Appendix D – Cellular Anatomy

Cells are the basic organizational unit of life; all organisms are composed of cells. The functioning of cells is dictated by common physiological characteristics.

- Cells reproduce by cell duplication / division
- The information to build a cell and to permit cellular function is encoded in its genes (DNA/RNA)
- Cells respond to stimuli
- Cells engage in various mechanical activities and enzymatically controlled chemical reactions
- Cellular activity is fueled by chemical energy
- Cells undergo a remarkable amount of self-regulation

Cells are typically 10 to 30 microns in length (except for muscle cells and neurons). This small size is dictated by the short distance that substances can diffuse and the finite number of copies of genes. The basic organization of a mammalian cell is shown in Figure D.1. Please use this illustration as a reference as we go through the chapter.

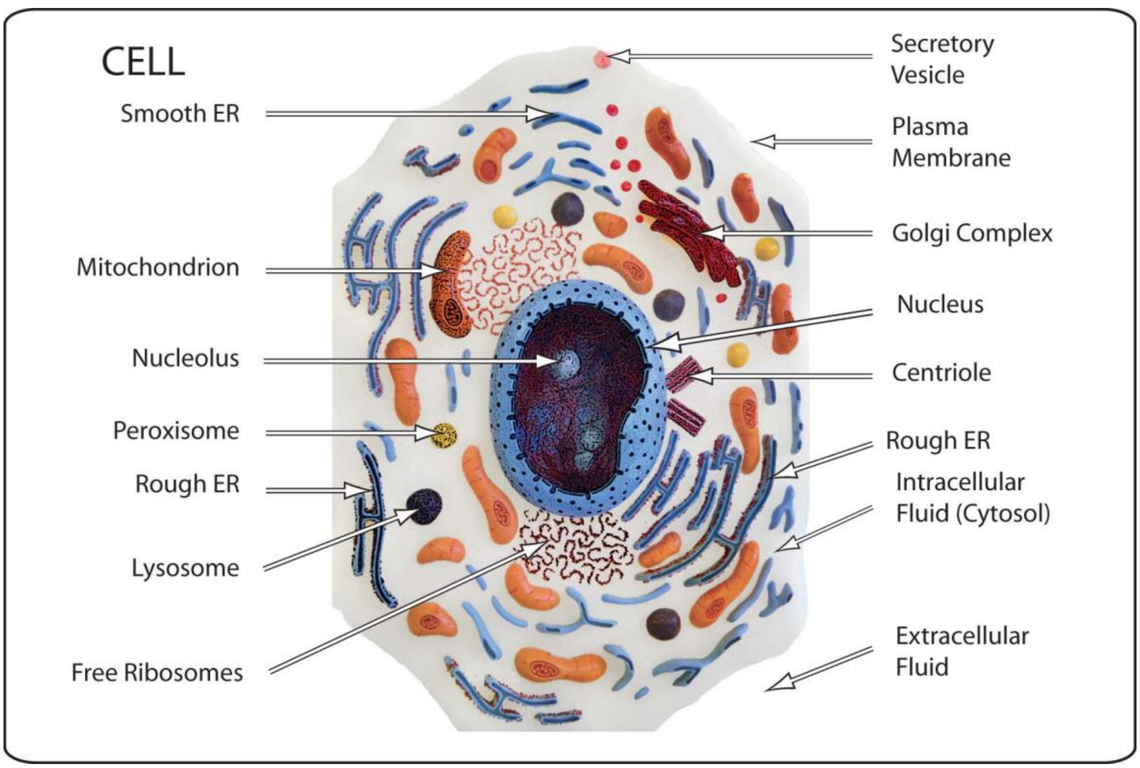

Figure D.1 © 2010 David G. Ward, PhD

Plasma Membrane

Cells are surrounded by **extracellular fluid** and contain **intracellular fluid**. Both the extracellular fluid and the intracellular fluid are composed mainly of water and various solutes. Some critical solutes are sodium, potassium, calcium and chloride ions. The plasma membrane separates the extracellular fluid from the intracellular fluid.

Phospholipid Bilayer

The plasma membrane is composed of a phospholipid bilayer and various proteins, either embedded in the bilayer (integral proteins) or on the surfaces of the bilayer (peripheral proteins). The basic organization of the phospholipid bilayer is shown in Figure D.2.

The phospholipid bilayer is composed predominantly of phosphatidylcholine, phosphatidylinositol, sphingomyelin, and cholesterol. These molecules are described in more detail in the next chapter. Together, these molecules:

- Enclose the contents of the cell so that cellular activity can proceed without outside interference
- Prevent the unrestricted passage of water and water soluble molecules, such as nutrients and electrolytes from one side of the membrane to the other

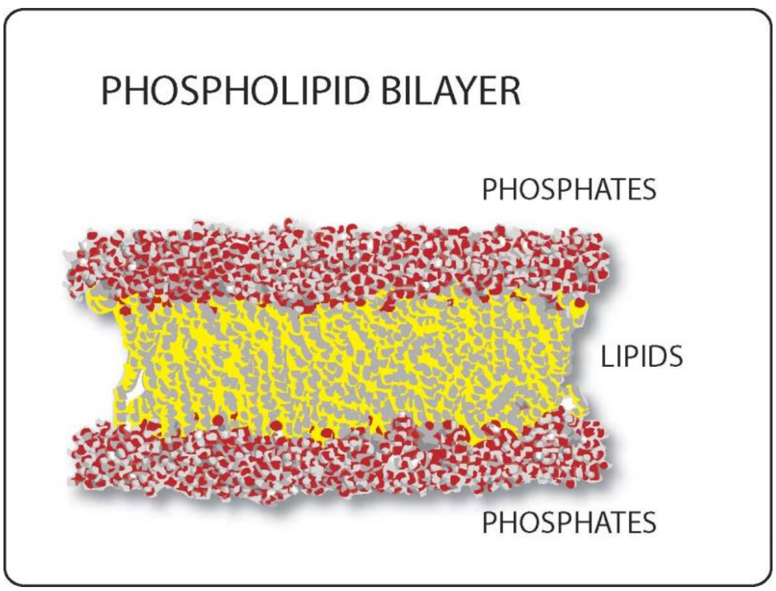

Figure D.2 © 2007 David G. Ward, PhD

The integral proteins are embedded in and pass through the phospholipid bilayer. Receptor sites of integral proteins of the plasma membrane usually face the extracellular fluid. In contrast the peripheral proteins of the plasma membrane attach to the surfaces of the phospholipid bilayer, either on the intracellular side or on the extracellular side. Carbohydrate chains attach to the extracellular side. The role of these molecules in membrane transport and cellular signaling are described in more detail in chapters 6 and 7. Together, these membrane molecules:

- Transport specific water soluble substances, such as nutrients and electrolytes from one side of the membrane to the other.
- Mediate cellular responses to external stimuli: Membrane receptors combine with certain molecules (Ligands).
- Mediate intercellular interactions: Membrane molecules allow cells to recognize and signal one another, to adhere when appropriate, and to exchange materials and information.

Membranous Organelles

All of the material inside of the cell except for the **nucleus** is called the **cytoplasm**. The membranous organelles include the nucleus, mitochondria, endoplasmic reticulum, Golgi complex, and various vesicles (including lysosomes, and peroxisomes). The **membranous organelles** are composed of double or single phospholipid bilayers.

Nucleus

The **nuclear envelope** is composed of double phospholipid bilayers forming a double walled membrane with pores. The membranes of the nuclear envelope serve as a barrier to keep ions, and proteins from passing between the nucleus and the cytoplasm. The basic organization of the nucleus is shown in Figure D.3.

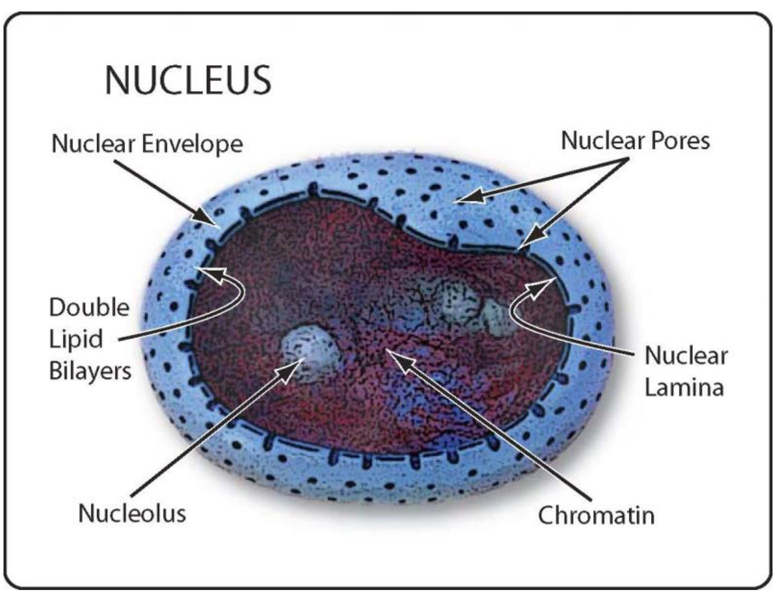

Figure D.3 © 2007 David G. Ward, PhD

- The two membranes are fused frequently forming **nuclear pores** that contain complex assemblies of proteins.

- The outer membrane is generally covered with ribosomes and is often seen to be continuous with the rough endoplasmic reticulum.
- The inner membrane is bound to a dense filamentous meshwork called the **nuclear lamina**, inner most dark layer. The nuclear lamina provides support for the nuclear envelope and attachment sites for chromatin fibers.
- Nuclear pores allow for the movement of proteins and ribonucleic acids (RNAs) in both directions between the nucleus and cytoplasm. Movement is controlled by the nuclear pore complex (NPC), which is located inside the nuclear pore.
- In the non-dividing cell, the portions of the DNA that encode ribosomal RNA (rRNA) are clustered in one or more irregularly shaped structures called **nucleoli**.

The nucleus contains **chromatin** which is composed of deoxyribonucleic acid (DNA) and associated histone and non-histone proteins. DNA wraps around disks of histone proteins forming **nucleosomes**. The nucleosome coils up to form the loop domains. The loop domains come together to form the chromosomes at the beginning of mitosis. The loop domains uncoil after cell division is complete. The organization of the chromosomes and DNA is shown in Figure D.4.

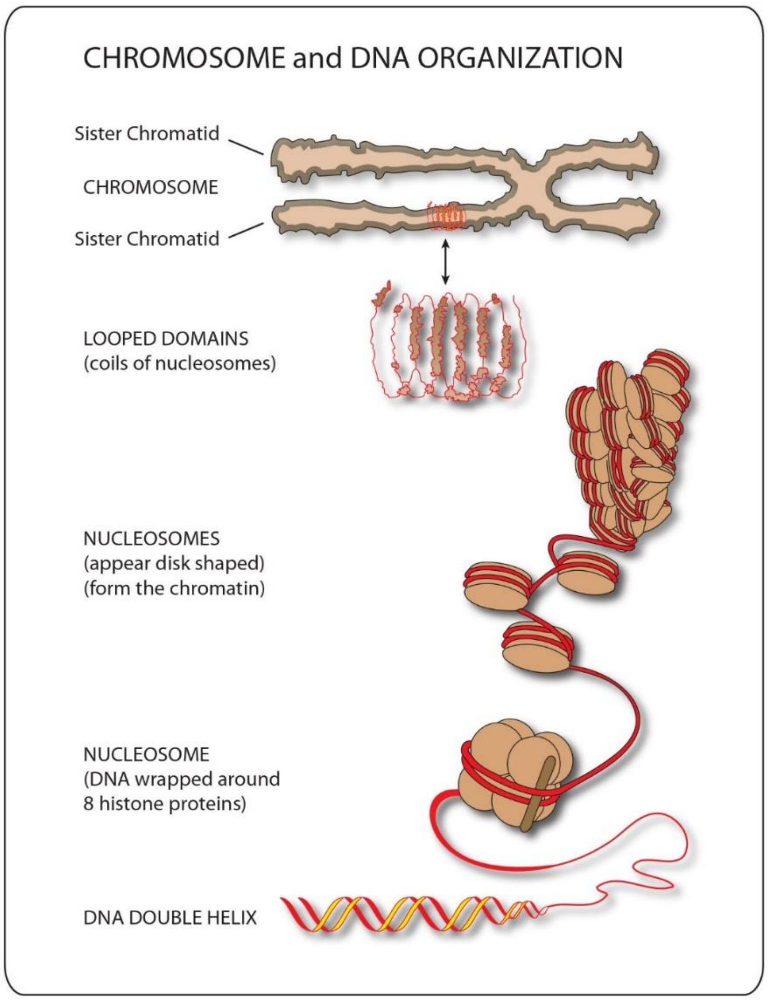

Figure D.4 © 2014 David G. Ward, PhD

Mitochondria

Mitochondria are composed of double phospholipid bilayers forming an outer membrane and an inner membrane. Much of the inner membrane forms deep folds called **cristae**. The inner membrane surrounds an aqueous compartment called the **matrix**. The matrix contains a high concentration of water soluble proteins, especially enzymes. Located between the inner and outer membrane is another aqueous compartment called the **intermembrane space**. The basic organization of the mitochondrion is shown in Figure D.5.

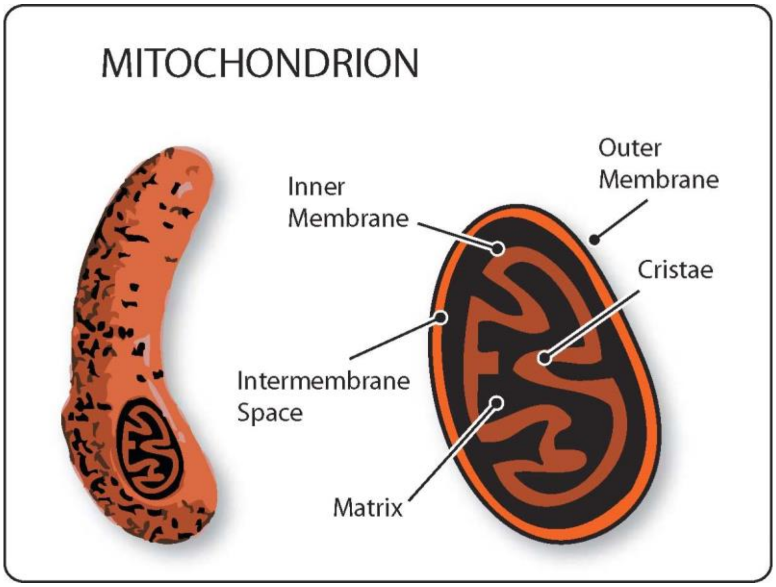

Figure D.5 © 2007 David G. Ward, PhD

- The matrix is the site of decarboxylation of pyruvate and of the tricarboxylic acid (TCA) cycle.
- The inner membrane contains a large number of polypeptides and is the location of most of the machinery required for the synthesis of ATP, especially oxidative phosphorylation (also known as the electron transport chain).

Endoplasmic reticulum (ER)

The endoplasmic reticulum consists of interconnected membranes that are composed of a single phospholipid bilayer. These membranes form tubing that act as transportation pathways and storage sites. The basic organization of rough endoplasmic reticulum is shown in Figure D.6.

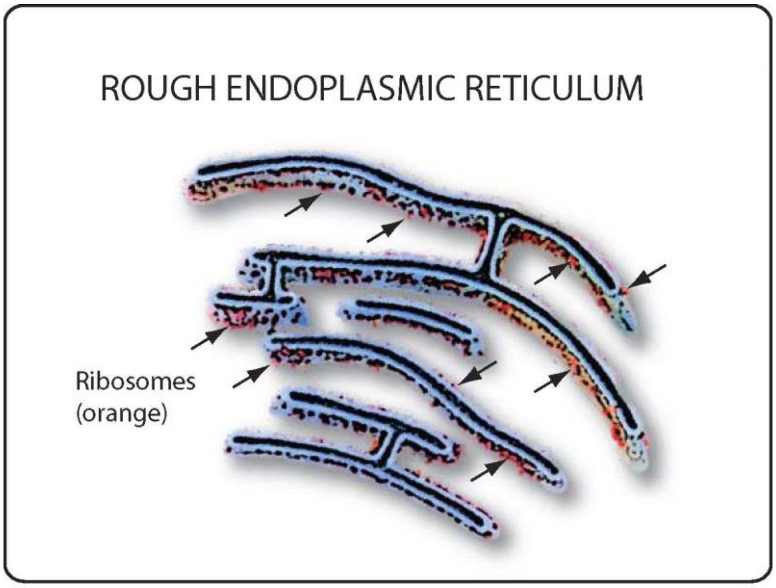

Figure D.6 © 2007 David G. Ward, PhD

- The **Rough Endoplasmic Reticulum (RER)** consists of flattened sacs that typically are an extension of the outer membrane of the nuclear envelope. Both the nuclear envelope and the RER are covered with **ribosomes** on the surface of the membranes facing the cytosol. The RER is the site for synthesizing secretory proteins. Non-secretory proteins are synthesized on free ribosomes.
    - Proteins in the ER typically leave in transport vesicles produced by budding of the ER membrane. Budding is the pinching off of pieces of the tubular membrane.
- The **Smooth Endoplasmic Reticulum (SER)** consists of tubular structures that form an interconnecting system of pipelines curving through the cytoplasm. There are few if any ribosomes on the membranes. The functions of the SER vary with the type of cell. In endocrine cells the SER is involved in synthesizing steroid hormones. In liver cells, the SER is involved in detoxification of organic compounds and in the conversion of stored glycogen to glucose. In muscle and some other cells, calcium is stored in the cisternal space of the SER. Regulated release of calcium from the SER triggers contraction of skeletal muscle cells and fusion of secretory vesicles with the plasma membrane. We will be considering these functions in more detail in subsequent chapters.

Golgi complex

The Golgi complex consists of flattened, disk-like membranous sacs, call **cisterna**, that are composed of a single phospholipid bilayer. The cisterna facing the endoplasmic reticulum is called the **cis-cisterna**. The cisterna facing the plasma membrane is called the **trans-cisterna**. The cisterna in between the cis-cisterna and tran-cisterna is called the **medial-cisterna**. The basic organization of the Golgi complex is shown in Figure D.7.

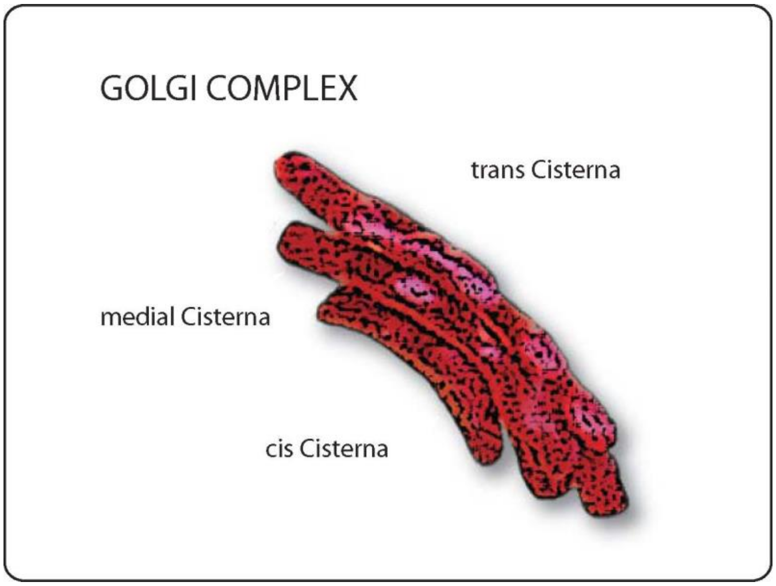

Figure D.7 © 2007 David G. Ward, PhD

- The Golgi complex acts as a processing plant. The Golgi complex is involved in modifying proteins from the endoplasmic reticulum and in synthesizing complex polysaccharides.
- Proteins in the Golgi complex typically leave in vesicles produced by budding of the Golgi membrane.

Vesicles

There are many types of vesicles, including transport vesicles, secretory vesicles, and lysosomes and peroxisomes. Vesicles are composed of a single phospholipid bilayer.

- **Secretory Vesicles** are vesicles that have budded from the Golgi complex and contain proteins or other substances intended for secretion out of a cell.
- **Lysosomes** are vesicles that have budded from the Golgi complex and contain many digestive enzymes. Lysosomes are common in phagocytic cells and digest cellular debris and pathogens.
- **Peroxisomes** are vesicles that are derived in part from the ER and in part from free ribosomes, and contain many metabolic enzymes that generate hydrogen peroxide as a by-product. Peroxisomes are involved in various aspects of lipid metabolism, especially oxidation of long chain fatty acids, and synthesizing phospholipids.

Summary of Membranous organelles

Figure D.8 summarizes the relationship among the nucleus, endoplasmic reticulum, ER buds, Golgi complex, vesicles and plasma membrane. The membranous organelles together with the ribosomes play a critical role in the synthesis and transport of proteins, lipids and carbohydrates. The roles of the nucleus, endoplasmic reticulum and Golgi complex in protein synthesis are considered further in chapter 5.

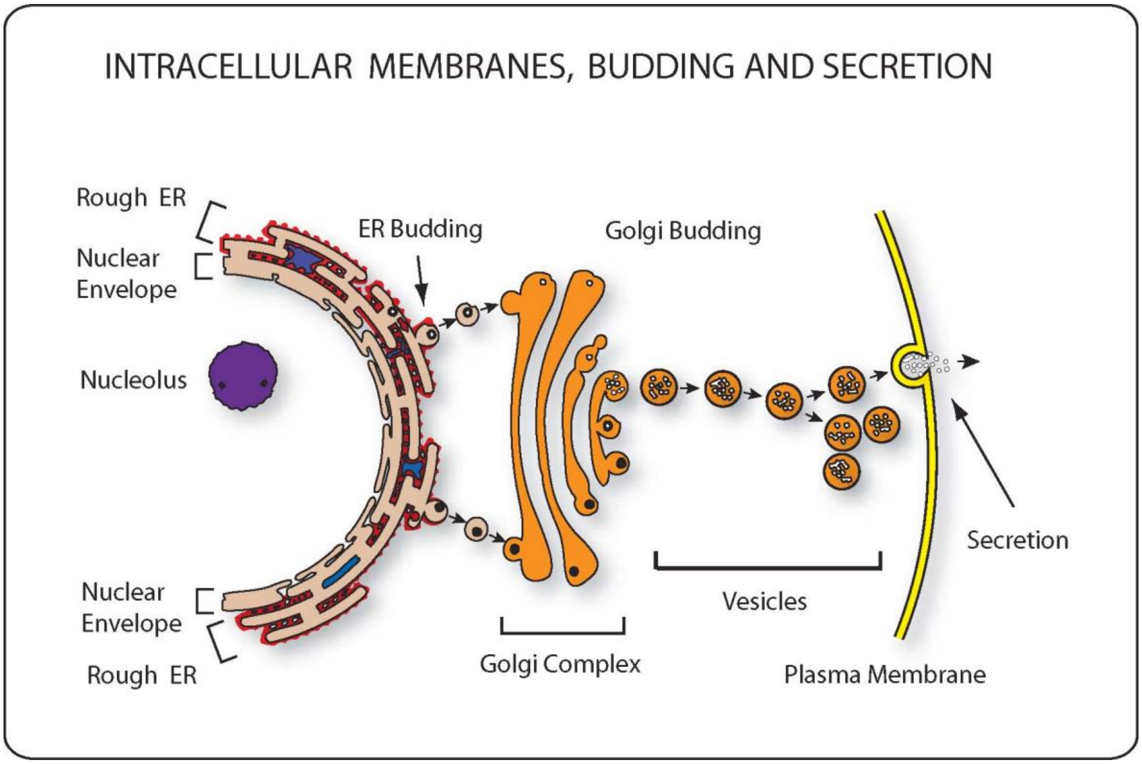

Figure D.8 © 2007 David G. Ward, PhD

Non-Membranous Organelles

The non-membranous organelles are of course the molecular clusters in the cell that are not bounded by phospholipid bilayers. These include the ribosomes, the cytoskeleton, and other structures such as the centrioles.

Ribosomes

Ribosomes are composed of subunits of ribosomal RNA and protein and may be free of or attached to ER. The basic organization of free ribosomes is shown in Figure D.9.

- Ribosomes function to build proteins using messenger and transfer RNA. First, one piece of ribosomal RNA and protein, a **small ribosomal subunit** (40S**)**, attaches to messenger RNA. Then a second piece of ribosomal RNA and protein, a **large ribosomal subunit** (60S), joins with the small subunit. The role of ribosomes in the construction of proteins was considered in chapter 3.

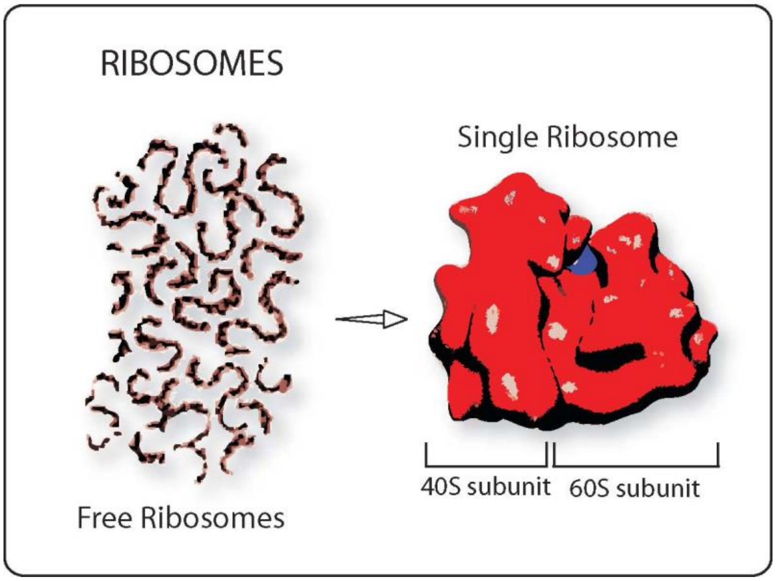

Figure D.9 © 2007 David G. Ward, PhD

Cytoskeleton

The cytoskeleton is composed of microtubules, microfilaments (**actin**), and intermediate filaments. They function as a cytoskeleton, in intracellular transport, and in mobility.

- **Microtubules** are hollow, cylindrical protein structures that form part of the cytoskeleton and part of mitotic spindles, centrioles, cilia and flagella. Kinesins and dyneins are motor proteins that move along microtubules. Microtubules move substances and organelles within cells, and anchor organelles and mRNA.
- **Microfilaments** are actin proteins involved in movement. **Myosin** proteins are motor proteins that move along microfilaments (actin).
- Intermediate filaments are protein filaments that provide mechanical stability to cells.
- **Centrioles** are composed of 9 evenly spaced bundles of 3 microtubules per bundle and play a critical role in separation of chromatids during cell division.