Introduction to Metabolism

January 13, 2003

Bryant Miles

Metabolism is the process through which living systems acquire and use free energy to carry out functions. In BICH 410 you learned the composition and structure of biological molecules. In BICH 411, you are going learn the reactions and pathways by which biomolecules are synthesized and degraded.

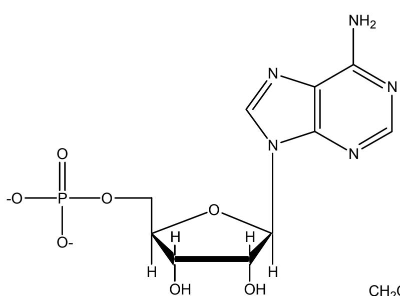
Metabolism requires highly coordinated cellular activity.
Metabolism performs 4 functions

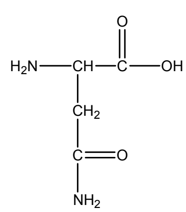
1. Obtain energy for the cell.
2. Convert nutrients into macromolecules.
3. Assemble macromolecules into cellular structures.
4. Degrade macromolecules as required for biological function.

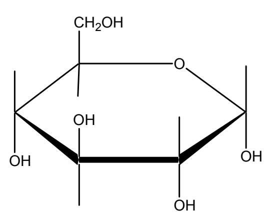
Metabolism consists of catabolism and anabolism.
Catabolism is the degradation pathways to salvage components and energy from biomolecules such as nucleotides, proteins, lipids and polysaccharides. The process generates energy.

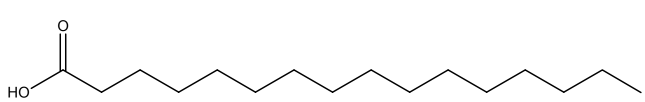
Anabolism is the biosynthesis of biomolecules such as nucleotides, proteins, lipids and polysaccharides from simple precursor molecules. This process requires energy.

Biomolecules are composed predominantly of carbon, hydrogen, oxygen and nitrogen.









All living things require a source of energy, carbon, oxygen and nitrogen.

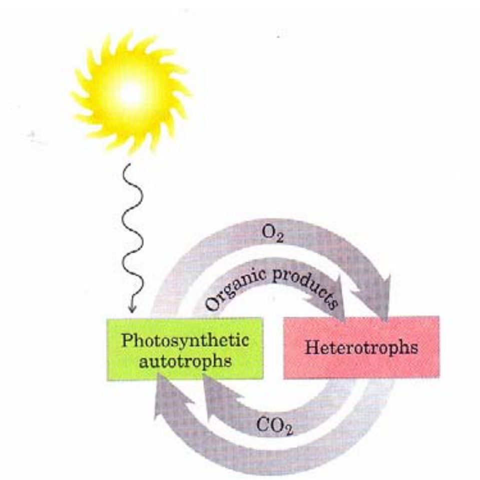
I. Energy and Carbon
Autotrophs – Self feeding.

Autotrophs are prokaryotes that can produce all of their cellular components from simple molecules such as H_2O, CO_2, NH_3 and H_2S. These are self sufficient cells that utilize CO_2 from the atmosphere as the carbon source.

Chemolithotrophs-obtain free energy via the oxidation of inorganic compounds such as NH_3, H_2S or Fe^{+2}.

Photoautrophs – obtain free energy from light photons via photosynthesis.

Heterotrophs – Feeding on others.



Heterotrophs obtain energy by oxidation of organic compounds (carbohydrates, lipids, or protein).

Heterotrophs obtain carbon from glucose, proteins and lipids. Ultimately Heterotrophs depend on autotrophs for these organic compounds,

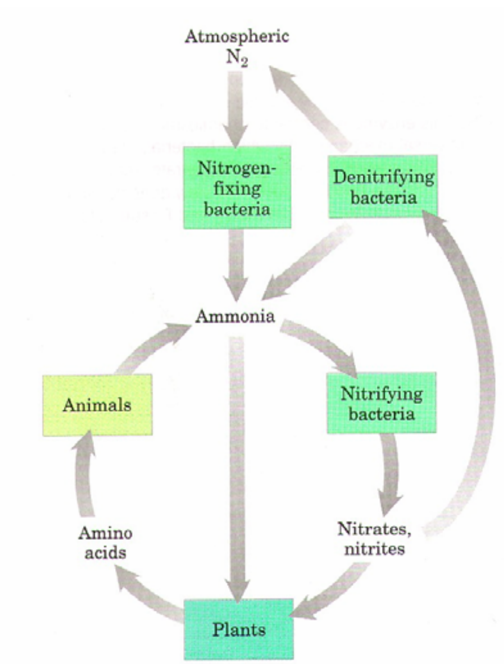
Plant cells are of two types:

1. Autotrophic-the green leaf cells are autotrophic.
2. Heterotrophic-root cells are example of heterotrophic cells of plants.

II. Oxygen

Living organisms can obtain oxygen from the atmosphere or from water.

Aerobes – live in the presence of oxygen. They use oxygen to oxidize organic nutrients.
Anaerobes – Live in the absence of oxygen. Catabolize nutrients without molecular oxygen.
Obligate anaerobes- are poisoned by oxygen.



Facultative – Some organisms can live in either aerobic or anaerobic conditions. They are called faculatives. Examples are yeast and *E. coli*.

III. Nitrogen

All living things require nitrogen. Most animals obtain nitrogen from amino acids. Plants are able to use ammonia or nitrates as nitrogen sources.

Nitrogen N_2 is the major gas component of our atmosphere (80%). It is relatively inert. The Earth's crust contains very little nitrogen. Only a few organisms can **fix** N_2. All living organisms depend on these nitrogen fixing microorganisms such as cyanobacteria and blue-green algae. Many nitrogen fixing bacteria live in the soil. Some nitrogen fixing bacteria live symbiotically in the nodules of the roots of plants.
Nitrifying Bacteria – oxidize ammonia into nitrates.
Denitrifying Bacteria - reduce nitrates into ammonia.

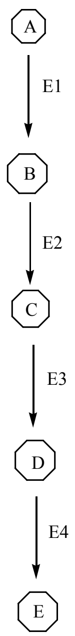
Metabolic Pathways

Enzymes are the basic units of metabolism. The substrates of these enzymes are called metabolites. A metabolic pathway is a series of connected enzymatic reactions that produce a specific product.

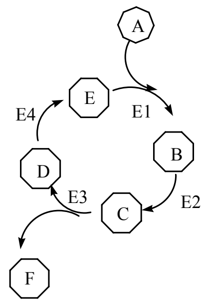
Metabolic pathways consist of sequential steps. There are more than 2,000 metabolic reactions, each catalyzed by a distinct enzyme.

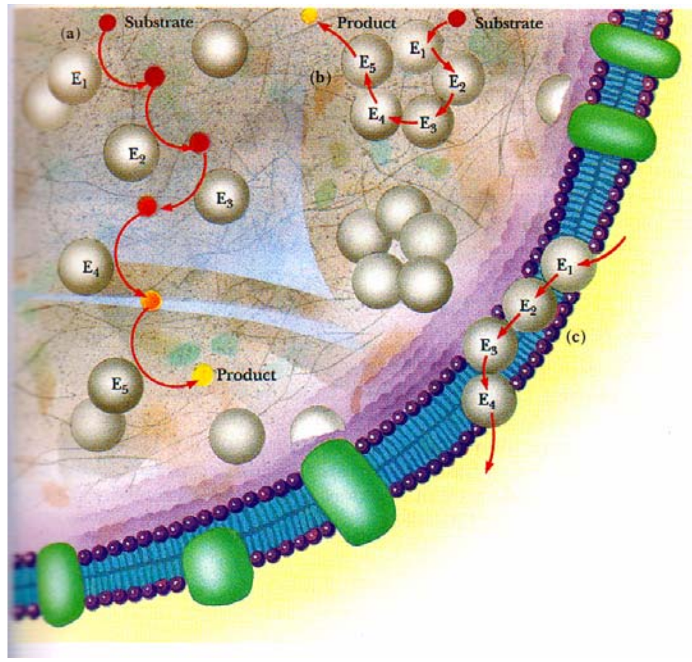
The enzymes may be physically separate requiring the intermediate metabolites to diffuse from one active site to the next or enzymes may form a multienzyme complex where the intermediate metabolites are passed directly from one active site to the next. Some pathways reside within membranes. In this case the enzyme and the substrates diffuse in the two dimensions of the bilipid membrane.

Linear Metabolic Pathway



Circular Metabolic Pathway





Recent research reveals that soluble enzymes are organized into ultra structures in the cell where consecutively acting enzymes are associated into multiple enzyme complexes called **metabolons**.

The catabolic and anabolic pathways are related.

Catabolism
Complex metabolites are degraded into simpler products such as acetyl units linked to coenzyme A. The degradation process releases free energy. The free energy is conserved by the reduction of $NADP^{+} \rightarrow NADPH$ or by coupling exergonic reactions to ATP synthesis.

The striking characteristic of catabolic pathways is that a divergent range of biomolecules converge by forming common intermediates.

Anabolism
Complex biomolecules are synthesized from simple precursors. This process is endergonic. This process requires the free energy of ATP hydrolysis, $ATP \rightarrow ADP + Pi$ or NADH oxidation, $NADH \rightarrow NAD^{+}$.

The striking feature of anabolic pathways is that they begin with a few common metabolites as starting materials and diverge into a wide range of biomolecules.

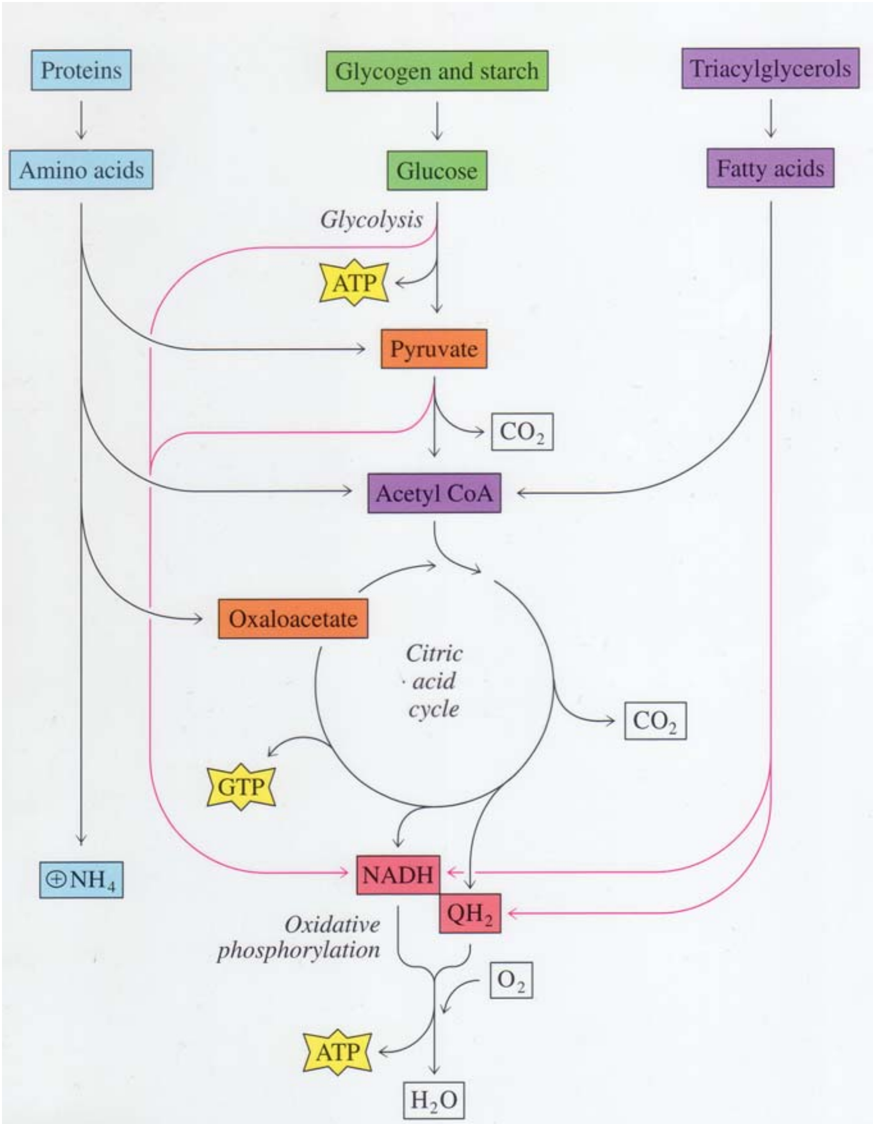
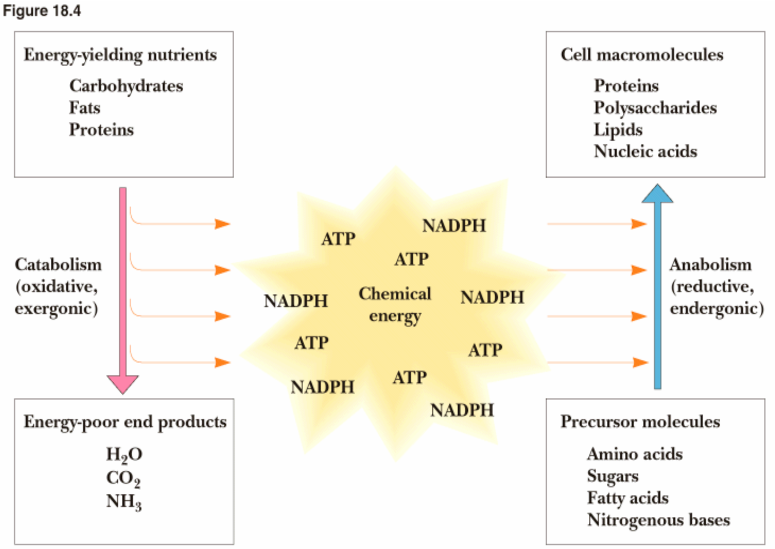


Figure 18.4



Saunders College Publishing

examples of each type of pathway in the following chapters.

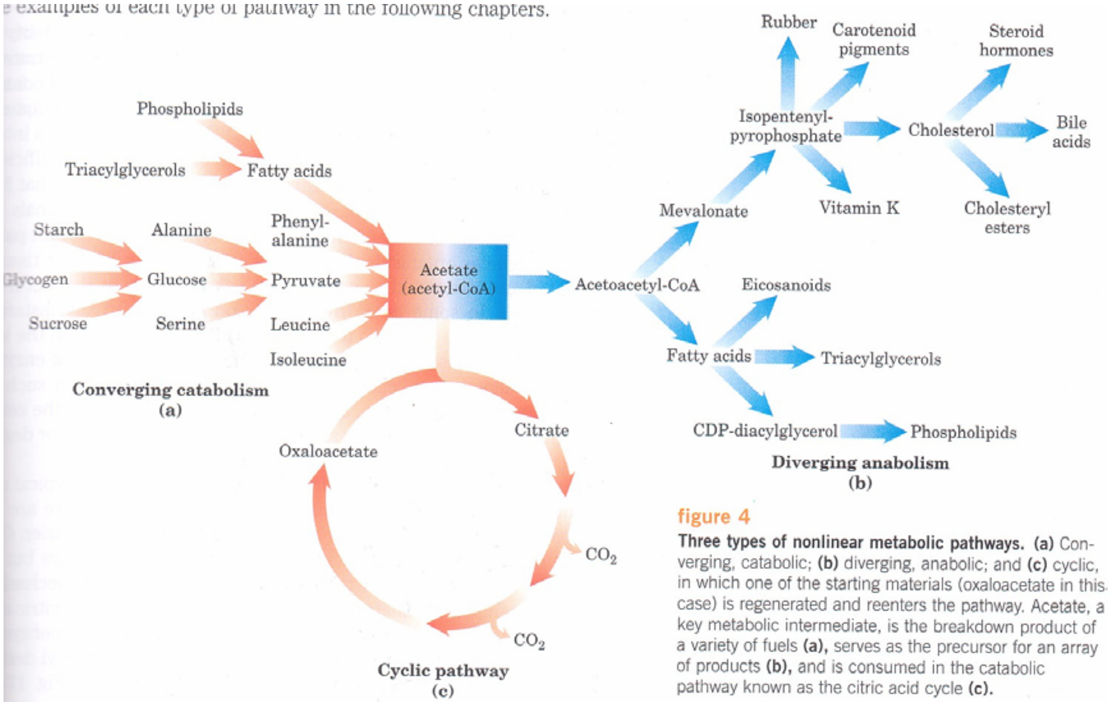
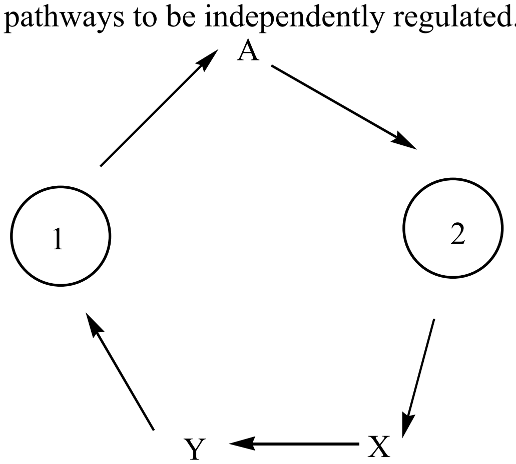


figure 4
Three types of nonlinear metabolic pathways. (a) Converging, catabolic; **(b)** diverging, anabolic; and **(c)** cyclic, in which one of the starting materials (oxaloacetate in this case) is regenerated and reenters the pathway. Acetate, a key metabolic intermediate, is the breakdown product of a variety of fuels **(a)**, serves as the precursor for an array of products **(b)**, and is consumed in the catabolic pathway known as the citric acid cycle **(c)**.

Four Principles of Metabolic Pathways

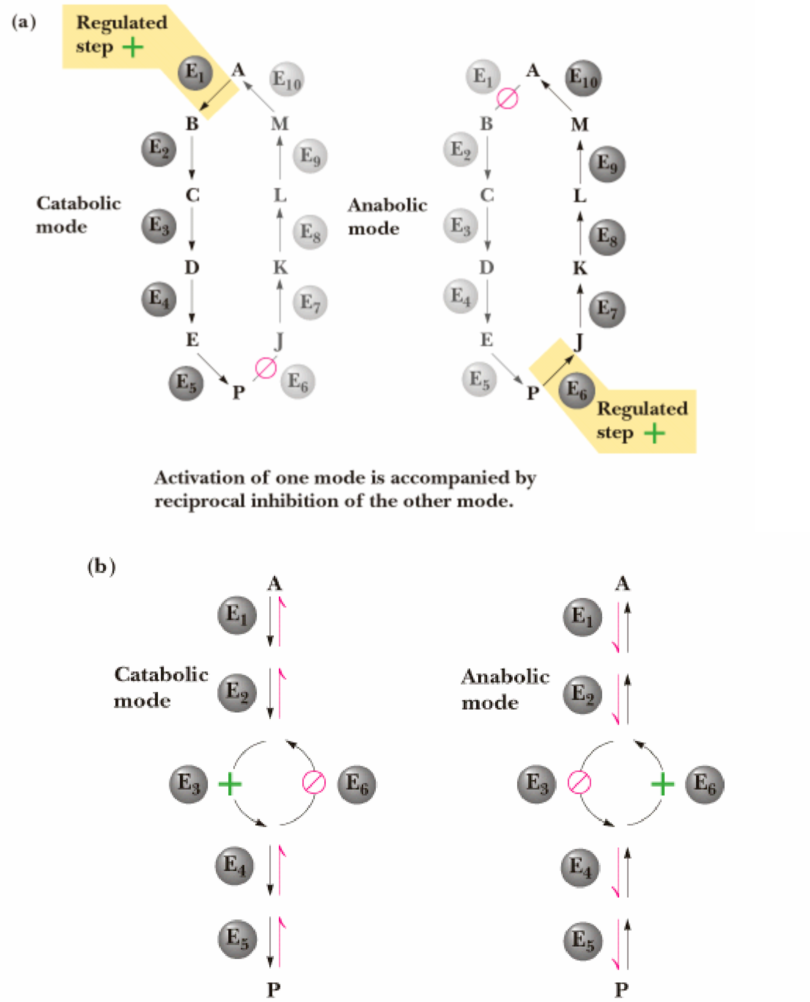
1. **Metabolic pathways are irreversible**
   Metabolic pathways are highly exergonic which gives the pathway direction. Consequently if two metabolites are interconvertible, the pathway from the first to the second must be different than the pathway of the second back to the first. This independent interconversion allows the two pathways to be independently regulated.



2. **Every metabolic pathway has a first committed step**
   Most of the reactions in a metabolic pathway are close to equilibrium, but every pathway has an irreversible highly exergonic reaction that commits the intermediate it produces to continue down the pathway.

3. **All metabolic pathways are regulated**
   The control of the metabolic flux of metabolites through a pathway is accomplished by regulating the rate determining step of the pathway which often is the first committed step of the pathway.

Figure 18.7



Saunders College Publishing

4. Metabolic pathways in eukaryotes occur is specific cellular locations.

Compartmentalization of Metabolic Pathways

Eukaryotes use organelles to compartmentalize metabolic pathways allowing different metabolic pathways to occur in specific locations.

Mitochondrion - Citric acid cycle, oxidative phosphorylation, amino acid catabolism.

Cytosol – Glycolysis, pentose phosphate pathway, fatty acid biosynthesis, gluconeogenesis.

Nucleus – DNA replication, RNA transcription, RNA processing.

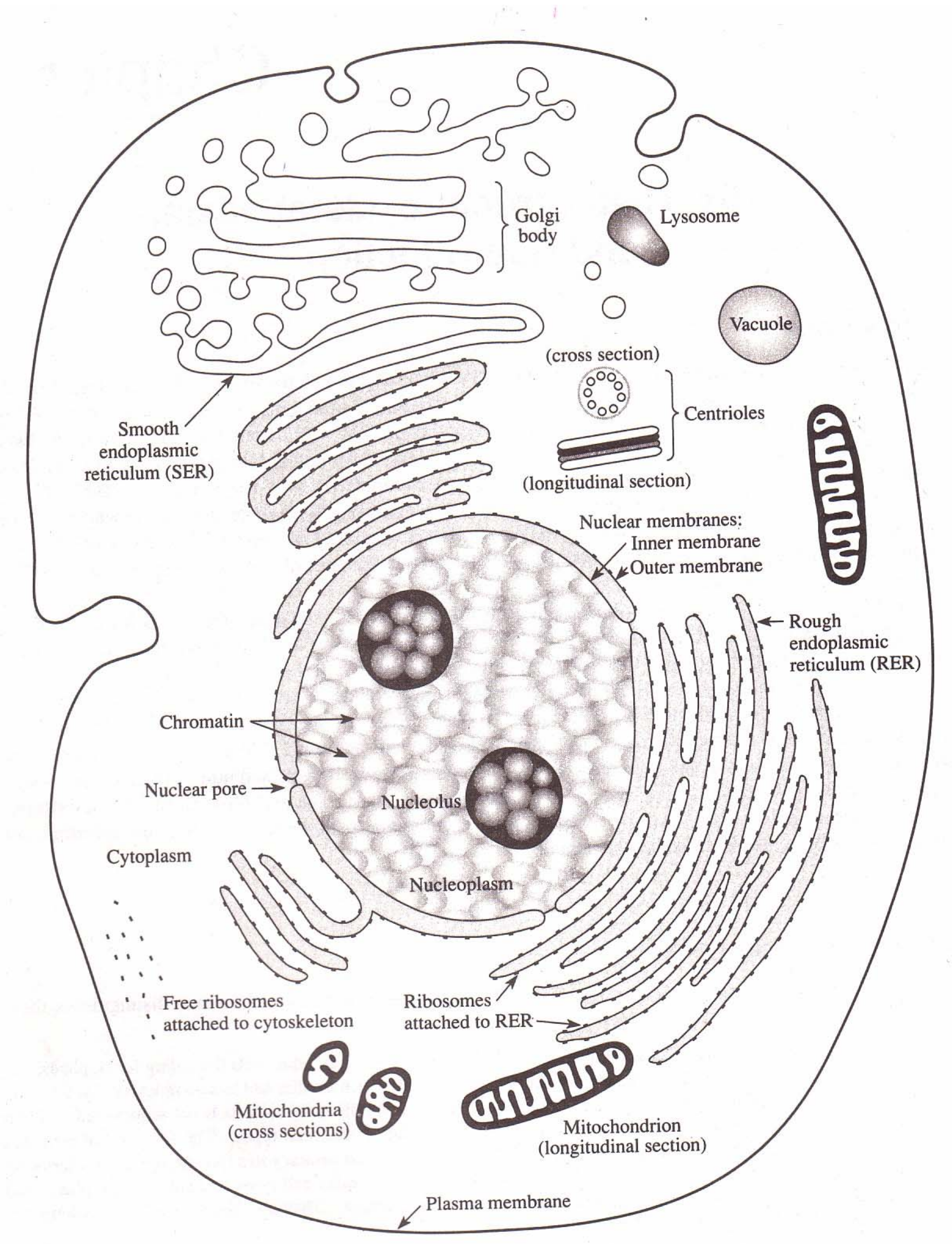
Lysosomes – Enzymatic digestion of cellular components.

Golgi Apparatus – Post translational modification of membrane and secretory proteins, formation of plasma membranes and secretory vesicles.

Rough Endoplasmic Reticulum – Synthesis of membrane-bound and secretory proteins.

Smooth Endoplasmic Reticulum – Lipid and steroid biosynthesis.

Peroxisomes - Oxidative reactions involving amino acid oxidases and catalase, glyoxylate cycle reactions in plants.



In multicellular organisms compartmentation is carried a step further to the level of tissues and organs. For example, the liver is largely responsible for the synthesis of glucose from noncarbohydrate precursors to maintain a constant level of glucose in the blood stream. Adipose tissue is specialized for the storage of triacylglycerols.