Oxford Resources for IB
Diploma Programme

2023 EDITION

BIOLOGY

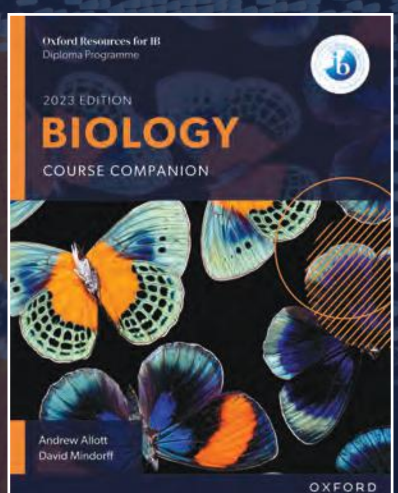
STUDY GUIDE

Boost student confidence and encourage an effective approach to revision with this Study Guide, ideal for use alongside the 2023 Oxford Resources for IB DP Biology Course Book. Packed with clear and concise explanations, diagrams, and practice questions, this student-friendly resource helps learners focus on crucial concepts and knowledge.

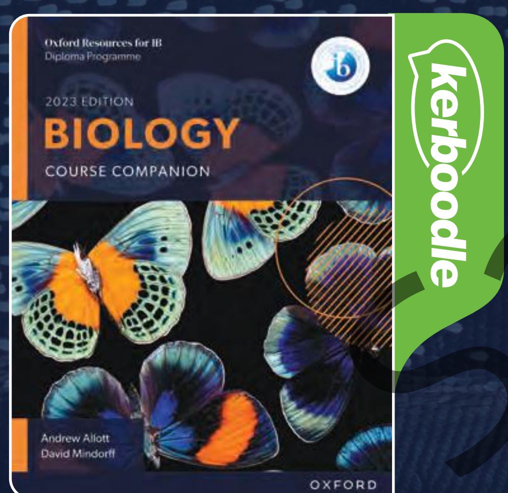
You can trust Oxford's IB Study Guides to:

- Comprehensively cover all key topics, matched to the 2023 IB subject guide
- Cement understanding of SL and HL ideas in an easy-to-digest bitesize format
- Use clear and accessible language to support EAL learners.

Also available in this series:



9781382016339



9781382042666

OXFORD UNIVERSITY PRESS

www.oup.com

How to get in touch:
web www.oxfordsecondary.com
email schools.enquiries.uk@oup.com
tel +44 (0)1536 452620

FOR FIRST ASSESSMENT IN 2025

ISBN 978-1-382-01643-8
9 781382 016438

Oxford Resources for IB Diploma Programme 2023 EDITION BIOLOGY STUDY GUIDE OXFORD

Oxford Resources for IB
Diploma Programme

2023 EDITION

BIOLOGY

Andrew Allott

STUDY GUIDE

OXFORD

Contents

A1.1 Water

1. Water is essential for life

Water with substances dissolved in it is an aqueous solution. The first living cells originated in aqueous solutions, sometimes called "primeval soup".

A medium is something in which processes can occur. The eight processes of life happen in water, so after more than three billion years of evolution, water is still the medium for life.

Metabolism: because aqueous solutions are liquid, both the water and solutes dissolved in it are free to move and, in some cases, react chemically. Reactants and products of most chemical reactions in living organisms (= metabolism) are dissolved in water.

Nutrition: the reactions of both photosynthesis and digestion take place in aqueous solution.

Growth: cytoplasm is an aqueous solution, so cells must absorb water by osmosis to increase in size.

Reproduction: sperm swim to the egg through water; mammalian foetuses are supported by water in the uterus.

Movement: aquatic organisms swim through water or drift in currents; pumping of blood and sap transports substances dissolved in water.

Response to stimuli: nerve impulses are movements of dissolved Na^+ and K^+ ions; hormone transport is in blood.

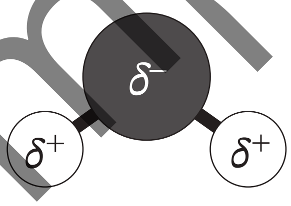
Excretion: urine is an aqueous solution of waste products; excretion of waste gases (for example, CO_2) requires a moist surface.

Homeostasis: blood plasma and tissue fluid are aqueous solutions that are regulated to form a stable and ideal internal environment for cells.

2. Hydrogen bonds

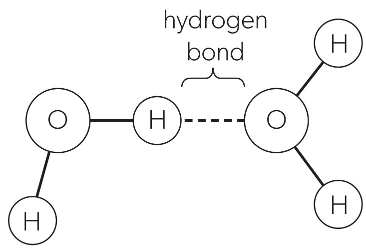
A **molecule** is two or more atoms joined together by one or more covalent bonds. A covalent bond is formed when two atoms share a pair of electrons. In some cases, the nucleus of one of the atoms is more attractive to the electrons than the other, so the electrons are not shared equally. The consequence of this is that the covalent bond is polar, with one of the atoms having a slight positive charge and the other a slight negative charge. Molecules with polar covalent bonds have **polarity**.

Water molecules are polar. A hydrogen nucleus is less attractive to electrons than an oxygen nucleus, so in a water molecule the two hydrogen atoms have a slight positive charge and the oxygen atom has a slight negative charge.



▸ *Water molecule with delta plus and delta minus poles*

The two bonds between oxygen and hydrogen atoms in a water molecular are **intramolecular**. An **intermolecular** bond can form between the positive pole of one water molecule and the negative pole of another water molecule. This is called a **hydrogen bond**.



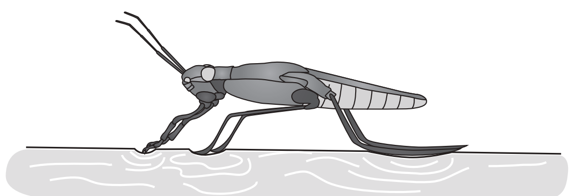
Individual hydrogen bonds are weak, but water molecules are small so relatively large numbers of the bonds form in a volume of water. Collectively, these bonds influence the properties of water markedly.

3. Cohesion

Water molecules stick to each other (cohere) because of the hydrogen bonds that form between them.

- Strong pulling forces (tensions) are exerted to suck water up to the tops of the tallest trees in tubular xylem vessels. Because of the cohesion resulting from hydrogen bonds, the columns of water molecules in these vessels rarely break despite powerful suction forces.
- The surface of water on ponds is used as a habitat by some animals, even though they are denser than water (e.g. the insect *Gerris lacustris* pictured right).

To break through the water surface, hydrogen bonds would have to be broken, which requires more energy than is available. This effect of water surfaces forming a cohesive structure that resists breakage is called surface tension.



4. Adhesion

Whereas cohesion is water molecules sticking to each other, adhesion is water sticking to another substance. Adhesion happens if the other substance is hydrophilic.

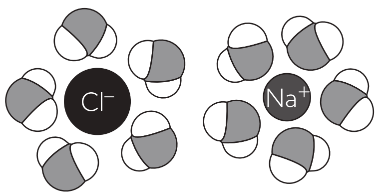
Hydrophilic substances are attractive to water because they can make intermolecular bonds with the water molecules.

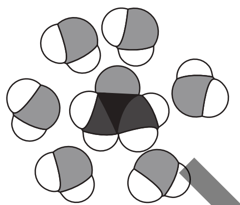
Polar and charged materials are hydrophilic.

- Polar substances such as cellulose in plant cell walls form hydrogen bonds with water. Cell walls therefore tend to remain saturated with water and draw more water from the nearest supply if they have become unsaturated due to evaporation, for example when a leaf transpires.
- Capillary action is water being drawn through narrow spaces because it adheres to the surfaces of the spaces. Water moves through pores in dry soils by this process because the solids in the soil—humus (dead organic matter) and particles of sand, silt and clay—are hydrophilic. The water can move upwards.

5. Water is a solvent

A wide range of hydrophilic molecules and ions dissolve in water. Polar molecules dissolve by forming hydrogen bonds with water. Ions with positive charges form electrostatic interactions with the δ^- poles of water molecules and negative ions with the δ^+ poles. For example, sodium chloride dissolves in water like so:





Urea molecules are polar and dissolve with hydrogen bonds between positive and negative poles of the urea and water molecules.

Most chemical reactions in cells are catalysed by enzymes and take place in aqueous solution, which allows both enzymes and substrates to move, so substrate–active site collisions can occur.

Transport systems in plants and animals rely on the solvent properties. Blood plasma, xylem sap and phloem sap are all aqueous solutions that are pumped to transfer the solutes from one part of the plant or animal to another.

If a substance is not hydrophilic it is said to be **hydrophobic**. This does not mean that it is repelled by water, but that water molecules are more strongly attracted to each other than to the non-polar molecules of hydrophobic substances. Hydrophobic substances are therefore insoluble in water. They can also form a barrier to water and hydrophilic substances. The wax on leaf surfaces and oils on human skin are hydrophobic and prevent dehydration. Hydrocarbon tails in the centre of cell membranes form a barrier that allows cells to regulate the movement of hydrophilic substances across the membrane.

6. Physical properties of water

Air and water have markedly different physical properties, with consequences for animals that swim in water or fly in the air. This can be illustrated with black-throated loons (birds that dive in water to feed and also fly) and the ringed seal (a mammal that only comes out of the water to breed).

Buoyancy—solids float in fluids if their density is lower. Consider the densities in the table. The seal's density is close to that of seawater so it can float easily. The loon's density is far higher than that of air so it beats its wings to remain airborne.

	Density (mg per cm^3)
Pure water	1,000
Seawater	1,025
Air	1.225
Loon	700–850
Seal	1,025–1,045

Viscosity—resistance to flow of a fluid due to cohesion between the molecules. Water has high viscosity due to hydrogen bonding. Air's viscosity is more than 50 times less. The seal has to overcome much more resistance when it swims through water than the loon when it flies in air.

Thermal conductivity—the ability of a material to transfer heat. Water's thermal conductivity is more than 20 times that of air. The seal is therefore more vulnerable to hypothermia in the cold northerly habitats of these species.

Specific heat capacity—the quantity of heat needed to raise the temperature of a gram of a material by one degree. It takes 3,500 times as much heat to raise the temperature of a given volume of water by a degree than air because water is much denser. Water therefore heats up and cools down much more slowly than air; marine and freshwater habitats are much more thermally stable than terrestrial habitats.

AHL

7. Extraplanetary origin of water on Earth

The Earth was formed from gas and dust about 4.5 billion years ago. Initially any water would have boiled and been lost, so the 1.4 billion cubic kilometres of water now on Earth must have arrived later, when the Earth had cooled down, so the water could remain liquid and be retained.

The leading hypothesis is that the water was brought when asteroids containing ice collided with the early Earth. The ice would have melted, adding to the volume of liquid water in the growing oceans.

Two factors promote the retention of water in a liquid state on Earth:

- strong gravitational pull due to Earth's size
- intensity of sunlight due to distance from the Sun keeps the Earth below 100°C and mostly above 0°C.

8. Extra-terrestrial life and water

Water is a unifying feature in biology—it is the medium of life for all species on Earth. We may reasonably expect life only to be found on planets in the universe that have liquid water. When we are searching for extra-terrestrial life, we need not look on dry planets!

To retain liquid water, a planet must be large enough for gravity to be strong and temperatures must be warm enough for ice to melt, but not so hot that water boils. The planet must be in the "Goldilocks zone" which is the range of distances from a star that keep temperatures between 0 and 100°C.

Planet	Distance from Sun (km)	Average temperature (°C)
Venus	108×10^6	+462
Earth	149×10^6	+14
Mars	216×10^6	−60

Meanings of terms

Acid—a substance that can donate one or more protons and so become negatively charged, for example deoxyribonucleic acid (DNA).

Atom—a unit of matter with positively charged protons grouped in the nucleus and negatively charged electrons in orbitals around the nucleus; atoms have no net charge because the number of protons and electrons is equal.

Base—a substance that can accept one or more protons (H^+) and so become positively charged, for example adenine and other bases in DNA.

Catalyst—a substance that increases the rate of a reaction but is itself unchanged at the end of the reaction.

Concentration—the amount of substance per unit volume.

Condensation—a reaction in which two molecules are combined into one molecule and water is eliminated.

Covalent bond—a region of high electron density between two atoms due to the sharing of a pair of electrons, which attracts the nuclei of both atoms, holding them together.

Hydrogen bond—an attraction between an electronegative atom (such as oxygen) and a hydrogen atom bonded to another electronegative atom.

Hydrolysis—the separation of one molecule into two using hydrogen (H) and hydroxyl groups (OH) released by splitting a water molecule.

Hydrophilic—having an affinity (attraction) for water.

Hydrophobic—having a low affinity for water and more affinity for non-polar molecules.

Intermolecular force—an attraction between molecules.

Intramolecular force—a bond between atoms within a molecule.

Ion—an atom or molecule that has become positively charged by losing one or more electrons or negatively charged by gaining one or more electrons.

Ionic bond—a bond formed by attraction between positively- charged and negatively charged ions or between positively- charged and negatively charged groups on molecules.

Isotope—one of the two or more alternative forms of an element, with the same number of protons and electrons per atom as other forms, but a different number of neutrons.

Macromolecule—a molecule with a molecular mass of more than 10,000

Molecule—two or more atoms joined together by one or more covalent bonds.

Oxidation—a reaction in which hydrogen is removed, electrons are removed, or oxygen is added.

Pigment—a substance that absorbs wavelengths of visible light and so appears coloured.

Polymer—a molecule consisting of a series of many subunits linked by covalent bonds; an oligomer has fewer than 10 subunits.

Radioactive—a type of isotope with an unstable nucleus which can emit radiation (α, β or γ rays).

Reduction—a reaction in which hydrogen is added, electrons are added, or oxygen is removed.

Solute—a dissolved substance in a solution.

Solvent—a liquid that can dissolve other substances to make a solution.

Synthesis—the production of more complex molecules from simpler substances by one or more chemical reactions.

A1.2 Nucleic acids

1. DNA is the universal genetic material

Living organisms are constructed out of molecules. Genes are the instructions for doing this and are themselves constructed out of molecules.

A key feature in the unity of life is that the molecule used as genetic material in all living organisms is DNA (deoxyribonucleic acid).

Some viruses, including coronaviruses (such as Covid) use RNA instead of DNA as genetic material, but viruses are not usually considered to be living. Also, DNA and RNA are very similar—they are the two types of nucleic acid.

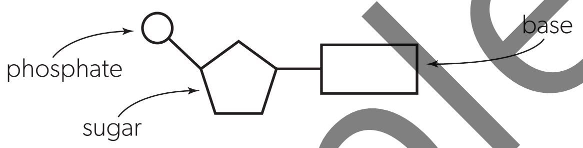
2. Nucleotides

The subunits in both DNA and RNA are nucleotides.

Each nucleotide consists of three parts:

- a pentose sugar, with five carbon atoms and a five-atom "ring"
- a phosphate
- a base, whose molecules contain nitrogen and have either one or two rings.

In diagrams of nucleotides, these parts are usually shown as pentagons, circles and rectangles, respectively. The figure shows how the sugar, the phosphate and the base are linked up in a nucleotide.



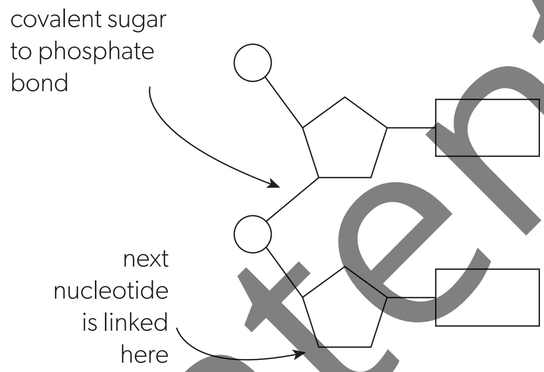
4. Nitrogenous bases

There are four different bases in both DNA and RNA, three of which are the same. These bases can be arranged in any sequence along a strand of nucleotides. The sequence forms the basis of the genetic code that all organisms use to store information.

Nucleic acid	One-ring bases (pyrimidines)		Two-ring bases (purines)	
DNA	C	Cytosine	A	Adenine
	T	Thymine	G	Guanine
RNA	C	Cytosine	A	Adenine
	U	Uracil	G	Guanine

3. Sugar–phosphate "backbone" of DNA and RNA

The nucleotides in a strand of DNA or RNA are linked together by covalent bonds between the pentose sugar of one nucleotide and the phosphate of the next one.

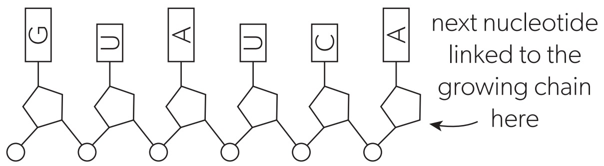


However many nucleotides have been linked up, another can always be added to the end of the chain where a pentose sugar can make a bond with the phosphate of a free nucleotide.

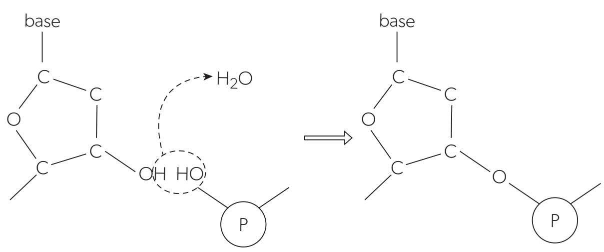
Sugars and phosphates alternate in RNA and DNA molecules, with an unbroken chain of covalently bonded atoms in the sequence $[–O–P–O–C–C–C–]_n$ where n is the number of nucleotides. Because this chain of atoms is covalently bonded, it gives strength to DNA and RNA molecules, helping them to store information reliably for long periods.

5. Formation of RNA

The pentose sugar in RNA is ribose. There is a single strand of nucleotides, linked by covalent sugar–phosphate bonds.



Water is produced by bonding sugar to phosphate, so it is a condensation reaction.

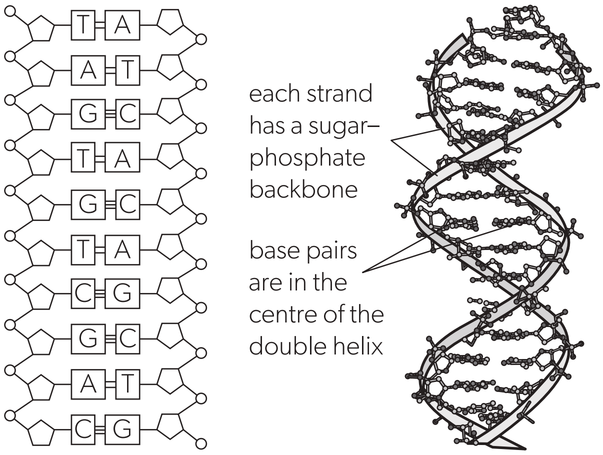


RNA is an example of a polymer—a molecule composed of repeating subunits (monomers) linked together by covalent bonds (see *Topics B1.1* and *B1.2* for more examples of polymers).

6. DNA as a double helix

There are two strands of nucleotides in DNA, which are linked by hydrogen bonding between their bases.

Each base will only form hydrogen bonds with one other base, so two base pairs only are possible: adenine with thymine and cytosine with guanine (A-T and C-G). They are known as complementary base pairs.



The two strands are antiparallel—they run alongside each other but in opposite directions.

The strands are wound together to form a double helix, which is the overall shape of a DNA molecule.

7. Comparing DNA and RNA

There are three differences between DNA and RNA.

1. The pentose is ribose in RNA but deoxyribose in DNA.
2. DNA has the base thymine but RNA has uracil instead.
3. RNA usually has one strand of nucleotides whereas DNA usually has two.

8. Complementary base pairing

Complementary base pairing has three roles in cells:

DNA replication—sequences of bases in DNA can be copied accurately, so the genetic information of a cell can be passed on to daughter cells.

Transcription—RNA can be made with the same base sequence as one of the two strands of a DNA molecule. Messenger RNA (mRNA) carries the base sequence of a protein-coding gene to the ribosome.

Translation—a base sequence can be used to determine the amino acid sequence in a polypeptide. Messenger RNA carries a series of three-base codons. Each transfer RNA molecule (tRNA) has one three-base anticodon and it carries one amino acid. Ribosomes link codons to anticodons by complementary base pairing, allowing the base sequence of every codon to be translated into a specific amino acid in a polypeptide (see *Topic D1.2*).

9. Diversity of DNA base sequences

Bases can be arranged in any sequence in DNA. Because any of the four bases could occupy each position along a DNA strand, the number of possible sequences is 4^n, where n is the number of bases. Even with just 10 bases there are over a million possible sequences. A typical gene has over a thousand bases and whole genomes have billions of bases. The number of possible sequences and therefore DNA's capacity to store information is effectively limitless.

10. Conservation of the genetic code

Each of the 64 codons of the genetic code indicates either one of the 20 amino acids or the end of the polypeptide. There are 1.5101095×10^{84} ways of assigning meanings to the 64 codons, but all organisms use the same meanings, with only minor variations. This universality of the genetic code suggests strongly that all life evolved from the same original ancestor, with minor differences added since then.

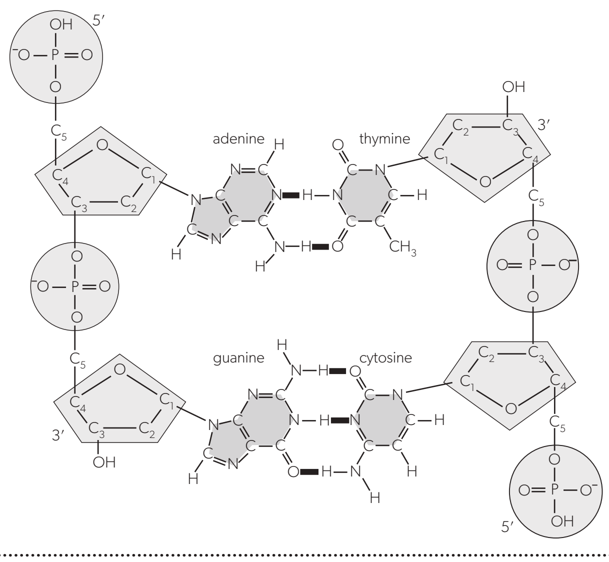
11. 3′ and 5′ ends of RNA and DNA

AHL

The two ends of a strand of nucleotides in DNA or RNA are different. They are known as the 3′ and 5′ ends (3 prime and 5 prime). The 3′ end has a pentose sugar (ribose or deoxyribose) to which the phosphate of another nucleotide can be linked. The phosphate would bond with the –OH group on the C3 of the deoxyribose. The 5′ end has a phosphate, attached to the C5 of a pentose.

When a new strand of DNA or RNA is being constructed, each extra nucleotide is added to the pentose at the 3′ end of the growing strand. This is done by bonding the phosphate of a free nucleotide, which is the nucleotide's 5′ end. Nucleotides are therefore added in a 5′ to 3′ direction.

The two strands in a DNA molecule are antiparallel because they run in opposite directions. Each end of a DNA double helix therefore has one strand with a 3′ end and one with a 5′ end.



AHL

12. Purines bond with pyrimidines

The nitrogenous bases in DNA are in two chemical groups:

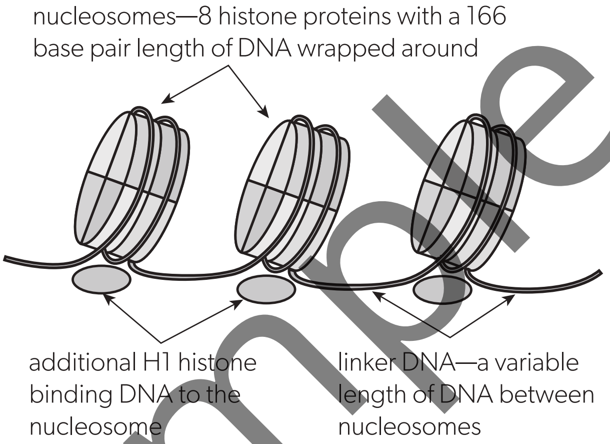
- adenine and guanine are purine bases with two rings of atoms
- cytosine and thymine are pyrimidine bases with one ring.

Each base pair in DNA therefore has one purine and one pyrimidine. As a consequence, the two base pairs are of equal width and require the same distance between the two sugar–phosphate backbones in the double helix. This helps to make the structure of DNA stable and allows any sequence of bases in genes to fit in a DNA molecule.

13. Nucleosomes

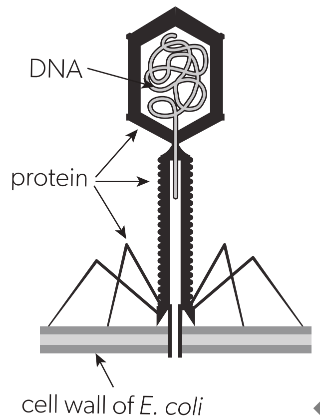
Nucleosomes are disc-like structures, used by eukaryotes to package DNA into condensed chromosomes and also to help control replication and transcription.

Each nucleosome has a core of eight histone proteins with a DNA wound round twice and one more histone securing the structure. There is some linker DNA between adjacent nucleosomes. Eukaryotic DNA looks like a string of beads in electron micrographs because of nucleosomes.

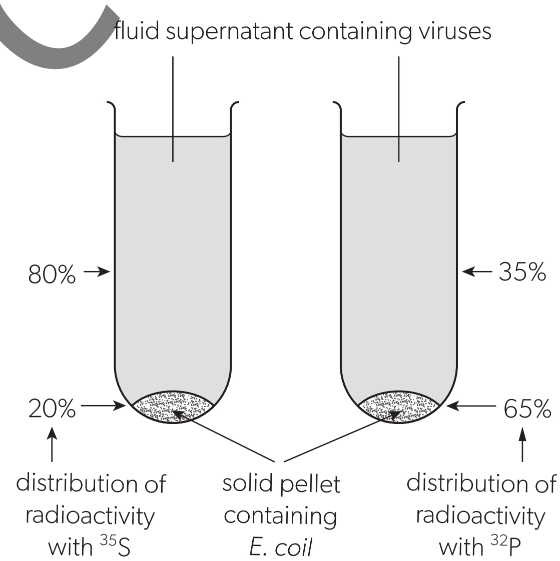


14. The Hershey–Chase experiment

In the early 1950s it was still unclear whether genes were made of DNA or protein. Hershey and Chase used the T2 virus to investigate this. T2 infects *E. coli*, which is a bacterium. Proteins of T2 start being produced inside *E. coli* soon after the virus comes into contact with it. This can only happen if genes of the virus are inside *E. coli*. To identify the genetic material, Hershey and Chase had to find out which part of the virus had entered the bacterium.



Viruses such as T2 consist only of DNA and protein, so their genes must be made of one of these materials. DNA contains the element P (phosphorus) but not S (sulfur), and protein contains S but not P. Hershey and Chase prepared one strain of T2 with its DNA labelled with the radioactive isotope ^{32}P and another with its protein radioactively labelled with ^{35}S. These two strains of T2 were mixed separately with *E. coli*. After leaving enough time for the bacteria to be infected, the mixture was agitated in a high-speed mixer and then centrifuged at 10,000 rpm to separate a solid pellet containing the bacteria from a liquid supernatant containing viruses. A Geiger counter was used to locate the radioactivity. The results are shown in the diagram.



Analysis of results

With ^{32}P most of the radioactivity is in the pellet, showing that much of the viral DNA is inside the bacteria. With ^{35}S most of the radioactivity is in the supernatant, showing the protein coats of the viruses remained outside the bacteria and were shaken off by the mixer. The small proportion of radioactivity in the pellet with ^{35}S can be explained by some protein coats remaining attached to the bacteria and by the presence of some fluid containing protein coats in the pellet. This and other experiments carried out by Hershey and Chase gave strong evidence for genetic material (genes) being composed of DNA rather than protein.

AHL

15. Chargaff's data

Before the structure of DNA had been discovered, the amounts of each of the four bases were measured.

- The amounts of each base were not equal—not 25%.
- The percentages were the same in different tissues from one species, for example spleen and thymus tissue from cattle, but there were differences between species.

Erwin Chargaff drew attention to other trends in the numbers of bases that applied to the DNA of all the species investigated, including eukaryotes and prokaryotes:

adenine = thymine and guanine = cytosine

purines (A + G) = 50% and pyrimidines (T + C) = 50%

The table gives a sample of Chargaff's data:

Source of DNA	Purines		Pyrimidines	
	% A	% G	% C	% T
Mycobacterium tuberculosis—bacteria	15.1	34.9	35.4	14.6
Human—a mammal	29.3	20.0	20.7	30.0
Octopus—a mollusc	33.2	17.6	17.6	31.6
Corn (maize)—a plant	26.8	23.2	22.8	27.2

Crick and Watson discovered the reason for these trends:

- DNA contains complementary pairs of bases
- a purine base always pairs with a pyrimidine
- adenine pairs with thymine, and cytosine with guanine.

NOS

Progress in science often follows technological developments that allow new experimental techniques

The isotopes of an element have the same chemical properties but there are physical differences that allow them to be distinguished in experiments. Radioisotopes can be detected by the radiation that they emit. When radioisotopes were made available to scientists as research tools from the 1940s onwards, experiments such as that of Hershey and Chase became possible.

NOS

Scientists can use evidence to falsify a claim formulated as a hypothesis, theory or model

DNA was discovered in the 19th century. The tetranucleotide hypothesis was proposed in the early 20th century. This suggested that DNA molecules are a chain of alternating sugar and phosphate groups, with a base attached to each sugar and a repeating sequence of the four bases. A prediction based on the tetranucleotide hypothesis is that there must be equal numbers of the four bases A, C, G and T.

Chargaff's data showed that the numbers are not equal, so the tetranucleotide hypothesis must be false. The base sequence of DNA might therefore be variable, so it could be the genetic material. This realization started the race to discover the structure of DNA.

A well-designed experiment has two possible outcomes:

- results that fit the hypothesis, which could therefore be true
- results that prove the hypothesis to be false.

Even if many experiments provide support for a hypothesis, it is still possible that a future experiment will falsify it, because scientists can never do every possible experiment. This is called the problem of induction. It is a strength of science, not a weakness—scientists must keep an open mind: "Think it possible that you might be mistaken".

NOS

Introducing nature of science

Science is an academic discipline, with different methods and different fields of study from other disciplines such as history. The scientific method is a very powerful tool for making discoveries about the natural world. In IB Group 4 sciences, the elements of scientific investigation are known as the *nature of science*.

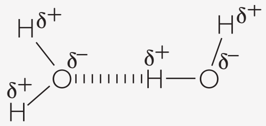
The biology programme includes selected contexts through which a general understanding of the nature of science can be developed, for example the formulation and testing of hypotheses. These are indicated by the NOS tab in this Study Guide.

General understanding of the nature of science will help with some questions in IB Biology exams, but definitions of nature of science terms or concepts do not need to be memorized.

End of topic questions—A1 Questions

A1.1 Water

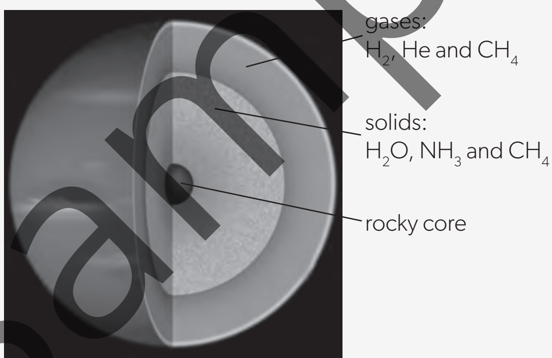
1. The diagram shows water molecules.
   a. State how many intermolecular bonds and intramolecular bonds are shown in the diagram. (2)
   b. Distinguish between the two types of bond shown in the diagram. (3)



   c. The photo shows drops of water on the upper and lower surfaces of a glass block. The drop on the upper surface is wider and shallower. Explain the shapes of the drops, using the concepts of cohesion and adhesion. (3)

2. Identify what is defined by each of these statements:
   a. a unit of matter with one or more positively charged protons in a nucleus and an equal number of negatively charged electrons in orbitals around the nucleus (1)
   b. two or more atoms joined together by one or more covalent bonds (1)
   c. an atom or molecule that has become positively charged by losing one or more electrons, or negatively charged by gaining one or more electrons. (1)

3. (HL only) About two-thirds of the mass of the planet Neptune is water.



   a. Discuss which of the eight processes of life are dependent on H_2O. (7)
   b. Outline features that make Neptune unsuitable for life. (3)
   c. Identify the origin of H_2O on Neptune. (3)

A1.2 Nucleic acids

1. The table shows the base composition of genetic material from different sources.

Source of genetic material	*Base composition (%)*				
	A	C	G	T	U
Cattle thymus gland	28.2	22.5	21.5	27.8	0.0
Cattle spleen	27.9	22.1	22.7	27.3	0.0
Cattle sperm	28.7	22.0	22.2	27.2	0.0
Pig thymus gland	30.0	20.7	20.4	28.9	0.0
Salmon	29.7	20.4	20.8	29.1	0.0
Wheat	27.3	22.8	22.7	27.1	0.0
Yeast	31.3	17.1	18.7	32.9	0.0
E. coli (bacteria)	26.0	25.2	24.9	23.9	0.0
Human sperm	31.0	18.4	19.1	31.5	0.0
Influenza virus	23.0	24.5	20.0	0.0	32.5

   a. Deduce the type of genetic material used by:
      i. cattle (1)
      ii. *E. coli* (1)
      iii. influenza viruses. (1)
   b. Suggest a reason for the difference between cattle thymus gland, spleen and sperm in measurements of base composition. (1)
   c. i. Explain why the total amount of adenine plus guanine is close to 50% in the genetic material of many of the species in the table. (3)
      ii. Identify two other trends in the base composition of the species that have 50% adenine plus guanine. (2)
   d. i. Identify a species in the table that does not follow the trends described in **c**. (1)
      ii. Explain the reasons for the base composition of this species being different. (2)

2. a. Draw a diagram to show the structure of DNA. Include a total of six nucleotides in your diagram. (9)
   b. Describe **three** features of DNA that make it ideal as a genetic material. (6)

3. a. (HL only) Distinguish between:
      i. 3′ and 5′ ends of an RNA molecule (2)
      ii. ribose and deoxyribose (2)
      iii. purines and pyrimidines (2)
      iv. nucleotides and nucleosomes. (2)
   b. State what an isotope is.(3)
   c. Distinguish between radioactive and non-radioactive isotopes. (3)
   d. Describe how Hershey and Chase used isotopes to distinguish between protein and DNA in their experiments. (4)