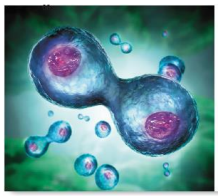

3
The Cell

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MODULE 3.1 INTRODUCTION TO CELLS

BASIC PROCESSES OF CELLS

The following *basic processes* are common to all cell types:

- Cell metabolism
- Transport of substances
- Communication
- Cell reproduction

BASIC PROCESSES OF CELLS

Cell metabolism – sum of all *chemical reactions* that a cell carries out to maintain life:

- **Anabolic reactions** – building reactions; small molecules are *bonded together* to form macromolecules
- **Catabolic reactions** *break down* macromolecules back into smaller molecules
- **Oxidation-reduction** reactions convert energy in chemical bonds of nutrients into form of energy cell can use to *fuel its processes*, namely ATP

BASIC PROCESSES OF CELLS

Transport of substances cell has produced or ingested to a variety of destinations is a vital process

Communication between cell and itself, its surrounding environment, and other cells is carried out by various methods including *chemical* and *electrical signals*

Cell reproduction by cell division – process that is necessary for *growth* and *development* and for *replacement* of old and damaged cells

OVERVIEW OF CELL STRUCTURE

Most animal cells have *3 basic components*:

- **Plasma membrane**
- **Cytoplasm**
- **Nucleus**

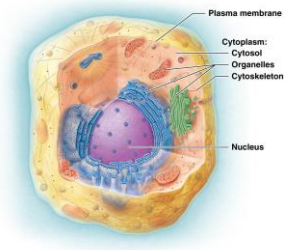


Figure 3.1 The basic components of a generalized cell.

Overview of Cell Structure

Plasma membrane surrounds each cell, *isolating* its internal structures and processes from external environment:

- Provides cell with structural *support*, means of *communication* with its surroundings and other cells, and cell *identification*
- Defines intracellular space (contains **intracellular fluid** (**ICF**)), or **cytosol**, and separates it from extracellular space (contains **extracellular fluid** (**ECF**))

Overview of Cell Structure

Cytoplasm consists of:

- **Cytosol** – intracellular fluid; mostly water with dissolved solutes, inclusions or storage molecules, and proteins; site of many important chemical reactions
- **Organelles** – variety of cellular machines with *very specific functions*; suspended in cytosol; serve to separate potentially *damaging chemical reactions* from surrounding cell structures (**compartmentalization**)
- **Cytoskeleton** – network of *protein filaments*; creates and maintains *shape*; holds organelles in *place*; provides means of *transportation* for substances within cell

Overview of Cell Structure

Most cells contain a single roughly spherical organelle called the **nucleus**:

- Enclosed in phospholipid bilayer similar to plasma membrane; termed **nuclear envelope**
- Contains most of cell's **DNA** and is primary location for *making* most **RNA**
- DNA and RNA control more specific organelle functions by *coding for and synthesizing proteins*

Overview of Cell Structure

Cell Size and Diversity:

- Cells vary widely in size and structure to enable them to better perform specialized functions
- Note that this *structural variation* is an example of **Structure-Function Core Principle**

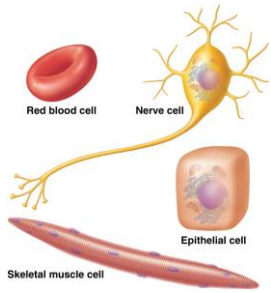


Figure 3.2 Cell diversity. Note that cells are not drawn to same scale.

Module 3.2 Structure of the Plasma Membrane

The Phospholipid Bilayer

In order for plasma membrane to form an effective barrier between ECF and cytosol, molecules that make up membrane (**phospholipid bilayer**) must have two *key properties*:

- Molecules must have parts that *interact with water* in both fluid compartments without *falling apart*
- Molecules must have parts that *repel water*, keeping ECF and cytosol separated

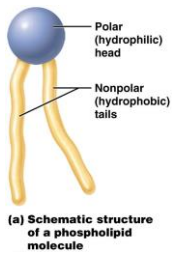


Figure 3.3a The formation of a phospholipid bilayer.

THE PHOSPHOLIPID BILAYER

In order for plasma membrane to form an effective barrier between ECF and cytosol, molecules that make up membrane (**phospholipid bilayer**) must have two *key properties* (continued):

- Phospholipids are **amphiphilic** – have both a phosphate group (*hydrophilic* polar head) facing each fluid compartment and two fatty acids (*hydrophobic* tails) that face one another forming a *water-resistant barrier*

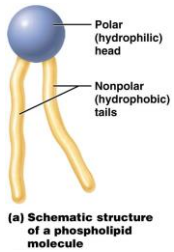


Figure 3.3a The formation of a phospholipid bilayer.

THE PHOSPHOLIPID BILAYER

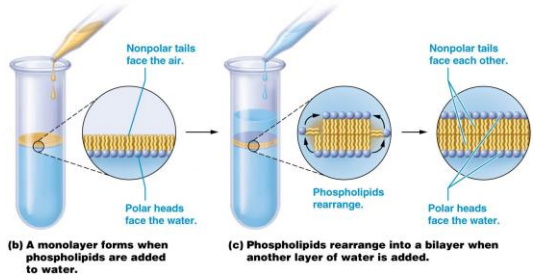


Figure 3.3b, c The formation of a phospholipid bilayer.

FLUID MOSAIC MODEL OF THE PLASMA MEMBRANE

Fluid Mosaic Model (**Figures 3.4**, **3.5**) – describes plasma membrane as *dynamic fluid structure* with multiple components, some with ability to *move within bilayer* as phospholipids move themselves

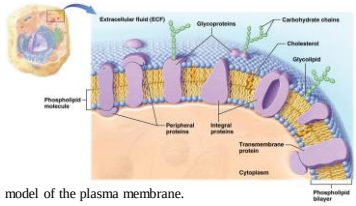


Figure 3.4 The fluid mosaic model of the plasma membrane.

FLUID MOSAIC MODEL OF THE PLASMA MEMBRANE

Membrane proteins, a main component of plasma membranes, exist in *two basic types*:

- **Integral proteins** – span entire plasma membrane; also called **transmembrane** proteins
- **Peripheral proteins** are found only on *one side* of plasma membrane or other

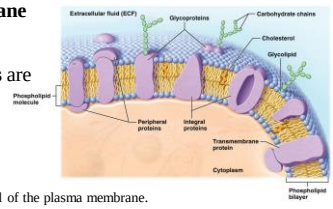


Figure 3.4 The fluid mosaic model of the plasma membrane.

FLUID MOSAIC MODEL OF THE PLASMA MEMBRANE

Functions of membrane proteins include:

- Transport substances across plasma membrane as **protein channels**; others are **carrier proteins** that directly bind to and transport substances into and out of cell

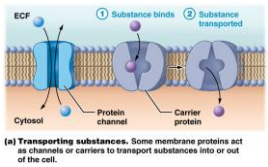


Figure 3.5a Functions of membrane proteins.

FLUID MOSAIC MODEL OF THE PLASMA MEMBRANE

Functions of membrane proteins include (continued):

- **Receptors** that bind to chemical messengers called **ligands**; trigger sequence of events within cell when bound; note that this is an example of **Cell-Cell Communication Core Principle**

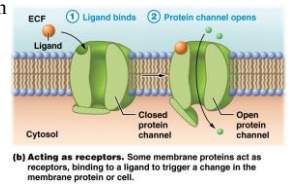
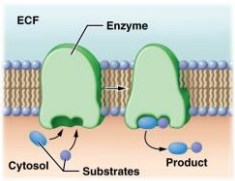


Figure 3.5b Functions of membrane proteins.

Fluid Mosaic Model of the Plasma Membrane

Functions of membrane proteins include (continued):

- **Enzymes** – *speed up* chemical reactions; vital to maintaining homeostasis



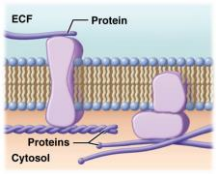
(c) Acting as enzymes. Some membrane proteins act as enzymes, catalyzing chemical reactions.

Figure 3.5c Functions of membrane proteins.

Fluid Mosaic Model of the Plasma Membrane

Functions of membrane proteins include (continued):

- **Structural support** – when bound to cytoskeleton; give cells *shape* and help maintain *structural integrity*



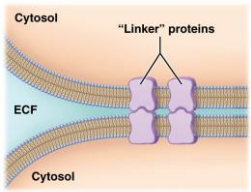
(d) Providing structural support. Some membrane proteins provide structural support by binding to other proteins in the ECF and/or cytosol.

Figure 3.5d Functions of membrane proteins.

Fluid Mosaic Model of the Plasma Membrane

Functions of membrane proteins include (continued):

- **Link** adjacent cells to one another, *anchoring* cells within a tissue and/or allowing cell to cell *communication*



(e) Linking adjacent cells. Some membrane proteins link adjacent cells together.

Figure 3.5e Functions of membrane proteins.

Fluid Mosaic Model of the Plasma Membrane

Other membrane components include lipids, carbohydrates, glycolipids, and glycoproteins:

- **Cholesterol** – lipid molecule, *stabilizes* plasma membrane's *fluid structure* during temperature changes
- **Glycolipids** and **glycoproteins**, carbohydrate bound to either *lipid* or *protein* respectively, serve to identify cell as part of body and for cell recognition

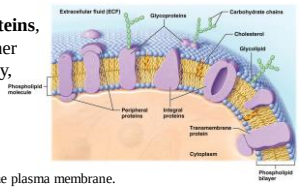


Figure 3.4 The fluid mosaic model of the plasma membrane.

Drugs and Membrane Receptors

Many drugs are designed to resemble **ligands** that *bind to membrane receptors*:

- **Agonists** – mimic ligand's actions by *stimulating* receptor (example: narcotic pain killers such as **morphine** mimic actions of **endorphins**)
- **Antagonists** – inhibit ligand's actions by *blocking* receptor (example: **antihistamines** block receptors for **histamine**)

Module 3.3 Transport Across the Plasma Membrane

Selective Permeability

The phospholipid bilayer is **selectively permeable**, *allowing* certain molecules to cross it while *prohibiting* passage of other molecules; critical to survival of cell

- Substance may cross plasma membrane in several ways; some do not require expenditure of energy (**passive transport** mechanisms); other processes do require energy (**active transport** processes)

Selective Permeability

- *Three variables* determine how a substance is able to move across the plasma membrane by passive or active transport:
  - Type of substance
  - Plasma membrane permeability to substance
  - Concentration of substance in cytosol and ECF

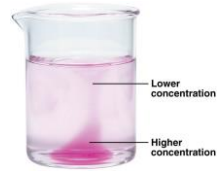
Passive Transport Processes

Passive transport include the following processes (**Table 3.1**):

- Diffusion
  - Simple diffusion
  - Facilitated diffusion
- Osmosis

Passive Transport Processes

- **Concentration gradient** – basic force that drives many types of *passive transport*
- Notice that more dye molecules are found in fluid on *bottom* of beaker than on *top*; difference is a **concentration gradient**, a form of *potential energy*; **Core Principle**
- Dye molecules will scatter due to their own *kinetic energy*, which all molecules have as long as *thermal energy* (heat) is present
- Movement will continue until the dye is *uniform* throughout container; condition called **equilibrium**



Passive Transport Processes

Diffusion – movement of solute molecules from *high* to *low* concentration; moving *down* or *with* its concentration gradient until **equilibrium** is reached

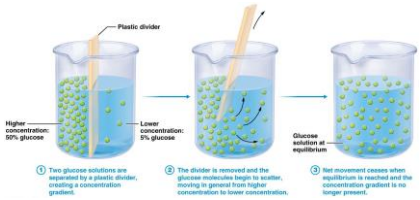


Figure 3.6 Diffusion and equilibrium.

Passive Transport Processes

- **Simple diffusion** – mostly *nonpolar solutes* like oxygen, carbon dioxide, lipids, and hydrocarbons; pass straight through phospholipid bilayer without need for membrane protein

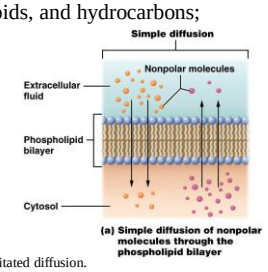


Figure 3.7a Passive transport: simple and facilitated diffusion.

Passive Transport Processes

- **Facilitated diffusion** involves *charged* or *polar solutes* such as ions and glucose; cross phospholipid bilayer with help of a membrane protein (**carrier** or **channel**)

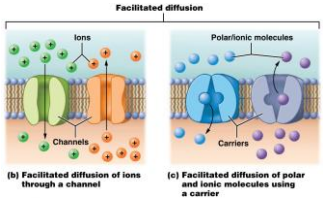
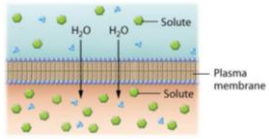


Figure 3.7b, c Passive transport: simple and facilitated diffusion.

Passive Transport Processes

- **Osmosis** is a passive process in which a *solvent* (usually water) moves across a membrane
- Water moves from area with *lower concentration of solute* (more water molecules) across membrane to area with *higher concentration of solute* (less water molecules)



- **Osmotic pressure** – *driving force* exerted by solute molecules; causes water molecules to move until equilibrium (no net movement) is reached

Table 3.1 Plasma Membrane Transport.

Passive Transport Processes

Water moves across plasma membranes by two methods:

- Water passes through channel proteins known as **aquaporins**; *primary route* for osmosis of water
- A *small amount* of water is able to pass through phospholipid bilayer directly

Concept Boost: Understanding Water Movement in Osmosis

- More concentrated glucose solution (on left) has fewer water molecules
- During osmosis, water moves from solution with higher number of water molecules to one with lower number (on right); water itself has a gradient
- So **osmosis** can be defined as movement of water across a selectively permeable membrane down its concentration gradient

Figure 3.8 Passive transport: osmosis.

Concept Boost: Understanding Water Movement in Osmosis

- At equilibrium, concentration of water molecules on either side of membrane is equal; *gradient is gone*
- Results in change in volume of fluid in each side of container; water molecules leave side B so its volume decreases; as water molecules move into side A, its volume increases
- These volume changes have *important consequences* for our cells; discussed next

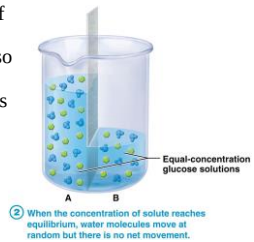


Figure 3.8 Passive transport: osmosis.

Passive Transport Processes

Tonicity – way to compare *osmotic pressure gradients* between two solutions – cytosol and ECF

- Normally ECF is **isotonic** to cytosol; both fluids have approximately same concentration of solute; no *net movement of water* across plasma membrane and *no volume changes* in either fluid compartment

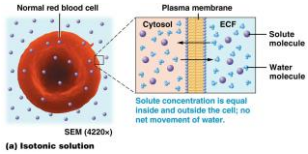


Figure 3.9a Tonicity: effects of isotonic, hypertonic, and hypotonic solutions on cell volume.

Passive Transport Processes

Tonicity (continued):

- **Hypertonic** ECF – solute concentration of ECF is higher than inside cell; more water molecules inside cell than outside; osmotic pressure gradient *pulls water out of cell* and cell *shrinks* or **crenates**

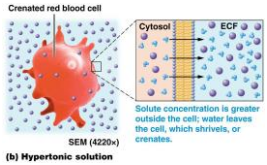


Figure 3.9b Tonicity: effects of isotonic, hypertonic, and hypotonic solutions on cell volume.

Passive Transport Processes

Tonicity (continued):

- **Hypotonic** ECF – solute concentration of ECF is lower than inside cell; more water molecules in ECF than inside cell; osmotic pressure gradient *pulls water into cell* causing the cell to *swell* and possibly *rupture* or **lyse**

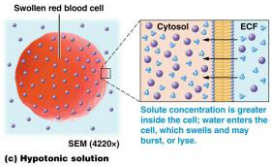


Figure 3.9c Tonicity: effects of isotonic, hypertonic, and hypotonic solutions on cell volume.

Passive Transport Processes

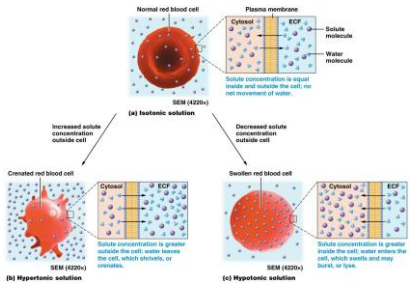


Figure 3.9 Tonicity: effects of isotonic, hypertonic, and hypotonic solutions on cell volume.

Dehydration, Sports Drinks, and Water

- Strenuous exercise results in water and electrolyte loss through sweating; ECF becomes *hypertonic*; hypertonic ECF draws water out of cells by osmosis
- **Sports drinks** (mixtures of water, electrolytes, and carbohydrates) are *hypotonic*; drinking them helps replenish water that was lost, making ECF mildly hypotonic to cells; causes water to move back into cells until normal cytosol concentration is restored
- **Plain water** rehydrates just as well but care must be taken in severe dehydration; water can rehydrate cells too quickly or overhydrate (hypotonic ECF); results in cellular swelling and possibly water poisoning

Active Transport via Membrane Proteins

- **Active transport** processes *require energy* in form of **ATP** to proceed as solutes move against their concentration gradients from low concentration to high concentration
- Both **primary** and **secondary** active transport processes use plasma membrane carrier proteins called **pumps**

Active Transport via Membrane Proteins

There are 3 types of pumps found in the plasma membrane:

- **Uniport** pumps transport a single substance through plasma membrane in one direction, either *into or out of cell*
- **Symport** pumps transport *two or more substances* through plasma membrane in same direction, either *into or out of cell*
- **Antiport** pumps transport *two or more substances* in opposite directions through plasma membrane

Active Transport via Membrane Proteins

Primary active transport involves pump in plasma membrane that binds and transports solute against its concentration gradient using energy from *hydrolysis of ATP*

- **Sodium-potassium pump** (**Na^+/K^+ pump** or **Na^+/K^+ ATPase**) is most vital for maintenance of Na^+ and K^+ concentration gradient homeostasis (**Figure 3.10**)
- Na^+ concentration is 10 times greater in ECF than cytosol and K^+ concentration is 10 times greater in cytosol than in ECF
- Pump maintains these steep concentration gradients by transporting *3 Na^+ out and 2 K^+ into the cell* against their concentration gradients for *every ATP molecule hydrolyzed*

Active Transport via Membrane Proteins

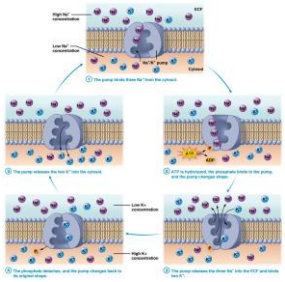


Figure 3.10 Primary active transport by the Na^+, K^+ pump.

Active Transport via Membrane Proteins

Secondary active transport uses ATP *indirectly* to fuel a transport pump

- ATP is used to create and maintain a concentration gradient of one substance

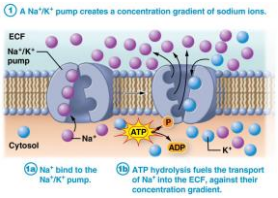


Figure 3.11 Secondary active transport.

Active Transport via Membrane Proteins

Secondary active transport (continued):

- Moving this substance across plasma membrane down its concentration gradient provides energy to move another substance against its concentration gradient

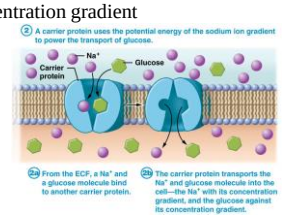
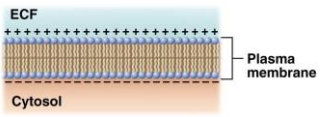


Figure 3.11 Secondary active transport.

Consequences of Ion Transport across the Plasma Membrane

Introduction to **Electrophysiology**

- There is a *separation of charges* across the plasma membrane
- A thin layer of positive charges lines the outside of membrane and a thin layer of *negative charges* lines inside of membrane



Consequences of Ion Transport across the Plasma Membrane

Introduction to **Electrophysiology** (continued):

- Separation of charges creates **electrical gradient**; provides energy to do work
- Electrical potential found across plasma membrane is known as a **membrane potential**; study of these potentials is called **electrophysiology**
- **Resting membrane potential** – membrane potential when cell is at rest; measured in **millivolts** (**mV**); value is negative meaning *inside of cell* is more negative than surrounding ECF

ACTIVE TRANSPORT VIA VESICLES

Active transport using carrier proteins and channels is effective but has limitations; large polar macromolecules are *too big to fit* so must be transported by other means – vesicles:

- **Vesicles** are small sacs filled with large molecules too big to transport by other means
- Enclosed in a phospholipid bilayer; allows them to *fuse with* or be *formed from* plasma membrane or other membrane-bound organelles
- Active transport process; requires energy from ATP to proceed

ACTIVE TRANSPORT VIA VESICLES

Endocytosis:

- **Phagocytosis** ("cell eating") – process where cells ingest large particles like bacteria or dead or damaged cells or parts of cell

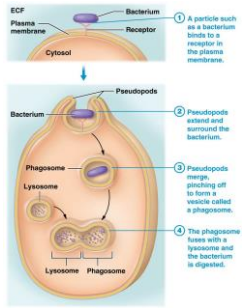


Figure 3.12 Endocytosis: phagocytosis.

ACTIVE TRANSPORT VIA VESICLES

Endocytosis (continued):

- **Pinocytosis** (fluid-phase endocytosis or "cell drinking") – process where cells engulf fluid droplets from ECF

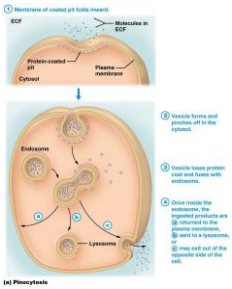


Figure 3.13a Endocytosis: pinocytosis and receptor-mediated endocytosis.

ACTIVE TRANSPORT VIA VESICLES

Endocytosis (continued):

- **Receptor-mediated endocytosis** – similar to pinocytosis; uses receptors to fill vesicles with a *specific* molecule

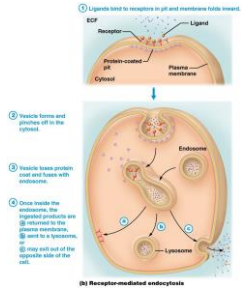


Figure 3.13b Endocytosis: pinocytosis and receptor-mediated endocytosis.

ACTIVE TRANSPORT VIA VESICLES

- **Exocytosis** – large molecules *exit cell*; known as **secretion**; vesicles fuse with plasma membrane, opening into ECF
- **Transcytosis** – molecules are brought into cell by endocytosis, transported across cell to opposite side, and then secreted by exocytosis

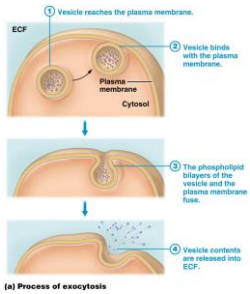


Figure 3.14a Exocytosis.

ACTIVE TRANSPORT VIA VESICLES

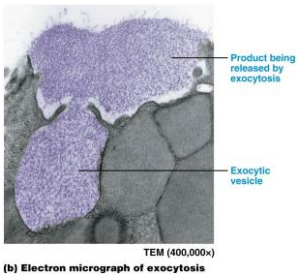
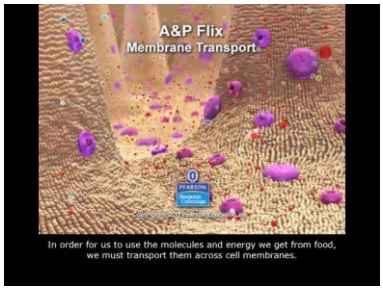


Figure 3.14b Exocytosis.

A&P FLIX: MEMBRANE TRANSPORT



MODULE 3.4 CYTOPLASMIC ORGANELLES

CYTOPLASMIC ORGANELLES

- **Organelles** are cellular machinery with *specific functions* vital to maintaining homeostasis; some are separated from cytosol by membrane (compartmentalization) while others are not enclosed in a membrane (**Figure 3.15**)
  - Membrane-bound include: mitochondria, peroxisomes, endoplasmic reticulum, Golgi apparatus, and lysosomes; perform functions that could be *destructive to rest of cell*
  - Organelles that are not enclosed in membrane include: ribosomes and centrosomes

CYTOPLASMIC ORGANELLES

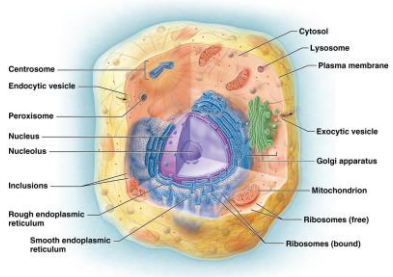


Figure 3.15 The cell and its organelles.

MITOCHONDRIA

Mitochondria (**Figures 3.16**, **3.17**; **Table 3.2**); "power plant" of cell; membrane-bound organelles involved in chemical energy production; provide *majority of ATP* used in cell:

- Each mitochondrion has its own DNA, enzymes, and ribosomes (organelle involved in protein synthesis)
- Membrane is double bilayer structure with *smooth* outer membrane and inner membrane that is *highly folded* into **cristae**

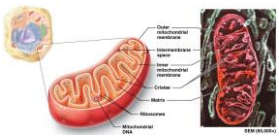


Figure 3.16 Structure of the mitochondrion.

MITOCHONDRIA

- Each membrane has its own *unique enzymes* and *proteins* required to perform specific functions (**Figure 3.17**):
  - **Outer membrane** – large channels that allow molecules from cytosol to enter inner membrane space (between two phospholipid bilayers)
  - **Inner membrane** – more selective; transports only necessary solutes into matrix (innermost space) using specific transport proteins
- Matrix contains mitochondrial DNA, proteins, and enzymes specific for breakdown of organic fuels by **oxidative** (requires oxygen) **catabolism** to produce ATP

MITOCHONDRIA

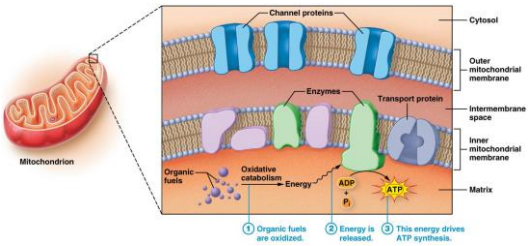
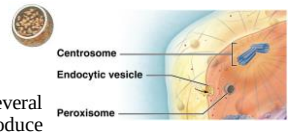


Figure 3.17 Function of the mitochondrion.

PEROXISOMES

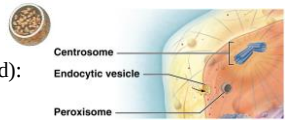


Peroxisomes – membrane-bound organelles

- Use oxygen to carry out several chemical reactions that produce **hydrogen peroxide** (H_2O_2); oxidizes toxic chemicals to less toxic compounds that can be eliminated from body before causing damage
- *Catabolic reactions*; break down *fatty acids* into smaller molecules that can be used for energy production or other anabolic reactions

Table 3.2 Cytoplasmic Organelles and **Figure 3.15** The cell and its organelles.

PEROXISOMES



Peroxisomes – membrane-bound organelles (continued):

- Certain *phospholipids* synthesized in peroxisomes are critical to plasma membranes of specific cells or nervous system.

Table 3.2 Cytoplasmic Organelles and **Figure 3.15** The cell and its organelles.

RIBOSOMES

- **Ribosomes** (**Table 3.2**); tiny granular nonmembrane-bound organelles where **protein synthesis** takes place
  - Composed of large and small subunits; each made of *ribosomal proteins* and *ribosomal RNA* (rRNA)
  - *Free in cytosol*; usually make proteins needed within cell itself
  - *Bound to membranes* of other cellular structures; produce proteins destined for export outside cell, for export to lysosomes, or for insertion into a membrane

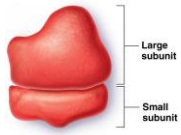


Figure 3.18 Schematic structure of the ribosome.

THE ENDOMEMBRANE SYSTEM

The Endomembrane System (**Figures 3.19**, **3.20**, **3.21**; **Table 3.2**):

- Form **vesicles** that exchange proteins and other molecules; synthesize, modify, and package molecules produced within cell

THE ENDOMEMBRANE SYSTEM

The Endomembrane System (**Figures 3.19**, **3.20**, **3.21**; **Table 3.2**) (continued):

- Plasma membrane, nuclear envelope, and following organelles are components of the system (**Figure 3.19**):
  - **Endoplasmic reticulum (ER)**
    - **Rough endoplasmic reticulum (RER)**
    - **Smooth endoplasmic reticulum (SER)**
  - **Golgi apparatus**
  - **Lysosomes**

THE ENDOMEMBRANE SYSTEM

Endoplasmic reticulum (ER) – large folded phospholipid bilayer continuous with the nuclear envelope; exists in two forms: **rough ER** (**RER**) has *ribosomes* bound to it and **smooth ER** (**SER**) does not

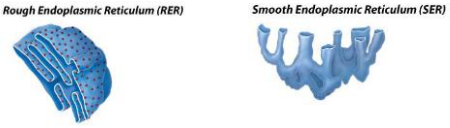


Table 3.2 Cytoplasmic Organelles.

THE ENDOMEMBRANE SYSTEM

Rough endoplasmic reticulum – ribosomes bound to membrane:

- Products enter RER lumen; incorrectly folded polypeptide chains are *detected* and sent to cytosol for *recycling*
- Most proteins that enter RER are for transport out of cell
- Packages secretory proteins into **transport vesicles** made of a phospholipid bilayer; sent to the Golgi apparatus for further processing
- Produces *membrane components* for membrane-bound organelles and *plasma membrane*, including integral and peripheral proteins

THE ENDOMEMBRANE SYSTEM

Smooth endoplasmic reticulum (**SER**) – not associated with ribosomes; essentially *no role in protein synthesis*; performs following vital functions:

- *Stores calcium ions* by pumping them out of cytosol for future use
- Capable of several *detoxification reactions*; limits damage caused by certain substances
- Involved in *lipid synthesis*, manufacturing majority of plasma membrane phospholipids and cholesterol as well as a number of lipoproteins and steroid hormones

THE ENDOMEMBRANE SYSTEM

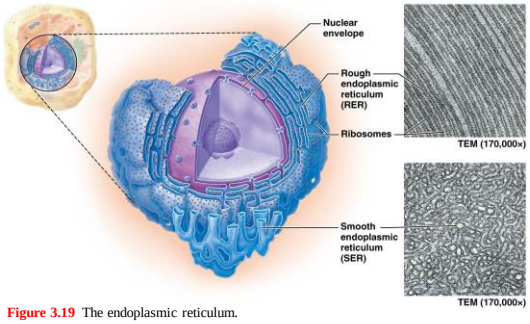


Figure 3.19 The endoplasmic reticulum.

THE ENDOMEMBRANE SYSTEM

Golgi apparatus – located between RER and plasma membrane – group of *flattened membranous sacs* filled with enzymes and other molecules (**Figure 3.20**)

- Proteins and lipids made by ER are further *modified, sorted, and packaged for export* in the Golgi
- Products packaged in Golgi can be *secreted from cell* by exocytosis, become part of the *plasma membrane*, or sent to the *lysosome*

Table 3.2 Cytoplasmic Organelles.

THE ENDOMEMBRANE SYSTEM

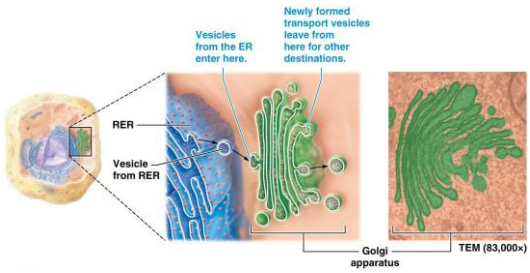


Figure 3.20 The Golgi apparatus.

Cystic Fibrosis

- In **cystic fibrosis**, some cells are missing a protein component of a *chloride ion channel*
- Causes deficient chloride ion transport in lungs and digestive and integumentary systems; results in *abnormally thick mucus*; blocks airways, causes digestive enzyme deficiencies, and very salty sweat
- Mutation causes **chloride channel protein** to misfold slightly in RER; protein therefore destroyed even though it *would be functional* if inserted into membrane
- In short, disease is caused by "overprotective" RER

The Endomembrane System

Lysosomes – organelles responsible for digestion of worn out cell components or whole cells in some cases:

- Contain *digestive enzymes* called **acid hydrolases**
- Macromolecules are broken down into smaller subunits that can be released to cytosol for disposal or reused to manufacture new macromolecules

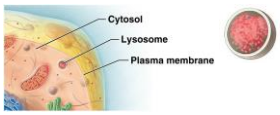


Table 3.2 Cytoplasmic Organelles and **Figure 3.15** The cell and its organelles.

The Endomembrane System

Summary of events involving endomembrane system functions (**Figure 3.21**):

(1a) SER makes lipids and (1b) RER makes proteins and (2) each product is packaged into vesicles for transport to Golgi

(3) Golgi sorts and further modifies both lipids and proteins and packs them into vesicles, which may take 3 pathways once they exit the Golgi:

- (4a) Vesicles may be sent to lysosomes where they undergo catabolic reactions
- (4b) Vesicles may be incorporated into plasma membrane or membrane of another organelle in cell
- (4c) Vesicles may be sent to the plasma membrane where they are secreted by exocytosis out of cell

Summary of Events Involving Endomembrane System Functions

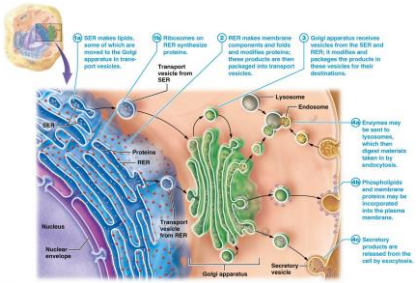


Figure 3.21 Function of the endomembrane system.

Lysosomal Storage Diseases

- Group of diseases resulting from *deficiency* of one or more *acid hydrolases* of lysosomes; examples include:
  - **Gaucher's disease** – deficiency causes accumulation of *glycolipids* in blood, spleen, liver, lungs, bone, and sometimes brain; most severe form is fatal in infancy or early childhood
  - **Tay-Sachs disease** – *glycolipids* accumulate in *brain lysosomes*, leading to progressive *neural dysfunction* and death by age 4–5

Lysosomal Storage Diseases

- Group of diseases resulting from *deficiency* of one or more *acid hydrolases* of lysosomes; examples include (continued):
  - **Hurler syndrome** – *large polysaccharides* accumulate in many cells (heart, liver, brain); death can result in childhood from organ damage
  - **Niemann-Pick disease** – *lipids* accumulate in lysosomes of spleen, liver, brain, lungs, and bone marrow; severe form causes organ damage and neural dysfunction

MODULE 3.5
THE CYTOSKELETON

THE CYTOSKELETON

Cytoskeleton – made of several types of **protein filaments**; *dynamic structure* able to *change function* based on needs of cell; plays a variety of critical roles:

- Gives the cell its characteristic shape and size by creating an *internal framework*
- Provides strength, structural integrity, and anchoring sites' support plasma and nuclear membranes as well as organelles
- Allows for *cellular movement* where protein filaments are associated with **motor proteins**
- Performing specialized functions in different cell types; for example, *phagocytosis* by macrophages, or *contraction* by muscle cells

TYPES OF FILAMENTS

Cytoskeleton contains three types of long *protein filaments*; composed of smaller *protein subunits* that allow for rapid *disassembly* and *reassembly*

- **Actin filaments**
- **Intermediate filaments**
- **Microtubules**

TYPES OF FILAMENTS

Actin filaments (**microfilaments**) are the thinnest filament; composed of *two intertwining strands* of actin subunits

- Provide structural support, bear tension, and maintain cell's shape
- Involved in *cellular motion* when combined with the motor protein **myosin**

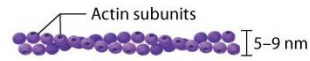


Table 3.3 Cytoskeletal Filaments.

TYPES OF FILAMENTS

Intermediate filaments – ropelike; made of different *fibrous proteins* including **keratin**; strong and *more permanent* structures

- Form much of *framework of cell* and anchor organelles in place
- Help organelles and nucleus maintain both their shape and size
- Help cells and tissues withstand *mechanical stresses*

Table 3.3 Cytoskeletal Filaments.

TYPES OF FILAMENTS

Microtubules – *largest filaments*; hollow rods or tubes composed of the subunit **tubulin**; can be *rapidly added or removed* allowing for size and shape changes within cell

- Maintain *internal architecture* of cell and keep organelles in alignment
- Motor proteins **dynein** and **kinesin** allow for *vesicles* to be transported along microtubule network

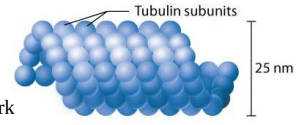


Table 3.3 Cytoskeletal Filaments.

Types of Filaments

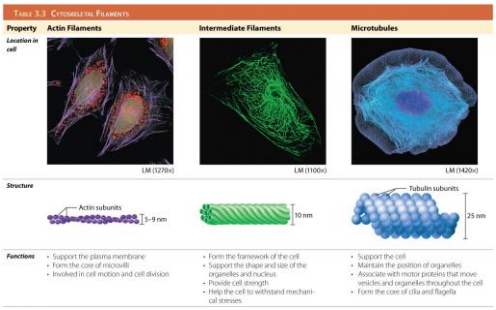


Table 3.3 Cytoskeletal Filaments.

Types of Filaments

Microtubules extend out from **centrosome** (consists of a *gel matrix* containing *tubulin subunits*) (**Figure 3.22**)

- When cell is not dividing, centrosome is a *microtubule-organization center* located close to nucleus
- A pair of **centrioles**, composed of a ring of *nine groups of three* modified microtubules, is critical for cellular division
- **Basal bodies** – modified microtubules found on internal surface of plasma membrane where flagella and cilia *originate*

Types of Filaments

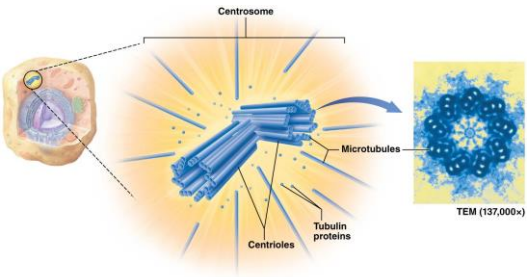


Figure 3.22 The centrosome with centrioles.

Cellular Extensions

Cellular extensions are formed by the inner framework of the cytoskeleton:

- **Microvilli**
- **Cilia**
- **Flagella**

Cellular Extensions

- **Microvilli**
  - Finger-like extensions of plasma membrane with actin filament core to help *maintain shape*; example of **Structure-Function Core Principle**
  - Increase **surface area** of cells in organs specialized for *absorption*

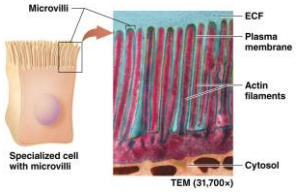


Figure 3.23 Microvilli.

Cellular Extensions

- **Cilia**
  - Hairlike projections composed of *microtubules* and *motor proteins*
  - Move in unison to propel substances past the cells (**Figure 3.24**, **Table 3.4**)
  - Found in *great numbers* on each cell

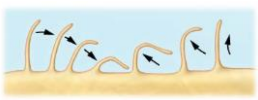


Table 3.4 Cilia and Flagella.

CELLULAR EXTENSIONS

- **Flagella**
  - Solitary; longer than cilia
  - Found only on *sperm cells*
  - Beat in a whiplike fashion propelling *entire cell* (unlike cilia – propel materials past the plasma membrane)

- Flagella and cilia both are structurally similar to **centrioles** except contain two central microtubules not found in centrioles (**Figure 3.24**, **Table 3.4**)

Table 3.4 Cilia and Flagella.

CELLULAR EXTENSIONS

TABLE 3.4 CILIA AND FLAGELLA

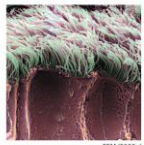
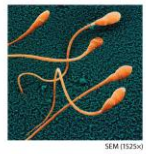
Property	Cilia	Flagella
Location in body	Cells lining the respiratory tract and the female reproductive tract	Sperm cell
	 SEM (5000×)	 SEM (1525×)
Structure	Short, hairlike extensions from the cell; contain an internal ring of nine microtubule pairs surrounding a central microtubule core	Single, long extension from the cell; same internal structure as cilia
Function	Coordinated beating motion sweeps substances past the cell	Whiplike motion propels the cell through liquid.
		

Table 3.4 Cilia and Flagella.

CELLULAR EXTENSIONS

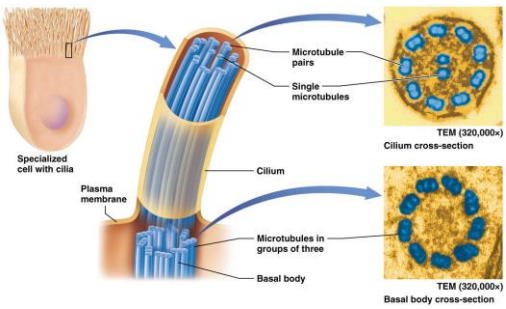


Figure 3.24 Structure of cilia and flagella (only cilium shown here).

PRIMARY CILIARY DYSKINESIA

- Rare genetic disorder characterized by defect in one or more *protein components of cilia* and *flagella*
- Affects many types of cells: respiratory passage linings, middle ear, uterine tubes (females), sperm (males)
  - Leads to *buildup of mucus* in lungs; increases *risk of infection*; progressive damage due to repeated infections and mucus plugs
  - Repeated ear infections may lead to *hearing loss*
  - Males may be infertile due to lack of *sperm motility*

MODULE 3.6 THE NUCLEUS

THE NUCLEUS

Nucleus – governing body that directs activities of the other cellular components; largely determines type of proteins and rate at which cell makes them (**Figure 3.25**):

- **DNA** housed in nucleus contains *code or plans* for nearly every protein in body
- These plans (**genes**) within DNA are executed by several different types of **RNA** to build a wide variety of proteins

THE NUCLEUS

Nucleus consists of three main structures:

- **Nuclear envelope** – membrane that surrounds **nucleoplasm** (cytosol-like gel containing many components – water, free nucleotides, enzymes, other proteins, DNA, and RNA)
- DNA and associated proteins are found in nucleoplasm as a *loose structural arrangement* known as **chromatin**
- One or more **nucleoli** are found suspended in nucleoplasm

THE NUCLEUS

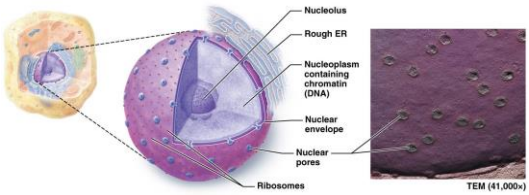


Figure 3.25 The nucleus.

NUCLEAR ENVELOPE

- **Nuclear Envelope** (**Figure 3.26**): double *phospholipid bilayer* similar to that of mitochondria; surrounds and encloses entire contents of nucleus:
  - Outer membrane has many *ribosomes* attached to surface; continuous with endoplasmic reticulum
  - Inner membrane lines interior of nucleus; supported by network of *intermediate filaments* (**nuclear lamina**)
  - **Nuclear pores** – found where outer and inner envelope membranes come in contact; serve to connect nucleoplasm with cytoplasm; allows substances to move between *two locations*

NUCLEAR ENVELOPE

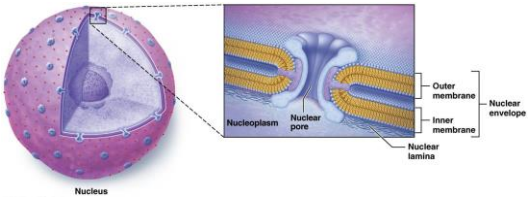


Figure 3.26 The nuclear pore.

CHROMATIN AND CHROMOSOMES

Chromatin – consists of one extremely long DNA molecule and its associated proteins; organize and fold molecule to conserve space (**Figure 3.27a**):

- **Nucleosome** – strand of DNA coiled around a group of **histone proteins**; appears like beads on a string
- Reduces length of strand by about *one-third*

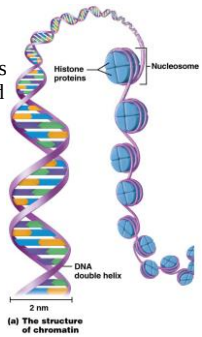


Figure 3.27a Chromatin.

CHROMATIN AND CHROMOSOMES

During periods of cell division, chromatin threads coil tightly and *condense* into thick structures called **chromosomes** (**Figure 3.27b**):

- Human cells contain *23 pairs* of chromosomes; one *maternal* and one *paternal* pair
- **Sister chromatids** – *identical copies* of each chromosome; made in preparation for cell division; connected to one another at region called **centromere**

CHROMATIN AND CHROMOSOMES

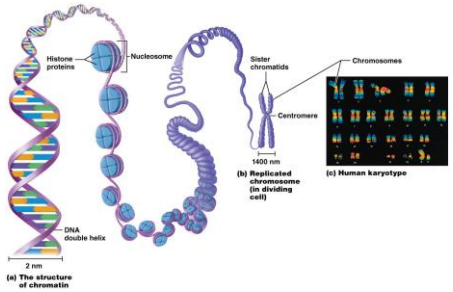


Figure 3.27 Chromatin and chromosomes.

CHROMATIN AND CHROMOSOMES

- **Nucleoli**: (singular – **nucleolus**) region in nucleus responsible for synthesis of *ribosomal RNA* and assembly of *ribosomes*

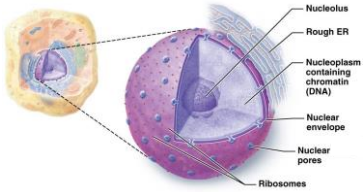


Figure 3.25 The nucleus.

MODULE 3.7
PROTEIN SYNTHESIS

PROTEIN SYNTHESIS

Protein synthesis – process of *manufacturing proteins* from DNA blueprint using RNA

- **Gene expression** – *production of protein* from specific gene
- Two processes actually make a specific protein:
  - **Transcription** – process where gene for specific protein is *copied*; creating **messenger RNA** (**mRNA**); exits through nuclear pore
  - **Translation** occurs in cytosol; mRNA binds with ribosome initiating synthesis of a polypeptide consisting of a specific *sequence of amino acids*
- DNA→Transcription→mRNA→Translation→Protein

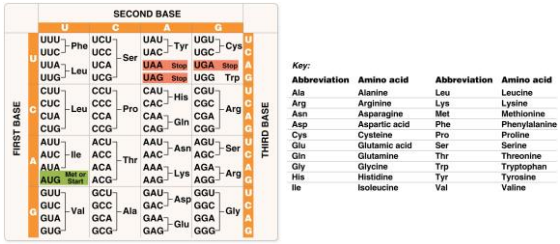
GENES AND THE GENETIC CODE

- **Gene** – long *chain of nucleotides*; segment of DNA that determines *specific sequence of amino acids* in a protein.
  - 4 different *nucleotides* in DNA (**A**,**T**, **G**, **C**); each *set of 3 nucleotides* (called **triplet**) represents a different amino acid; each amino acid may be represented by *more than one triplet*
  - During transcription each *DNA triplet* is transcribed into a *complementary RNA copy*; each 3-nucleotide sequence of mRNA copy is called a **codon**

GENES AND THE GENETIC CODE

- During translation at a ribosome, each codon is paired with a *complementary* **tRNA** (called an **anticodon**) with its specific amino acid attached; amino acid will be added to growing peptide chain
- **Genetic code** – list of which amino acid is specified by each DNA triplet (**Figure 3.28** on next slide)

GENES AND THE GENETIC CODE



Key:

Abbreviation	Amino acid	Abbreviation	Amino acid
Ala	Alanine	Leu	Leucine
Arg	Arginine	Lys	Lysine
Asn	Asparagine	Met	Methionine
Asp	Aspartic acid	Phe	Phenylalanine
Cys	Cysteine	Pro	Proline
Glu	Glutamic acid	Ser	Serine
Gln	Glutamine	Thr	Threonine
Gly	Glycine	Trp	Tryptophan
His	Histidine	Tyr	Tyrosine
Ile	Isoleucine	Val	Valine

Figure 3.28 The genetic code; mRNA codons corresponding to amino acids.

GENES AND THE GENETIC CODE

- **Mutations** – changes in DNA due to *mistakes in copying DNA* or *induced by agents* called **mutagens**
- Common mutagens include *ultraviolet light* and other forms of *radiation*, chemicals such as *benzene*, and infection with certain *viruses*
- DNA mutations are the basis for many *diseases*, including **cancer**

TOXICITY OF THE "DEATH CAP" MUSHROOM

- *Amanita phalloides* (and other *Amanita*) are responsible for 95% of mushroom-related fatalities worldwide
- A *phalloides* is tasty and resembles many nontoxic mushrooms; main toxin inhibits *RNA polymerase*; prevents formation of new strands of mRNA
- Essentially stops *protein synthesis* and disrupts many cell functions, leading to cell death
- *No antidote exists*, although some have shown promise
- Liver suffers most damage; patients who survive generally require a *liver transplant*

TRANSCRIPTION

- **Transcription** (**Figure 3.29**): process of making *mRNA copy* of DNA (called **transcript**); exits nucleus through a nuclear pore into cytoplasm where ribosomes are found
  - Transcript is built with help of the enzyme **RNA polymerase**; binds to a gene; brings in *complementary nucleotides*, linking them together to form **mRNA**
  - Transcription proceeds in *3 general stages* (**Figure 3.29**):
    - **Initiation**
    - **Elongation**
    - **Termination**

TRANSCRIPTION

- **Initiation** – beginning of transcription, begins when protein **transcription factors** bind to a **promoter region** near gene on template strand of DNA; RNA polymerase also binds to promoter; DNA *unwinds* with aid of enzyme **helicase**

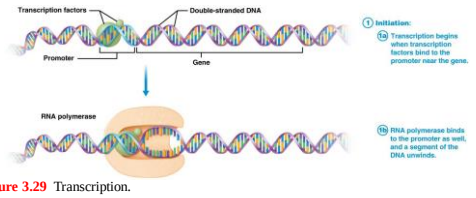


Figure 3.29 Transcription.

TRANSCRIPTION

- **Elongation** – process where RNA polymerase covalently bonds *complementary* (to DNA template) *nucleotides* to growing mRNA molecule

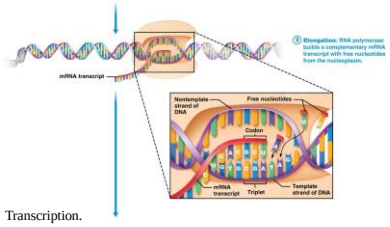


Figure 3.29 Transcription.

TRANSCRIPTION

- **Termination** – when *last triplet* of gene is reached and the newly formed **pre-mRNA** molecule is *ready for modification*

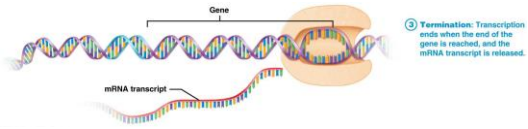


Figure 3.29 Transcription.

BIG PICTURE ANIMATION: TRANSCRIPTION

REVIEW

The process through which mRNA is made is termed

a. Translation
b. Replication
c. Synthesis
d. Transcription

REVIEW

The process through which mRNA is made is termed

a. Translation
b. Replication
c. Synthesis
d. Transcription

REVIEW

Transcription begins when transcription factors bind to the _____.

a. promoter
b. polymerase
c. nucleotide
d. helicase

REVIEW

Transcription begins when transcription factors bind to the _____.

a. promoter
b. polymerase
c. nucleotide
d. helicase

REVIEW

The enzyme that elongates the mRNA transcript is

a. Helicase
b. DNA polymerase
c. RNA polymerase
d. Hydrolase

REVIEW

The enzyme that elongates the mRNA transcript is

a. Helicase
b. DNA polymerase
c. RNA polymerase
d. Hydrolase

REVIEW

During transcription, free nucleotides from the nucleoplasm are hydrogen bonded to

a. Each other
b. Complementary nucleotides of the DNA template strand
c. Ribosomes
d. RNA polymerase

REVIEW

During transcription, free nucleotides from the nucleoplasm are hydrogen bonded to

a. Each other
b. Complementary nucleotides of the DNA template strand
c. Ribosomes
d. RNA polymerase

REVIEW

Transcription ends and the mRNA transcript is released during which stage of transcription?

a. Initiation
b. Elongation
c. Replication
d. Termination

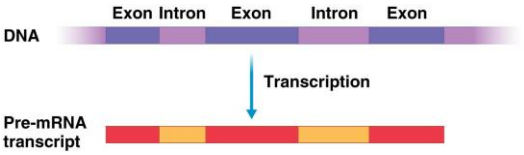
REVIEW

Transcription ends and the mRNA transcript is released during which stage of transcription?

a. Initiation
b. Elongation
c. Replication
d. Termination

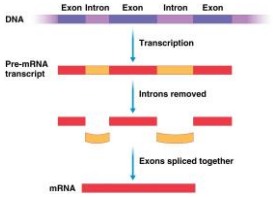
TRANSCRIPTION

- After transcription, the transcript (**pre-mRNA**) isn't ready; must first be *modified* in several ways
- Noncoding sections of a gene do <u>not</u> *specify an amino acid sequence* (called **introns**); sections that <u>do</u> *specify amino acid sequence* are called **exons**

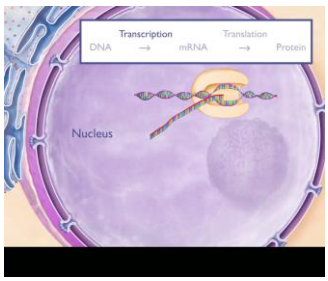


TRANSCRIPTION

- Copied introns in the pre-mRNA must be <u>removed</u> and the exons *spliced together*
- Called **RNA processing**; when complete, mRNA exits nucleus through nuclear pore; enters cytosol, ready for **translation** into protein



BIG PICTURE ANIMATION: RNA PROCESSING



TRANSLATION

- **Translation** (**Figures 3.30**, **3.31**): occurs at ribosome where nucleotide sequence of mRNA is translated into amino acid sequence with help of **transfer RNA** (**tRNA**)
- **tRNA** (**Figure 3.30**), made in nucleus, picks up specific amino acids and *transfers them* to a ribosome

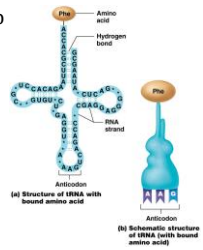


Figure 3.30 Transfer RNA (tRNA).

TRANSLATION

- **Anticodon** on one end of tRNA is a sequence of 3 nucleotides *complementary* to the **codon** of mRNA
- <u>Other</u> end of tRNA carries a <u>specific</u> amino acid molecule (<u>which</u> amino acid is determined by *anticodon*)

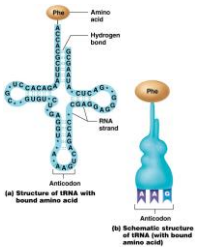


Figure 3.30 Transfer RNA (tRNA).

TRANSLATION

Each ribosome has 3 *binding sites for tRNA*:

- **A site** (**aminoacyl** site) binds to <u>incoming</u> tRNA carrying an amino acid
- **P site** (**peptidyl** site) is where amino acid is removed from its tRNA; <u>added</u> to *growing peptide chain*
- Empty tRNA then *exits ribosome* from **E site** (**exit** site); free to pick up <u>another</u> amino acid

TRANSLATION

Translation is organized into *3 stages* (like transcription):

- **Initiation** begins when **initiator tRNA** binds to mRNA *start codon* in the ribosome's *P site*

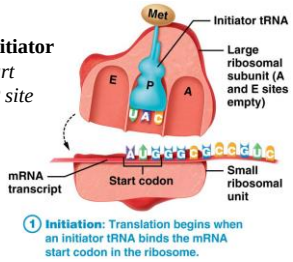


Figure 3.31 Translation.

TRANSLATION

Translation is organized into *3 stages* (continued):

- **Elongation** proceeds as next tRNA binds to open A site allowing two amino acids to be *covalently linked* by a peptide bond; first tRNA *exits* from E site and second tRNA moves into A site; P site is *open* for next tRNA to bind

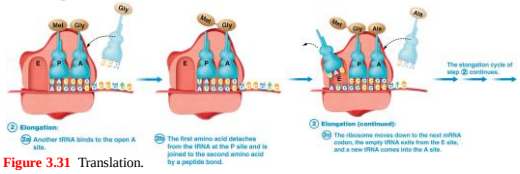


Figure 3.31 Translation.

TRANSLATION

Translation is organized into *3 stages* (continued):

- **Termination** – *end of translation*; occurs when ribosome reaches **stop codon** on mRNA and new peptide is *released*

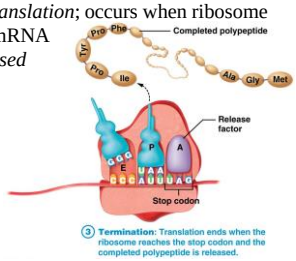
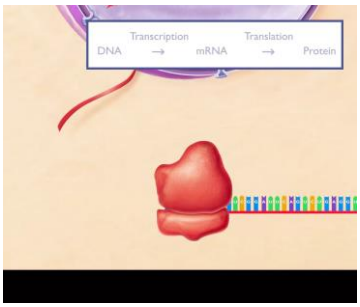


Figure 3.31 Translation.

BIG PICTURE ANIMATION: TRANSLATION



REVIEW

A strand of mRNA contains the

a. Instructions to build a ribosome
b. Instructions to build a protein
c. Instructions to build a carbohydrate
d. Instructions to build a lipid

REVIEW

A strand of mRNA contains the

a. Instructions to build a ribosome
b. Instructions to build a protein
c. Instructions to build a carbohydrate
d. Instructions to build a lipid

REVIEW

Protein synthesis is also called

a. Transcription
b. Replication
c. Translation
d. Differentiation

REVIEW

Protein synthesis is also called

a. Transcription
b. Replication
c. Translation
d. Differentiation

REVIEW

During translation, the language of _____ is translated into the language of _____.

a. Nucleotides, amino acids
b. Amino acids, nucleotides
c. Nucleotides, codons
d. Anticodons, nucleotides

REVIEW

During translation, the language of _____ is translated into the language of _____.

a. Nucleotides, amino acids
b. Amino acids, nucleotides
c. Nucleotides, codons
d. Anticodons, nucleotides

REVIEW

Which of the following is NOT correctly paired?

a. A ribosomal site; binds incoming tRNA carrying amino acid
b. P ribosomal site; where amino acid is added to growing protein
c. E ribosomal site; where tRNA departs to pick up a new amino acid
d. All of the above are correctly paired

REVIEW

Which of the following is NOT correctly paired?

a. A ribosomal site; binds incoming tRNA carrying amino acid
b. P ribosomal site; where amino acid is added to growing protein
c. E ribosomal site; where tRNA departs to pick up a new amino acid
d. All of the above are correctly paired

Review

The initiator tRNA carries the amino acid

a. Glutamine
b. Proline
c. Methionine
d. Glycine

Review

The initiator tRNA carries the amino acid

a. Glutamine
b. Proline
c. Methionine
d. Glycine

Translation

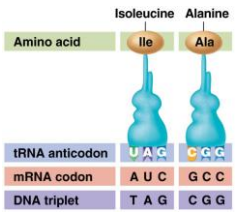
- Newly formed polypeptides must be *modified*, *folded properly*, and sometimes *combined with other polypeptides* to become fully functional proteins; process called **posttranslational modification**
  - Polypeptides destined for *cytosol* – synthesized on *free ribosomes*; fold either on their own or with help of other proteins
  - Polypeptides destined for *secretion* or *insertion* into an organelle or membrane – many require modifications performed in RER; synthesized on *bound ribosomes*; sent to the Golgi apparatus for *final processing*, *sorting*, *and packaging*

Big Picture Animation: Post-translational Modification

Concept Boost: Connecting a DNA Triplet to a Particular Amino Acid

- Notice that the *tRNA anticodon nucleotides* are the same as those in the *DNA triplet*, except that the nucleotide **T** in DNA is replaced by **U** in tRNA
- More practice (answers in text):

DNA triplet	T T C	C A A	A G G
mRNA codon			
tRNA anticodon			
Amino acid			



Putting It All Together: The Big Picture of Protein Synthesis

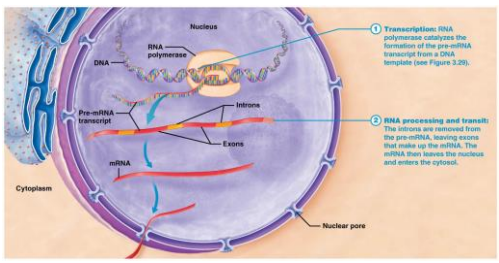


Figure 3.32 The Big Picture of Protein Synthesis.

PUTTING IT ALL TOGETHER: THE BIG PICTURE OF PROTEIN SYNTHESIS

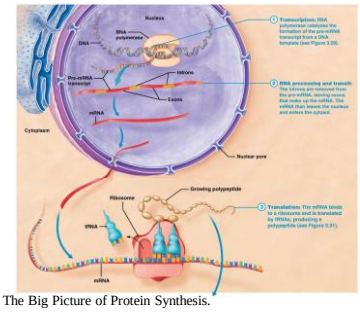


Figure 3.32 The Big Picture of Protein Synthesis.

PUTTING IT ALL TOGETHER: THE BIG PICTURE OF PROTEIN SYNTHESIS

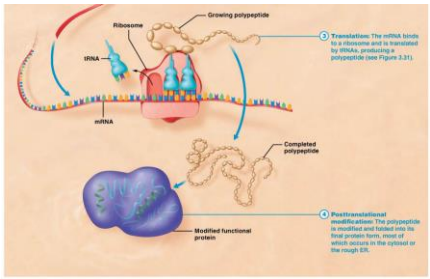


Figure 3.32 The Big Picture of Protein Synthesis.

PUTTING IT ALL TOGETHER: THE BIG PICTURE OF PROTEIN SYNTHESIS

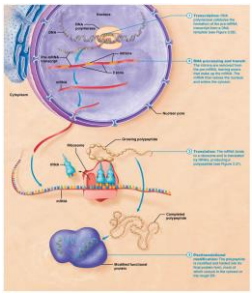


Figure 3.32 The Big Picture of Protein Synthesis.

REVIEW

Amino acids are added to the growing protein during translation by a _____ bond.

a. Peptide
b. Ionic
c. Hydrogen
d. Ester

REVIEW

Amino acids are added to the growing protein during translation by a _____ bond.

a. Peptide
b. Ionic
c. Hydrogen
d. Ester

REVIEW

The anticodon of the tRNA is complementary to the

a. DNA triplet
b. mRNA codon
c. DNA codon
d. mRNA triplet

REVIEW

The anticodon of the tRNA is complementary to the

a. DNA triplet

b. mRNA codon

c. DNA codon

d. mRNA triplet

REVIEW

The DNA triplet TAG is complementary to the mRNA codon _____.

a. ATC

b. UAG

c. CGG

d. AUC

REVIEW

The DNA triplet TAG is complementary to the mRNA codon _____.

a. ATC

b. UAG

c. CGG

d. AUC

REVIEW

The stop codon _____.

a. Binds a tRNA

b. Terminates transcription

c. Binds the release factor

d. Is part of the ribosome

REVIEW

The stop codon _____.

a. Binds a tRNA

b. Terminates transcription

c. Binds the release factor

d. Is part of the ribosome

REVIEW

Which of the following lists the events of protein synthesis in the correct order?

a. RNA processing and transit, transcription, translation, posttranslational modification

b. translation, posttranslational modification, transcription, RNA processing and transit

c. transcription, translation, posttranslational modification, RNA processing and transit

d. transcription, RNA processing and transit, translation, posttranslational modification

REVIEW

Which of the following lists the events of protein synthesis in the correct order?

a. RNA processing and transit, transcription, translation, posttranslational modification

b. translation, posttranslational modification, transcription, RNA processing and transit

c. transcription, translation, posttranslational modification, RNA processing and transit

d. transcription, RNA processing and transit, translation, posttranslational modification

MODULE 3.8: THE CELL CYCLE

THE CELL CYCLE

Cell theory is a biological principle that states that cells cannot *spontaneously appear*, but rather, they must come from division of cells that *already exist*; all forms of life, including humans, are result of repeated rounds of cell growth and division

- Almost all cells go through the **cell cycle**; process defined as ordered series of events from *formation of cell* to its *reproduction by cell division*
- Cell division is required for *growth* and *development* as well as for *tissue repair* and renewal

PHASES OF THE CELL CYCLE

Cell cycle includes two *main phases*: interphase and M phase or cell division (**Figures 3.33**, **3.34**, **3.35**)

- **Interphase** – period of *growth* and *preparation* for cell division; includes *3 subphases*:
  - **G_1 phase** (**1st gap**) – period where cell performs *normal daily metabolic activities*; production of new organelles, cytoskeleton, and other vital proteins prepares cell for next phase
  - **S phase** (**synthesis**) – period where *DNA syntihesis* (**replication**) occurs; vital for cell to proceed to next phase
  - **G_2 phase** (**2nd gap**) – another period of *cellular growth* where proteins required for cell division are *rapidly produced* and centrioles are *duplicated*

PHASES OF THE CELL CYCLE

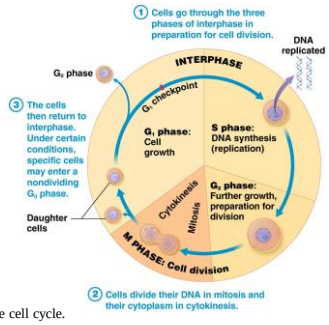


Figure 3.33 The cell cycle.

PHASES OF THE CELL CYCLE

- **DNA synthesis** or **replication** occurs in S phase; chromatin *unwinds* and each base pair is *duplicated* using an existing DNA strand as **template** to build a new strand; proceeds in the *following steps* (**Figure 3.34**):
  - DNA strands are *separated* by enzyme **helicase**

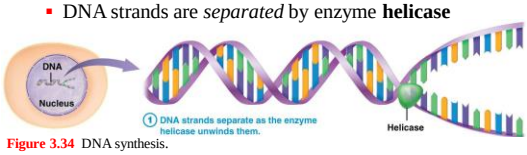


Figure 3.34 DNA synthesis.

PHASES OF THE CELL CYCLE

- **DNA synthesis** or **replication** (continued):
  - Enzyme **primase** builds **RNA primer** on the exposed DNA strands
  - Enzyme **DNA polymerase** *adds nucleotides* to RNA primer; necessary as enzyme is <u>only</u> able to add to an *existing chain of nucleotides*

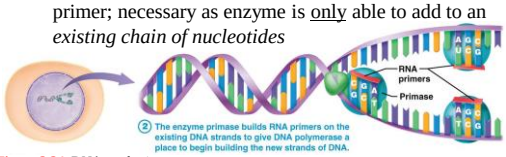


Figure 3.34 DNA synthesis.

PHASES OF THE CELL CYCLE

- **DNA synthesis** or **replication** (continued):
  - Enzyme **DNA polymerase** adds nucleotides to RNA primer; necessary as enzyme is <u>only</u> able to add to an *existing chain of nucleotides*

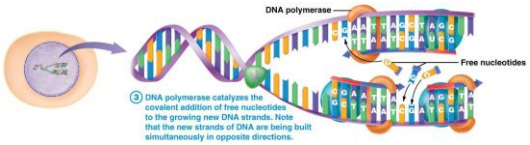


Figure 3.34 DNA synthesis.

PHASES OF THE CELL CYCLE

- **DNA synthesis** or **replication** (continued):
  - **DNA polymerase** proceeds in <u>opposite</u> directions *along each strand* as **helicase** separates them; RNA primers are eventually *removed* and *replaced* with DNA nucleotides
  - End result is two <u>identical</u> double helices each with *one old and one new strand*; called **semiconservative replication**; cell then proceeds into G_2 phase.

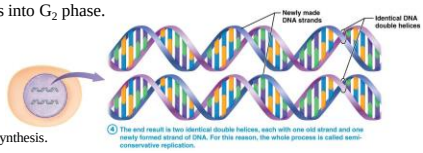


Figure 3.34 DNA synthesis.

PHASES OF THE CELL CYCLE

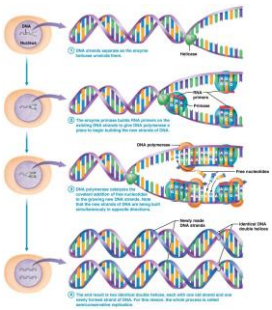
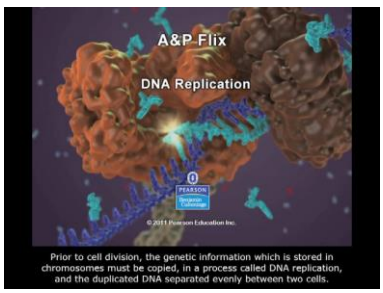


Figure 3.34 DNA synthesis.

A&P FLIX: DNA REPLICATION



REVIEW

The enzyme that catalyzes DNA synthesis during replication is

a. Primase
b. Helicase
c. DNA polymerase
d. DNA synthase

REVIEW

The enzyme that catalyzes DNA synthesis during replication is

a. Primase
b. Helicase
c. DNA polymerase
d. DNA synthase

REVIEW

The enzyme that gives DNA polymerase a place to begin building the new strand of DNA is

a. Primase
b. Helicase
c. DNA polymerase
d. DNA synthase

REVIEW

The enzyme that gives DNA polymerase a place to begin building the new strand of DNA is

a. Primase
b. Helicase
c. DNA polymerase
d. DNA synthase

REVIEW

DNA polymerase

a. Creates covalent bonds between complementary nucleotides
b. Removes DNA primers
c. Creates hydrogen bonds between adjacent nucleotides of the DNA strand
d. Can add nucleotides in only one direction along the template strand

REVIEW

DNA polymerase

a. Creates covalent bonds between complementary nucleotides
b. Removes DNA primers
c. Creates hydrogen bonds between adjacent nucleotides of the DNA strand
d. Can add nucleotides in only one direction along the template strand

REVIEW

DNA replication occurs in which phase of the cell cycle?

a. G_1
b. G_2
c. S
d. M

REVIEW

DNA replication occurs in which phase of the cell cycle?

a. G_1

b. G_2

c. S

d. M

REVIEW

Semiconservative replication means

a. Replication uses recycled nucleotides

b. New strands of DNA are simultaneously built in opposite directions

c. Nucleotides are added in only one direction along the template strand

d. Produces two identical double helices, each with one old strand and one newly formed strand of DNA

REVIEW

Semiconservative replication means

a. Replication uses recycled nucleotides

b. New strands of DNA are simultaneously built in opposite directions

c. Nucleotides are added in only one direction along the template strand

d. Produces two identical double helices, each with one old strand and one newly formed strand of DNA

PHASES OF THE CELL CYCLE

M is period of **cell division**; highlighted by two overlapping processes: **mitosis** and **cytokinesis** (**Figure 3.35**):

- **Mitosis** occurs when newly replicated genetic material is divided between two daughter cells
- **Cytokinesis** occurs when cell's proteins, organelles, and cytosol are divided *between two daughter cells*

PHASES OF THE CELL CYCLE

- **Interphase**
  - Nuclear envelope encloses nucleus
  - Centriole pairs *duplicated*
  - Nucleus and nucleolus are clearly *visible* and individual chromosomes are not *distinguishable*

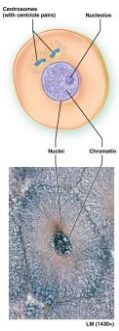


Figure 3.35a Interphase, mitosis, and cytokinesis.

PHASES OF THE CELL CYCLE

- **Mitosis** – division of genetic material; proceeds in following 4 stages (**Figure 3.35b**):
  - **Prophase**
  - **Metaphase**
  - **Anaphase**
  - **Telophase**

Phases of the Cell Cycle

- **Prophase**
  - Chromatin becomes compact; each individual chromosome has *two sister chromatids* joined at centromere
  - Nucleolus *disintegrates*, mitotic spindle *forms*, and a pair of centrioles (from newly duplicated centrosomes) *migrate* to opposite sides of cell to organize spindle fibers

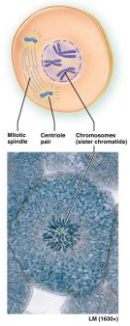


Figure 3.35b Interphase, mitosis, and cytokinesis.

Phases of the Cell Cycle

- **Prophase** (continued)
  - Spindle fibers from each centriole *attach to each sister chromatid* at the centromere
  - Prophase concludes when nuclear envelope begins to *break apart*

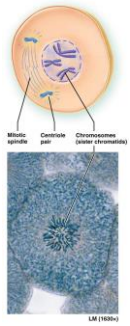


Figure 3.35b Interphase, mitosis, and cytokinesis.

Phases of the Cell Cycle

- **Metaphase**
  - 2nd and longest stage
  - Spindle fibers from opposite poles of cell *pull sister chromatids into line* along middle or **equator** of cell

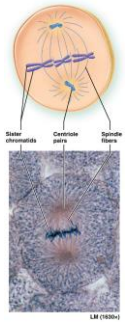


Figure 3.35b Interphase, mitosis, and cytokinesis.

Phases of the Cell Cycle

- **Anaphase**
  - 3rd stage; sister chromatids are *pulled apart* toward *opposite poles* and individual chromosomes are then called **daughter chromosomes**
  - Each new daughter cell will have *46 chromosomes* (23 pairs)
  - **Cytokinesis** may begin at end of this stage

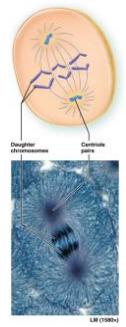


Figure 3.35b Interphase, mitosis, and cytokinesis.

Phases of the Cell Cycle

- **Telophase**
  - 4th and final stage
  - As daughter cells separate:
    - Nuclear envelope is *reassembled*
    - Nucleoli *reappear*
    - Chromosomes *uncoil*, becoming chromatin

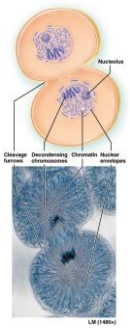


Figure 3.35b Interphase, mitosis, and cytokinesis.

Phases of the Cell Cycle

- **Cytokinesis** divides cytosol and organelles <u>equally</u> between *two new daughter cells*
  - Cells split apart as **actin** and **myosin** proteins *tighten around equator* creating a **cleavage furrow**
  - Eventually separates into two *genetically identical* cells

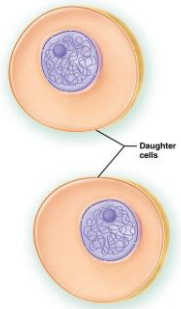
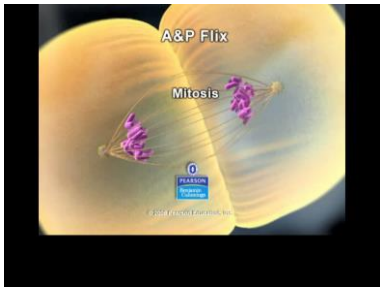


Figure 3.35c Interphase, mitosis, and cytokinesis.

A&P Flix: Mitosis



Spindle Poisons

- Mitotic spindle is critical to process of mitosis; if assembly or disassembly is inhibited by chemicals called **spindle poisons** (made by fungi and plants), errors in cell division occur that could lead to cell death

Spindle Poisons

- Examples:
  - **Vinca alkaloids** – inhibit microtubule function; fragment formed microtubules; used to treat *cancer*
  - **Colchicine** – inhibits assembly of microtubules; treats *gout*
  - **Griseofulvin** – inhibits function/assembly of microtubules in *fungi* (not humans); antifungal agent for skin, hair, and nails
  - **Taxanes** – prevent *disassembly* of microtubules; treat *cancer*
- Adverse effects – (especially in cells that divide rapidly like stomach, skin, and bone marrow) nausea, vomiting, hair loss, decreased blood cell production

Phases of the Cell Cycle

- Most cells in the body progress through the cell cycle but at *vastly different rates* depending on their function
- Other cells *remain in G_1 phase* after they have matured and never proceed through rest of cycle; this *non-dividing* state is called **G_0 phase**
- Cell cycle is *precisely controlled* so that cell *formation* is balanced with cell *death* (**Figures 3.33**, **3.36**)

Cell Cycle Control and Cancer

- **Checkpoints** act as *stop/go signals* for the cell; most important checkpoint, called **G_1 checkpoint**, occurs about three-fourths of way through G_1
- Cell responds to a variety of *extracellular signals*; may not *proceed with division* if the following conditions are not *favorable*:
  - There must be enough *nutrients* available in ECF to *support cell division*
  - Proteins called **growth factors** must be secreted into the ECF by other cells to *stimulate cell division*

Cell Cycle Control and Cancer

- Cell responds to a variety of *extracellular signals*; may not *proceed with division* if the following conditions are not *favorable* (continued):
  - *Density of cells* in tissue dictates how many new cells can be supported by available resources
  - Some cells must be *anchored* to neighboring cells and surrounding environment

Cell Cycle Control and Cancer

- Cells that cannot pass through checkpoints and cannot be repaired undergo a process of *programmed cell death* called **apoptosis**
- This "cellular suicide" will also occur for variety of other reasons; for example, during *fetal development* hands and feet are initially webbed; cells in "webs" die to separate fingers and toes
- When changes in DNA of a cell cause *loss of cell cycle control*, uncontrolled *cell division* results and cells may form a growth or mass known as a **tumor** (**Figure 3.36**)

Cell Cycle Control and Cancer

- **Benign** tumor – confined to its *original location* and *does not invade surrounding tissues*; may grow extremely large
- **Malignant** tumor – made up of *cancer cells*; example is *renal cell carcinoma* (kidney cancer cells) in **Figure 3.36**
  - Malignant cells are not inhibited by *high cellular density* or *loss of anchorage* to other cells; with enough nutrients, such cells appear to *grow and divide indefinitely*
  - Cells from malignant tumors are *able to spread* into other tissues (called **metastasis**) which can cause widespread tissue destruction and may result in death

Cell Cycle Control and Cancer

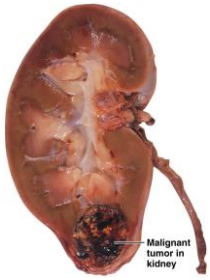


Figure 3.36 Cancerous tumor of kidney cells.