct DNA damage

C. Effects of Mutations
*genetic code protects against some mutations
*mutations in sex cells, fertilized egg, or early embryo can cause more damage than a mutation in an adult; not as many cells are affected in an adult



Remember – At the end of the chapter is a Chapter Summary that is your Study Guide for the Chapter 4 test.