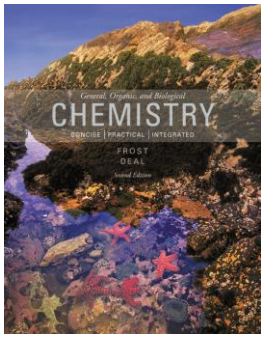

Lecture Presentation

Chapter 11

Nucleic Acids—Big Molecules with a Big Role

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Smyrna, GA

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Outline

- 11.1 Components of Nucleic Acids
- 11.2 Nucleic Acid Formation
- 11.3 DNA
- 11.4 RNA and Protein Synthesis
- 11.5 Putting it Together: The Genetic Code and Protein Synthesis
- 11.6 Genetic Mutations
- 11.7 Viruses
- 11.8 Recombinant DNA Technology

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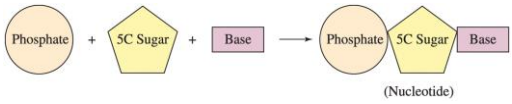
11.1 Components of Nucleic Acids

- Nucleic acids are strings of molecules called nucleotides.
- Nucleic acids are created from a set of four nucleotides in a given sequence.
- Nucleotides have three basic components: a nitrogenous base, a five-carbon sugar, and a phosphate functional group.



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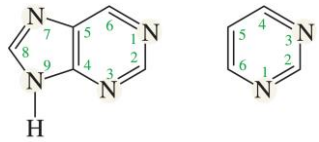
11.1 Components of Nucleic Acids

Nitrogenous bases

- There are four different nitrogenous bases found in a nucleic acid.
- Each of the bases has one of two nitrogen-containing aromatic rings, either a purine or a pyrimidine.



Purine *Pyrimidine*

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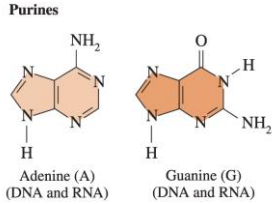
11.1 Components of Nucleic Acids

Nitrogenous bases

- DNA contains two purines, adenine (A) and guanine (G).



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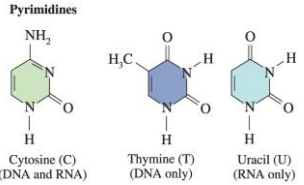
11.1 Components of Nucleic Acids

Nitrogenous bases

- DNA contains two pyrimidines, thymine (T) and cytosine (C).
- RNA contains the same bases, except that thymine is replaced with uracil (U).



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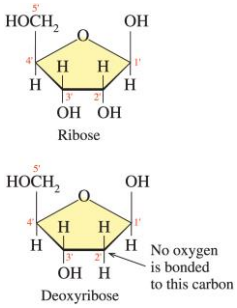
11.1 Components of Nucleic Acids

Ribose and deoxyribose

- Nucleotides also contain five-carbon pentose sugars.
- To distinguish the carbons in the nitrogenous bases from the carbons in the sugar rings, a prime symbol is added to the numbering of the sugars.



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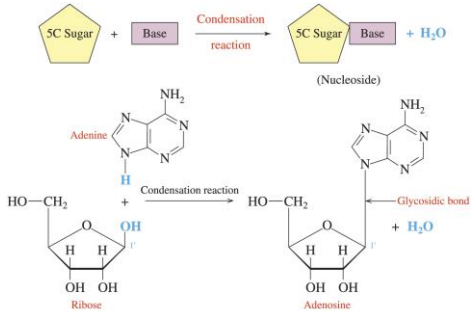
11.1 Components of Nucleic Acids

Condensation of the Components



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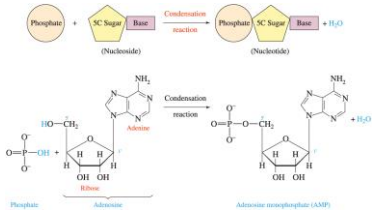
11.1 Components of Nucleic Acids

Naming Nucleotides

- A nucleo*tide* contains a nitrogenous base, a sugar, and a phosphate.
- A nucleo*side* contains only the sugar and nitrogenous base.



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11.1 Components of Nucleic Acids

Naming Nucleotides

- Nucleotides include the nucleoside name and the number of phosphates present.
- Nucleotide names often are abbreviated.
- The abbreviation indicates the type of sugar (ribose or deoxyribose) and the nitrogenous base.
- If deoxyribose is found in the nucleotide, a lowercase *d* is inserted at the beginning of the abbreviation.

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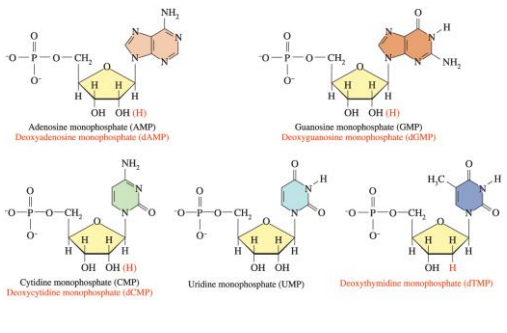
11.1 Components of Nucleic Acids



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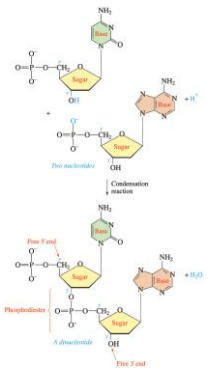
11.2 Nucleic Acid Formation

- Many nucleotides linked together form **nucleic acids**.
- Nucleotides are linked through **phosphodiester bonds.**
- Oxygens in the phosphate are connected between the 3′ and 5′ carbons of adjacent sugar molecules.



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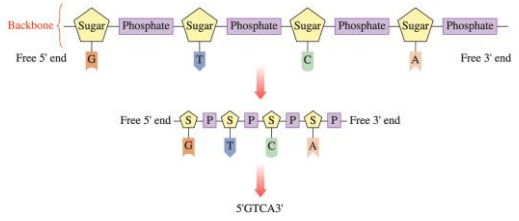
11.2 Nucleic Acid Formation



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11.3 DNA

- The base sequences in nucleic acids stored as DNA in the cell's nucleus hold the code for cellular protein production.
- A few key discoveries beginning in the late 1940s led to the structure of DNA.
- Erwin Chargaff noted that the amount of adenine (A) is always equal to the amount of thymine (T) (A = T), and the amount of guanine (G) is always equal to the amount of cytosine (C) (G = C).
- The number of purines equals the number of pyrimidines in DNA.

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11.3 DNA

- DNA's secondary structure is described as a **double helix**.
- This was first proposed in 1953 by James Watson and Francis Crick.
- A double helix can be envisioned as a twisted ladder.
- The two strands both have bases in the center. Their backbones run in opposite directions: antiparallel to each other. One strand goes in the 5′ to 3′ direction and the other strand goes in the 3′ to 5′ direction.
- Each of the rungs contains one base from each of the strands.
- The two bases in each ladder-rung associate through hydrogen bonding. All the rungs are the same length, so they must contain one purine and one pyrimidine.
- The pairs A–T and G–C are called complementary base pairs. Adenine and thymine form two hydrogen bonds, while guanine and cytosine form three hydrogen bonds.
- The DNA in one human cell contains about 3 billion base pairs.

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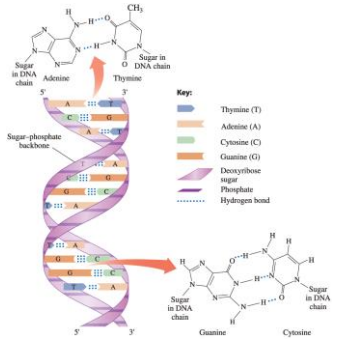
11.3 DNA



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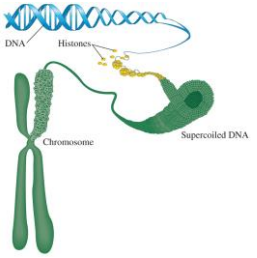
11.3 DNA

Tertiary structure: Chromosomes

- Because DNA has a helical twist, further twisting makes the DNA more compact.
- The 3 billion base pairs in one human cell would stretch out to about 6 feet in length.
- The DNA is separated into 46 pieces supercoiled around proteins called *histones*.
- These pieces of DNA pack into **chromosomes**.



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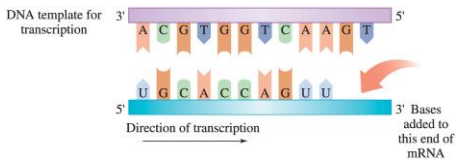
11.4 RNA and Protein Synthesis

Messenger RNA and Transcription

- In **transcription**, DNA's double helix unwinds so that a complementary copy can be made from one strand.
- The copy is the messenger RNA or mRNA.
- mRNA is a single-stranded piece of RNA containing the bases complementary to the original DNA strand.
- Gene copying is catalyzed by RNA polymerase.



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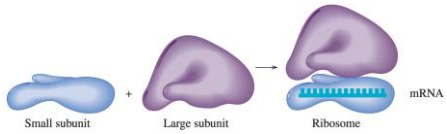
11.4 RNA and Protein Synthesis

Ribosomal RNA and the Ribosome

- The ribosome can be thought of as a protein factory.
- It is composed of ribosomal RNA (rRNA) and protein.
- It is the place where the nucleotide sequence of mRNA is interpreted into an amino acid sequence.
- The ribosome has two rRNA/protein subunits called the small subunit and the large subunit.
- The mRNA strand fits into a groove on the small subunit with the bases pointing toward the large subunit.



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11.4 RNA and Protein Synthesis

Transfer RNA and Translation

- The second step is **translation**.
- The facilitator for this process is the transfer RNA (**tRNA**). There are several areas on the tRNA sequence where complementary bases can hydrogen-bond. Doing so gives the tRNA a tightly compacted T-shaped structure.
- The tRNA has a three-base sequence (triplet) **anticodon** at its anticodon loop. When in the ribosome, the anticodon can hydrogen-bond to complementary bases on mRNA.
- The tRNA has an *acceptor stem* where it binds an amino acid.
- The only way to get an amino acid incorporated into a growing protein chain is by bringing it to the ribosome bonded to the tRNA. Each of the 20 amino acids has one or more tRNAs available to bring amino acids to the ribosome.

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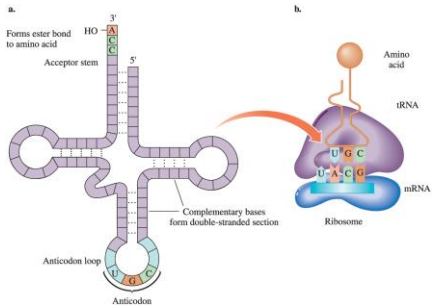
11.4 RNA and Protein Synthesis



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11.5 Putting It Together: The Genetic Code and Protein Synthesis

- The mRNA transcribed from the DNA contains a sequence of bases specifying the protein to be made.
- A given triplet called a codon in the mRNA translates to a specific amino acid.
- The genetic code shows the codons of mRNA for the 20 amino acids.
- Sixty-four codon combinations are possible from the four bases A, G, C, and U.
- The three codons UGA, UAA, and UAG are stop signals.

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11.5 Putting It Together: The Genetic Code and Protein Synthesis

TABLE 11.3 mRNA CODONS: The Genetic Code for Amino Acids

First Letter from 5′ End	Second Letter U	Second Letter C	Second Letter A	Second Letter G	Third Letter
U	UUU Phe	UCU Ser	UAU Tyr	UGU Cys	U
	UUC Phe	UCC Ser	UAC Tyr	UGC Cys	C
	UUA Leu	UCA Ser	UAA STOP	UGA STOP	A
	UUG Leu	UCG Ser	UAG STOP	UGG Trp	G
C	CUU Leu	CCU Pro	CAU His	CGU Arg	U
	CUC Leu	CCC Pro	CAC His	CGC Arg	C
	CUA Leu	CCA Pro	CAA Gln	CGA Arg	A
	CUG Leu	CCG Pro	CAG Gln	CGG Arg	G
A	AUU Ile	ACU Thr	AAU Asn	AGU Ser	U
	AUC Ile	ACC Thr	AAC Asn	AGC Ser	C
	AUA Ile	ACA Thr	AAA Lys	AGA Arg	A
	[a]AUG Met/start	ACG Thr	AAG Lys	AGG Arg	G
G	GUU Val	GCU Ala	GAU Asp	GGU Gly	U
	GUC Val	GCC Ala	GAC Asp	GGC Gly	C
	GUA Val	GCA Ala	GAA Glu	GGA Gly	A
	GUG Val	GCG Ala	GAG Glu	GGG Gly	G

[a]Codon that signals the start of a peptide chain.
STOP codons signal the end of a peptide chain.

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11.5 Putting It Together: The Genetic Code and Protein Synthesis

Protein Synthesis

Transcription

- DNA unwinds at the site of a gene.
- A complementary mRNA is created.
- The mRNA travels to the ribosome.

tRNA Activation

- Before the tRNA can be used in the ribosome, an amino acid must be attached to its acceptor stem.
- tRNA synthetase attaches the correct amino acid to the acceptor stem.
- The amino acid is then ready for use in protein synthesis.

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Protein Synthesis

Translation

- Protein synthesis begins when mRNA positions itself at the ribosome.
- The first codon in mRNA is the start codon, AUG.
- An activated tRNA with an anticodon of UAC and an attached methionine hydrogen bonds to the mRNA.
- A second activated tRNA enters the ribosome.
- The two amino acids join, forming a peptide bond, and the methionine detaches from the first tRNA.
- The deactivated tRNA leaves the ribosome, and the second tRNA shifts to the first position with a dipeptide attached.
- The shifting is translocation.
- The tRNAs return to be recharged.

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Protein Synthesis

Termination

- Eventually, the ribosome encounters a stop codon, and protein synthesis ends.
- The polypeptide chain is released from the ribosome.
- The initial amino acid methionine is often removed from the beginning of the polypeptide.
- The growing polypeptide folds into its tertiary structure, forming any disulfide links, salt bridges, or other interactions that make the polypeptide a biologically active protein.

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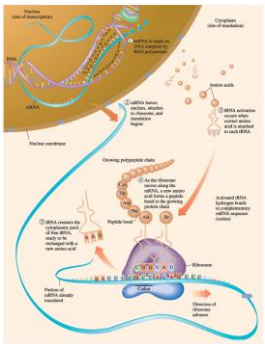

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11.6 Genetic Mutations

Any change in a DNA nucleotide sequence is called a mutation.

- No change in protein sequence.
- Sometimes a change in a base will have no effect.
- Only about 2.5% of the DNA in your chromosomes encodes for proteins. The rest of your DNA is nongene or commonly referred to as "junk" DNA.
- There is more than one codon that codes for each amino acid. For example, if the codon UUU were changed to UUC, the amino acid phenylalanine would still be placed in the polypeptide chain.
- These are called **silent mutations**.

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11.6 Genetic Mutations

Any change in a DNA nucleotide sequence is called a mutation.

- A change in protein sequence occurs, but it has no effect on protein function.
- If, for example, the codon AUU is mutated to GUU, then the amino acid isoleucine would be changed to valine.
- These two amino acids are similar in polarity and size, and such a substitution would not have much of an effect on the protein function.
- This is another type of silent mutation.

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11.6 Genetic Mutations

Any change in a DNA nucleotide sequence is called a mutation.

- A change in protein sequence occurs and affects protein function.
- If AUU were mutated to AAU, then isoleucine would be changed to asparagine: a nonpolar amino acid is replaced with a polar amino acid.
- Other mutations that can have a negative effect on protein synthesis include mutating a codon into a stop codon and inserting or deleting a base.
- The latter shifts the triplets that are read in the mRNA and would change the identity of all subsequent amino acids.

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11.6 Genetic Mutations

Sources of Mutations

- Sometimes when DNA replicates, errors occur. This is a spontaneous mutation.
- Environmental agents that produce mutations in DNA are **mutagens**: many mutagens are carcinogens.
- Viruses can also cause mutations.
- One common chemical mutagen is sodium nitrite ($NaNO_2$), a preservative in processed meats. In the presence of amines, sodium nitrite forms nitrosamines, which assist in the conversion of cytosine into uracil.
- If a mutation occurs in a somatic cell (any cell type other than egg or sperm), it affects only the individual organism and can cause conditions like cancer.
- Mutations that occur in germ cells (sperm or egg cells) can be passed on to future generations. Germ cell mutations cause genetic diseases. More than 4,000 genetic diseases have been identified.

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11.6 Genetic Mutations

TABLE 11.4 Some Genetic Diseases

Genetic Disease	Protein or Chromosomal Defect	Disease Symptoms
Galactosemia	The transferase enzyme required for the metabolism of galactose-1-phosphate is absent.	Cataracts, mental retardation.
Cystic fibrosis	Mutation in a gene producing a protein that regulates salt transport in and out of cells	Thick secretions of mucus, difficulty breathing, blocked pancreatic function
Down syndrome	Formation of three chromosomes, usually number 21, instead of a pair of chromosomes	Heart and eye defects, mental and physical problems
Familial hypercholesterolemia	Mutation in a gene on chromosome 19 regulating cholesterol levels	High cholesterol levels, early coronary heart disease (age 30–40)
Muscular dystrophy (Duchenne)	One of 10 forms of MD. A mutation in the X chromosome results in the low or abnormal production of *dystrophin*.	Muscle-atrophy disease appears around age 5, with death by age 20. Occurs in about 1 of 10,000 males.
Huntington's disease (HD)	Mutation in a gene on chromosome 4, which can now be mapped to test people in families with HD.	Nervous tremors leading to total physical impairment
Sickle-cell anemia	Defective hemoglobin from a mutation in a gene on chromosome 11	Anemia from decreased oxygen-carrying ability of red blood cells
Hemophilia	One or more defective blood-clotting factors	Poor blood coagulation, excessive bleeding, and internal hemorrhages
Tay-Sachs disease	Defective hexosaminidase A	Accumulation of lipids in the brain, resulting in mental retardation, loss of motor control, and early death

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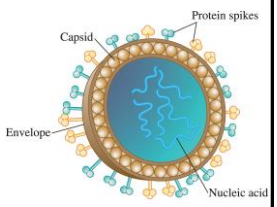
11.7 Viruses

- Viruses are small particles containing 3 to 200 genes that can infect any cell type.
- Viruses cannot make their own proteins or energy. They contain only parts needed to infect a cell.
- Viruses have their own nucleic acid but use the ribosomes and RNA of the infected cell—also called the host cell—to make their proteins.



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11.7 Viruses

TABLE 11.5 Some Diseases Caused by Viral Infection

Disease	Virus
Common cold	Coronavirus (more than 100 types)
Influenza	Orthomyxovirus
Warts	Papovavirus
Herpes	Herpesvirus
Leukemia, cancers, AIDS	Retroviruses
Hepatitis	Hepatitis A virus (HAV), hepatitis B virus (HBV), hepatitis C virus (HCV)
Mumps	Paramyxovirus
Epstein–Barr	Epstein–Barr virus (EBV)

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11.7 Viruses

- Viruses contain nucleic acid (DNA or RNA) in a protein coat called a **capsid**.
- Many viruses also have a protective **envelope** surrounding the capsid.
- The function of viruses is to monopolize the functions of the host cell.
- A virus infects a cell when an enzyme in the protein coat makes a hole in the host cell, allowing the viral nucleic acid to enter and mix with host cell material.

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11.7 Viruses

- If the virus contains DNA, the host cell begins to replicate the viral DNA.
- Viral DNA produces viral RNA, which makes the proteins for the virus.
- The completed virus particles are assembled and released from the cell to infect more cells.
- This release often occurs by budding.
- Vaccines are often inactive forms of viruses that boost immune response by causing the body to produce antibodies.
- Polio, mumps, chicken pox, and measles can be prevented through the use of vaccines.

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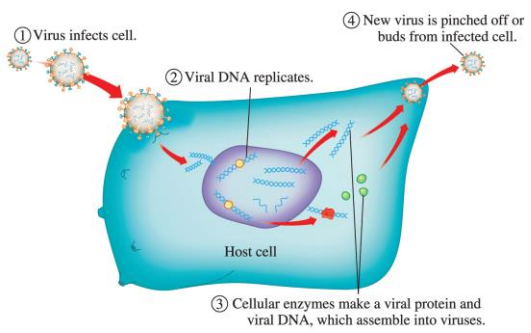
11.7 Viruses



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11.7 Viruses

- Retroviruses contains RNA as the nucleic acid.
- Once retroviral RNA gets into the cell, it must first make viral DNA through a process known as *reverse transcription*.
- Retroviruses contain an enzyme called reverse transcriptase that uses the viral RNA to viral DNA.
- The viral DNA uses the cell's enzymes and ribosomes to replicate virus particles.

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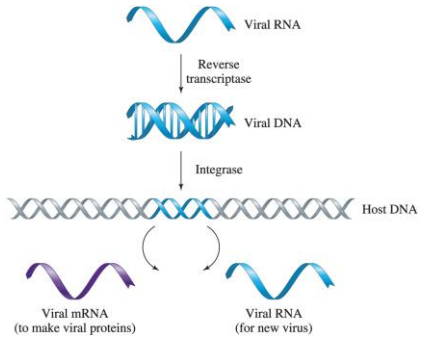
11.7 Viruses



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11.7 Viruses

HIV-1 and AIDS

- HIV-1 is a retrovirus responsible for AIDS (**A**cquired **I**mmune **D**eficiency **S**yndrome).
- HIV-1 infects white blood cells known as T4 lymphocytes that are part of the human immune system.
- Depletion of these immune cells reduces a person's ability to fight infections.
- To minimize damage to the host cell, viral therapies must inactivate unique parts of the virus life cycle.

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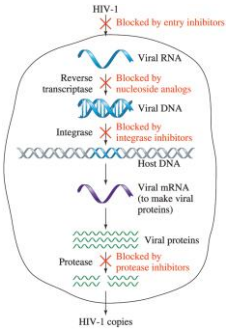
11.7 Viruses

HIV-1 and AIDS

- AIDS drugs attack HIV-1 at the points of reverse transcription and viral protein synthesis.
- Nucleoside analogs halt transcription if they are incorporated into viral DNA.
- Protease inhibitors prevent viral proteins from being clipped down to size.
- Cell entry drugs block insertion of RNA into the host cell.
- Integrase inhibitors prevent incorporation into host DNA.



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11.8 Recombinant DNA Technology

- **Recombinant DNA** involves recombining DNA from two different sources.
- In the process, often called *genetic engineering* or *gene cloning*, the genome of one organism is altered by splicing in a section of DNA containing a gene from a second organism.
- Inserting a higher organism's gene into an organism with a shorter life cycle produces the desired protein more quickly.
- Humans have been crossbreeding plants and animals for centuries, exchanging DNA for desired traits.
- The recombinant DNA techniques developed in the mid-1970s work more quickly, expand the usefulness of crossbreeding, and are more predictable.

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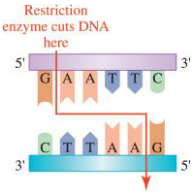
11.8 Recombinant DNA Technology

Identify and isolate a gene of interest.

- A gene of interest is located on a chromosome and removed.
- This is the *donor DNA*.
- Removal is by **restriction enzymes** that recognize specific sequences.



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11.8 Recombinant DNA Technology

Insert donor DNA into the organism DNA using a vector.

- A **vector** can incorporate donor DNA into the genome of the organism.
- A vector found in bacteria is a circular DNA called a **plasmid**.
- Using the same restriction enzymes, the plasmid is opened and the gene inserted.
- The vector DNA is incorporated into the bacterial DNA as the bacteria divide.

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11.8 Recombinant DNA Technology

Express the incorporated gene in the new organism.

- Bacteria that have the donor DNA will produce protein from the gene of interest as they undergo normal protein synthesis.
- Protein production of a nonnative gene is called **expression**.
- The protein can be subsequently isolated and purified.

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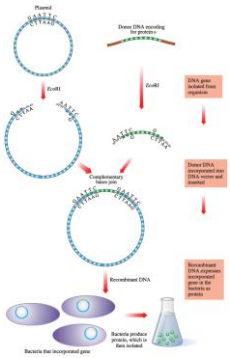
11.8 Recombinant DNA Technology



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11.8 Recombinant DNA Technology

- **Therapeutic proteins:** The human insulin gene has been incorporated into *E. coli*, allowing these bacteria to produce human insulin.
- **Genetically modified crops:** The insertion of genes into food plants affords crops advantages during growth.
- **Genetic testing:** Because of the Human Genome Project, we can now identify genes responsible for many genetic diseases.

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11.8 Recombinant DNA Technology

Nuclear Transplantation—Cloning

- The term clone means to make an exact copy.
- Cloning an organism creates a genetic copy of the original organism. This is done by taking the nuclear DNA from an adult cell (somatic cell) and transplanting it into an egg cell from which DNA has been removed.
- In some cases, such a cell behaves like a fertilized egg and will begin to divide, forming an embryo.
- The embryo can then be transplanted into a surrogate until it fully develops.
- The first cloned mammal, Dolly the sheep, was born in 1996 and was the sole survivor of 276 attempts to create and implant an embryo. Dolly survived about half the normal life expectancy.
- Since then, a number of other animals have been cloned.

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Chapter Eleven Summary

11.1 Components of Nucleic Acids

- Deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) are nucleic acids. They consist of strings of nucleotides.
- A nucleotide has three components: a nitrogenous base, a five-carbon sugar, and a phosphate.
- A nucleoside consists of the nitrogenous base and the five carbon sugar. The sugar deoxyribose is found in DNA, and the ribose is found in RNA.
- The bases adenine (A), guanine (G), and cytosine (C) are found in both DNA and RNA. Thymine (T) is a fourth base found in DNA, and uracil (U) is a fourth base found in RNA.
- Nucleotides are named as the nucleoside + the number of phosphates (up to three) bonded to it.
- The components of nucleosides, as well as those of nucleotides, link together through condensation reactions.

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Chapter Eleven Summary

11.2 Nucleic Acid Formation

- Each nucleic acid has a unique sequence that is its primary structure.
- Nucleic acids form when nucleotides undergo condensation linking sugar to phosphate. The 3 –OH on the sugar of one nucleotide bonds with the phosphate on the 5′ end of a neighboring nucleotide.
- The backbone of a nucleic acid is formed from alternating sugar-phosphate-to-sugar-phosphate groups.
- The nitrogenous bases dangle from the backbone. Each nucleic acid has single free 5′ and 3′ ends.

11.3 DNA

- A DNA molecule resembles a twisted ladder. It consists of two antiparallel strands of nucleic acid with bases facing inward. The strands are held together through the bases (rungs), which hydrogen-bond to bases on the other strand, giving DNA its secondary structure.
- A forms two hydrogen bonds to T, and G forms three hydrogen bonds to C.
- In most plants and animals, DNA is found in the cell nucleus and is compacted into a tertiary structure called a chromosome.
- Chromosomes also contain a protein component called a histone, around which the DNA is supercoiled.
- Humans have 23 pairs of chromosomes in their cells.

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Chapter Eleven Summary

11.4 RNA and Protein Synthesis

- RNA differs from DNA in that it contains a ribose sugar instead of a deoxyribose. Instead of thymine, RNA contains uracil that can hydrogen-bond to adenine.
- RNA is smaller than DNA and is single stranded. The three types of RNA that are involved in transforming the DNA sequence into a protein sequence in the cell are messenger RNA (mRNA), ribosomal RNA (rRNA), and transfer RNA (tRNA).
- The messenger RNA is involved in transcribing a complementary copy from gene DNA and taking that copy to the ribosome.
- Ribosomes are cell organelles where protein synthesis takes place. They consist of rRNA and protein.
- tRNA is a compact structure that acts as a conduit between the messenger RNA and an amino acid sequence.
- tRNA has two features: the anticodon at one end that is complementary to the codon sequence on the mRNA and the acceptor stem where an amino acid can attach.

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Chapter Eleven Summary

11.5 Putting it Together: The Genetic Code and Protein Synthesis

- The genetic code is a series of base triplet sequences on mRNA specifying the order of amino acids in a protein.
- The codon AUG signals the start of transcription, and the codons UAG, UGA, and UAA signal it to stop.
- Protein synthesis begins with transcription where an mRNA creates a complementary copy of a DNA gene.
- tRNA activation involves binding an amino acid to the tRNA, catalyzed by the enzyme tRNA synthetase.
- During translation, tRNAs bring the appropriate amino acids to the ribosome and peptide bonds form until termination when a stop codon is reached.
- The polypeptide becomes a functional protein upon release.

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Chapter Eleven Summary

11.6 Genetic Mutations

- Base alterations from normal cell DNA sequences are called mutations.
- Some mutations are silent and have no effect on protein synthesis, and some may change the sequence but not alter protein function. Others can affect protein sequence, structure, and function.
- Mutations can be random during DNA replication or they can be caused by mutagens like chemicals or radiation. A mutation in a germ cell can be inherited. If such a mutation results in a defective protein, a genetic disease results.

11.7 Viruses

- Viruses are particles containing DNA or RNA and a protein coat called a capsid. They invade a host cell and use the host cell's machinery to replicate more virus particles. Viruses containing RNA are called retroviruses. These viruses must go through an initial step of reverse transcription to make viral DNA from viral RNA.
- HIV-1 is a retrovirus. Several areas of retroviral replication have been studied, and promising drugs have been developed in recent years to slow down HIV-1 infection in AIDS patients.

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Chapter Eleven Summary

11.8 Recombinant DNA Technology

- Recombinant DNA technology involves the expression of a protein from one organism in a second organism.
- This can be accomplished after the gene of interest is isolated and clipped from a genome using a restriction enzyme.
- The gene of interest is incorporated into a vector that transports and incorporates the gene into the second organism. The host organism can then produce the protein of interest during transcription and translation.
- Gene cloning or making an exact copy of a gene is different from organism cloning, where an exact copy of an organism is produced.

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Chapter Eleven Study Guide

11.1 Components of Nucleic Acids

- Identify the five nitrogenous bases in nucleic acids.
- Distinguish the bases ribose and deoxyribose.
- Write nucleosides and nucleotides given their component parts.

11.2 Nucleic Acid Formation

- Write the product of a condensation of nucleotides.
- Abbreviate a nucleic acid using one-letter base coding.

11.3 DNA

- Characterize the structural features of DNA.
- Write the complementary base pairs for a single strand of DNA.

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Chapter Eleven Study Guide

11.4 RNA and Protein Synthesis

- List three types of RNA and their role in protein synthesis.
- Translate a DNA strand into its complementary mRNA.

11.5 Putting It Together

- Distinguish transcription from translation.
- Translate an mRNA sequence into a protein sequence using the genetic code.

11.6 Genetic Mutations

- Define genetic mutation.
- Determine changes in protein sequence if an mRNA sequence is mutated.

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Chapter Eleven Study Guide

11.7 Viruses

- List the differences between a virus and a cell.
- List the structural components of a virus.
- Describe how a virus infects a cell.

11.8 Recombinant DNA Technology

- Apply knowledge of nucleic acid structure to DNA technology.

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