Hole's Human
Anatomy and Physiology

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Chapter 4
Cellular Metabolism

Metabolic processes – all chemical reactions that occur in the body

Two types of metabolic reactions

Anabolism

- **larger molecules are made from smaller ones**
- **requires energy**

Catabolism

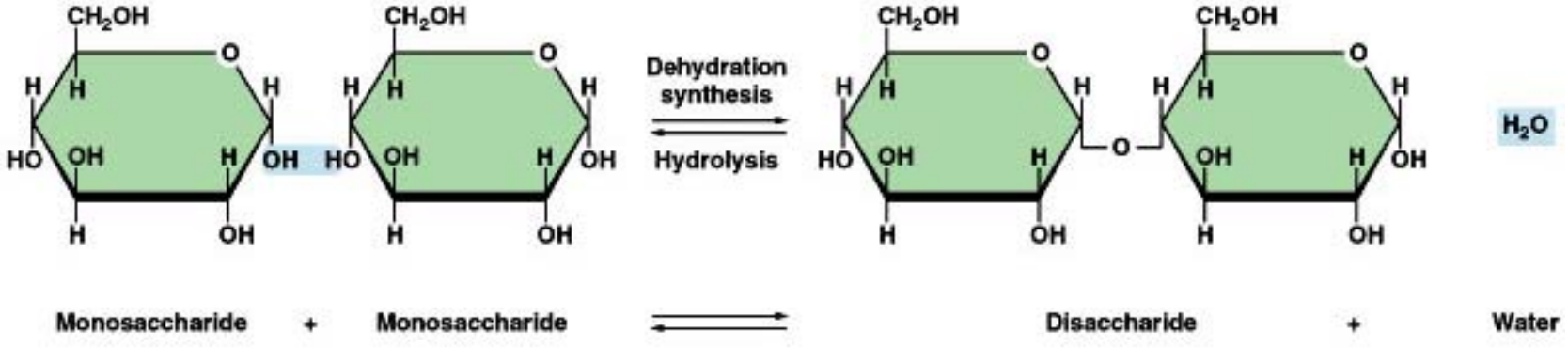
- **larger molecules are broken down into smaller ones**
- **releases energy**

Anabolism

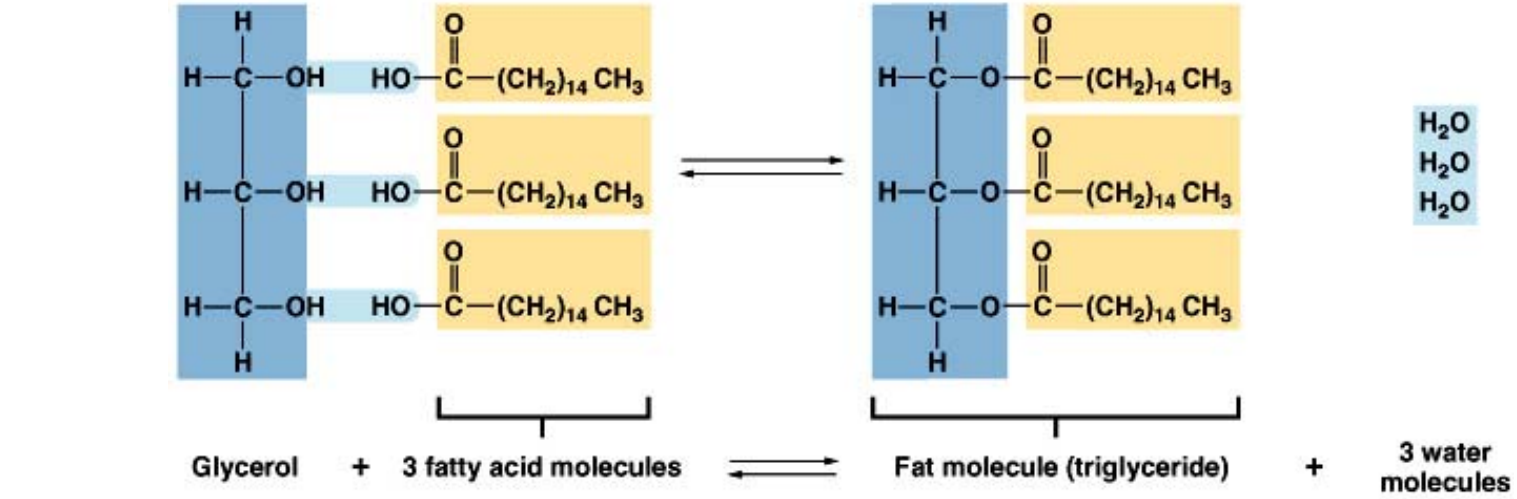
Anabolism provides the materials needed for cellular growth and repair

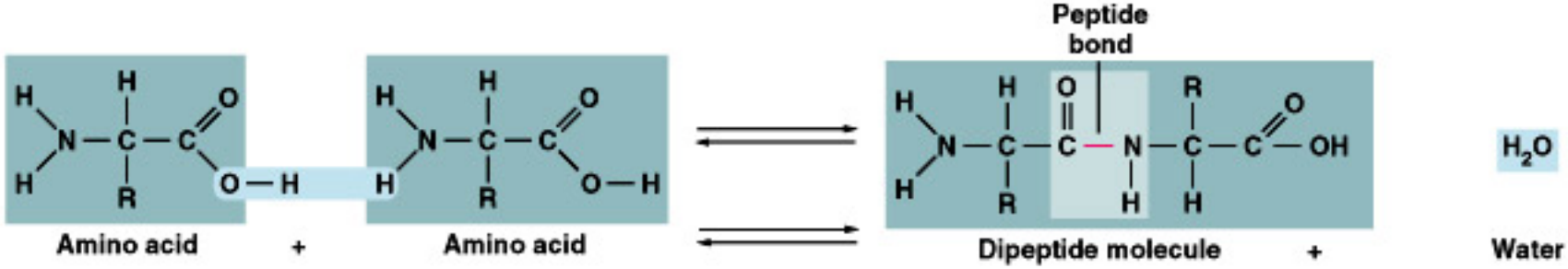
Dehydration synthesis

- **type of anabolic process**
- **used to make polysaccharides, triglycerides, and proteins**
- **produces water**



Anabolism


Glycerol
+
3 fatty acid molecules
Fat molecule (triglyceride)
+
3 water molecules
H_2O
H_2O
H_2O

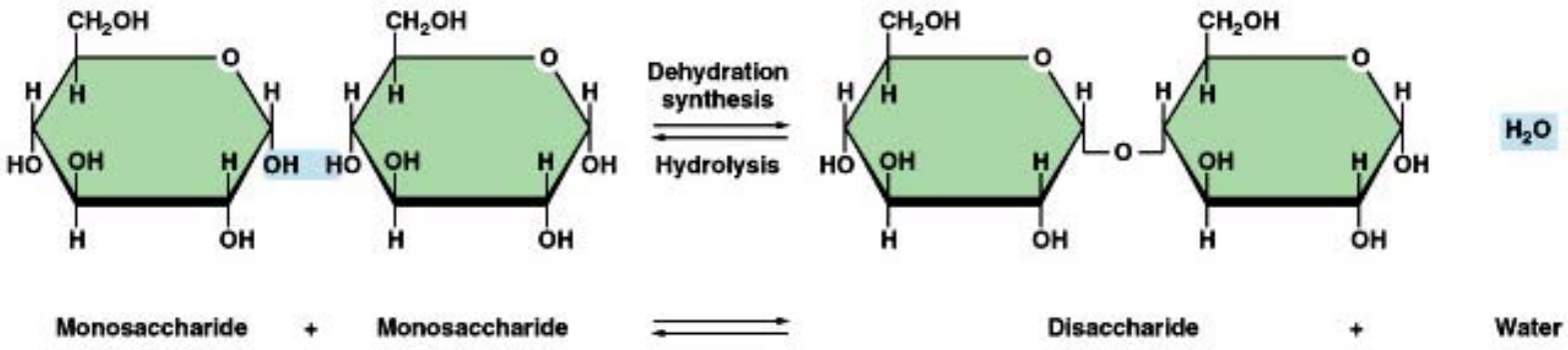

Peptide bond
Amino acid
+
Amino acid
Dipeptide molecule
+
Water
H_2O

Catabolism

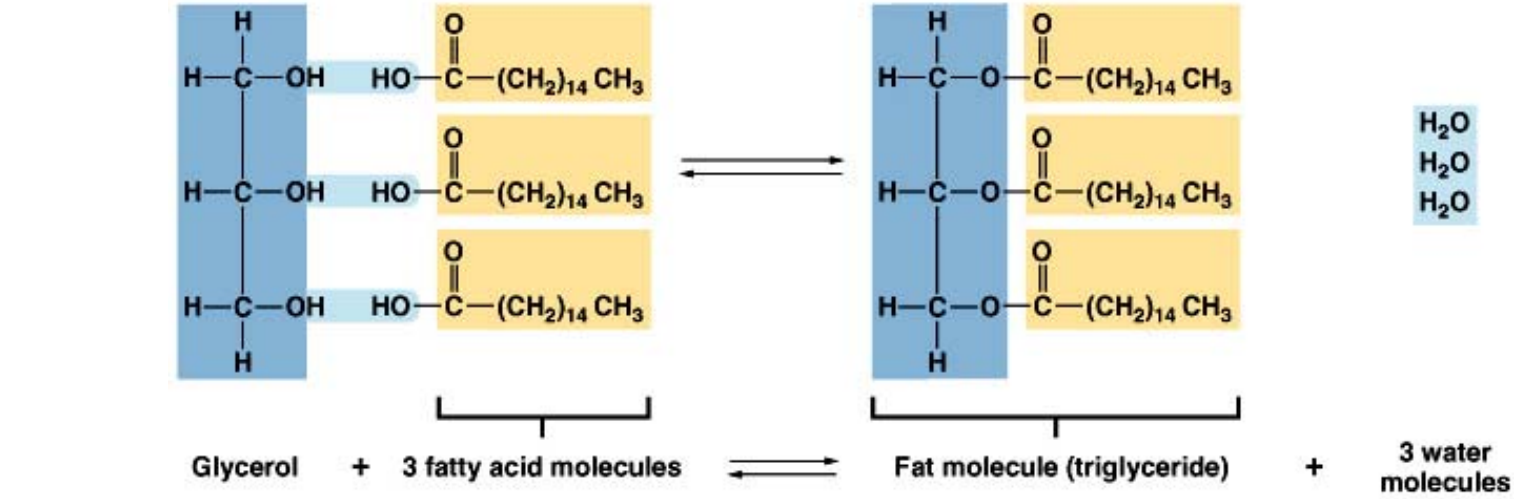
Catabolism breaks down larger molecules into smaller ones

Hydrolysis

- **a catabolic process**
- **used to decompose carbohydrates, lipids, and proteins**
- **water is used to split the substances**
- **reverse of dehydration synthesis**



Catabolism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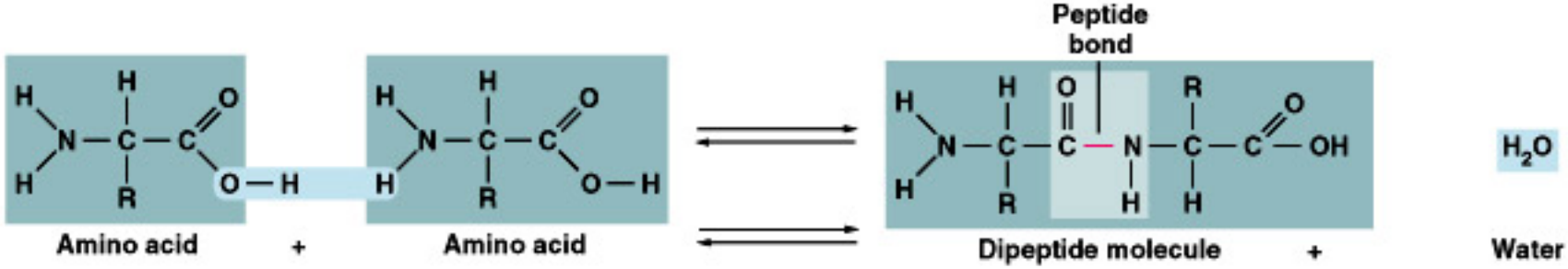
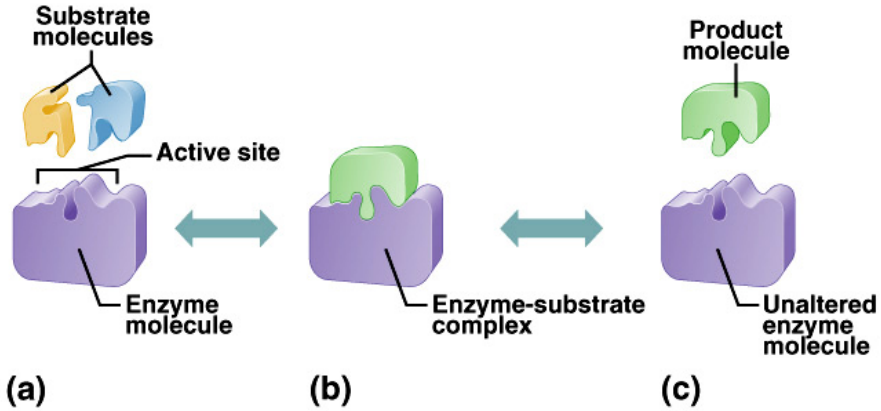

Peptide bond
Amino acid
+
Amino acid
Dipeptide molecule
+
Water
H_2O

Control of Metabolic Reactions

Enzymes

- control rates of metabolic reactions
- lower activation energy needed to start reactions
- most are globular proteins with specific shapes
- not consumed in chemical reactions
- substrate specific
- shape of active site determines substrate



Control of Metabolic Reactions

Metabolic pathways

- **series of enzyme-controlled reactions leading to formation of a product**
- **each new substrate is the product of the previous reaction**

Enzyme names commonly

- **reflect the substrate**
- **have the suffix – ase**
- **sucrase, lactase, protease, lipase**

Control of Metabolic Reactions

Cofactors

- make some enzymes active
- non protein component
- ions or coenzymes

Coenzymes

- organic molecules that act as cofactors
- vitamins

Factors that alter enzymes

- heat
- radiation
- electricity
- chemicals
- changes in pH

Energy for Metabolic Reactions

Energy

- **ability to do work or change something**
- **heat, light, sound, electricity, mechanical energy, chemical energy**
- **changed from one form to another**
- **involved in all metabolic reactions**

Release of chemical energy

- **most metabolic processes depend on chemical energy**
- **oxidation of glucose generates chemical energy to promote cellular metabolism**
- **cellular respiration releases chemical energy from molecules and makes it available for cellular use**

Cellular Respiration

Occurs in three series of reactions

1. **Glycolysis**
2. **Citric acid cycle**
3. **Electron transport chain**

Produces

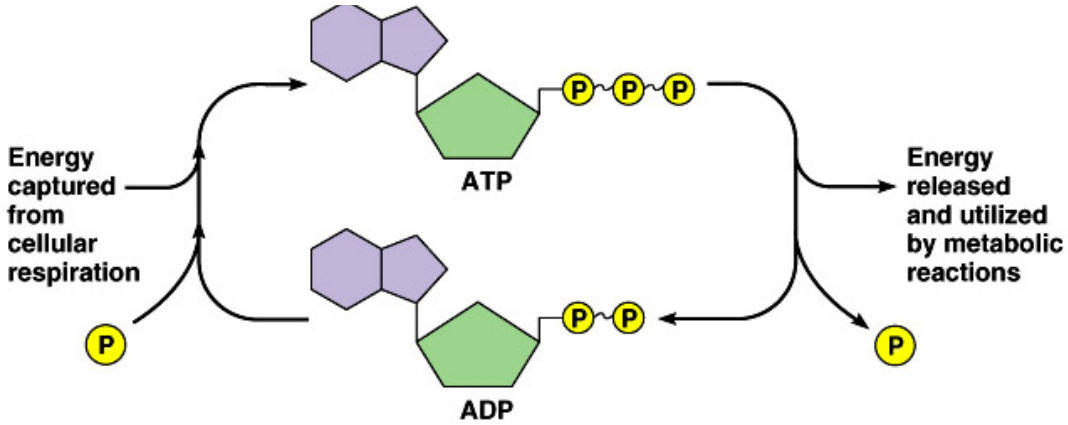
- **carbon dioxide**
- **water**
- **ATP (chemical energy)**
- **heat**

Includes

- **anaerobic reactions (without O_2) - produce little ATP**
- **aerobic reactions (requires O_2) - produce most ATP**

ATP Molecules

- each ATP molecule has three parts:
  - an adenine molecule
  - a ribose molecule
  - three phosphate molecules in a chain
- third phosphate attached by high-energy bond
- when the bond is broken, energy is transferred
- when the bond is broken, ATP becomes ADP
- ADP becomes ATP through phosphorylation
- phosphorylation requires energy released from cellular respiration



Glycolysis

- **series of ten reactions**
- **breaks down glucose into 2 pyruvic acid molecules**
- **occurs in cytosol**
- **anaerobic phase of cellular respiration**
- **yields two ATP molecules per glucose**

Summarized by three main events

1. **phosphorylation**
2. **splitting**
3. **production of NADH and ATP**

Glycolysis

Event 1 - Phosphorylation

- **two phosphates added to glucose**
- **requires ATP**

Event 2 – Splitting (cleavage)

- **6-carbon glucose split into two 3-carbon molecules**

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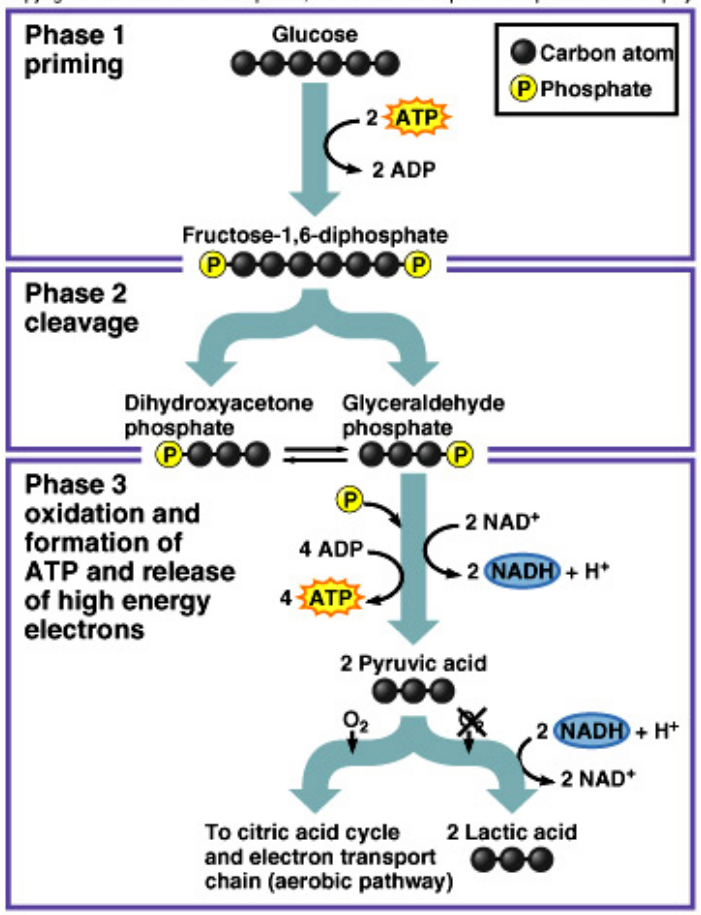

Glycolysis

Event 3 – Production of NADH and ATP

- **hydrogen atoms are released**
- **hydrogen atoms bind to NAD^+ to produce NADH**
- **NADH delivers hydrogen atoms to electron transport chain if oxygen is available**
- **ADP is phosphorylated to become ATP**
- **two molecules of pyruvic acid are produced**

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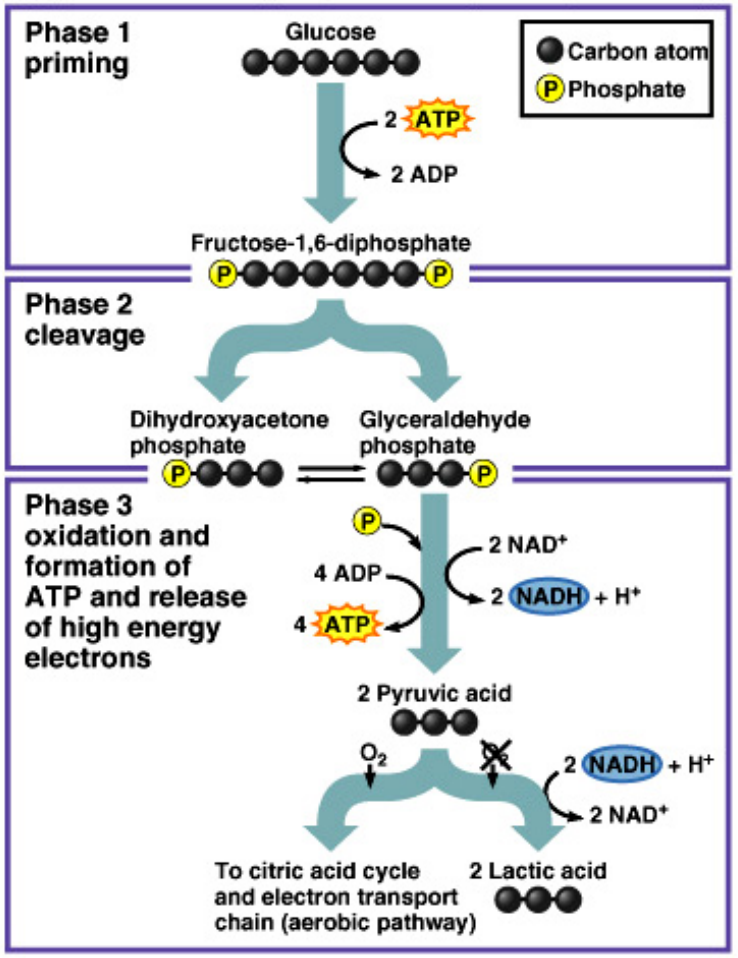

Anaerobic Reactions

If oxygen is not available -

- **electron transport chain cannot accept new electrons from NADH**
- **pyruvic acid is converted to lactic acid**
- **glycolysis is inhibited**
- **ATP production less than in aerobic reactions**

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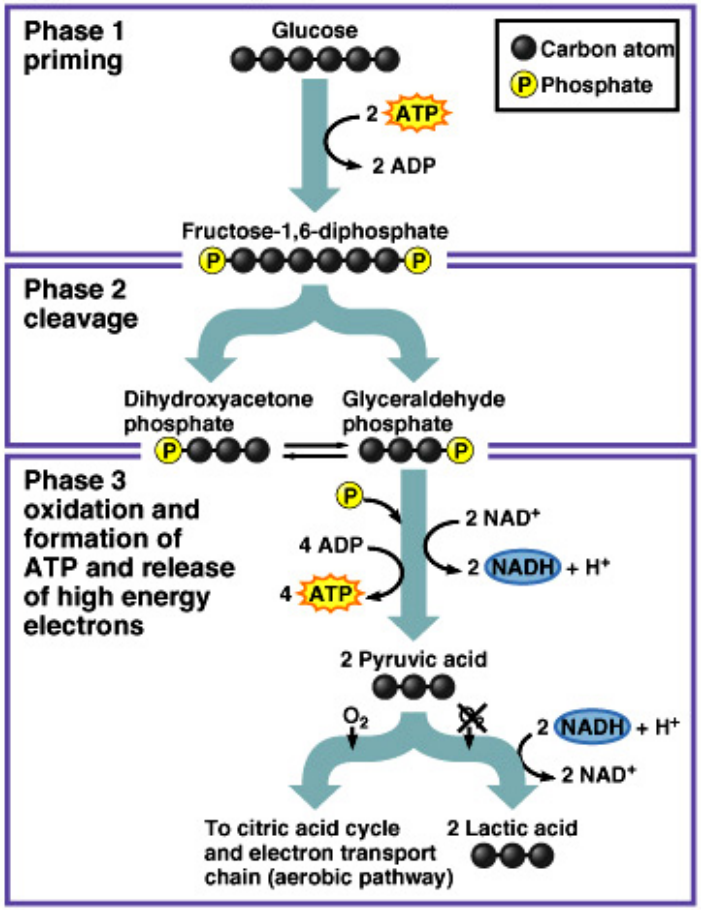

Aerobic Reactions

If oxygen is available –

- **pyruvic acid is used to produce acetyl CoA**
- **citric acid cycle begins**
- **electron transport chain functions**
- **carbon dioxide and water are formed**
- **36 molecules of ATP produced per glucose molecule**

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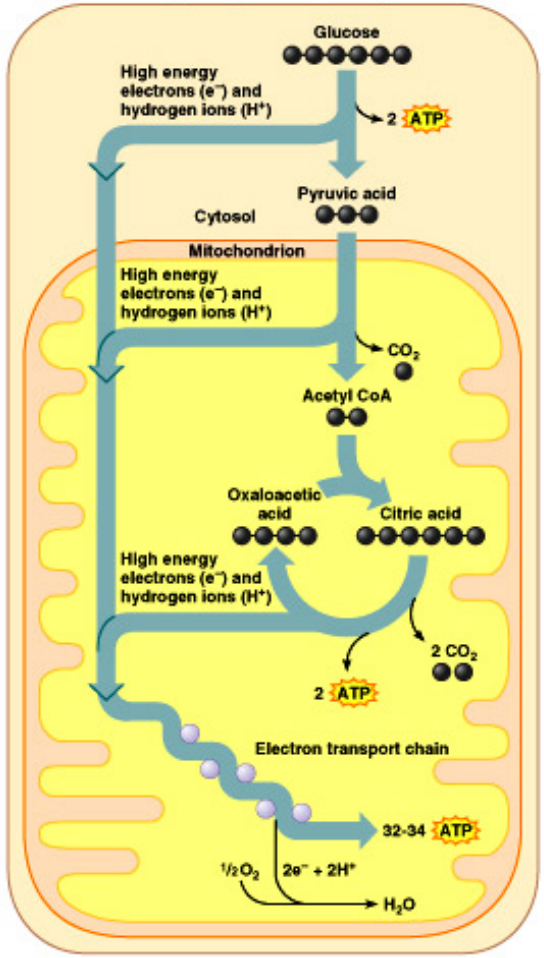

Citric Acid Cycle

- **begins when acetyl CoA combines with oxaloacetic acid to produce citric acid**
- **citric acid is changed into oxaloacetic acid through a series of reactions**
- **cycle repeats as long as pyruvic acid and oxygen are available**
- **for each citric acid molecule:**
  - **one ATP is produced**
  - **eight hydrogen atoms are transferred to NAD^+ and FAD**
  - **two CO_2 produced**

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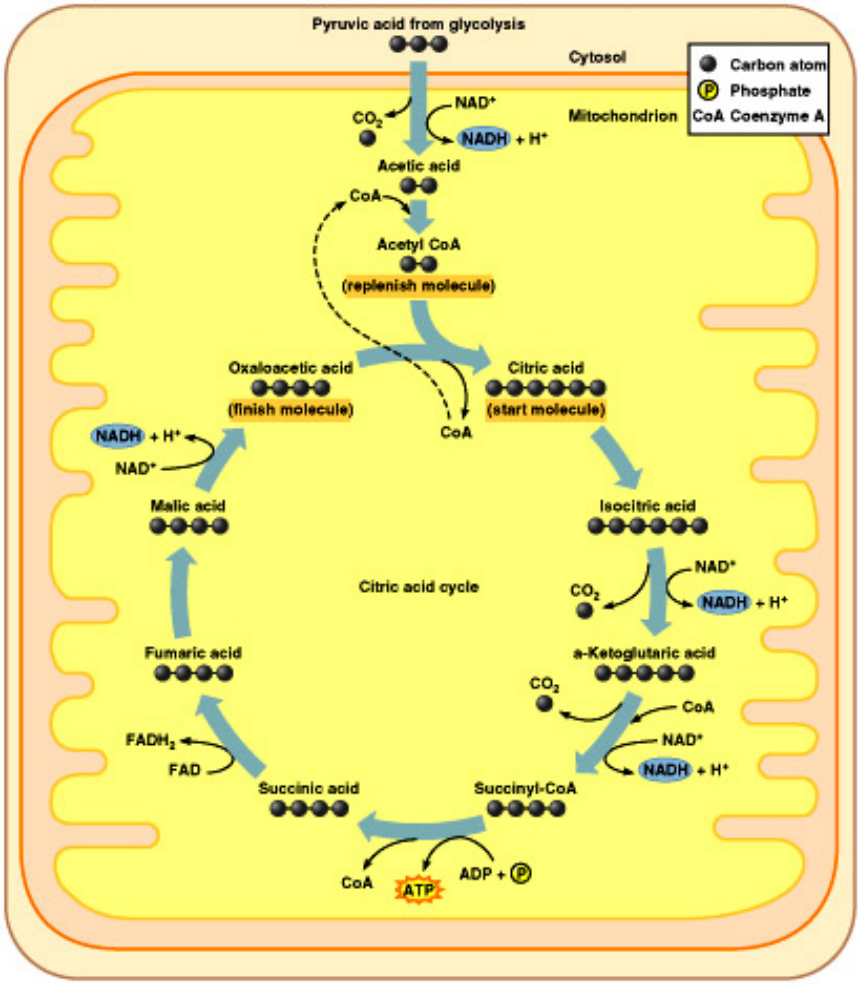
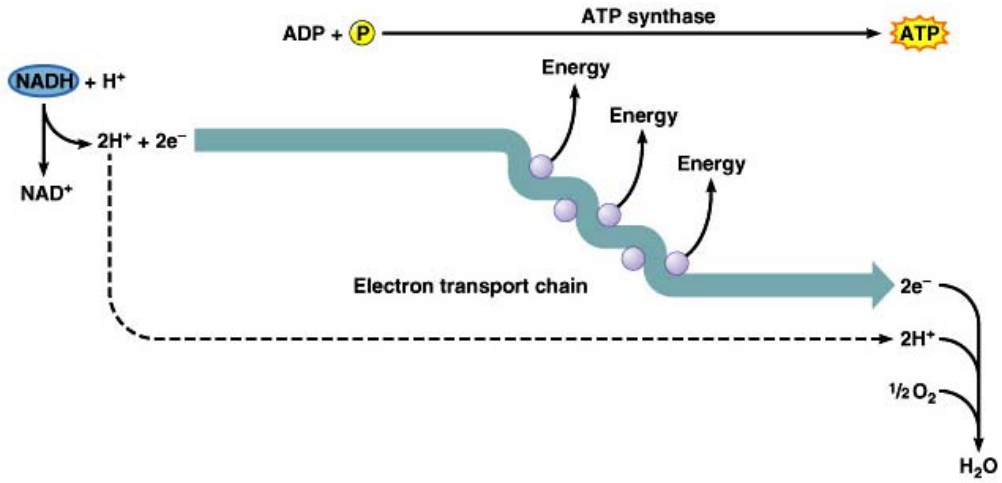


Electron Transport Chain

- **NADH and FADH2 carry electrons to the ETC**
- **ETC series of electron carriers located in cristae of mitochondria**
- **energy from electrons transferred to ATP synthase**
- **ATP synthase catalyzes the phosphorylation of ADP to ATP**
- **water is formed**



Summary of Cellular Respiration

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Glycolysis

1 The 6-carbon sugar glucose is broken down into two 3-carbon pyruvic acid molecules with a net gain of 2 ATP and the release of high energy electrons.

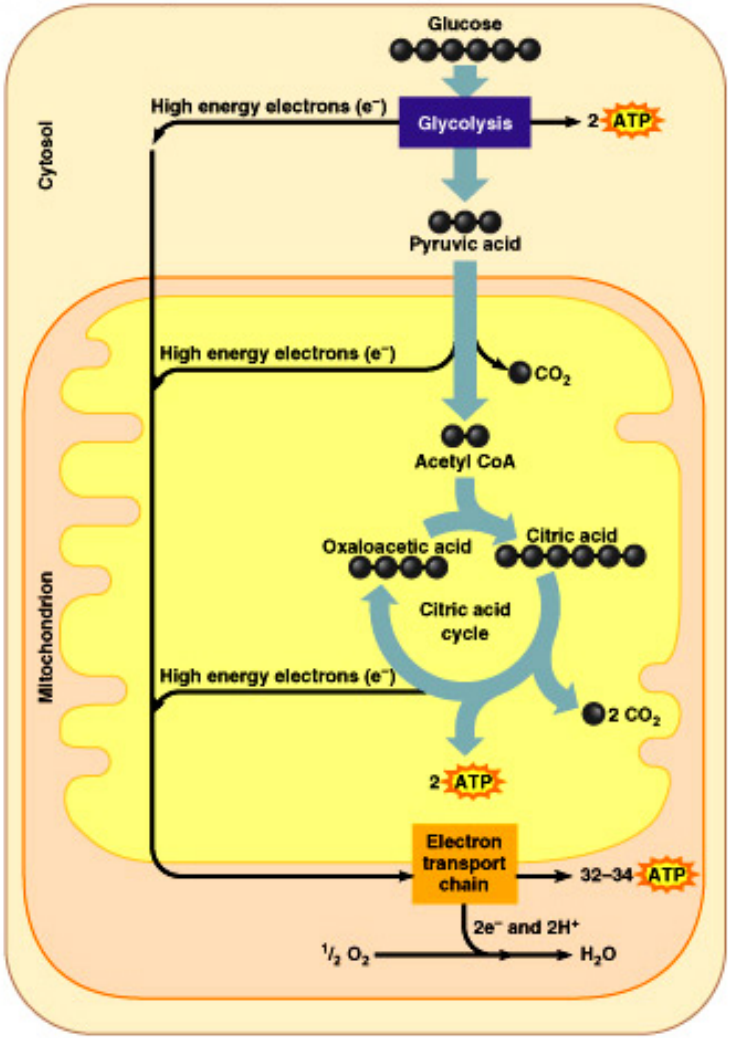
Citric Acid Cycle

2 The 3-carbon pyruvic acids generated by glycolysis enter the mitochondria. Each loses a carbon (generating CO_2) and is combined with a coenzyme to form a 2-carbon acetyl coenzyme A (acetyl CoA). More high energy electrons are released.

3 Each acetyl CoA combines with a 4-carbon oxaloacetic acid to form the 6-carbon citric acid, for which the cycle is named. For each citric acid a series of reactions removes 2 carbons (generating 2 CO_2's), synthesizes 1 ATP and releases more high energy electrons. The figure shows 2 ATP, resulting directly from 2 turns of the cycle per glucose molecule that enters glycolysis.

Electron Transport Chain

4 The high energy electrons still contain most of the chemical energy of the original glucose molecule. Special carrier molecules bring the high energy electrons to a series of enzymes that convert much of the remaining energy to more ATP molecules. The other products are heat and water. The requirement of oxygen in this last step is why the overall process is called aerobic respiration.



Summary of Catabolism of Proteins, Carbohydrates, and Fats

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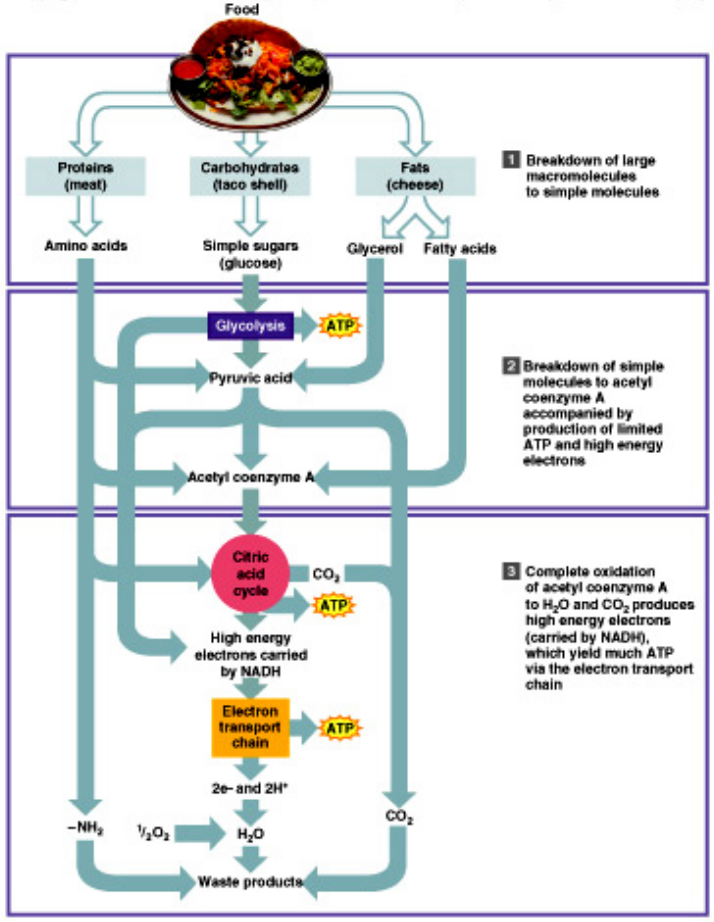

Carbohydrate Storage

Excess glucose stored as

- **glycogen (primarily by liver and muscle cells)**
- **fat**
- **converted to amino acids**

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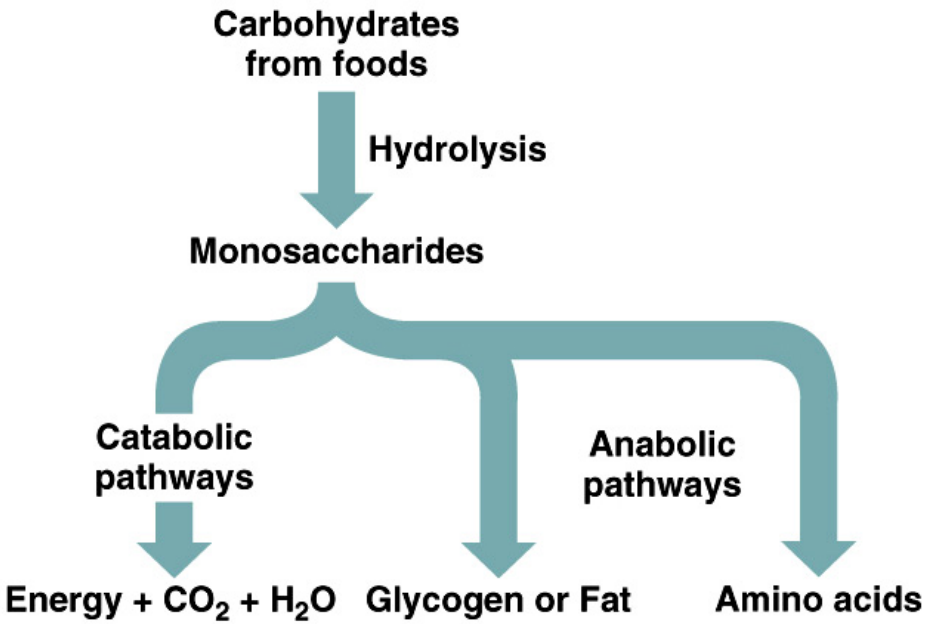
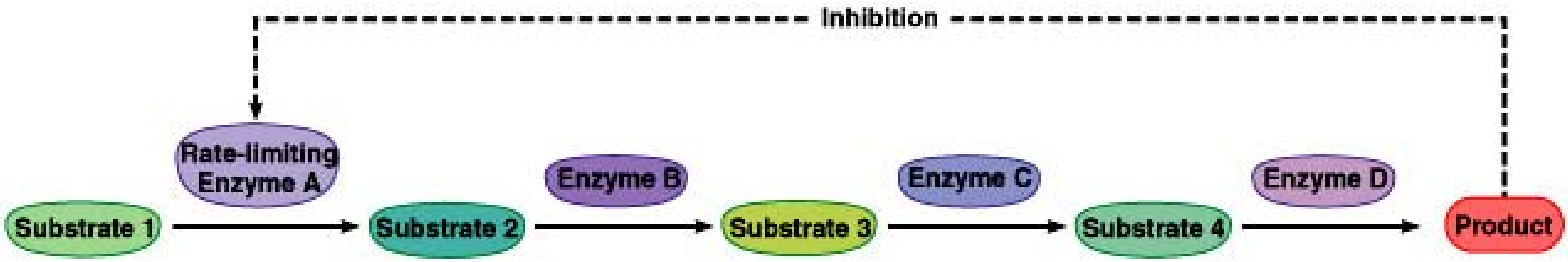


Regulation of Metabolic Pathways

- **limited number of regulatory enzymes**
- **negative feedback**



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Nucleic Acids and Protein Synthesis

Genetic information – instructs cells how to construct proteins; stored in DNA

Gene – segment of DNA that codes for one protein

Genome – complete set of genes

Genetic Code – method used to translate a sequence of nucleotides of DNA into a sequence of amino acids

Structure of DNA

- two polynucleotide chains
- hydrogen bonds hold nitrogenous bases together
- bases pair specifically (A-T and C-G)
- forms a helix
- DNA wrapped about histones forms chromosomes

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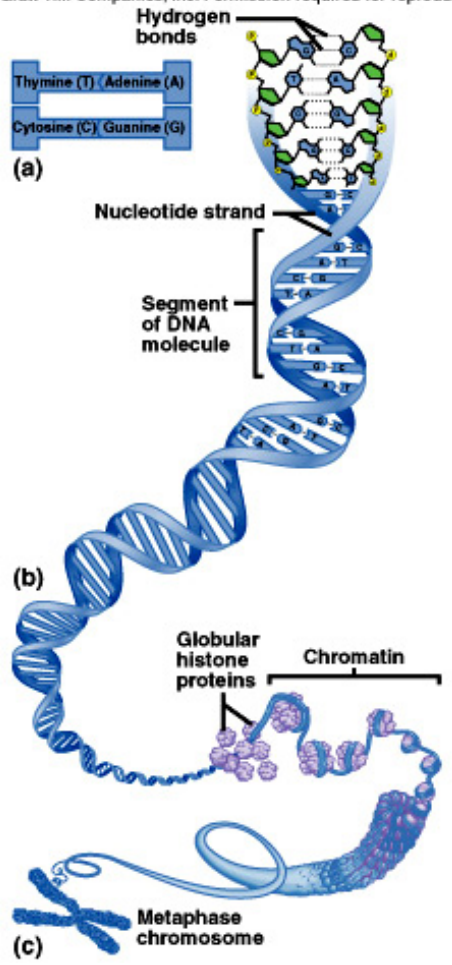
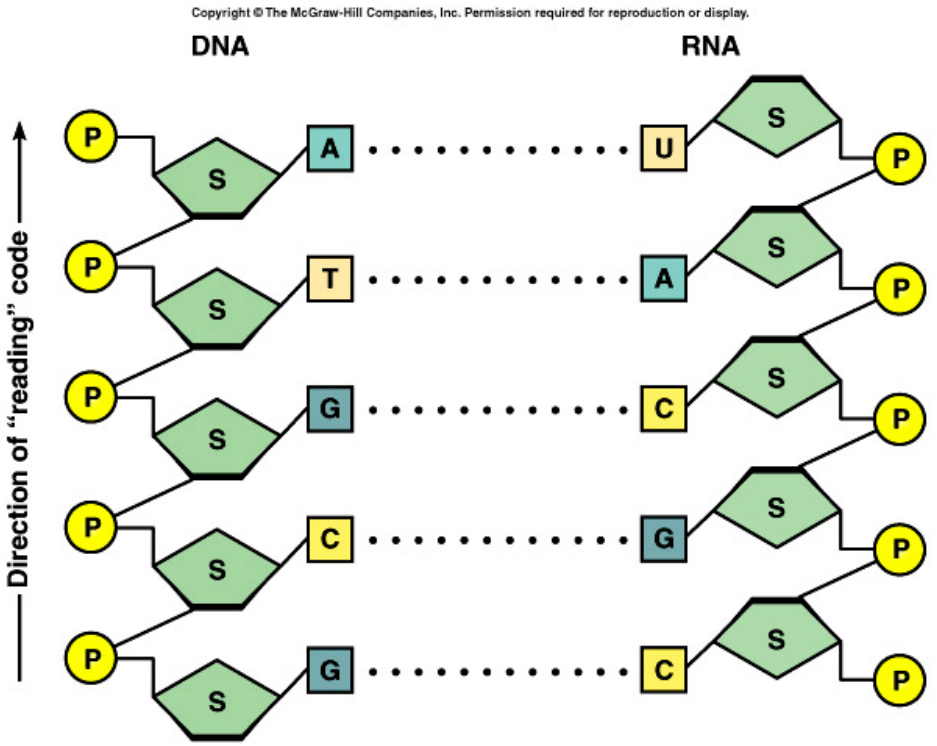


RNA Molecules

Messenger RNA (mRNA) -

- **delivers genetic information from nucleus to the cytoplasm**
- **single polynucleotide chain**
- **formed beside a strand of DNA**
- **RNA nucleotides are complementary to DNA nucleotides (exception – no thymine in RNA; replaced with uracil)**
- **making of mRNA (copying of DNA) is transcription**



RNA Molecules

Transfer RNA (tRNA) -

- **carries amino acids to mRNA**
- **carries anticodon to mRNA**
- **translates a codon of mRNA into an amino acid**

Ribosomal RNA (rRNA) –

- **provides structure and enzyme activity for ribosomes**

Protein Synthesis

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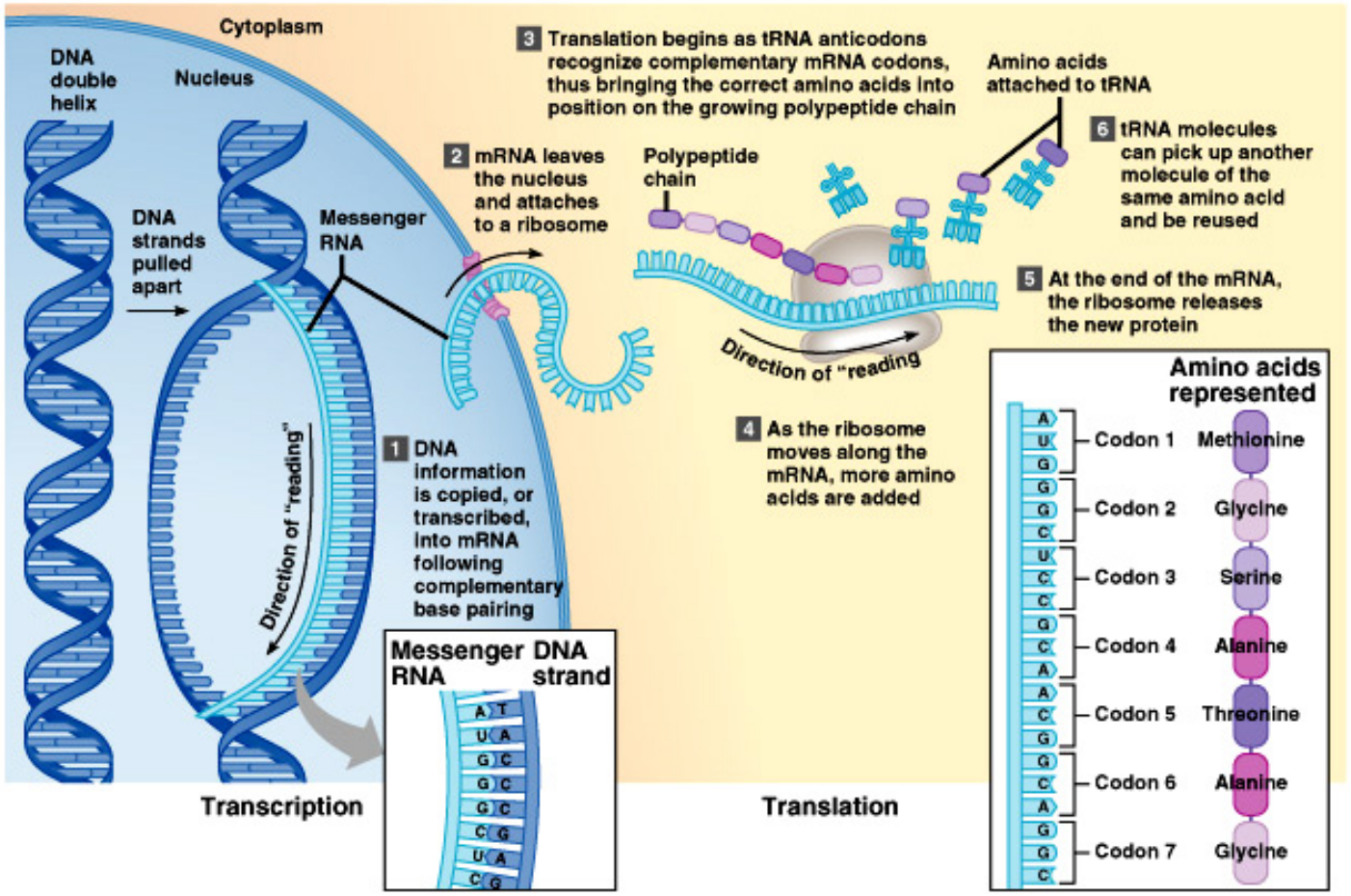

Protein Synthesis

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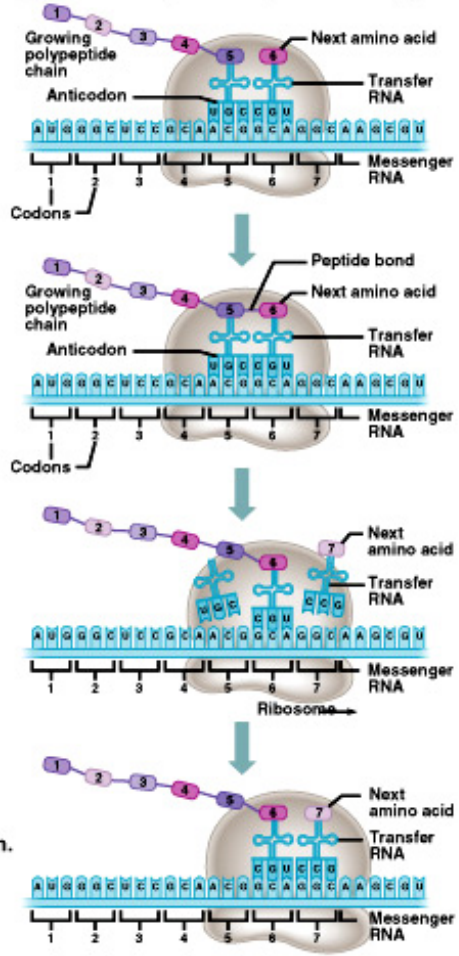
1 The transfer RNA molecule for the last amino acid added holds the growing polypeptide chain and is attached to its complementary codon on mRNA.

2 A second tRNA binds complementarily to the next codon, and in doing so brings the next amino acid into position on the ribosome. A peptide bond forms, linking the new amino acid to the growing polypeptide chain.

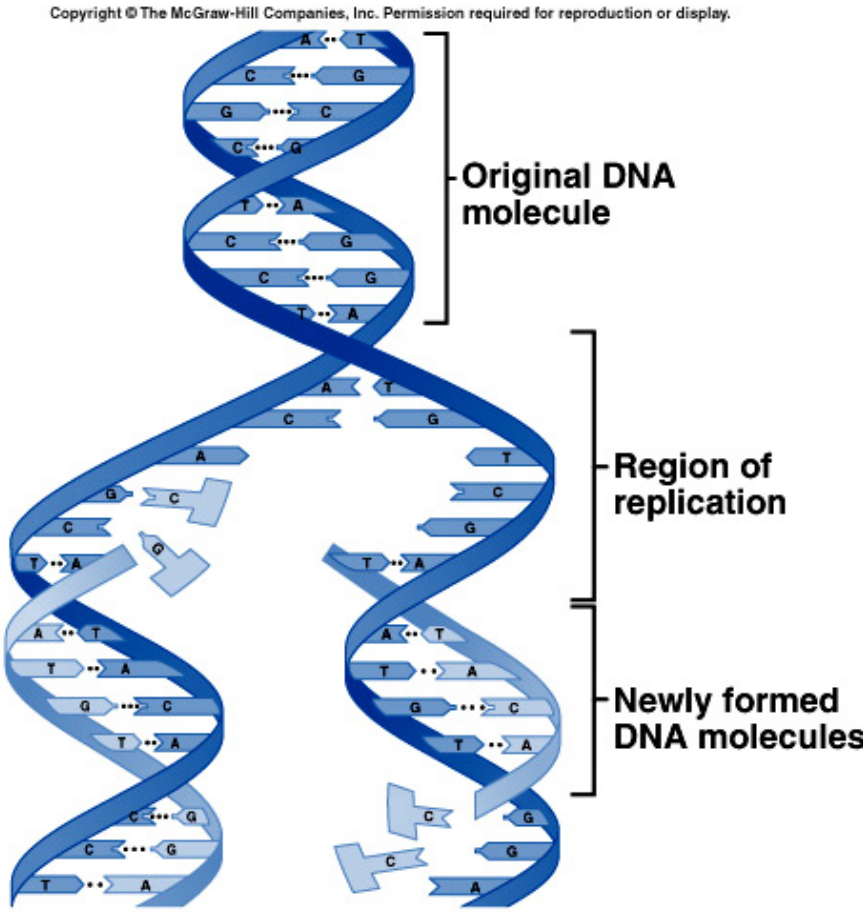
3 The tRNA molecule that brought the last amino acid to the ribosome is released to the cytoplasm, and will be used again. The ribosome moves to a new position at the next codon on mRNA.

4 A new tRNA complementary to the next codon on mRNA brings the next amino acid to be added to the growing polypeptide chain.



DNA Replication

- hydrogen bonds break between bases
- double strands unwind and pull apart
- new nucleotides pair with exposed bases
- controlled by DNA polymerase



Mutations

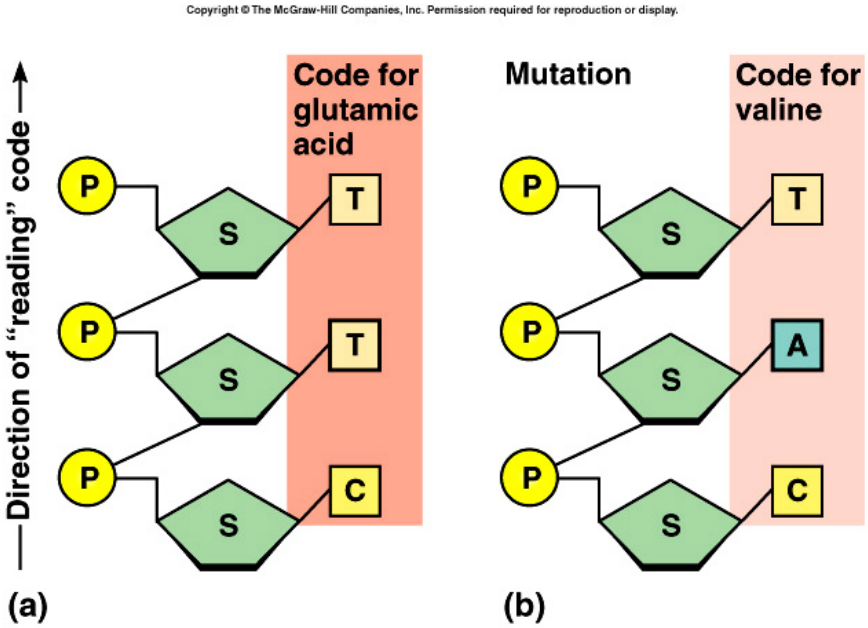
Mutations – change in genetic information

Result when

- **extra bases are added or deleted**
- **bases are changed**

May or may not change the protein

Repair enzymes correct mutations



Clinical Application

Phenylketonuria
PKU

- **enzyme that breaks down the amino acid phenylalanine is missing**
- **build up of phenylalanine causes mental retardation**
- **treated by diets very low in phenylalanine**