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Nucleic Acids and Molecular Biology

Biochemistry

DNA, RNA, structure and functions of nucleotides, DNA replication, transcription, translation, genetic code and basic molecular biology.

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CHAPTER 11

Nucleic Acids and Molecular Biology

Nucleotide structure, DNA, RNA, replication, transcription and translation

1. Nucleotides and nucleosides

Nucleic acids are polymers of nucleotides that store and express genetic information. A nucleotide contains a nitrogenous base, pentose sugar and phosphate group; a nucleoside contains base and sugar only. Purines are adenine (A) and guanine (G); pyrimidines are cytosine (C), thymine (T) and uracil (U). Nucleotides form 3 -5 phosphodiester bonds. ATP is an energy-transfer molecule; cAMP is a second messenger; NAD and FAD contain nucleotide components.

2. DNA versus RNA

Feature	DNA	RNA
Sugar	Deoxyribose	Ribose
Bases	A, G, C, T	A, G, C, U
Structure	Usually double-stranded helix	Usually single-stranded, may fold
Function	Long-term genetic information	Gene expression, regulation and catalysis

DNA strands are antiparallel (5 -> 3 and 3 -> 5). A pairs with T via two hydrogen bonds and G with C via three. DNA associates with histone proteins in chromatin; chromosomes are organized DNA-protein structures. Mitochondria also contain DNA.

3. Types of RNA

- mRNA: carries coding information to ribosomes.
- tRNA: delivers amino acids and recognizes codons by its anticodon.
- rRNA: structural and catalytic component of ribosomes.
- snRNA: participates in RNA splicing; miRNA and other noncoding RNAs regulate gene expression.

4. DNA replication

Semiconservative replication yields two DNA molecules, each containing one parental and one newly synthesized strand. Helicase unwinds DNA; topoisomerase reduces torsional stress; primase forms primers. DNA polymerase extends DNA in the 5 -> 3 direction, continuously on the leading strand and discontinuously on

the lagging strand (Okazaki fragments). Primers are removed and replaced, and DNA ligase joins fragments. Proofreading and repair help maintain fidelity. Telomerase helps maintain chromosome ends in selected cells.

5. Transcription

RNA polymerase copies a DNA template into RNA in the 5 -> 3 direction. In eukaryotes, most protein-coding transcripts undergo 5 capping, splicing (introns removed, exons joined) and 3 polyadenylation before export. Transcription factors and regulatory sequences control expression.

6. Translation and genetic code

At ribosomes, mRNA codons specify amino acids or stop signals. Aminoacyl-tRNA synthetases attach appropriate amino acids to tRNA. Initiation assembles the ribosome; elongation adds amino acids via peptide bonds; termination releases the polypeptide. Folding and post-translational modifications generate functional proteins.

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Genetic code feature	Explanation
Triplet	Three bases form one codon
Degenerate	Several codons may encode the same amino acid
Unambiguous	Each standard codon specifies one amino acid or stop signal
Nearly universal	Broadly conserved, with some exceptions
Start / stop	AUG usually starts translation; UAA, UAG and UGA are standard stop codons

7. Mutations and molecular techniques

Substitution may be silent, missense or nonsense; insertion/deletion may cause a frameshift if not in multiples of three. DNA damage does not always become a permanent mutation. PCR amplifies selected DNA using primers, polymerase and temperature cycles; reverse-transcription PCR begins with RNA converted to cDNA. Sequencing reads nucleotide order. Genetic tests require appropriate consent, interpretation and confidentiality.

8. Structure of a nucleotide and the double helix

A base attaches to the pentose sugar through an N-glycosidic bond. A phosphate group attaches to the sugar and allows polymer formation through phosphodiester bonds. The negatively charged sugar-phosphate backbone lies outside the DNA helix; paired nitrogenous bases face inward. Complementary pairing allows each strand to serve as a template for copying and repair.

Comparison of major molecular processes

Feature	Replication	Transcription	Translation
Template	DNA	DNA	mRNA
Product	DNA	RNA	Polypeptide

Main machinery	DNA polymerase and accessory proteins	RNA polymerase and regulatory proteins	Ribosome, tRNA and factors
Building blocks	Deoxyribonucleotides	Ribonucleotides	Amino acids
Eukaryotic site	Primarily nucleus	Primarily nucleus	Cytoplasmic ribosomes

9. Gene expression and regulation

A gene contains information for a functional RNA or protein product. Promoters and other regulatory sequences influence transcription. Epigenetic processes, including DNA methylation and histone modification, can alter gene expression without changing the underlying nucleotide sequence. Post-transcriptional control includes RNA stability, splicing and translation efficiency. Protein modifications and degradation further alter activity.

10. Clinical example: molecular diagnosis

PCR uses repeated cycles of strand separation, primer annealing and primer extension. A positive nucleic-acid result indicates detection of a target sequence under the assay conditions; it does not necessarily prove viable infectious organisms. Correct specimen type, collection timing, contamination control and interpretation in clinical context are critical.

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11. Clinical and nursing applications

Sickle cell disease illustrates a missense variant in beta-globin. Molecular tests can detect pathogens or inherited variants; results depend on sampling, timing and test design. Explain specimen collection, respect genetic privacy and refer genetic counselling needs. Molecular biology supports drug development, cancer classification and infectious disease diagnosis.

12. Important Examination Questions

Long Answer Questions

1. 1. Describe DNA structure, replication, transcription and translation.
2. 2. Compare DNA and RNA and describe the major types of RNA.
3. 3. Explain genetic code, translation and the clinical role of molecular testing.

Short Answer Questions

1. 1. Write a short note on DNA versus RNA.
2. 2. Write a short note on genetic code.
3. 3. Write a short note on PCR.

Very Short Answer Questions

1. 1. Which bases are purines? - Adenine and guanine.
2. 2. What enzyme joins Okazaki fragments? - DNA ligase.
3. 3. What is a codon? - Three adjacent nucleotide bases specifying an amino acid or stop signal in translation.

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4. 4. Which RNA is a core catalytic component of the ribosome? - rRNA.

Additional objective question

Which RNA carries amino acids? - tRNA.

13. Quick Revision

- DNA stores genetic information; RNA has multiple roles in its expression.
- A nucleotide contains base, sugar and phosphate; a nucleoside lacks phosphate.
- DNA replication is semiconservative; polymerases extend nucleic acids 5 to 3 .
- AUG is a common start codon; UAA, UAG and UGA are standard stop codons.

Conclusion

Molecular biology explains inheritance, protein synthesis and the principles behind genetic and molecular laboratory investigations.

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Practice questions

Choose one best answer. The answer key and explanations follow the questions.

1. Which component distinguishes a nucleotide from a nucleoside?

A. Phosphate group
B. Pentose sugar
C. Nitrogenous base
D. Carbon atoms

2. Which RNA delivers amino acids to the ribosome and recognizes codons through an anticodon?

A. mRNA
B. tRNA
C. rRNA
D. snRNA

3. Which enzyme joins DNA fragments during replication?

A. Helicase
B. Primase
C. DNA ligase
D. RNA polymerase

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Answer key and explanations

1. A - Phosphate group

A nucleotide contains base, sugar and phosphate; a nucleoside lacks phosphate.

2. B - tRNA

Transfer RNA delivers amino acids and pairs its anticodon with codons.

3. C - DNA ligase

DNA ligase joins fragments after primer removal and replacement.

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