Cell Metabolisms

Characteristics of Enzymes

- Most are globular proteins that act as biological catalysts
- Holoenzymes consist of an apoenzyme (protein) and a cofactor (usually an ion)
- Enzymes are chemically specific
- Frequently named for the type of reaction they catalyze
- Enzyme names usually end in *-ase*
- Lower activation energy

Characteristics of Enzymes

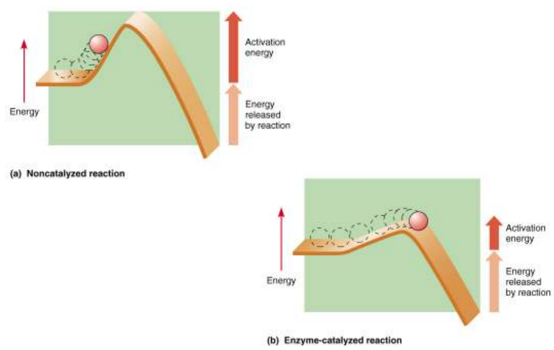


Figure 2.19

Mechanism of Enzyme Action

- Enzyme binds with substrate
- Product is formed at a lower activation energy
- Product is released

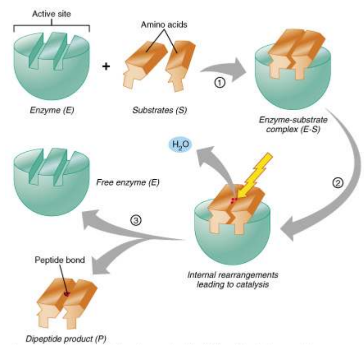


Figure 2.20

Nucleic Acids

- Composed of carbon, oxygen, hydrogen, nitrogen, and phosphorus
- Their structural unit, the nucleotide, is composed of N-containing base, a pentose sugar, and a phosphate group
- Five nitrogen bases contribute to nucleotide structure – adenine (A), guanine (G), cytosine (C), thymine (T), and uracil (U)
- Two major classes – DNA and RNA

Deoxyribonucleic Acid (DNA)

- Double-stranded helical molecule found in the nucleus of the cell
- Replicates itself before the cell divides, ensuring genetic continuity
- Provides instructions for protein synthesis

Structure of DNA

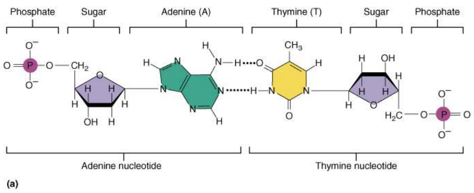


Figure 2.21a

Structure of DNA

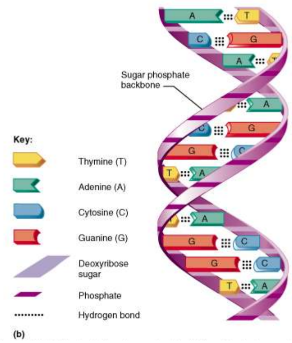


Figure 2.21b

Ribonucleic Acid (RNA)

- Single-stranded molecule found in both the nucleus and the cytoplasm of a cell
- Uses the nitrogenous base uracil instead of thymine
- Three varieties of RNA: messenger RNA, transfer RNA, and ribosomal RNA

Adenosine Triphosphate (ATP)

- Source of immediately usable energy for the cell
- Adenine-containing RNA nucleotide with three phosphate groups

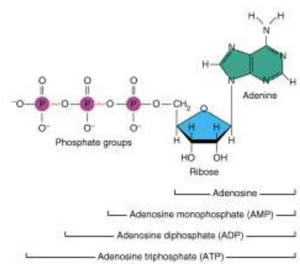


Figure 2.22

Nucleus

- Nuclear envelope, nucleoli, and chromatin
- Gene-containing control center of the cell
- Contains the genetic library with blueprints for nearly all cellular proteins
- Dictates the kinds and amounts of proteins to be synthesized

Nucleus

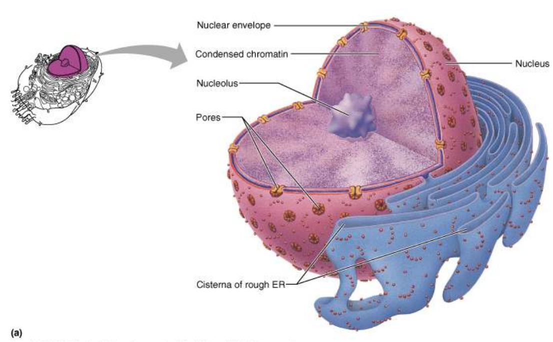


Figure 3.26a

Nuclear Envelope

- Selectively permeable double membrane barrier containing pores
- Encloses jellylike nucleoplasm, which contains essential solutes
- Outer membrane is continuous with the rough ER and is studded with ribosomes
- Inner membrane is lined with the nuclear lamina, which maintains the shape of the nucleus
- Pore complex regulates transport of large molecules into and out of the nucleus

Nucleoli

- Dark-staining spherical bodies within the nucleus
- Site of ribosome production

Chromatin

- Threadlike strands of DNA and histones
- Arranged in fundamental units called nucleosomes
- Form condensed, barlike bodies of chromosomes when the nucleus starts to divide

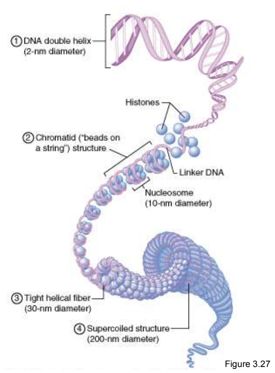


Figure 3.27

Cell Cycle

- Interphase
  - Growth (G_1), synthesis (S), growth (G_2)
- Mitotic phase
  - Mitosis and cytokinesis

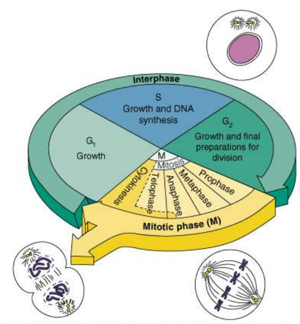


Figure 3.28

Interphase

- G_1 (gap 1) – metabolic activity and vigorous growth
- G_0 – cells that permanently cease dividing
- S (synthetic) – DNA replication
- G_2 (gap 2) – preparation for division

DNA Replication

- The DNA unwinds from the nucleosome
- Helicase untwists the DNA double helix into two complementary nucleotide chains (replication bubble)
- Freed nucleotide strands serve as templates for semiconservative replication

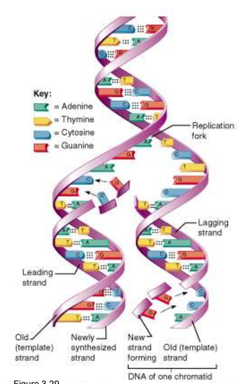


Figure 3.29

DNA Replication

- DNA polymerase creates leading and lagging strands
- Short lagging strands of DNA are spliced together by DNA ligase
- Histones associate with DNA and form chromatids that are united by a centromere

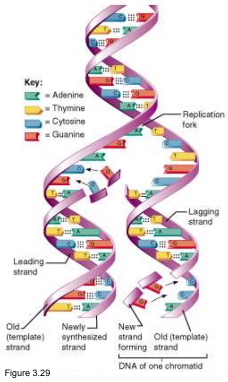


Figure 3.29

Cell Division

- Essential for body growth and tissue repair
- Mitosis – nuclear division
- Cytokinesis – division of the cytoplasm

Mitosis

- Prophase
- Metaphase
- Anaphase
- Telophase

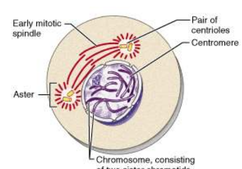
Cytokinesis

- Cleavage furrow formed in late anaphase by contractile ring
- Cytoplasm is pinched into two parts after mitosis ends

Early and Late Prophase

- Asters are seen as chromatin condenses into chromosomes
- Nucleoli disappear
- Centriole pairs separate and the mitotic spindle is formed

Early and Late Prophase



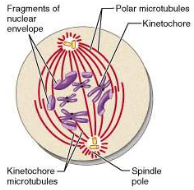
Early prophase

As mitosis begins, microtubule arrays called *asters* ("stars") are seen extending from the centrioles. Early in *prophase*, the first and longest phase of mitosis, the chromatin threads coil and condense, forming barlike *chromosomes* that are visible with a light microscope. Since DNA replication has occurred during interphase, each chromosome is actually made up of two identical chromatin threads, now called *chromatids*. The chromatids of each chromosome are held together by a small, buttonlike body called a *centromere*. After the chromatids separate, each is considered a new chromosome.

As the chromosomes appear, the nucleoli disappear, and the cytoskeletal microtubules disassemble. The centriole pairs separate from one another. The centrioles act as focal points for growth of a new assembly of microtubules called the **mitotic spindle.** As these microtubules lengthen, they push the centrioles farther and farther apart, propelling them toward opposite ends (poles) of the cell.

Figure 3.30.1

Early and Late Prophase



Late prophase

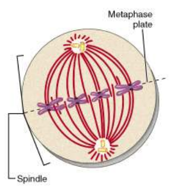
While the centrioles are still moving away from each other, the nuclear membrane fragments, allowing the spindle to occupy the center of the cell and to interact with the chromosomes. Meanwhile, some of the growing spindle microtubules attach to special protein–DNA complexes, called *kinetochores* (ki-ne´to-korz), on each chromosome's centromere. Such microtubules are called *kinetochore microtubules*. The remaining spindle microtubules, which do not attach to any chromosomes, are called *polar microtubules*. The tips of the polar microtubules are linked near the center; these push against each other forcing the poles apart. The kinetochore microtubules, on the other hand, pull on each chromosome from both poles, resulting in a tug-of-war that ultimately draws the chromosomes to the middle of the cell.

Figure 3.30.2

Metaphase

- Chromosomes cluster at the middle of the cell with their centromeres aligned at the exact center, or equator, of the cell
- This arrangement of chromosomes along a plane midway between the poles is called the metaphase plate

Metaphase



Metaphase

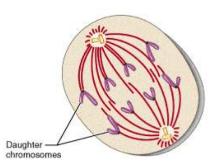
Metaphase is the second phase of mitosis. The chromosomes cluster at the middle of the cell, with their centromeres precisely aligned at the exact center, or *equator*, of the spindle. This arrangement of the chromosomes along a plane midway between the poles is called the *metaphase* plate.

Figure 3.30.3

Anaphase

- Centromeres of the chromosomes split
- Motor proteins in kinetochores pull chromosomes toward poles

Anaphase



Anaphase

Anaphase, the third phase of mitosis, begins abruptly as the centromeres of the chromosomes split, and each chromatid now becomes a chromosome in its own right. The kinetochore fibers, moved along by motor proteins in the kinetochores, rapidly disassemble at their kinetochore ends by removing tubulin subunits, and gradually pull each chromosome toward the pole it faces. By contrast the polar microtubules slide past each other and lengthen (a process presumed to be driven by kinesin motor molecules), and push the two poles of the cell apart, causing the cell to elongate. Anaphase is easy to recognize because the moving chromosomes look V-shaped. The centromeres, which are attached to the kinetochore microtubules, lead the way, and the chromosomal "arms" dangle behind them. Anaphase is the shortest stage of mitosis; it typically lasts only a few minutes.

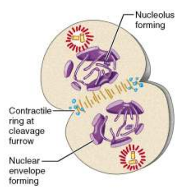
This process of moving and separating the chromosomes is helped by the fact that the chromosomes are short, compact bodies. Diffuse threads of extended chromatin would tangle, trail, and break, which would damage the genetic material and result in its imprecise "parceling out" to the daughter cells.

Figure 3.30.4

Telophase and Cytokinesis

- New sets of chromosomes extend into chromatin
- New nuclear membrane is formed from the rough ER
- Nucleoli reappear
- Generally cytokinesis completes cell division

Telophase and Cytokinesis



Telophase and cytokinesis

Telophase begins as soon as chromosomal movement stops. This final phase is like prophase in reverse. The identical sets of chromosomes at the opposite poles of the cell uncoil and resume their threadlike extended–chromatin form. A new nuclear membrane, derived from the rough ER, reforms around each chromatin mass. Nucleoli reappear within the nuclei, and the spindle breaks down and disappears. Mitosis is now ended. The cell, for just a brief period, is binucleate (has two nuclei) and each new nucleus is identical to the original mother nucleus.

As a rule, as mitosis draws to a close, *cytokinesis* completes the division of the cell into two daughter cells. Cytokinesis occurs as a contractile ring of peripheral microfilaments forms at the *cleavage furrow* and squeezes the cells apart. Cytokinesis actually begins during late anaphase and continues through and beyond telophase.

Figure 3.30.5

Control of Cell Division

- Surface-to-volume ratio of cells
- Chemical signals such as growth factors and hormones
- Contact inhibition
- Cyclins and cyclin-dependent kinases (Cdks) complexes

Control of Cell Division

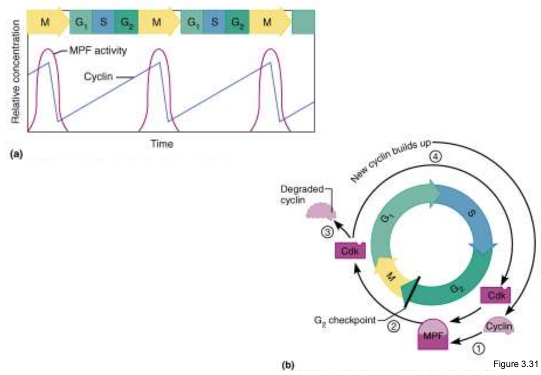


Figure 3.31

Signal Mechanism of Protein Synthesis

- mRNA – ribosome complex is directed to rough ER by a signal-recognition particle (SRP)
- SRP is released and polypeptide grows into cisternae
- The protein is released into the cisternae and sugar groups are added

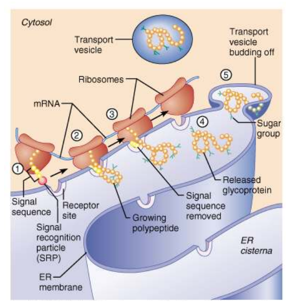


Figure 3.17

Signal Mechanism of Protein Synthesis

- The protein folds into a three-dimensional conformation
- The protein is enclosed in a transport vesicle and moves toward the Golgi apparatus

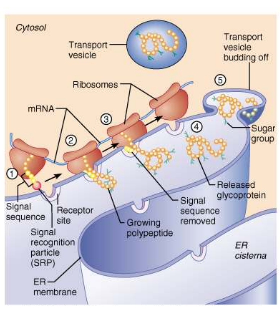


Figure 3.17

Protein Synthesis

- DNA serves as master blueprint for protein synthesis
- Genes are segments of DNA carrying instructions for a polypeptide chain
- Triplets of nucleotide bases form the genetic library
- Each triplet specifies coding for an amino acid

Transcription

- Transfer of information from the sense strand of DNA to mRNA
- mRNA is synthesized from DNA using transcription factors and RNA polymerase
- Each DNA triplet codes for a corresponding 3-base sequence of RNA, called a codon
- There are 64 different codons
- Introns are removed from pre-mRNA to produce functional mRNA

Translation

- Translation of DNA is coded through mRNA to an amino acid sequence (polypeptide)
- Involves all three types of RNA – mRNA, tRNA, and rRNA
- Occurs in the cytoplasm at the ribosomes

Translation

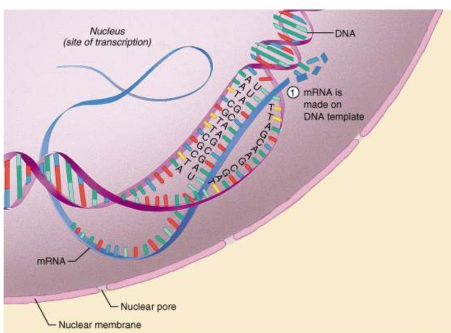


Figure 3.32

Translation

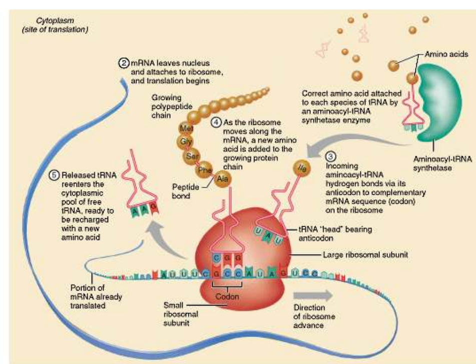


Figure 3.32 continued

Roles of the Three Types of RNA

- Messenger RNA (mRNA) carries the genetic information from DNA in the nucleus to the ribosomes in the cytoplasm
- Transfer RNAs (tRNAs) bound to amino acids base pair with the codons of mRNA at the ribosome to begin the process of protein synthesis
- Ribosomal RNA (rRNA) is a structural component of ribosomes

Information Transfer from DNA to RNA

- DNA triplets are transcribed into mRNA codons by RNA polymerase
- Codons base pair with tRNA anticodons at the ribosomes
- Amino acids are peptide bonded at the ribosomes to form polypeptide chains
- Start and stop codons are used in initiating and ending translation

Information Transfer from DNA to RNA

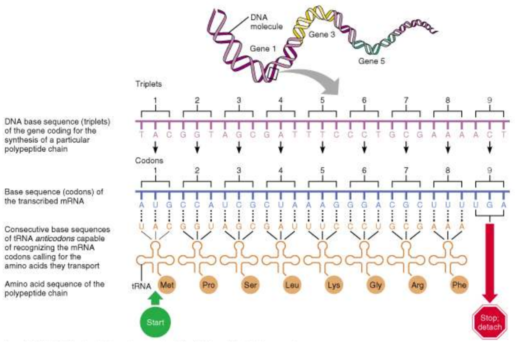


Figure 3.34

Protein Degradation

- Nonfunctional organelle proteins are degraded by lysosomes
- Ubiquitin attaches to soluble proteins and they are degraded in proteasomes

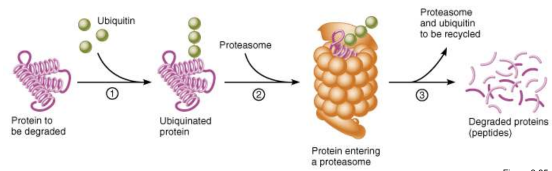


Figure 3.35

Extracellular Materials

- Body fluids and cellular secretions
- Extracellular matrix

Operation of a G protein

- An extracellular ligand (first messenger), binds to a specific plasma membrane protein
- The receptor activates a G protein that relays the message to an effector protein

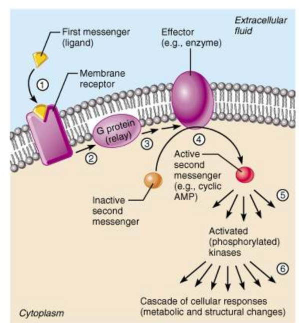


Figure 3.14

Operation of a G protein

- The effector is an enzyme that produces a second messenger inside the cell
- The second messenger activates a kinase
- The activated kinase can trigger a variety of cellular responses

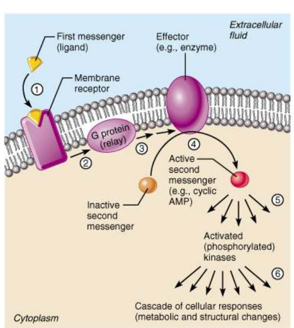


Figure 3.14