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**AP Biology Exam Review : Molecular Genetics and Biotechnology (Unit 6)**

**Textbook Chapters:** 16 (The Molecular Basis of Inheritance), 17 (From Gene to Protein), 18 (The Genetics of Viruses and Bacteria), 19 (Eukaryotic Genomes: Organization, Regulation, and Evolution), 20 (DNA Technology and Genomics)

**Topic Outline:**

1. Nucleic Acid Structure
* Understand the difference between DNA structure in prokaryotes vs. eukaryotes
1. Prokaryotic DNA = in a single circular chromosome ; some small circular sections of plasmid DNA
2. Eukaryotic DNA = multiple linear chromosomes
* Be able to describe the experiments leading to the discovery of DNA as the cell’s genetic material. Key scientists include
1. Franklin, Watson, Crick, Wilkins
2. Griffith
3. Hershey / Chase
4. Avery-MacLeod-McCarty
* Explain the differences between DNA and RNA structure (see CC’s below)
1. DNA Replication
* Be able to explain how DNA replicates using the following enzymes: DNA polymerase, helicase, single-stranded binding proteins, topoisomerase, and ligase
* Explain how the creation of the leading strand is different from the creation of the lagging strand (use the terms 3’ and 5’)
* Explain how DNA replication is a semi-conservative process and given experimental evidence to support this theory (Meselson-Stahl Experiment)
1. Protein Synthesis
* Explain how proteins are made from DNA and RNA in the processes of transcription and translation (for details see CC’s below)
* Be able to identify the organelles, enzymes, etc. involved in the following processes:
1. Transcription
2. mRNA processing
3. Translation

***CC 3.A.1: DNA, and in some cases RNA, is the primary source of heritable information.***

***a. Genetic information is transmitted from one generation to the next through DNA or RNA.***

***Evidence of student learning is a demonstrated understanding of each of the following:***

***1. Genetic information is stored in and passed to subsequent generations through DNA molecules and, in***

***some cases, RNA molecules.***

***2. Noneukaryotic organisms have circular chromosomes, while eukaryotic organisms have multiple linear***

***chromosomes, although in biology there are exceptions to this rule.***

***3. Prokaryotes, viruses and eukaryotes can contain plasmids, which are small extra-chromosomal, double stranded circular DNA molecules.***

***4. The proof that DNA is the carrier of genetic information involved a number of important historical***

***experiments. These include:***

***i. Contributions of Watson, Crick, Wilkins, and Franklin on the structure of DNA***

***ii. Avery-MacLeod-McCarty experiments***

***iii. Hershey-Chase experiment***

***5. DNA replication ensures continuity of hereditary information.***

***i. Replication is a semiconservative process; that is, one strand serves as the template for a new,***

***complementary strand.***

***ii. Replication requires DNA polymerase plus many other essential cellular enzymes, occurs***

***bidirectionally, and differs in the production of the leading and lagging strands.***

***b. DNA and RNA molecules have structural similarities and differences that define function.***

***Evidence of student learning is a demonstrated understanding of each of the following:***

***1. Both have three components — sugar, phosphate and a nitrogenous base — which form nucleotide***

***units that are connected by covalent bonds to form a linear molecule with 3' and 5' ends, with the***

***nitrogenous bases perpendicular to the sugar-phosphate backbone.***

***2. The basic structural differences include:***

***i. DNA contains deoxyribose (RNA contains ribose).***

***ii. RNA contains uracil in lieu of thymine in DNA.***

***iii. DNA is usually double stranded, RNA is usually single stranded.***

***iv. The two DNA strands in double-stranded DNA are antiparallel in directionality.***

***3. Both DNA and RNA exhibit specific nucleotide base pairing that is conserved through evolution: adenine pairs with thymine or uracil (A-T or A-U) and cytosine pairs with guanine (C-G).***

***i. Purines (G and A) have a double ring structure.***

***ii. Pyrimidines (C, T and U) have a single ring structure.***

***4. The sequence of the RNA bases, together with the structure of the RNA molecule, determines RNA***

***function.***

***i. mRNA carries information from the DNA to the ribosome.***

***ii. tRNA molecules bind specific amino acids and allow information in the mRNA to be translated***

***to a linear peptide sequence.***

***iii. rRNA molecules are functional building blocks of ribosomes.***

***iv. The role of RNAi includes regulation of gene expression at the level of mRNA transcription.***

***c. Genetic information flows from a sequence of nucleotides in a gene to a sequence of amino acids in a***

***protein.***

***Evidence of student learning is a demonstrated understanding of each of the following:***

***1. The enzyme RNA-polymerase reads the DNA molecule in the 3' to 5' direction and synthesizes***

***complementary mRNA molecules that determine the order of amino acids in the polypeptide.***

***2. In eukaryotic cells the mRNA transcript undergoes a series of enzyme-regulated modifications.***

***To demonstrate student understanding of this concept, make sure you can explain:***

***i. Addition of a poly-A tail***

***ii. Addition of a GTP cap***

***iii. Excision of introns***

***3. Translation of the mRNA occurs in the cytoplasm on the ribosome.***

***4. In prokaryotic organisms, transcription is coupled to translation of the message. 5. Translation involves energy and many steps, including initiation, elongation and termination. The salient features include:***

***i. The mRNA interacts with the rRNA of the ribosome to initiate translation at the (start) codon.***

***ii. The sequence of nucleotides on the mRNA is read in triplets called codons.***

***iii. Each codon encodes a specific amino acid, which can be deduced by using a genetic code chart. Many amino acids have more than one codon.***

***iv. tRNA brings the correct amino acid to the correct place on the mRNA.***

***v. The amino acid is transferred to the growing peptide chain.***

***vi. The process continues along the mRNA until a “stop” codon is reached.***

***vii. The process terminates by release of the newly synthesized peptide/protein.***

***d. Phenotypes are determined through protein activities.***

***To demonstrate student understanding of this concept, make sure you can explain:***

* ***Enzymatic reactions***
* ***Transport by proteins***
* ***Synthesis***
* ***Degradation***
1. **Why do cells regulate gene expression?**
* Cells in multicellular organisms express different genes based on the cell type (ex: the gene for hemoglobin protein is highly expressed / used in red blood cells)
* Cells in unicellular organisms express different genes based on their stage in life / environmental requirements (ex: when a bacterial cell encounters a food source, the cell must begin producing digestive enzymes)
* Cells need to be able to stop expression of genes when they no longer need a particular gene product (protein) and increase expression of genes when their corresponding gene product is needed to respond to a change in the environment (negative feedback)

**Prokaryotic Gene Regulation**

* In bacteria, genes are often clustered into units called operons (ex: genes that create all the enzymes in a metabolic pathway) ; if genes are clustered, it makes them easier to regulate as a unit
* An operon consists of three parts:
	+ An operator that controls the access of RNA polymerase to the genes. The operator is found within the promoter site or between the promoter and the protein coding genes of the operon
	+ The promoter, which is where RNA polymerase attaches to begin transcription of the genes
	+ The genes of the operon. This is the entire stretch of DNA required for creating proteins.
* A regulatory gene can be found some distance away from the operon. It makes repressor proteins that may bind to the operator site. When a repressor protein is in the operator site, RNA polymerase cannot transcribe the genes of the operon. This turns the operon off
* Types of Operons: repressible operon (normally in “on” mode, but can be turned off, and inducible operon (normally in “off mode” but can be turned on—lac operon)

**Eukaryotic Gene Regulation**

* Whereas prokaryotic cells regulate gene expression by regulating transcription, eukaryotic gene expression can be regulated at any step along the pathway from gene to functional protein
* The different cell types in multicellular eukaryotic organisms (ex: skin cells, blood cells) are not due to different genes being present (the same set of DNA is found in each cell in a multicellular organisms. Instead, the cell types result from differential gene expression, the expression of different genes by cells with the same genome.

**Regulation Based on Chromatin Structure**

* DNA is normally bound to histone proteins. (DNA + protein forms a complex called a nucleosome.) The more tightly bound it is, the more inaccessible it is for transcription.
* DNA Methylation = the addition of methyl groups to DNA. It causes the DNA to be more tightly packaged, thus reducing gene expression
* Histone Acetylation = acetyl groups are added to amino acids of histone proteins, thus making the chromatin less tightly packed and encouraging transcription

**Regulation at the Transcription Level**

* In the promoter region, binding of RNA polymerase / transcription factors controls speed of transcription
* Enhancer sequences, “upstream” from gene… binding of proteins called activators (AKA enhancer binding proteins) in this region speeds up transcription
* Generally eukaryotic genes are not organized in operon… genes coding for enzymes in the same metabolic pathway may be scattered on different chromosomes, but their expression may be controlled by the same activator molecules

**Post-Transcriptional Control**

* Alternative splicing of introns from pre-mRNA 🡪 creation of different proteins
* Micro RNA’s (miRNA’s) and small interfering RNA’s (siRNA’s) are single-stranded RNA molecules that can bind to mRNA and degrade the mRNA or block translation

**Post-Translational Control**

* May need to alter the protein before it can be used
	+ Cleavage – cutting polypeptide chain to produce a functional protein
	+ Ex: proinsulin (1 chain) 🡪 insulin (2 chains)
	+ Chemical modification – add sugars, phosphates, etc. to make the protein “act” different
	+ Ubiquitin tag – identifies proteins for degradation by proteasomes

***CC 3.B.1: Gene regulation results in differential gene expression, leading to cell specialization.***

***a. Both DNA regulatory sequences, regulatory genes, and small regulatory RNAs are involved in gene***

***expression.***

***Evidence of student learning is a demonstrated understanding of each of the following:***

***1. Regulatory sequences are stretches of DNA that interact with regulatory proteins to control***

***transcription.***

***To demonstrate student understanding of this concept, make sure you can explain:***

***i. Promoters***

***ii. Terminators***

***iii. Enhancers***

***2. A regulatory gene is a sequence of DNA encoding a regulatory protein or RNA.***

***b. Both positive and negative control mechanisms regulate gene expression in bacteria and viruses.***

***Evidence of student learning is a demonstrated understanding of each of the following:***

***1. The expression of specific genes can be turned on by the presence of an inducer.***

***2. The expression of specific genes can be inhibited by the presence of a repressor.***

***3. Inducers and repressors are small molecules that interact with regulatory proteins and/or regulatory***

***sequences.***

***4. Regulatory proteins inhibit gene expression by binding to DNA and blocking transcription (negative***

***control).***

***5. Regulatory proteins stimulate gene expression by binding to DNA and stimulating transcription (positive control) or binding to repressors to inactivate repressor function.***

***6. Certain genes are continuously expressed; that is, they are always turned “on,” e.g., the ribosomal***

***genes.***

***c. In eukaryotes, gene expression is complex and control involves regulatory genes, regulatory elements and***

***transcription factors that act in concert.***

***Evidence of student learning is a demonstrated understanding of each of the following:***

***1. Transcription factors bind to specific DNA sequences and/or other regulatory proteins.***

***2. Some of these transcription factors are activators (increase expression), while others are repressors***

***(decrease expression).***

***3. The combination of transcription factors binding to the regulatory regions at any one time determines***

***how much, if any, of the gene product will be produced.***

***d. Gene regulation accounts for some of the phenotypic differences between organisms with similar genes.***

***CC 3.B.2: A variety of intercellular and intracellular signal transmissions mediate gene expression.***

***a. Signal transmission within and between cells mediates cell function.***

***To demonstrate student understanding of this concept, make sure you can explain:***

* ***Mating pheromones in yeast trigger mating genes expression and sexual reproduction.***
* ***Morphogens stimulate cell differentiation and development.***
* ***Changes in p53 activity can result in cancer.***
* ***HOX genes and their role in development.***

***CC 4.A.3: Interactions between external stimuli and regulated gene expression result in specialization of cells, tissues and organs.***

***a. Differentiation in development is due to external and internal cues that trigger gene regulation by proteins***

***that bind to DNA.***

***b. Structural and functional divergence of cells in development is due to expression of genes specific to a***

***particular tissue or organ type.***

***c. Environmental stimuli can affect gene expression in a mature cell.***

1. Mutations and Increasing Genetic Diversity
* Changes to the DNA sequence are not all harmful…some can increase genetic variability 🡪 more possible forms of traits so that not all organisms can be killed off by any one factor (ex: a disease that kills all tall people)
* They can be spontaneous errors in replication or they can be caused by mutagens (environmental factors like radiation, chemicals, cigarette smoke, etc.)
* If a mutagen causes changes in genes that regulate the cell cycle / cell division it is considered a carcinogen (a cancer-causing factor)
* Some mutations are neutral (happen in introns that do not code for proteins)
* Some mutations are harmful (change protein function in a negative way)
* Types of Mutations:
1. Point mutation: change in one base pair of a gene (substitution: replace one base with another)
2. Silent – changes one base, but codes for the same amino acid (due to redundancy)
3. Missense – codes for another amino acid (changes protein sequence and usually function)
	* + Example: sickle cell disease… one T substituted for A in the gene coding for hemoglobin protein
* Nonsense – code changes to a stop codon (makes a nonfunctional protein that is terminated early)
* Frameshift mutation: the mutation effects all nucleotides / codon groupings farther along the DNA / RNA code
* Insertion – adding extra nucleotides (causes a frameshift if you are not adding exactly three extra bases)
* Deletion – removing nucleotides (causes a frameshift if you are not removing exactly three bases)

Example: O blood type allele involves a deletion in the A blood type code

***CC 3.C.1: Changes in genotype can result in changes in phenotype.***

***a. Alterations in a DNA sequence can lead to changes in the type or amount of the protein produced and the***

***consequent phenotype.***

***Evidence of student learning is a demonstrated understanding of the following:***

***1. DNA mutations can be positive, negative or neutral based on the effect or the lack of effect they have on the resulting nucleic acid or protein and the phenotypes that are conferred by the protein.***

***b. Errors in DNA replication or DNA repair mechanisms, and external factors, including radiation and reactive chemicals, can cause random changes, e.g., mutations in the DNA.***

***Evidence of student learning is a demonstrated understanding of the following:***

***1. Whether or not a mutation is detrimental, beneficial or neutral depends on the environmental context.***

***Mutations are the primary source of genetic variation.***

***CC 3.C.2: Biological systems have multiple processes that increase genetic variation.***

***a. The imperfect nature of DNA replication and repair increases variation.***

***CC 4.C.1: Variation in molecular units provides cells with a wider range of functions.***

***a. Multiple copies of alleles or genes (gene duplication) may provide new phenotypes.***

***To demonstrate student understanding of this concept, make sure you can explain:***

***1. A heterozygote may be a more advantageous genotype than a homozygote under particular***

***conditions, since with two different alleles, the organism has two forms of proteins that may provide***

***functional resilience in response to environmental stresses.***

***2. Gene duplication creates a situation in which one copy of the gene maintains its original function, while***

***the duplicate may evolve a new function.***

***To demonstrate student understanding of this concept, make sure you can explain:***

* ***The antifreeze gene in fish***
1. Viral and Bacterial Genetics and Reproduction
* Viral Replication
1. Lytic vs. Lysogenic Cycle of Viral Infection
2. Life Cycle of a Retrovirus (ex: HIV)
* Bacterial Reproduction and Genetic Recombination
1. Transformation
2. Transduction
3. Conjugation
4. Transposition

***CC 3.C.3: Viral replication results in genetic variation, and viral infection can introduce genetic variation into the hosts.***

***a. Viral replication differs from other reproductive strategies and generates genetic variation via various***

***mechanisms.***

***Evidence of student learning is a demonstrated understanding of each of the following:***

***1. Viruses have highly efficient replicative capabilities that allow for rapid evolution and acquisition of new phenotypes.***

***2. Viruses replicate via a component assembly model allowing one virus to produce many progeny***

***simultaneously via the lytic cycle.***

***3. Virus replication allows for mutations to occur through usual host pathways.***

***4. RNA viruses lack replication error-checking mechanisms, and thus have higher rates of mutation.***

***5. Related viruses can combine/recombine information if they infect the same host cell.***

***6. HIV is a well-studied system where the rapid evolution of a virus within the host contributes to the***

***pathogenicity of viral infection.***

***b. The reproductive cycles of viruses facilitate transfer of genetic information.***

***Evidence of student learning is a demonstrated understanding of each of the following:***

***1. Viruses transmit DNA or RNA when they infect a host cell.***

***2. To foster student understanding of this concept, instructors can choose an illustrative example such as:***

***4. Transduction in bacteria***

***5. Transposons present in incoming DNA***

***6. Some viruses are able to integrate into the host DNA and establish a latent (lysogenic) infection. These***

***latent viral genomes can result in new properties for the host such as increased pathogenicity in***

***bacteria.***

***CC 3.A.1: DNA, and in some cases RNA, is the primary source of heritable information.***

***a. Genetic information is transmitted from one generation to the next through DNA or RNA.***

***Evidence of student learning is a demonstrated understanding of each of the following:***

***1. Genetic information in retroviruses is a special case and has an alternate flow of information: from RNA to DNA, made possible by reverse transcriptase, an enzyme that copies the viral RNA genome into DNA. This DNA integrates into the host genome and becomes transcribed and translated for the assembly of new viral progeny.***

***CC 3.C.2: Biological systems have multiple processes that increase genetic variation.***

***b. The horizontal acquisitions of genetic information primarily in prokaryotes via transformation (uptake of***

***naked DNA), transduction (viral transmission of genetic information), conjugation (cell-to-cell transfer) and***

***transposition (movement of DNA segments within and between DNA molecules) increase variation.***

1. Biotechnology
* Gel Electrophoresis
1. You should be able to analyze gel banding patterns
2. You should be able to use the results of a gel showing DNA bands of different sizes created by restriction enzyme “chopping” of plasmid DNA to create a “map” of the plasmid
* Bacterial Transformation (with recombinant DNA)
1. You should be able to analyze results of a bacterial transformation experiment
* Polymerase Chain Reaction

***CC 3.A.1: DNA, and in some cases RNA, is the primary source of heritable information.***

***b. Genetic engineering techniques can manipulate the heritable information of DNA and, in special cases, RNA.***

***To demonstrate student understanding of this concept, make sure you can explain:***

* ***Electrophoresis***
* ***Plasmid-based transformation***
* ***Restriction enzyme analysis of DNA***
* ***Polymerase Chain Reaction (PCR)***

***c. Illustrative examples of products of genetic engineering include:***

* ***Genetically modified foods***
* ***Transgenic animals***
* ***Cloned animals***
* ***Pharmaceuticals such as human insulin, growth hormone, or clotting factor***