A1.2 Nucleic Acids

IB / A Level exam preparation notes

Focus: heredity, DNA/RNA structure, replication accuracy, evidence for DNA as genetic material	**Best use:** quick revision + exam-answer planning + last-minute recall

Guiding questions

- How does the structure of nucleic acids allow hereditary information to be stored?
- How does the structure of DNA facilitate accurate replication?

Big picture in one view

- DNA is the universal long-term genetic material of all living organisms; some viruses use RNA, but viruses are not considered living.
- Both DNA and RNA are polymers of nucleotides. Each nucleotide contains a phosphate group, a pentose sugar and a nitrogenous base.
- The sugar-phosphate backbone is held together by strong covalent bonds; the sequence of bases stores the information.
- DNA has two antiparallel strands with complementary base pairs: A-T and C-G.
- Complementary base pairing allows DNA to replicate accurately because each old strand can act as a template for a new strand.

1. Core ideas you must know

- **DNA:** deoxyribonucleic acid; stores long-term hereditary information.
- **RNA:** ribonucleic acid; involved in gene expression and protein synthesis.
- **Gene:** a sequence of DNA bases carrying information for a polypeptide or functional RNA.
- **Nucleotide:** phosphate + pentose sugar + nitrogenous base.
- **Complementary base pairing:** specific hydrogen bonding between bases.
- **Antiparallel:** the two DNA strands run in opposite directions: one 5'->3', the other 3'->5'.

2. DNA as the universal genetic material

All living organisms use DNA for long-term information storage. This universality supports the idea of common ancestry. Mutations that affect evolution occur in DNA and can be inherited. A cell's identity depends on the proteins it can make, and the instructions for those proteins are encoded in DNA base sequences.

High-yield exam point

Every cell in a multicellular organism contains the same DNA, but different cell types express different genes.

3. Structure of a nucleotide

A nucleotide has three parts: one phosphate group, one pentose sugar and one nitrogenous base. In IB diagrams, draw these using a circle (phosphate), pentagon (sugar) and rectangle (base).

Part	Role / detail
Phosphate group	Part of the repeating backbone; contributes phosphorus.
Pentose sugar	Ribose in RNA, deoxyribose in DNA.
Nitrogenous base	A, T, C, G in DNA; A, U, C, G in RNA.

Key carbon positions: the phosphate is attached to the 5' carbon of the sugar; the nitrogenous base is attached to the 1' carbon; the next nucleotide links through the 3' carbon.

4. Sugar-phosphate backbone and polymer formation

Nucleotides join by condensation reactions. The sugar of one nucleotide bonds covalently to the phosphate of the next, producing a strong sugar-phosphate backbone. Because these are covalent bonds, nucleic acid strands are stable.

Remember this calculation

A strand with n nucleotides is formed by n - 1 condensation reactions, so n - 1 water molecules are released.

Example: a 12-nucleotide RNA strand forms 11 water molecules during polymerization.

5. Bases and the code

Nucleic acid	Bases present
DNA	Adenine (A), Thymine (T), Cytosine (C), Guanine (G)
RNA	Adenine (A), Uracil (U), Cytosine (C), Guanine (G)

There are **8 nucleotide types in total**: four in DNA and four in RNA. Even if both contain adenine, an RNA nucleotide and a DNA nucleotide are not identical because the sugars differ.

6. RNA structure and roles

RNA is usually single-stranded. Its backbone alternates ribose and phosphate, with bases extending outward. Because RNA uses uracil rather than thymine and contains ribose rather than deoxyribose, it can usually be identified quickly in diagrams.

- **mRNA:** carries a copy of the genetic information from DNA to the ribosome.
- **tRNA:** brings the correct amino acid to a growing polypeptide.
- **rRNA:** combines with proteins to form ribosomes.
- **ATP:** a single-nucleotide nucleic acid used for cellular energy transfer.

7. DNA structure

DNA is a double-stranded molecule. The two strands are held together by hydrogen bonds between complementary base pairs. A pairs with T, and C pairs with G. The strands are antiparallel, and the overall molecule forms a double helix.

What to include in a labelled DNA diagram

- two antiparallel strands
- sugar-phosphate backbone on the outside
- bases in the centre
- A-T and C-G pairing only
- hydrogen bonds between paired bases
- 5' and 3' ends if directionality is being tested

8. DNA vs RNA

Feature	DNA	RNA
Number of strands	Double-stranded	Single-stranded
Sugar	Deoxyribose	Ribose
Unique base	Thymine	Uracil
Typical shape	Double helix	Varied; often single-stranded
Role	Permanent genetic code of cells	Gene expression and protein synthesis

Ribose has one more oxygen atom than deoxyribose. This is why DNA is called **deoxy**ribonucleic acid.

9. Why complementary base pairing matters

Complementarity depends on hydrogen bonding. A only pairs with T in DNA, and C only pairs with G. When DNA strands separate, each exposed strand acts as a template. Free nucleotides pair with the exposed bases, allowing accurate copying of the original sequence.

Direct answer to the replication question

- DNA has two strands, so each original strand can act as a template.
- Base pairing is specific: A-T and C-G only.
- Hydrogen bonding ensures the correct partner is added.
- As a result, the new DNA sequence is copied with very high accuracy.

10. Storage of genetic information

The information in DNA lies in the **sequence** of its bases, not in the backbone. Triplets of bases form meaningful units of code. Because DNA molecules can be extremely long, the number of possible base sequences is enormous.

- There are 4 possible bases for each position.
- For a triplet, the number of combinations is $4 \times 4 \times 4 = 64$.
- Long DNA molecules therefore have a near-limitless capacity for storing information.

Exam wording to remember

DNA stores information with great economy because a huge number of different sequences can be produced from just four bases over very long molecules.

11. Universal genetic code and genetic uniqueness

The genetic code is universal: the same triplet code specifies the same amino acid in all living organisms. This supports universal common ancestry. Organisms differ because their DNA base sequences differ, not because the code is read differently.

Humans share more than 99% of their DNA sequence with one another, but sequence differences still create genetic uniqueness.

12. Nucleosomes and DNA packaging

DNA is extremely long, so it must be packaged efficiently. DNA wraps around a core of eight histone proteins. An additional histone helps hold the nucleosome structure together, and the DNA between nucleosomes is called linker DNA. Many nucleosomes coil further to form chromosomes.

Structure	Essential point
Nucleosome core	DNA wrapped around 8 histone proteins
Additional histone	Helps stabilize the structure
Linker DNA	DNA segment between adjacent nucleosomes
Chromosome	Highly condensed DNA-protein structure

13. Evidence that DNA is the genetic material

Hershey-Chase experiment

Hershey and Chase used bacteriophages to test whether DNA or protein is the genetic material. They labelled DNA with radioactive phosphorus-32 and protein with radioactive sulfur-35.

- DNA contains phosphorus in phosphate groups, but not sulfur.
- Some amino acids in proteins contain sulfur, but DNA does not.
- After infection, phosphorus-32 was detected inside bacteria, showing that DNA entered the cells.
- Sulfur-35 stayed with the protein coats outside the cells.
- Conclusion: DNA, not protein, is the genetic material.

Chargaff's rule

Chargaff measured base ratios in DNA from different organisms. He found that the amount of adenine is approximately equal to thymine, and guanine is approximately equal to cytosine.

Ratio pattern	Interpretation
A ≈ T	Supports complementary pairing
G ≈ C	Supports complementary pairing
Not all four bases equal	Falsifies the tetranucleotide hypothesis

Nature of science link

Chargaff's data did not prove every detail of DNA structure by itself, but it ruled out an incorrect model and guided later work by Watson and Crick.

14. HL extension

Directionality

Nucleic acid strands have a 5' end and a 3' end. New strands are synthesized from 5' to 3'. In DNA, the two strands are antiparallel.

Purine-pyrimidine bonding

Adenine and guanine are purines (double ring). Thymine and cytosine are pyrimidines (single ring). A purine always pairs with a pyrimidine, keeping DNA a constant width.

15. Distinguish DNA from RNA in diagrams

- Uracil present -> RNA.
- Thymine present -> DNA.
- Single strand -> usually RNA.
- Double strand with complementary base pairing -> DNA.
- Ribose sugar -> RNA; deoxyribose sugar -> DNA.

16. Common mistakes to avoid

- Do not say DNA replication uses random pairing. Pairing is specific and template-based.
- Do not confuse hydrogen bonds between bases with covalent bonds in the backbone.
- Do not say ATP is not a nucleic acid - it is a single-nucleotide nucleic acid.
- Do not say viruses are living organisms in this syllabus context.
- Do not forget that DNA strands are antiparallel.

17. Rapid recall checklist

Must recall	Answer
DNA base pairs	A-T and C-G

Must recall	Answer
RNA unique base	Uracil
DNA sugar	Deoxyribose
RNA sugar	Ribose
Bonds in backbone	Covalent
Bonds between DNA bases	Hydrogen
Strand synthesis direction	5' to 3'
Purines	A and G
Pyrimidines in DNA	T and C

18. Short model answers to textbook-style questions

Q1. How many nucleotide types exist within DNA and RNA?
Eight in total: four DNA nucleotides and four RNA nucleotides.

Q2. Why are adenine and guanine classed as purines?
Both have a double-ring nitrogenous base structure.

Q3(a). Why is DNA often written only as a base sequence?
Because the information lies in the order of bases; the sugar-phosphate backbone is repetitive.

Q3(b). Why is one DNA strand enough to show a sequence?
Because complementary base pairing allows the opposite strand to be inferred.

Q4. A sequence contains uracil. What does that tell you?
It is RNA, not DNA.

Q5. Which is not a nucleic acid: DNA, ATP, PCR, RNA?
PCR. It is a laboratory technique, not a nucleic acid.

Q6. If 22% of bases in DNA are cytosine, what are the others?
Guanine = 22%; adenine = 28%; thymine = 28%.

Q7 (HL). Why are adenine and cytosine not complementary?
Their hydrogen-bonding pattern does not match, so stable complementary pairing cannot occur.

Q8. Why did radioactive phosphorus indicate DNA in Hershey-Chase?
DNA contains phosphorus in phosphate groups, whereas protein does not.

Q9. Which statement best describes a chromosome?
A length of DNA coiled around many groupings of eight histones, each with one additional histone. (Option B)

19. Answers to the embedded challenge questions

1. In the polymer (excluding the first nucleotide), sugar carbons bonded to phosphate groups are the 3' and 5' carbons.
2. Within a nucleotide, the phosphate group is attached to the 5' carbon.
3. The nitrogenous base is attached to the 1' carbon.
5. A 12-nucleotide RNA strand is formed by 11 condensation reactions, so 11 water molecules are released.
9. ATP is called triphosphate because it contains three phosphate groups.
10. The sugar in ATP is ribose.
11. The nitrogenous base is adenine.
12. If one DNA strand starts 3' on the left, then the opposite ends are: X = 5', Y = 5', Z = 3'.

Final exam summary

- Hereditary information is stored in the sequence of bases in DNA.
- DNA is suitable for accurate replication because it is double-stranded and complementary.
- RNA differs from DNA in sugar, base type and strand structure.
- Experimental evidence for DNA includes Hershey-Chase and Chargaff's data.
- HL: directionality and purine-pyrimidine pairing strengthen explanation of DNA stability and replication.

End of notes