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Teacher view



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Notebook



Glossary

A1. Unity and diversity: Molecules / A1.2 Nucleic acids



Reading  
assistance



(https://intercom.help/kognity)



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## ? Guiding question(s)

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

Keep the guiding questions in mind as you learn the science in this subtopic. You will be ready to answer them at the end of this subtopic. The guiding questions require you to pull together your knowledge and skills from different sections, to see the bigger picture and to build your conceptual understanding.

Every year, many animals around us go extinct, despite conservation efforts to save them. Can scientists revive extinct animals? It sounds like a storyline from 'Jurassic Park' on the comeback of the T-rex, but it could be possible thanks to fast-moving developments in molecular biology – the study of the structure and function of molecules and their interactions within biological systems.

In the 1800s, the passenger pigeon (*Ectopistes migratorius*) was a common bird in North America, but by the early 1900s it had become extinct due to excessive hunting (**Figure 1**).



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**Figure 1.** A passenger pigeon flock being hunted in Louisiana. From the 'Illustrated Shooting and Dramatic News', 1875.

Source: "Passenger pigeon shoot" [https://commons.wikimedia.org/wiki/File:Passenger\\_pigeon\\_shoot.jpg](https://commons.wikimedia.org/wiki/File:Passenger_pigeon_shoot.jpg) by Smith Bennett is in the public domain (Wikimedia/Smith Bennett), CC BY-NC-ND

The last-known passenger pigeon, named Martha, sadly died in 1914. However, scientists came together in 2012 to discuss bringing back the passenger pigeon. How would that be possible?

It is possible thanks to the unique properties of nucleic acids, DNA and RNA, which allow hereditary information to be stored. You will learn more about these properties of nucleic acids in this subtopic.

You can read more about the Passenger Pigeon Project and reasons for wanting to reverse its extinction [here](https://reviverestore.org/about-the-passenger-pigeon/) <https://reviverestore.org/about-the-passenger-pigeon/>.



## Theory of Knowledge

How is science both a body of knowledge and a process?

Knowledge is constantly evolving and reason is one way of knowing. As science is cumulative in its nature, scientists take the knowledge they have and then synthesise new knowledge based on new evidence. Scientists apply the knowledge in new contexts that helps to find solutions to existing problems. Technological developments have opened up new possibilities for research and thus new solutions and inventions.



## Prior learning

Before you study this subtopic make sure that you understand the following:



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- Hydrogen bonding in water (see [subtopic A1.1](#) [\(/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43193/\)](#)).
- Metabolism (see [subtopic C1.1](#) [\(/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43208/\)](#)).
- Basic fundamental organic chemistry such as drawing molecular structures and formulas.

A1. Unity and diversity: Molecules / A1.2 Nucleic acids

# Nucleic acids and their structure

A1.2.1: DNA as the genetic material of all living organisms    A1.2.2: Components of a nucleotide    A1.2.3: The sugar—phosphate backbone of DNA and RNA  
A1.2.4: Bases in each nucleic acid that form the basis of a code



## Learning outcomes

By the end of this section you should be able to:

- Draw and explain the structure of a nucleotide.
- Describe the formation of the sugar—phosphate backbone by nucleotide polymerisation in DNA and RNA.
- State and compare the nitrogenous bases in each nucleic acid (DNA and RNA).

Humans and chimps look and behave alike in many ways. To better understand how closely they are related, biologists compare their genetic material. Did you know that you have a genetic similarity of 98.9% with chimpanzees? But what is your genetic material? How can humans and chimps be so similar but yet so different?

## DNA as the genetic material of all living organisms

You may have heard of a molecule called DNA (deoxyribonucleic acid). This polymer is your ‘blueprint’. It contains your genes, which are a code that will determine all of your unique and not-so-unique characteristics. DNA is a type of biological macromolecule called a nucleic acid.

Nucleic acids are chains of repeating monomers called nucleotides. Nucleotides join together to form the nucleic acid polymer by a condensation reaction called polymerisation. Therefore nucleotides are considered to be the building blocks of nucleic acids.

There are two types of nucleic acids in living organisms: DNA (deoxyribonucleic acid) and RNA (ribonucleic acid).



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DNA is the genetic material of all living organisms. Viruses, to the contrary, are infectious agents that are considered non-living as they need a host to replicate. Some viruses use RNA as their genetic material such as the virus that caused the recent pandemic; the SARS-Cov-2 virus.

## Higher level (HL)

### Making connections


More detail is given on the origin of cells and characteristics of living things and other reasons why viruses are considered to be 'non-living' in subtopic A2.1 (</study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43202/>).

There is more on viruses in subtopic A2.3 (</study/app/bio/sid-422-cid-755105/book/big-picture-hl-id-43527/>).

In 1869, Friedrich Miescher performed experiments on white blood cells that led to the extraction and discovery of DNA. You can replicate Miescher's DNA extraction at home. Follow the simple procedure explained in the following activity.

### Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Thinking skills — Experimenting with new strategies for learning
- **Time required to complete activity:** 30 minutes
- **Activity type:** Pair activity

Try this virtual lab to see the steps involved in DNA extraction using split peas: How To Extract DNA From Anything Living  (<https://learn.genetics.utah.edu/content/labs/extraction/howto/>).

### Observations and conclusion

- Describe what the DNA looks like.
- What can you conclude about the solubility of DNA in water compared with its solubility when alcohol and salt are present?
- Why is it important for scientists to be able to extract DNA from an organism's cells?
- Evaluate if this virtual lab supports the idea that DNA is the genetic material of all living organisms.

Section

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Feedback



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## Practical skills

**Tool 1:** Experimental techniques — Measuring variables

**Tool 2:** Technology — Applying technology to collect data

DNA extraction is a simple experimental technique, yet it is based on significant scientific concepts. DNA is mostly found enclosed within membranes and to extract it you need to disintegrate the membranes. In addition, DNA extraction is based on the solubility of DNA in different solvents. It is a routine procedure used in research and diagnostics to collect data and come up with conclusions.

Simulations help you conduct experiments in non-lab setups, enhance your experimental techniques in a virtual environment and provide rich learning experiences.



## Creativity, activity, service

**Strand:** Activity

**Learning outcome:** Demonstrate the skills and recognise the benefits of working collaboratively

Educate younger students in your school about DNA! Plan and hold a science experience in the lab or create a video demonstrating DNA extraction using the activity given above.

# Components of a nucleotide

The basic structures of DNA and RNA are very similar as they are both made of nucleotide monomers. DNA and RNA nucleotides have three components (**Figure 1**):

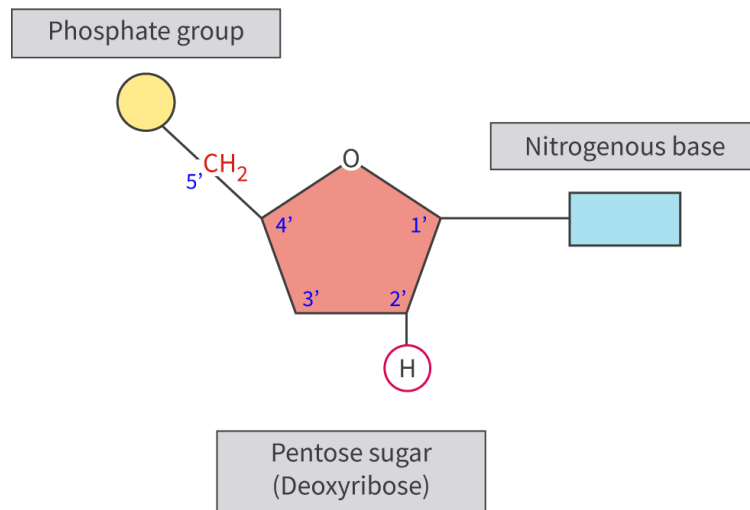
- a pentose sugar: a simple sugar made up of five carbon atoms
- a nitrogenous base: a molecule that contains nitrogen and acts as a base
- a phosphate group: a functional group made up of phosphorus and oxygen.



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**Figure 1.** Structure of a DNA nucleotide.

More information for figure 1

This diagram represents the structure of a DNA nucleotide. The nucleotide consists of three main components:

1. **Phosphate Group:** Located on the left side, depicted as a circle connected to the pentose sugar. It is labeled as "Phosphate group."
2. **Pentose Sugar (Deoxyribose):** Illustrated as a pentagon in the center of the diagram. The corners of the pentagon are labeled with 1', 2', 3', 4', and 5' to indicate the carbon positions, important for understanding nucleotide bonding. The exterior of the pentagon is labeled "Pentose sugar (Deoxyribose)," and the structure includes elements like O (oxygen), H (hydrogen), and CH<sub>2</sub>.
3. **Nitrogenous Base:** Positioned on the right side, shown as a rectangle connected to the pentose sugar. It is labeled "Nitrogenous base."

The diagram visually distinguishes each of these components using shapes: a circle for the phosphate group, a pentagon for the sugar, and a rectangle for the base. This representation aids in visualizing how these components are connected in a DNA molecule.

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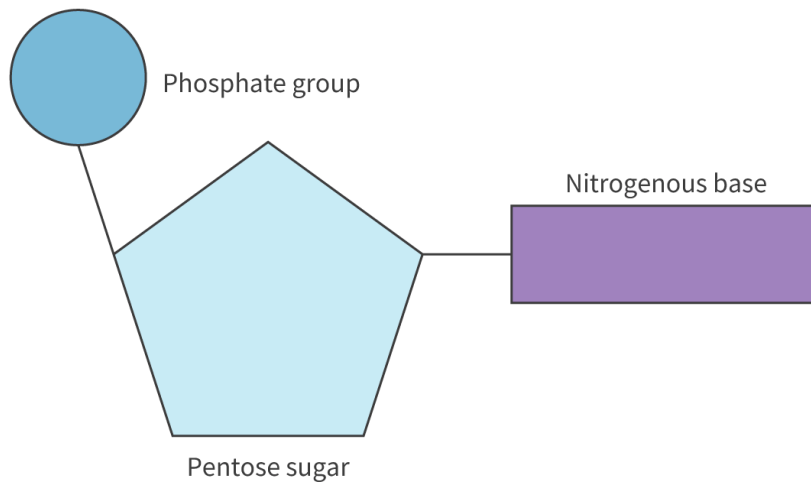
The nucleotide can be represented more simply (**Figure 2**) using a circle for the phosphate group, a pentagon for the pentose sugar and a rectangle for the nitrogenous base. It is useful to know the locations of the 3' (or 3 prime) and 5' (or 5 prime) carbon atoms in the pentose sugar to understand the bonding between nucleotides, but you do not need to memorise the positions of these.



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**Figure 2.** Simplified structure of a nucleotide.

More information for figure 2

The image is a simplified diagram illustrating the structure of a nucleotide. It features three main components:

1. A circle on the left represents the phosphate group.
2. A pentagon in the center symbolizes the pentose sugar, which is significant for understanding the nucleotide's structure, particularly the locations of the 3' (3 prime) and 5' (5 prime) carbon atoms, important for nucleotide bonding.
3. A rectangle on the right depicts the nitrogenous base.

Lines connect these three shapes, indicating their relationship in forming the complete nucleotide structure.

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You will practise drawing simple nucleotides later in this section.

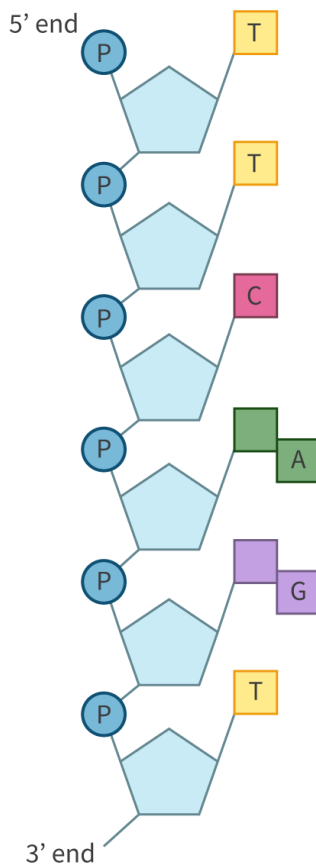
## Sugar—phosphate bonding

The nucleotide units link together through a covalent bond to form a single strand of DNA and RNA. The bond forms between the phosphate group attached to the 5' C of one pentose sugar and the hydroxyl (–OH) group attached to the 3' C of another sugar, releasing one molecule of water with the use of energy. The linking of nucleotides creates a continuous chain of covalently bonded atoms in each strand of DNA and RNA nucleotides, which forms a strong sugar–phosphate backbone in the polymer of DNA and RNA. The linking of nucleotides also creates two ends, namely the 5' end, which is the phosphate, and the 3' end, which is the –OH group in the sugar (**Figure 3**).



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**Figure 3.** Sugar—phosphate backbone of nucleotide polymer.

More information for figure 3

The image is a diagram illustrating the sugar-phosphate backbone of a nucleotide polymer. The diagram shows a vertical sequence, starting from the 5' end and ending at the 3' end. Each nucleotide is represented by a pentagon, which signifies the sugar molecule, attached to a circle labeled 'P' for the phosphate group. These units are linked in a linear sequence. From top to bottom, the bases attached to the sugars are Thymine (T), Thymine (T), Cytosine (C), Adenine (A), Guanine (G), and Thymine (T). The connection between each unit forms the backbone of the polymer, showing the directional flow from one end to the other, illustrating how the nucleotides are connected to form a single strand of a nucleic acid like DNA or RNA, highlighting the alternating pattern of the sequences.

[Generated by AI]

## Concept

Adding the nucleotides to the growing chain takes place in the 5'—3' direction. The 3' end refers to the —OH group of one sugar; the 5' end refers to the phosphate group of another sugar.

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# Bases in each nucleic acid

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There are five different types of nitrogenous bases: guanine (G), adenine (A), thymine (T), cytosine (C) and uracil (U).

Bases are classified into two main types:

- Purines have two rings in their structure.
- Pyrimidines have one ring in their structure.

Thymine, cytosine and uracil are examples of pyrimidines, while adenine and guanine are classified as purines. In a strand of a nucleic acid (DNA or RNA) the sequence of the nitrogenous bases forms the basis of the genetic code. DNA nucleotides are composed of adenine, guanine, cytosine and thymine, while RNA nucleotides are composed of adenine, guanine, cytosine and uracil. Watch **Video 1** for a summary of the types of bases in nucleic acids.

Purines vs Pyrimidines | Understanding Nitrogenous Bases of RNA a...



**Video 1.** Understanding nitrogenous bases.

In the following activity you will use circles, pentagons and rectangles to represent relative positions of phosphates, pentose sugars and bases in nucleotides, then model the linking of nucleotides and practise correct labelling.



## Activity

- **IB learner profile attribute:**
  - Reflective
  - Communicator
- **Approaches to learning:**
  - Self-Management: Drafting, revising and improving work



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- Communication: Using terminology, symbols and communication conventions consistently and correctly

- **Time required to complete activity:** 30 minutes
- **Activity type:** Individual and pair activity

### Task 1: Draw a generic nucleotide

You need to be able to produce diagrams of nucleotides using circles, pentagons and rectangles to represent relative positions of phosphates, sugars and bases. You will practise later how to draw DNA and RNA nucleotides.

- Draw one simple molecule of a nucleotide.
- Make sure that the pentose sugar is drawn as a pentagon, the phosphate group is drawn as a circle and the nitrogenous base is drawn as a rectangle.
- Make your diagram clear and label the following:
  - nitrogenous base
  - pentose sugar
  - phosphate group.

### Task 2: Model a polymer of nucleotides.

Print the image provided in the download button below and use the parts to create your nucleotide polymer. Cut and paste multiple nucleotides and join together to form one chain of nucleotides to form one polymer. You can paste these onto a separate paper.

[Model a nucleotide polymer](#)

([https://d3vrb2m3yrmyfi.cloudfront.net/media/edusys\\_2/content\\_uploads/Biology A1.2.1-4 ACTIVITY.6dada165e9baaf9d34a2.pdf](https://d3vrb2m3yrmyfi.cloudfront.net/media/edusys_2/content_uploads/Biology A1.2.1-4 ACTIVITY.6dada165e9baaf9d34a2.pdf)).

Once you have assembled your polymer you can label the following parts:

- nitrogenous base
- pentose sugar
- covalent bond
- phosphate group
- sugar—phosphate backbone in the polymer.

## 5 section questions ▾

A1. Unity and diversity: Molecules / A1.2 Nucleic acids

# RNA and DNA polymers

A1.2.5: RNA as a polymer   A1.2.6: DNA as a double helix   A1.2.7: Differences between DNA and RNA



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## Learning outcomes

By the end of this section you should be able to:

- Draw and identify diagrams of the structure of single DNA and RNA nucleotides.
- Draw and identify diagrams of the structure of DNA and RNA polymers.
- Explain the complementary pairing in a double-strand structure of DNA.
- Describe the helix shape of a DNA molecule.

There is a fascinating theory called the RNA world hypothesis [↗](#)

(<https://www.khanacademy.org/science/ap-biology/natural-selection/origins-of-life-on-earth/a/rna-world#:~:text=The%20RNA%20world%20hypothesis%20suggests,central%20to%20life%20on%20Earth>) that suggests that life on Earth may have initially evolved through the use of RNA instead of DNA as its genetic material. More detail is given in section A2.1.2–6 (</study/app/bio/sid-422-cid-755105/book/the-origins-of-cell-hl-id-43955/>). But how are RNA and DNA different?

The basic structures of DNA and RNA are similar as both are composed of nucleotides; however, the structures of DNA and RNA nucleotides are different. You will find out the similarities and differences in this section.

## RNA as a polymer of nucleotide monomers

The pentose sugar in the DNA nucleotide is deoxyribose – a five-carbon sugar. In DNA, the nitrogenous bases are called adenine, guanine, cytosine and thymine.

The pentose sugar in the RNA nucleotide is ribose – also a five-carbon sugar. In RNA nucleotides, the thymine is replaced by uracil, so RNA has the following nitrogenous bases in its structure: adenine, guanine, cytosine and uracil.

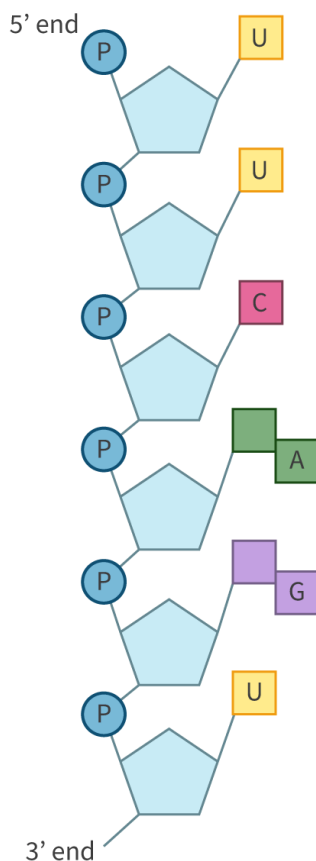
RNA nucleotides join together to form the polymer of RNA. The nucleotide units link together through covalent bonds to form a single strand of RNA. The bond forms between the phosphate group attached to the 5' C of one ribose sugar and the –OH group attached to the 3' C of another sugar, releasing one molecule of water with the use of energy. The linking of nucleotides creates a continuous chain of covalently bonded nucleotides to form a single-stranded RNA molecule (**Figure 1**).



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**Figure 1.** RNA polymer.

More information for figure 1

The image is a diagram depicting a chain of RNA nucleotides. It illustrates a single strand of RNA with phosphate groups labeled as 'P' connected to pentagon-shaped ribose sugars. The chain starts at the 5' end and ends at the 3' end. Attached to each sugar is a base labeled as a square. The sequence of bases from the 5' to 3' end is Uracil (U), Uracil (U), Cytosine (C), Adenine (A), Guanine (G), and Uracil (U). These bases are distinguished by different colors: U bases are yellow, C is pink, A is green, and G is purple. Arrows or lines indicate the covalent bonds that join the phosphate, sugar, and base to form the nucleotide connections, as well as the sequence from 5' to 3'.

[Generated by AI]



## Practical skills

### Tool 2: Technology — Applying technology to process data

Advances in technology and the development of molecular visualisation software have had a profound impact on the scientific community. You can use such software to study the RNA and DNA polymers to enhance your understanding of their 3D structures.



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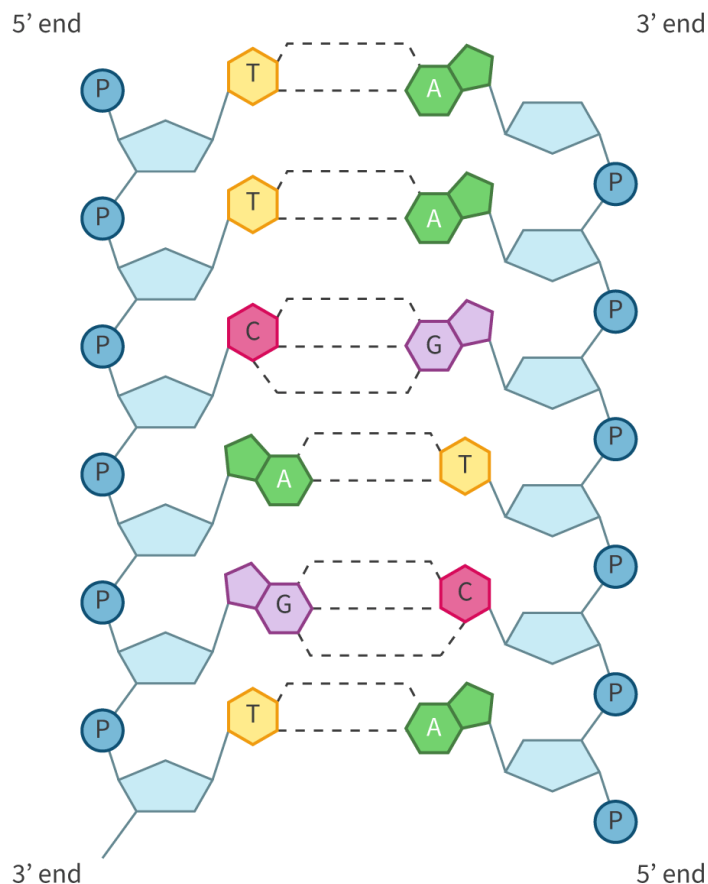
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## DNA as a double helix

DNA nucleotides join together to form the polymer of DNA. The nucleotide units link together through covalent bonds to form a single strand of DNA. The bond forms between the phosphate group attached to the 5' C of one deoxyribose sugar and the –OH group attached to the 3' C of another sugar, releasing one molecule of water with the use of energy. The linking of nucleotides creates a continuous chain of covalently bonded nucleotides.

The DNA molecule is double-stranded, meaning it has two strands, and it is helical in shape. The two strands are linked to each other by complementary base pairing between nitrogenous bases. Adenine binds with thymine, and guanine binds with cytosine by hydrogen bonding. The base pairing is important to stabilise the double helix structure of the DNA. The two strands run in opposite directions: they are 'antiparallel', one strand runs from the 5' to 3' direction, and the opposite strand runs from 3' to 5'.

You need to be able to draw the antiparallel strands of DNA showing adenine (A) paired with thymine (T) and guanine (G) paired with cytosine (C) (see **Figure 2**).



**Figure 2.** The DNA polymer.

More information for figure 2



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The diagram illustrates the double helix structure of DNA, showing two antiparallel strands. Each strand is composed of a sugar-phosphate backbone represented by alternating pentagons and circles, labeled with 'P' for phosphate. The strands are labeled with '5' end' and '3' end' to indicate directionality.

Between the two strands, pairs of nitrogenous bases are depicted as colored hexagons. Adenine (A), colored green, is paired with thymine (T), colored yellow, and connected by dashed lines symbolizing hydrogen bonding. Similarly, guanine (G), colored purple, pairs with cytosine (C), colored red. Each pair of bases is consistent along the strands, maintaining the rule of complementary base pairing. The order from top to bottom includes the following pairings: T-A, T-A, C-G, A-T, G-C, and T-A.

This represents the molecular arrangement of base pairs within DNA, crucial for understanding DNA replication and function.

[Generated by AI]

Use the molecular visualisation in **Interactive 2** to study the 3D structure of the DNA polymer.



We're sorry, but something went wrong. If this problem persists, try restarting the app or contact our helpdesk. (30010003)

### Interactive 2. The DNA polymer 3D model.

More information for interactive 2



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This interactive 3D model provides a detailed representation of a double-stranded DNA segment consisting of 12 nucleotide pairs, oriented in a right-handed helical fashion. The DNA structure resembles a spiral staircase, with the sugar-phosphate backbone forming the handrails and the base pairs acting as the steps.

Users can interact with the model by clicking the right-side arrow to explore different structural components of DNA. The first tab, DNA Backbone, highlights the anti-parallel polarity of DNA strands. A directional arrow on the backbone indicates the polarity of each strand, where one strand follows the 3'-5' direction, and the complementary strand runs in the 5'-3' direction. Clicking again reveals the DNA Backbone and Bases, where the nitrogenous bases are introduced with distinct colors. Adenine is shown in red, cytosine in purple, guanine in green, and thymine in blue. Further interaction leads to the Nitrogenous Bases tab, which isolates the DNA backbone while displaying separate models of each nitrogenous base attachment, allowing users to analyze their pairings in more detail.

Users can also adjust magnification to closely examine each nucleotide link. Additionally, a list tab on the left-hand side enables easy navigation between different structural views, providing an interactive way to understand DNA's molecular composition and its role in genetic encoding.

## Differences between DNA and RNA

There are many similarities between RNA and DNA structures, but what are the differences between these nucleic acids?

RNA has the same bases except for thymine, which is replaced by uracil (U). DNA is made up of two strands held together by hydrogen bonds to form a double helix, while RNA is a single-stranded molecule.

As mentioned, RNA nucleotides have ribose sugar while DNA nucleotides have deoxyribose sugar. You need to learn how to draw and recognise diagrams of ribose and deoxyribose. Study the images in **Table 1**, which summarise the differences between DNA and RNA, and practise sketching the pentose sugars.

**Table 1.** Differences between DNA and RNA molecules.

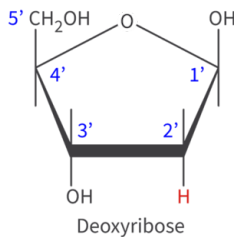
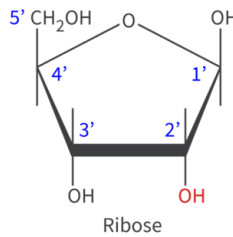
	DNA	RNA
Pentose sugar	Deoxyribose	Ribose



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	DNA	RNA
Pentose sugar structure	 <p>Deoxyribose</p> <p> More information</p> <p>The image depicts the chemical structure of deoxyribose, a five-carbon sugar, in a closed ring form. Each carbon atom is labeled 1' to 5'. The 1' carbon is bonded to an OH group. The 2' carbon has a hydrogen (H) atom instead of an OH group, indicating it is deoxyribose rather than ribose. The 3' and 4' carbons are bonded to OH groups. The 5' carbon is bonded to a CH<sub>2</sub>OH group. At the top of the ring is an oxygen atom bridging the 1' and 4' carbons.</p> <p>[Generated by AI]</p>	 <p>Ribose</p> <p> More information</p> <p>The image is a diagram illustrating the structure of a ribose molecule. It depicts a five-membered ring composed of four carbon atoms and one oxygen atom. The carbons in the ring are labeled as 1', 2', 3', 4', starting from the rightmost carbon in a clockwise direction. Attached to the 1' carbon is a hydroxyl group labeled as OH. The 2' carbon also has a hydroxyl group, but it's highlighted in red, signifying its significance, and this carbon is connected to the ring via two lines suggesting its involvement in a broader structural connection. The 3' carbon has a hydroxyl group extending downward. Attached to the 4' carbon is a CH<sub>2</sub>OH group which protrudes outside the ring to the left with a label 5' next to it. The top of the ring features the oxygen atom labeled O with a circle around it, showing its central role in the ring.</p> <p>[Generated by AI]</p>
Nitrogenous base	Adenine, guanine, cytosine and <b>thymine</b>	Adenine, guanine, cytosine and <b>uracil</b>



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## Nucleotide Structure

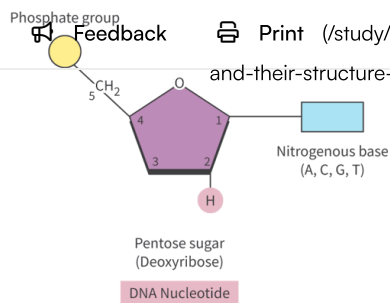
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Feedback

Print

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Assign



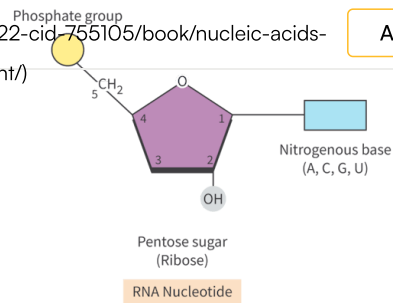
More information

This image is a diagram illustrating the structure of a DNA nucleotide. The diagram is composed of three main components: a phosphate group, a pentose sugar (deoxyribose), and a nitrogenous base.

1. The phosphate group is represented by a yellow circle at the top left labeled "Phosphate group."
2. The pentose sugar is depicted as a purple pentagon in the center labeled "Pentose sugar (Deoxyribose)," and has five points numbered from 1 to 5.
3. The nitrogenous base is shown as a blue rectangle on the right side of the pentagon, labeled "Nitrogenous base (A, C, G, T)."

The diagram shows a connection between the phosphate group and the pentose sugar at position 5 (labeled CH<sub>2</sub>-O). Another connection exists between the pentose sugar at position 1 and the nitrogenous base. A hydrogen atom labeled "H" is connected to position 2 of the pentose sugar. At the bottom, the diagram is labeled "DNA Nucleotide."

[Generated by AI]



More information

The image is a diagram illustrating the structure of an RNA nucleotide. It consists of three main components connected together. On the left is a yellow circle labeled 'Phosphate group.' This is connected to a pentagon labeled 'Pentose sugar (Ribose)' in the center, with its corners numbered 1 to 5. A CH<sub>2</sub> group connects the phosphate group to position 5 of the ribose. An 'OH' group is shown at position 2 of the ribose. On the right, a rectangle labeled 'Nitrogenous base (A, C, G, U)' represents the nitrogenous base that connects to position 1 of the ribose. Below the diagram, there is a label 'RNA Nucleotide' indicating the type of structure displayed.

[Generated by AI]

Polymer structure

Double-stranded molecule  
connected by hydrogen bonding

Single-stranded molecule

**Video 1** gives an overview of the nucleic acids.



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## Nucleic Acids



### Video 1. Nucleic acids.

Try the following activity to consolidate your learning.



### Activity

- **IB learner profile attribute:**
  - Reflective
  - Communicator
- **Approaches to learning:** Self-management — Drafting, revising and improving academic work
- **Time required to complete activity:** 30 minutes
- **Activity type:** Individual activity

#### Task 1: RNA nucleotide/RNA polymer

1. Start by drawing a simple diagram of the structure of a single RNA nucleotide, using the pentagon, circle and rectangle shapes for the pentose sugar, phosphate group and nitrogenous base.
2. Label your diagram.
3. Now add a second nucleotide to create an RNA polymer, ensuring the bonding is correctly placed between the phosphate group (attached to the 5' C of one pentose sugar and the —OH group attached to the 3' C of another sugar).
4. Add the specific names of the bases, the sugar and the type of bonding between nucleotides.

Make sure you:

- Understand that RNA nucleotides consist of A, C, G and U but not T.
- Know the pentose in RNA is ribose.
- Label the bond between the nucleotides.
- Show that the RNA molecule is single-stranded.



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- Identify the 5' and 3' ends of the polymer.

### Interactive 3. How to Draw and Label RNA Nucleotide and RNA Polymer.

More information for interactive 3

An interactive slideshow demonstrates the step-by-step process for drawing an RNA nucleotide and forming an RNA polymer using simple shapes.

A four-segmented grey tile at the bottom of the page shows the number of slides in the interactive. As each slide is viewed, the specific segment turns blue. Below this, the slide numbers are indicated out of four slides with right and left arrows. Users can use these arrows to navigate between pages. The “Fullscreen” icon at the bottom right allows you to view the slide in full-screen.

Read below to know what each slide demonstrates.

Slide 1 reads “For tips on drawing stages, go to the next slide” at the bottom. No visual elements are presented on this slide.

Slide 2 reads “Draw one RNA molecule” at the top left. An illustration of a single RNA nucleotide is shown using basic shapes at the top right. The ribose sugar is represented by a purple pentagon, the phosphate group is represented by a circle, and the nitrogenous base (A, U, G, or C) is represented by a blue rectangle. The phosphate group and the nitrogenous base are attached to the ribose sugar through covalent bonds at different locations.

Slide 3 shows the same nucleotide components with labels, and reads “Add labels” at the top left. In the illustration, the circle is labelled phosphate, the rectangle is labelled nitrogenous bases (A, U, G, C), and the pentagon is labelled ribose.

Slide 4 reads “Add another nucleotide to make a polymer and add labels” at the top left. A second nucleotide is added below the first. A covalent bond is drawn between the ribose of the first nucleotide and the phosphate of the second nucleotide. An RNA polymer is formed with two RNA nucleotides. The first nucleotide is labelled as the 5' end, while the bottom second nucleotide is labelled as the 3' end.

### Task 2: DNA nucleotide/DNA polymer

1. Start by drawing a simple diagram of the structure of a single DNA nucleotide, using the pentagon, circle and rectangle shapes for the pentose sugar, phosphate group and nitrogenous base.
2. Label your diagram.
3. Now add a second nucleotide to create a DNA polymer, ensuring the bonding is correctly placed between the phosphate group (attached to the 5' C of one pentose sugar and the —OH group attached to the 3' C of another sugar).



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4. Add the specific names of the bases, the sugar and the type of bonding between nucleotides.

5. Next add complementary nucleotides to build a DNA polymer.

Make sure you:

- Understand that DNA nucleotides consist of A, C, G and T.
- Know the pentose in DNA is deoxyribose.
- Show that the DNA molecule is double-stranded.
- Identify the 5' and 3' ends of the polymer.
- Label the bonds between the nucleotides.
- Show your understanding of the complementary base pairing, (A-T and C-G).
- Show your understanding of the antiparallel nature of the DNA molecule.
- Show the hydrogen bonding between complementary base pairing. (You do not need to memorise that A-T pairs have two and C-G pairs have three hydrogen bonds.)

#### Interactive 4. How to Draw and Label DNA Nucleotide and DNA Polymer.

More information for interactive 4

An interactive slideshow demonstrates the step-by-step process for drawing a DNA nucleotide and forming a DNA polymer using simple shapes.

A four-segmented grey tile at the bottom of the page shows the number of slides in the interactive. As each slide is viewed, the specific segment turns blue. Below this, the slide numbers are indicated out of five slides with right and left arrows. Users can use these arrows to navigate between pages. The "Fullscreen" icon at the bottom right allows you to view the slide in full-screen.

Read below to know what each slide demonstrates.

Slide 1 reads: For tips on drawing stages, go to the next slide, at the bottom. No visual elements are presented on this slide.

Slide 2 reads: Draw one DNA nucleotide, at the top left. An illustration of a single DNA nucleotide is shown using basic shapes. The deoxyribose sugar is represented as a pentagon, the phosphate group is represented as a circle, and the nitrogenous base (A, U, G, or C) is represented as a rectangle. The phosphate group and nitrogenous base are attached to the deoxyribose sugar molecule through covalent bonds to represent the actual structure of a DNA nucleotide.

Slide 3 reads: Add labels, at the top left. The slide shows the DNA nucleotide structure with labels. The circle is labelled phosphate, the rectangle is labelled with nitrogenous bases (A, U, G, C), and the pentagon is labelled deoxyribose.



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Slide 4 reads: Add another nucleotide to make a strand and add labels, at the top left. A second nucleotide is added below the first, and the bond line between the sugar and phosphate structure is marked as a "Covalent bond." A covalent bond is drawn between the deoxyribose sugar of the first nucleotide and the phosphate group of the second nucleotide. The top nucleotide is labelled as the 5' end, while the bottom nucleotide is labelled as the 3' end. The nitrogenous base of the first nucleotide is labelled as cytosine, and the nitrogenous base of the second nucleotide is labelled as thymine.

Slide 5 reads: Add the second DNA strand, at the top left. The illustration shows the addition of a nucleotide to the top nucleotide with guanine as the nitrogenous base, a phosphate group, and an inverted deoxyribose sugar molecule. The cytosine and guanine are bonded through three hydrogen bonds. Similarly, the thymine in the bottom nucleotide is paired with another nucleotide with adenine as the nitrogenous base, a phosphate group, and an inverted deoxyribose sugar molecule. The adenine and thymine are bonded through two hydrogen bonds. The bond between deoxyribose sugar and phosphate group in the bottom right nucleotide is marked as a "covalent bond."

The final structure is a double-stranded DNA molecule with two strands that run in opposite directions (antiparallel). The two DNA strands have a sugar-phosphate backbone. The strand on the top runs from the 5' end to the 3' end. The strand on the bottom runs from the 3' end to the 5' end, showing the antiparallel orientation. The slide demonstrates complementary base pairing (C-G and A-T), double-strand structure, and direction of DNA strands.

### Task 3: Ribose/deoxyribose

Now that you have acquired knowledge about the components of DNA (deoxyribose) and RNA (ribose), it is important to develop your skills in drawing the structures of ribose and deoxyribose.

Make sure you:

- Draw the sugar as a pentagon.
- Number the carbon atoms clockwise from 1 to 5.
- Add carbon number 5 as a branch.
- Label OH and H correctly at carbon number 2.

### Interactive 5. How to Draw and Label Ribose and Deoxyribose.

More information for interactive 5



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An interactive slideshow demonstrates the steps for drawing the structures of deoxyribose and ribose sugar molecules.

A three-segmented grey tile at the bottom of the page shows the number of slides in the interactive. As each slide is viewed, the specific segment turns blue. Below this, the slide numbers are indicated out of five slides with right and left arrows. Users can use these arrows to navigate between pages. The “Fullscreen” icon at the bottom right allows you to view the slide in full-screen.

Read below to know what each slide demonstrates.

**Slide 1:** An instruction: For tips on drawing stages, go to the next slide, which is given at the bottom.

**Slide 2:** An illustration of a deoxyribose structure, shown as a five-membered ring (pentagon). The ring contains five carbon atoms and one oxygen atom, with the oxygen located at the top center of the pentagon. The carbon atoms are numbered clockwise starting from the carbon to the right of the oxygen. The 1' carbon has an OH (hydroxyl) group attached. The 2' carbon has only a hydrogen (H) atom highlighted in red indicating that it is deoxygenated. This is an important feature that distinguishes deoxyribose from ribose sugar. The 3' carbon has an OH group. The 4' carbon is part of the ring and connects to the 5' carbon with the molecular formula  $\text{CH}_2\text{OH}$ . The term “Deoxyribose” is given at the bottom.

**Slide 3:** An illustration of a ribose sugar molecule shown as a five-membered ring (pentagon) with five carbon atoms with one oxygen atom at the center. Carbon atoms are numbered clockwise, starting from the carbon to the right of the oxygen. The carbon atoms at the 1', 2', and 3' positions have an OH group. The 4' carbon connects to the 5' carbon, which lies outside the ring and has  $\text{CH}_2\text{OH}$  as its molecular formula. The term “Ribose” is given at the bottom.

The absence of an oxygen atom at the 2' carbon atom in the deoxyribose sugar molecule distinguishes it from the ribose sugar molecule. Hence, the name “deoxy.”

## 5 section questions ▾

A1. Unity and diversity: Molecules / A1.2 Nucleic acids

# Complementary base pairing

A1.2.8: Role of complementary base pairing    A1.2.9: Capacity of DNA for storing information    A1.2.10: Evidence of universal common ancestry



## Learning outcomes

By the end of this section you should be able to:

- Explain the importance of complementary base pairing in allowing genetic information to be replicated and expressed.
- Explain that diversity of any length of DNA molecule and base sequence is possible, as there is an enormous capacity of DNA for storing data.
- Outline the conservation of the genetic code across all life forms as evidence of universal common ancestry.



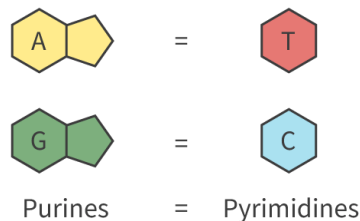
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There are around 30 trillion cells in your body; do all your cells have the same DNA? With very few exceptions (e.g. gametes and red blood cells), all cells in the human body have the same DNA. However, different cell types exhibit distinct appearances and functions. Examples include neurons, white blood cells, muscle cells and skin cells. These cells share the same DNA but differ in protein composition, and structural features, allowing them to carry out specialised tasks. How can cells that look different and have different functions have the same DNA?

## Role of complementary base pairing

The DNA double helix is composed of two right-handed helical polynucleotide chains coiled around the same central axis. The bases are inside the helix and the sugar-phosphate backbone is on the outside.

The two strands are linked to each other by complementary base pairing between nitrogenous bases (**Figure 1**). Adenine binds to thymine and guanine binds to cytosine by hydrogen bonding. The base pairing is important to stabilise the structure of the double helix.



**Figure 1.** Complementary base pairing.

 More information for figure 1

The diagram illustrates complementary base pairing in DNA. It shows adenine (A) paired with thymine (T), and guanine (G) paired with cytosine (C). Both adenine and guanine, which are purines, are depicted on the left. They are connected by lines to thymine and cytosine, the pyrimidines, depicted on the right, indicating the hydrogen bonds between them. The diagram visually represents the fundamental mechanism for DNA's double helix structure and its replication accuracy, where adenine only pairs with thymine, and guanine only pairs with cytosine, maintaining the genetic code.

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Complementary base pairing in DNA is also significant to functions of the cells. During cell division the DNA undergoes replication, which is the copying of the DNA to double its amount and prepare the cell for division. The accuracy of DNA replication is critical to the cell as the base sequence should be the same during cell divisions. Complementary base pairing plays a role in maintaining the base sequence during copying as adenine always pairs with thymine and guanine always pairs with cytosine. Replication uses one of the DNA strands as a template to create a new one, therefore the DNA sequence stays the same during cell divisions.

One of the main functions of DNA is to code for proteins. Complementarity is also significant in gene expression, the process by which the genetic code in the DNA is translated into a protein. The gene can be expressed (switched on) or not expressed (switched off). Complementarity ensures that the same protein is produced every time the gene is expressed – the same complementary base pairs mean the same code, therefore the same protein is produced and this is significant because it maintains the characteristics of the cell and the organism.

### Making connections

DNA replication is required for reproduction and for growth and tissue replacement in multicellular organisms. Not all genes in a cell are expressed at any given time. Transcription is a key stage at which expression of a gene can be 'switched on and off'. The base sequence of mRNA is translated into the amino acid sequence of a polypeptide.

Replication, transcription and translation are detailed in subtopic D1.1 (</study/app/bio/sid-422-cid-755105/book/big-picture-id-43546/>).

## The unity and diversity of the genetic code

Did you know that DNA can be used as a coding system to store large amounts of data? How is this possible?

How many possible combinations could you form out of the four nitrogenous bases A, T, C, G for a 10 base pair length of DNA?

Similar to the outcomes of flipping a coin 10 times with 2 possibilities for each toss. This should be equal to  $4^{10} = 1\,048\,576$  possibilities. Scale this up to the approximate length of human DNA which is around 3 billion base pairs.

Any base sequence is possible in a given length of DNA. This means that DNA has enormous capacity for storing coded information.

## Conservation of the genetic code

The genetic code refers to the instructions in a gene in the form of base sequences that become translated into a functional protein. All living organisms use the same genetic code. Therefore, the information stored in DNA will be translated into the same protein whether it is read by a bacterium, human, or fungus. The genetic code is conserved in all forms of life and this serves as evidence that all living organisms came from a common ancestor. It is interesting to note that viruses, not considered living organisms, are incapable of translating DNA on their own.



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## Making connections

Nucleotides and their role in the genetic code as the basis of triplet codons, and the mechanism of translation into proteins are covered in [subtopic D1.2 \(/study/app/bio/sid-422-cid-755105/book/big-picture-id-43547/\)](/study/app/bio/sid-422-cid-755105/book/big-picture-id-43547/).



## International Mindedness

The discovery of the DNA structure exemplifies the significance of international mindedness in scientific achievements. By valuing diverse perspectives and engaging in collaborative efforts, scientists from different countries were able to unravel the fundamental building blocks of life, leading to many applications that benefit humanity as a whole.

This is a simplified timeline highlighting some key discoveries and researchers involved in the understanding of DNA. Note that many other scientists also made significant contributions to the field:

- 1869: Friedrich Miescher discovered DNA while studying the chemical composition of white blood cells. He named it 'nuclein'.
- 1952: Alfred Hershey and Martha Chase conducted experiments demonstrating that DNA, not protein, is the genetic material of viruses.
- Early 1950s: Erwin Chargaff observed the base pairing rules, stating that the amount of adenine (A) is equal to thymine (T) and the amount of cytosine (C) is equal to guanine (G) in DNA.
- Early 1950s: Rosalind Franklin used X-ray crystallography to capture images of DNA fibres, providing critical data on the structure and dimensions of DNA molecules.
- 1953: James Watson and Francis Crick proposed the double helix structure of DNA, building on the work of others, including Franklin's data.
- 1962: Watson, Crick and Maurice Wilkins were awarded the Nobel Prize in Physiology or Medicine for their discovery of the structure of DNA.

To learn more about the timeline of DNA discovery, watch **Video 1**.

### The Discovery of the Structure of DNA | AMS OpenMind



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**Video 1.** The discovery of the structure of DNA.

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Try the activity to check your understanding of complementary base pairing and the structure of DNA.

**Activity**

- **IB learner profile attribute:** Reflective
- **Approaches to learning:** Self-management skills — Drafting, revising and improving academic work.
- **Time required to complete activity:** 7 minutes
- **Activity type:** individual activity

Complete the missing DNA strand in **Interactive 1**.

Diagram illustrating a DNA double helix structure. The left strand is partially missing, showing a sugar-phosphate backbone (S and P) and bases C, G, A, T. The right strand is partially missing, showing a sugar-phosphate backbone (S, S, A, C, T, G) and a missing phosphate group (P) at the bottom.

Check



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**Interactive 1.** Complementary base pairing.



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An interactive schematic illustrates complementary base pairing in DNA. It displays two antiparallel strands. The strand on the left consists of four phosphate groups P, four sugar molecules S, and the nitrogenous bases cytosine C, guanine G, adenine A, and thymine T. Each sugar molecule is linked to two phosphate groups, forming the sugar-phosphate backbone.

The nitrogenous bases are attached to the sugar molecules in the following order: C to the first sugar, G to the second, A to the third, and T to the fourth. C and G have triple bonds, and A and T have double bonds. The sugars are represented as pentagons, with upward-pointing pentagons present on the left strand.

On the right, separate components— upward-pointing pentagon sugar S, downward-pointing pentagon S, adenine A, cytosine C, thymine T, guanine G, phosphate group P, and single bond—are provided as drag-and-drop options for pairing with the corresponding components on the left.

After arranging the drag-and-drop options into the respective places on the right strand, users can check the results using a check button on the bottom left. A point score, rated out of 15, is displayed at the bottom left when the user selects the check button. A retry option is available when the drag-and-drop options are placed incorrectly or if some placements are missed.

Read below for the solution:

C, G, A, and T are paired with G, C, T, and A, respectively. Each base on the right is connected to a downward-pointing pentagon S, and a P group is also connected to each downward-pointing pentagon sugar. A single bond connects the P to the S below it.

## 5 section questions

A1. Unity and diversity: Molecules / A1.2 Nucleic acids

# DNA base sequences (HL)

A1.2.11: Directionality of RNA and DNA (HL)   A1.2.12: Purine-to-pyrimidine bonding (HL)   A1.2.13: Structure of a nucleosome (HL)

## Higher level (HL)

### Learning outcomes

By the end of this section you should be able to:

- Explain the significance of 5'—3' linkage in the sugar-phosphate backbone of DNA for replication, transcription and translation.
- Describe how complementary base pairing stabilises the DNA double helix.
- Explain the structure of a nucleosome.



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Read the word 'TOP' from left to right and then from right to left, what did you notice?

Upon reading the word 'TOP' from left to right and then from right to left, you likely made an observation. As you examined the word in both directions, you would have noticed a change in the meaning. This contrast showcases the effect of reversing the sequence of letters, resulting in a completely different word. This observation exemplifies the significance of the order of letters in forming words. But how does this relate to the directionality of DNA and RNA?

## The directionality of RNA and DNA

Complementary base pairing is the underlying basis for the processes of replication, transcription and translation:

- Replication is the copying of DNA to create a new DNA molecule (see subtopic D1.1 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43546/)).
- Transcription is the process in which the DNA is used as a template to produce RNA (see subtopic D1.2 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43547/)).
- Translation is the process in which the transcribed RNA is translated by the ribosomes to produce proteins (see subtopic D1.2 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43547/)).

These three processes occur in a 5' to 3' direction. The 5' carbon has a phosphate group attached to it and the 3' carbon has an –OH attached to it. The reading direction should be consistent to ensure the conservation of the DNA base sequence during DNA copying and to ensure that the same protein is produced every time the gene is transcribed. **Video 1** explains this in more detail.

The enzymes needed for these three processes are also specific. For example, DNA polymerase, which is responsible for DNA replication, can only attach to the 3' –OH group. Less energy is needed for the processes to take place in the 5' to 3' direction. The direction is significant because of the orientation of the enzymes that will be used for these processes.

The definition to 5' end and 3' end of a DNA strand - Simple animated...



**Video 1.** 5' and 3' ends of a DNA strand.

More information for video 1



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It is an animated video explaining the step-by-step process of DNA replication, transcription and translation.

At the beginning of the video an onscreen text appears reading: The definition to the 5' end and 3' end of a DNA strand. Which is followed by a double-helix DNA molecule (twisted ladder shape) on screen. The two strands are colour coded: one in blue, the other in red. A legend on the right side shows adenine is coloured yellow, thymine is green, cytosine is blue and guanine is red.

Onscreen text reads: "This is a DNA molecule in its native form: the double helix. When the DNA double helix is unfolded, it is clear to see that the DNA molecule is formed by 2 DNA strands."

The DNA double helix unwinds and the DNA strands unfold into two separate lines. The onscreen text reads "So how to locate the 3 prime end and the 5 prime end?"

The top strand (blue) has a 3' end on the left, a 5' prime end on the right. The bottom strand (blue) is opposite: 5' on the left, 3' on the right. The narrative text in red reads "If the 3' end is here, then the opposite end is ALWAYS the 5' end" and "For the other side of strand also the opposite, and of course 3' end here."

Further, a close-up of a single nucleotide (building block of DNA), at the 5' end is shown. The text reads "Let's have a closer look at 1 nucleotide." Base (adenine, thymine etc) is highlighted by a red circle and seen protruding from the sugar (pentagon coloured light blue). Next, Hydroxyl group (OH) is highlighted by the red circle, labelled "Deoxyribose" coloured orange). Lastly, the Phosphate group is highlighted by the red circle. The narrative text reads "The 5' and 3' origins from the sugar group by positions of the 5 carbons." The carbons (C) become highlighted in red. Text reading "The position of the carbons have a number which is used for 5' and 3' indication" appears next and the carbons are labelled 1-5 (in blue) from right to left. Carbon number 5 forms the 5' end to which the phosphate group is attached and Carbon number 3 becomes the 3' end to which the hydroxyl group is attached.

Next, the narrative text reads "The 5' and 3' indication is used for directionality of DNA strands." "Because in vivo DNA synthesis ALWAYS happens from 5' to 3'." Animated DNA polymerase enzyme (TAQ) (coloured orange), moves along the blue template strand, adding nucleotides to the 3' end of the growing strand (red). A red arrow shows that DNA synthesis always occurs from 5' to 3'. The enzyme reads the template strand in the 3'→5' direction but builds the new strand in the 5'→3' direction.

The key takeaway is that all DNA processes occur 5'→3' because it is energy efficient and ensures accurate genetic copying.

## Making connections

Sections D1.1.6 (/study/app/bio/sid-422-cid-755105/book/directionality-of-dna-replication-hl-id-46377/) and D1.1.1 (/study/app/bio/sid-422-cid-755105/book/dna-replication-basics-id-45740/) and subtopic D1.2 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43547/) cover DNA replication, enzymes involved in replication and the directionality of DNA polymerase in more detail.

## Purine and pyrimidine pairing role to stabilise the double helix

A pyrimidine always pairs with a purine:

- thymine (T) pairs with adenine (A), via the formation of two hydrogen bonds
- cytosine (C) pairs with guanine (G), via the formation of three hydrogen bonds.

If adenine binds with guanine the length of the pair will be too long, and if thymine binds with cytosine the length of the pair will be too short. This complementary base pairing of adenine–thymine and cytosine–guanine stabilises the DNA as the length of the base pairs is consistent throughout the DNA double helix. The bonds between adenine and thymine create a similar

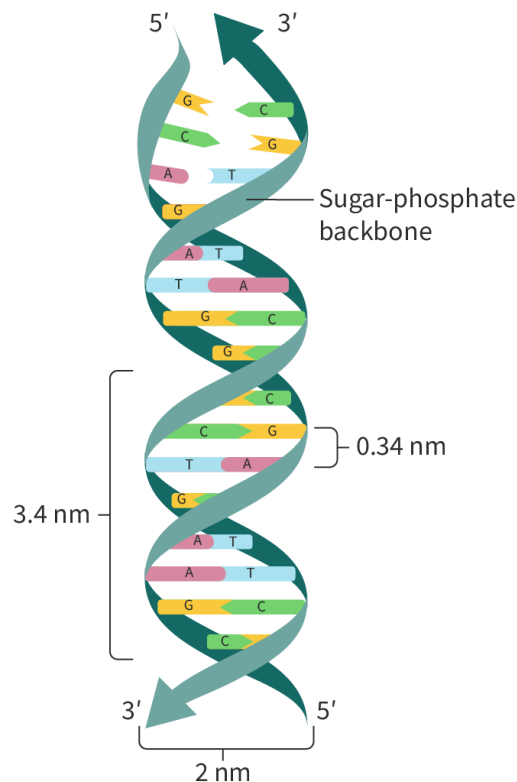


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shape to guanine and cytosine to accommodate the diameter (about 2 nm), which is the pitch of the helix (**Figure 1**). Purines cannot combine with other purines due to double-ring structures. The higher the bond specificity, the higher the stability and the stronger the bond.



**Figure 1.** The double helix dimensions.

More information for figure 1

The image is a diagram of a DNA double helix structure. It features two intertwined strands forming the familiar helical shape of DNA. Each strand comprises a sugar-phosphate backbone, which is highlighted and labeled in the image. The strands are held together by pairs of nitrogenous bases: adenine (A) pairs with thymine (T), and cytosine (C) pairs with guanine (G). These base pairs are represented by labeled bars that span the gap between the two sugar-phosphate backbones. The dimensions of the helix are specified in the diagram: the diameter of the helix is 2 nanometers, while the repeating unit length (one complete turn of the helix) is 3.4 nanometers. The distance between each consecutive base pair is 0.34 nanometers. Arrows on the structure indicate the directionality of each strand, labeled as 5' to 3' and 3' to 5', which are standard notations in DNA structure that represent the orientation of the molecular chain.

[Generated by AI]

If mismatching occurs during DNA replication, the point of mismatch should be detected due to the incorrect length of the base pair and be fixed to avoid mistakes in DNA replication. However, in some cases the mismatch persists, which can lead to structural instability in the DNA double helix at the point of the mismatch, possibly causing termination of cell division, cell death or cancers.



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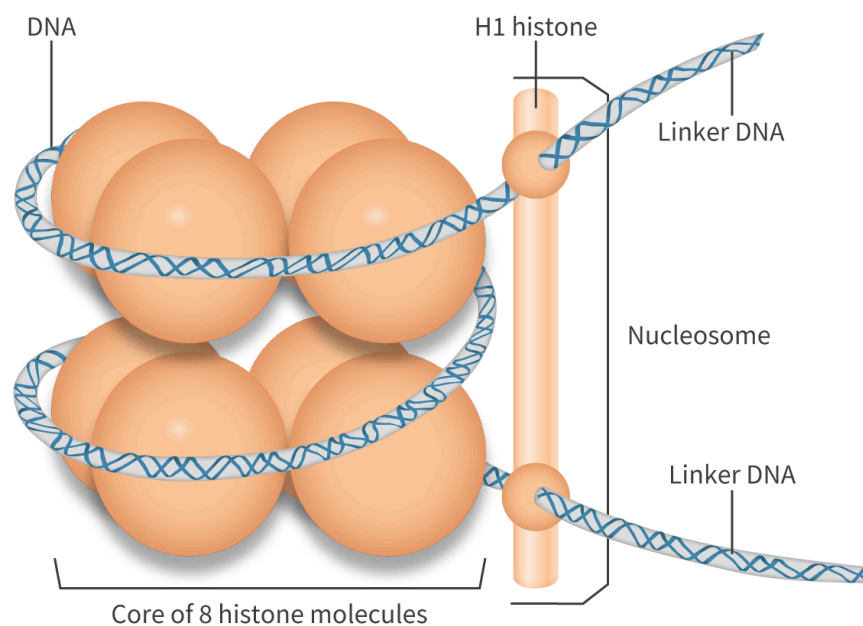
## Nucleosomes

Think of a pair of identical twins. They look alike and even share the same DNA! But do they behave the same? No, we all behave as individuals. To what extent are your characteristics influenced by your environment versus your DNA?

According to the principles of biochemistry, the length of DNA in human cells is around 2 metres. How does 2 metres of DNA fit into the nucleus? Think about what happens when you twist an elastic band repeatedly – eventually it will form an additional pattern of coils.

Eukaryotic DNA, which is enclosed in the nucleus, is always associated with proteins called histones. This is in contrast to prokaryotic DNA, which is found in the cytoplasm and lacks histones, and is therefore often referred to as ‘naked’ DNA. A nucleosome consists of a length of DNA of about 150 base pairs, wrapped around a core of eight histones (which are actually four pairs of four different histones) and a special histone named H1.

The nucleosomes are linked, with the DNA strand from one nucleosome flowing directly into the next nucleosome. This section of DNA is called a DNA linker (**Figure 2**). The overall appearance of DNA in this form has been likened to a ‘string of beads’. **Figure 3** shows the relationship between the nucleosomes, the DNA and a chromosome.



**Figure 2. Nucleosomes.**

More information for figure 2

The image is a labeled diagram illustrating the structure of nucleosomes. It shows DNA strands wrapped around a core of eight histone molecules forming a nucleosome unit. The DNA strand, labeled as "DNA," circles the histones twice. A section of the DNA, labeled as "Linker DNA," connects one nucleosome to the next, representing the DNA strands that link multiple nucleosomes together like beads on a string. H1 histone, shown linked to the DNA, is situated where the DNA exits the nucleosome, playing a role in securing the DNA in place. The labels also denote the specific "Core of 8 histone molecules" and "Nucleosome," describing the fundamental structural unit of chromatin.

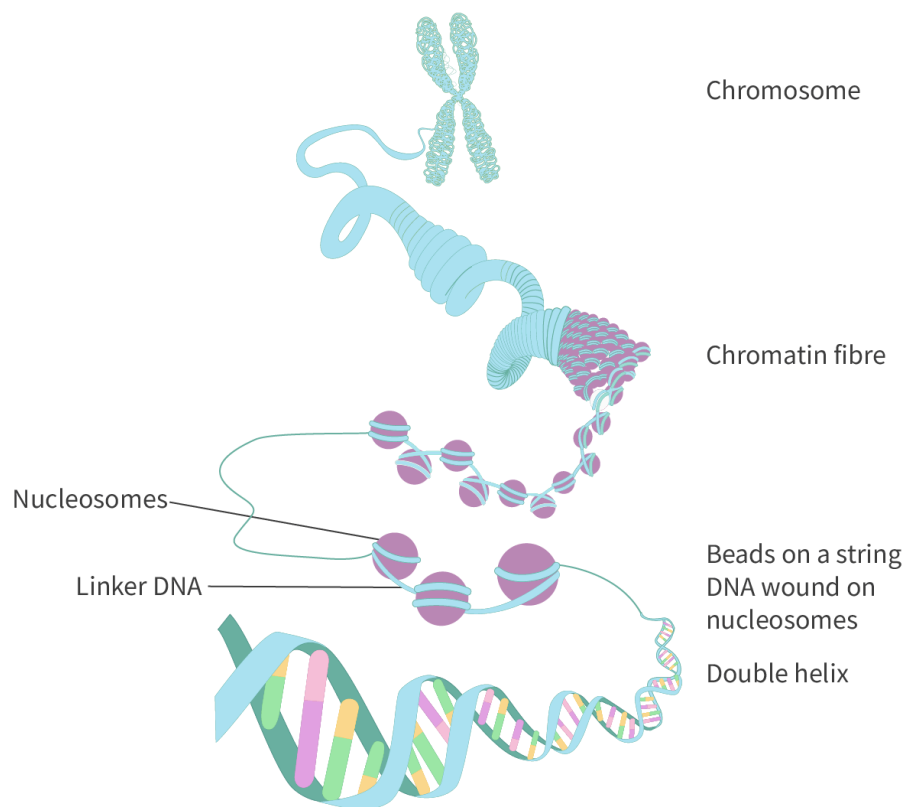
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**Figure 3.** The relationship between nucleosomes and chromosomes

More information for figure 3

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This diagram illustrates the hierarchical structure of DNA packaging in cells, progressing from the DNA double helix to the complete chromosome. At the bottom, the double helix of DNA is depicted, indicating the structure that serves as the fundamental unit. Above this, the DNA wraps around nucleosomes—protein complexes that help in compacting the DNA. This level is labeled "Nucleosomes." The nucleosomes appear as small spheres arranged in a "beads on a string" format, which illustrates how the DNA strand winds around these forms.

The next level of structure is the chromatin fiber, depicted as a coiling of the nucleosome chain, labeled "Chromatin fibre." The chromatin fiber undergoes further folding and coiling, ultimately forming into the visible X-shaped structure of the chromosome, located at the top of the diagram. This sequence represents how the extensive length of DNA is compacted to fit within the cell nucleus while maintaining the ability for certain regions to be accessed as needed for biological functions such as transcription and replication.

Labeled components in the diagram include "Nucleosomes," "Linker DNA," "Chromatin fibre," "Beads on a string DNA wound on nucleosomes," and "Chromosome." Each label corresponds to a specific part of the DNA structure being highlighted and detailed in the visualization.

[Generated by AI]

Because some eukaryotes have large genomes, a certain amount of packaging (folding, coiling and uncoiling) is required to fit the genetic material into the nucleus. Nucleosomes help to supercoil the DNA while still ensuring appropriate access to it. Access to DNA occurs when the



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coils unwind and histones are moved out of the way so that DNA can be copied or transcribed. Nucleosomes can be considered to be the repeat units of eukaryotic chromatin, which is further coiled to form chromosomes. **Video 2** shows the 3D organisation of our DNA.

Molecular Visualizations of DNA (2003) Drew Berry wehi.tv



**Video 2.** 3D organisation of our DNA.

You need to be able to use molecular visualisation software to study the association between proteins and DNA with a nucleosome. Follow the steps in the activity to access one of the platforms and answer related questions.

### Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Thinking skills — Experimenting with new strategies for learning
- **Time required to complete activity:** 20 minutes
- **Activity type:** Pair activity

#### Your task

Access the visualisation software at one of the sites listed below to study the association between proteins and DNA with a nucleosome, and then answer the questions.

3D View: 1AOL (rcsb.org)  (<https://www.rcsb.org/3d-view/jsmol/1AOL/1>)

Nucleosome Structure (callutheran.edu) 

([http://earth.callutheran.edu/Academic\\_Programs/Departments/BioDev/omm/jsmol/nucleos](http://earth.callutheran.edu/Academic_Programs/Departments/BioDev/omm/jsmol/nucleos)

Histone - Proteopedia, life in 3D  (<https://proteopedia.org/wiki/index.php/Histone>)

1. Rotate the 3D model and describe how the histones are associated with the DNA within the nucleosome.
2. List the types of histone protein found in the core of the nucleosome.



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3. State how many base pairs of double-helical DNA are wrapped around in the histone.
4. Outline why the nucleosome is often referred to as the histone octamer.
5. Sketch a simple diagram to show the association between histone proteins and DNA.

## 5 section questions ▾

A1. Unity and diversity: Molecules / A1.2 Nucleic acids

# Hershey and Chase and Chargaff's data (HL)

A1.2.14: The Hershey—Chase experiment (HL)    A1.2.15: Chargaff's data (HL)

## Higher level (HL)

### Learning outcomes

By the end of this section you should be able to:

- Explain how the findings of the Hershey—Chase experiment support the conclusion that DNA is the genetic material.
- Explain how Chargaff's data on the relative amounts of pyrimidines and purine bases across forms of life provided convincing evidence for complementary base pairing.

How do we know what we know about DNA? In summer 1940, Rosalind Franklin said 'Science, for me, gives an explanation for life. In so far as it goes, it is based on fact, experience and experiment'. So what are the early discoveries that contributed to our current understanding of the DNA structure and function?

DNA was first isolated by Friedrich Miescher in 1869. Although Miescher suggested that DNA has a role in heredity, it took another 90 years before the structure was determined by Watson and Crick using a physical model. The model was developed with the help of Rosalind Franklin's work in X-ray, in which she indicated the helical structure of the DNA. Other scientists have also made important contributions to the discovery of DNA structure and function, namely Chargaff, Hershey and Chase, who you will learn about in this section.



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## Theory of Knowledge

Scientists see themselves connected to the global community and assume a sense of responsibility towards its members.

Cooperation enables the distillation of ideas and distribution of effort and resources; competition is a stimulus to work. Scientific research is a social, cooperative effort, but prestige and competition are also a driving force of discovery. The first individual or group to have their work peer-reviewed and published gains considerable prestige and also an improved likelihood of further funding for their research programme. Cooperation allows for efficient completion of major projects requiring considerable time and resources.

To what extent do the roles of cooperation and competition contribute to gaining scientific knowledge?

The Hershey–Chase experiment and Erwin Chargaff’s experiment were significant in the DNA timeline as both aided in the understanding of the structure and function of DNA.

For a long time, scientists deliberated whether genetic material was protein or DNA. Most biologists were aware of the role that chromosomes play in heredity, but chromosomes consist of DNA and protein.



## Nature of Science

### Aspect: Experiments

You should appreciate that technological developments can open up new possibilities for experiments. When radioactive materials were made available to scientists as research tools, the Hershey—Chase experiment became possible.

## Evidence from the Hershey—Chase experiment

In an interesting experiment, Alfred Hershey and Martha Chase were able to convince the scientific community that it was DNA, and not protein, that made up genetic material. They used a T2 bacteriophage, which is a virus that infects bacterial cells. This virus injects its DNA into the bacterial cell while its protein coat stays on the outside (**Figure 1**).



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**Figure 1.** Bacteriophage electron micrograph.

Source: "Phage"  (<https://commons.wikimedia.org/wiki/File:Phage.jpg>)" by Professor Graham Beards is licensed under CC BY-SA 3.0  (<https://creativecommons.org/licenses/by-sa/3.0/deed.en>)

Hershey and Chase used radioactive phosphorus and sulfur to label the DNA and protein in the viruses. Phosphorus is found in DNA but not protein, and sulfur is found in protein but not DNA. This was an elegant and simple way to determine what part of the virus entered the bacterium.

Through their experiment, Hershey and Chase found that:

- When bacteriophages containing radioactive phosphorus ( $^{32}\text{P}$ ) were allowed to infect non-radioactive bacteria, all the infected cells became radioactive. Additionally, the next generation of bacteriophages, produced from the infected bacteria, were all radioactive.
- However, when the bacteria were infected with bacteriophages labelled with radioactive sulfur ( $^{35}\text{S}$ ) and the virus coats removed (by agitating them in an electric blender), almost no radioactivity could be detected in the infected cells.

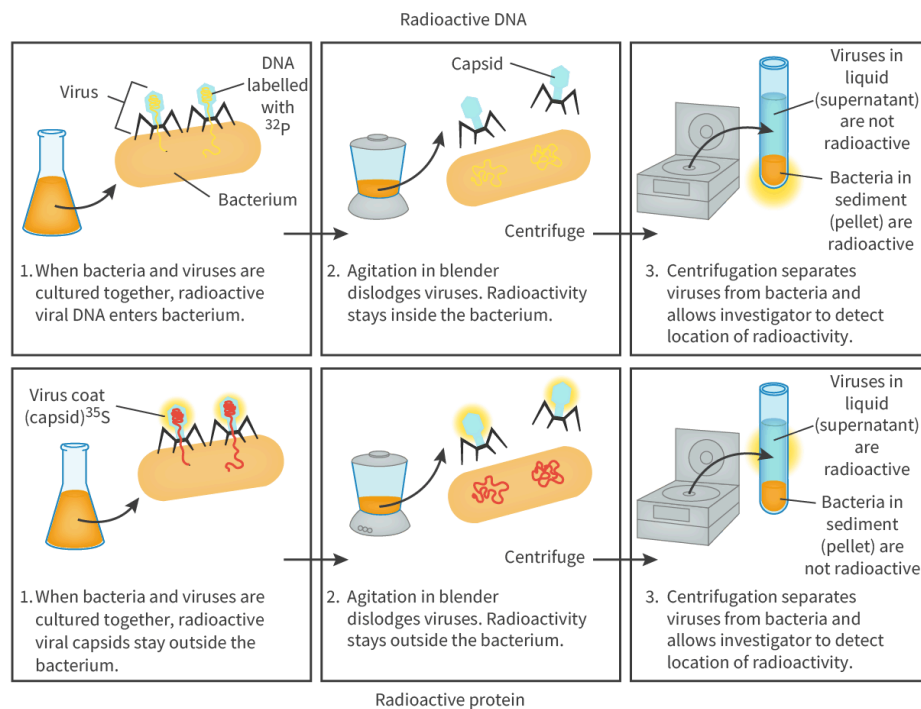
The steps they used are shown in **Figure 2**.



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**Figure 2. The Hershey–Chase experiment.**

[More information for figure 2](#)

The diagram illustrates the Hershey–Chase experiment, demonstrating the processes for radioactive DNA and protein.

**Top Row - Radioactive DNA** 1. The first panel shows viruses labeled with DNA tagged with  $^{32}\text{P}$  infecting a bacterium. It is labeled with text: "1. When bacteria and viruses are cultured together, radioactive viral DNA enters bacterium." 2. The second panel illustrates a blender dislodging viruses, with the text: "2. Agitation in blender dislodges viruses. Radioactivity stays inside the bacterium." 3. The third panel depicts a centrifuge separating viruses from bacteria, followed by text: "3. Centrifugation separates viruses from bacteria and allows investigator to detect location of radioactivity. Viruses in liquid (supernatant) are not radioactive. Bacteria in sediment (pellet) are radioactive."

**Bottom Row - Radioactive Protein** 1. The first panel shows viruses with protein coats labeled with  $^{35}\text{S}$  infecting a bacterium. It includes text: "1. When bacteria and viruses are cultured together, radioactive viral capsids stay outside the bacterium." 2. The second panel shows the blender process again, with the text: "2. Agitation in blender dislodges viruses. Radioactivity stays outside the bacterium." 3. The third panel shows the separation through centrifugation, with text: "3. Centrifugation separates viruses from bacteria and allows investigator to detect location of radioactivity. Viruses in liquid (supernatant) are radioactive. Bacteria in sediment (pellet) are not radioactive."

[Generated by AI]

Watch **Video 1** to learn about the Hershey–Chase experiment.



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## The Hershey and Chase Experiment | Discovery of DNA as the geneti...

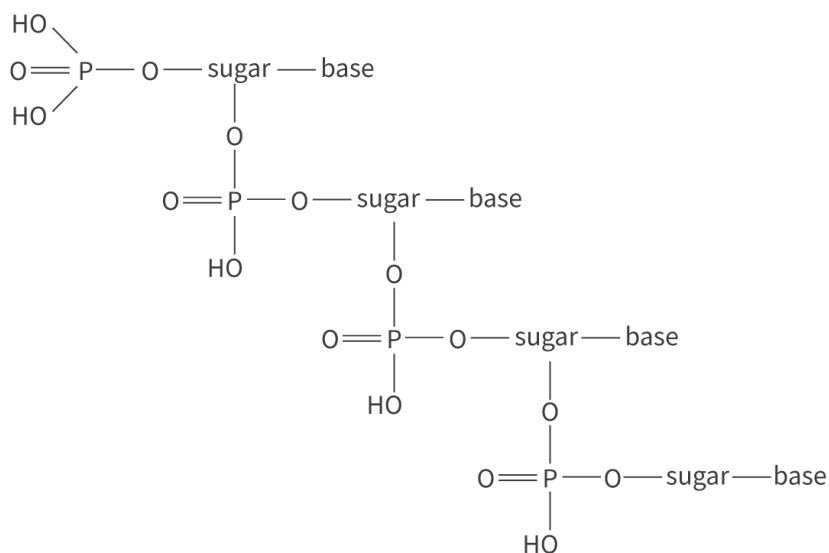


**Video 1.** The Hershey—Chase experiment.

These findings suggest that the DNA component of the bacteriophages is injected into the bacterial cell, while the protein component remains outside. As the DNA entered the bacteria and caused the formation of radioactive bacteriophages, it showed that DNA was the genetic material.

### Chargaff's data

Before the work of Erwin Chargaff it was thought that DNA was single-stranded and was organised into repeating units of tetranucleotides. Refer to **Figure 3**, which implies that the DNA was made up of equal amounts of adenine, guanine, cytosine and thymine.



**Figure 3.** The tetranucleotide model.

More information for figure 3



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The image is a diagram of a tetranucleotide model, illustrating three nucleotide units connected sequentially. Each unit consists of a phosphate group, a sugar group and a base. The phosphate group is shown at the left-end of each nucleotide, with the chemical structure 'O-P-O' repeating vertically. The sugar, represented as "sugar," connects the



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phosphate to the base, represented by the word "base" on the right side of each unit. The structure repeats three times, showing the linkage typical of a nucleotide chain. This model reflects the earlier belief that DNA was composed of repeating tetranucleotide structures, integrating equal parts adenine, guanine, cytosine, and thymine.

[Generated by AI]

Erwin Chargaff analysed different samples of DNA using a technique called paper chromatography to separate the components of the DNA and measure the relative concentrations of the bases adenine, thymine, guanine and cytosine. His conclusion, using samples from different organisms, was that the amount of adenine is equal to the amount of thymine and the amount of cytosine is equal to the amount of guanine. These findings supported the double helix model and gave clues about complementary base pairing.

This crucial evidence was eventually used by Crick and Watson to build their double helix model.

## Nature of Science

### Aspect: Falsification


You should understand how the 'problem of induction' is addressed by the 'certainty of falsification'. In this case, Chargaff's data falsified the tetranucleotide hypothesis that there was a repeating sequence of the four bases in DNA.

Try the following activity to understand how Hershey and Chase came up with their conclusion.

## Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Thinking skills: Providing a reasoned argument to support conclusions
- **Time required to complete activity:** 30 minutes
- **Activity type:** Group activity

Follow the steps in the simulation to replicate the Hershey—Chase experiment:

<http://genecube.org/HersheyChase/HersheyChase.html>   
(<http://genecube.org/HersheyChase/HersheyChase.html>).

Click on the 'Info and to do' button for instructions on how to operate the simulation.

Through their experiment, Hershey and Chase found that:



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When bacteriophages containing radioactive phosphorus ( $^{32}\text{P}$ ) were allowed to infect non-radioactive bacteria, all the infected cells became radioactive. Additionally, the next generation of bacteriophages, produced from the infected bacteria, were all radioactive. However, when the bacteria were infected with bacteriophages labelled with radioactive sulfur ( $^{35}\text{S}$ ) and the virus coats removed (by agitating them in an electric blender), almost no radioactivity could be detected in the infected cells.

Note: Pellets contain the infected bacteria and supernatants contain the virus.

Table 1 shows simplified data from the Hershey—Chase experiment.

Table 1. Simplified data.

Time of blending (minutes)	Percentage of isotopes in supernatant following infection with radioactive bacteriophage (extracellular)	
	$^{35}\text{S}$ (%)	$^{32}\text{P}$ (%)
0	18	18
2	75	30
4	77	35
6	80	35
8	80	35

- Use the data in Table 1 to draw a graph to show the difference in percentages of radioactive isotopes. Hint: The x-axis indicates the blending time; the y-axis indicates the percentage of isotopes in supernatant (extracellular) following infection with a radioactive bacteriophage.

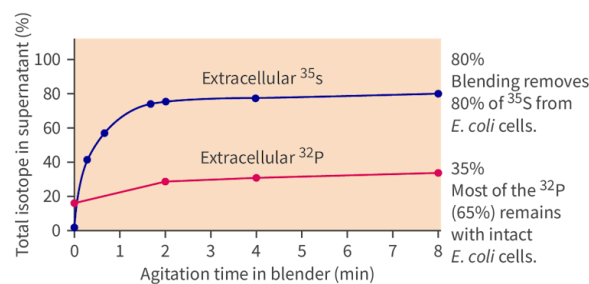


Figure 4. Change in the percentage of extracellular  $^{35}\text{S}$  and  $^{32}\text{P}$  over 8 minutes.



Explain why the genetic material was detected in the pellet not the supernatant.

- Explain the evidence from the data that the genetic material is DNA not protein.



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2. Evaluate the procedure carried out by Hershey and Chase to determine the nature of genetic material.

## 5 section questions ✓

A1. Unity and diversity: Molecules / A1.2 Nucleic acids

# Summary and key terms

- Nucleic acids are polymers of nucleotides. Nucleotides are made up of a pentose sugar, nitrogenous base and phosphate group that join together by a condensation reaction to form a polymer. The bond that forms is a covalent bond between the phosphate group attached to the 5' C of one pentose sugar and the -OH group attached to the 3' C of another sugar to form the sugar-phosphate backbone.
- RNA and DNA nucleotides are different. The pentose sugar present in RNA nucleotides is ribose, and its nitrogenous bases consist of adenine, guanine, cytosine and uracil. On the other hand, DNA nucleotides feature deoxyribose as their pentose sugar, and their nitrogenous bases include adenine, guanine, cytosine and thymine.
- DNA and RNA are two types of nucleic acids that play an important role in cell functions. Both DNA and RNA are polymers of nucleotides. The DNA polymer is double-stranded while the RNA polymer is single-stranded.
- Complementary base pairing plays a crucial role in facilitating precise and consistent DNA replication and gene expression. Moreover, it serves to stabilise the DNA double helix structure. This pairing mechanism relies on hydrogen bonding between the base pairs within the DNA molecule.
- The sequence of nitrogenous bases establishes the foundation of the genetic code. This genetic code is universally shared among all living organisms, providing evidence for the common ancestry of all life forms. Furthermore, DNA possesses a huge capacity for storing information.

## Higher level (HL)

- Replication, transcription and translation occur in a 5'-3' direction to ensure consistency of the reading frame.
- Eukaryotic DNA is always associated with proteins called histones in the nucleus. This is in contrast to prokaryotic DNA, which is found in the cytoplasm and lacks histones, and is therefore often referred to as 'naked' DNA.
- A nucleosome consists of a length of DNA of about 150 base pairs, wrapped around a core of eight histones (which are actually four pairs of four different histones) and a special histone named H1. Wrapping the DNA is significant to facilitate gene expression.



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- Alfred Hershey and Martha Chase conducted an experiment to prove that the genetic material is made up of DNA, and not protein.
- According to Chargaff, in any form of life the percentage of adenine is equal to the percentage of thymine and the percentage of cytosine is equal to the percentage of guanine. However, the concentrations of cytosine, guanine, adenine and thymine are different in different forms of life.



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## Key terms

**Review these key terms. Do you know them all? Fill in as many gaps as you can using the terms in this list.**

1. Nucleic acids are polymers of repeating units called \_\_\_\_\_.
2. There are two types of nucleic acids: deoxyribonucleic acid and \_\_\_\_\_.
3. Nucleotides are made up of a \_\_\_\_\_ base, \_\_\_\_\_ sugar and \_\_\_\_\_ group.
4. There are two main types of nitrogenous bases: \_\_\_\_\_ are bases that contain two rings such as adenine. \_\_\_\_\_ are nitrogenous bases that contain one ring such as thymine.
5. There are some differences between DNA and RNA. The main difference is that DNA contains \_\_\_\_\_ sugar, while RNA contains \_\_\_\_\_. The DNA molecule is \_\_\_\_\_, on the other hand the RNA molecule is \_\_\_\_\_.
6. Complementary \_\_\_\_\_ refers to the rule that adenine always binds with thymine and cytosine always binds with guanine in a DNA molecule.
7. [HL] The eukaryotic DNA is associated with proteins called \_\_\_\_\_ to form structures called \_\_\_\_\_ that are important in regulating \_\_\_\_\_.
8. [HL] Hershey and Chase discovered that the \_\_\_\_\_ is DNA not proteins.
9. [HL] Chargaff concluded that in any form of life the percentage of \_\_\_\_\_ is equal to the percentage of thymine and the percentage of cytosine is equal to the percentage of \_\_\_\_\_.

nucleosomes

pentose

deoxyribose

nucleotides

double stranded

gene expression

genetic material

ribonucleic acid

purines

adenine

histones

guanine

phosphate

base pairing

single stranded

ribose

Pyrimidines

nitrogenous



Check

### Interactivity 1. Nucleic Acids: Key Terms and Concepts Quiz.



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A1. Unity and diversity: Molecules / A1.2 Nucleic acids



# Checklist

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## What you should know

After studying this subtopic you should be able to:

- Draw and explain the structure of a nucleotide.
- Describe the formation of the sugar-phosphate backbone by nucleotide polymerisation in DNA and RNA.
- State and compare the nitrogenous bases in each nucleic acid (DNA and RNA).
- Draw and identify diagrams of the structure of single DNA and RNA nucleotides.
- Draw and identify diagrams of the structure of DNA and RNA polymers.
- Explain the complementary pairing in a double-strand structure of DNA.
- Describe the alpha helix shape of a DNA molecule.
- Explain the importance of complementary base pairing in allowing genetic information to be replicated and expressed.
- Explain that diversity of any length of DNA molecule and base sequence is possible, as there is an enormous capacity of DNA for storing data.
- Outline the conservation of the genetic code across all life forms as evidence of universal common ancestry.

## Higher level (HL)

- Explain the significance of 5'—3' linkage in the sugar-phosphate backbone of DNA for replication, transcription and translation.
- Describe how complementary base pairing stabilises the DNA double helix.
- Explain the structure of a nucleosome.
- Explain how the findings of the Hershey-Chase experiment support the conclusion that DNA is the genetic material.
- Explain how Chargaff's data on the relative amounts of pyrimidines and purine bases across forms of life demonstrated complementary base pairing.

A1. Unity and diversity: Molecules / A1.2 Nucleic acids

# Investigation



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- **IB learner profile attribute:** Thinkers, Communicators

- Communication skills – Presenting data appropriately.
- **Time required to complete activity:** 1 hour
- **Activity type:** Individual work/Pair work

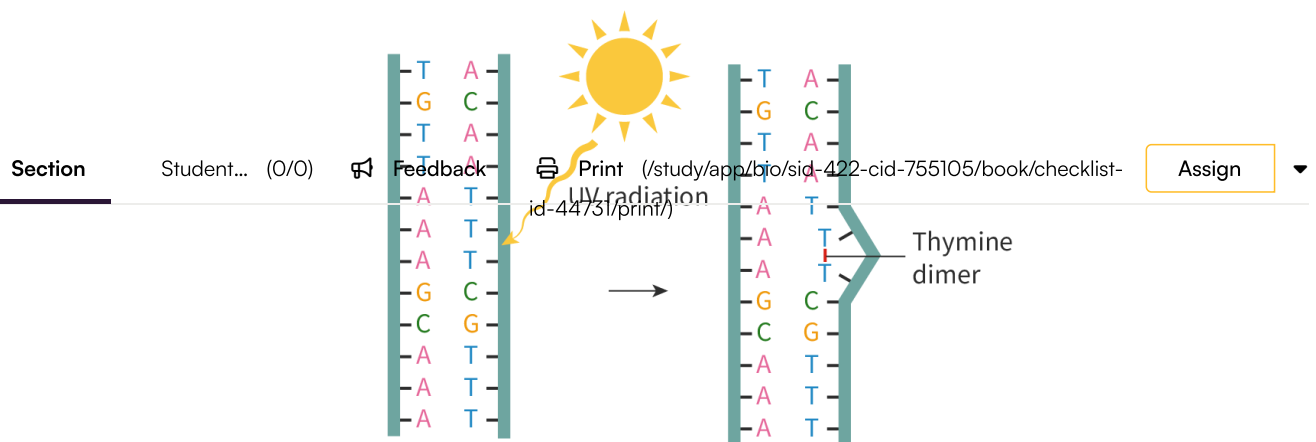
## Your task

Have you ever thought about why sunlight exposure can impact the structure of your DNA?

How effective is the use of sunscreen in protecting your skin from DNA damage caused by exposure to sunlight?

## Task 1

The structure of the DNA double helix is very stable under normal conditions due to the cross-bridges between bases. However, under certain environmental conditions the structure of the DNA can change, which might cause damage to the DNA. Exposure to sunlight is a major risk factor for skin cancer as ultraviolet radiation from the sun can induce DNA damage. The exposure to UV-radiation from the sun can impact the structure of the DNA by causing two adjacent thymines on the same DNA strand to covalently bind, causing what is called the thymine dimer (**Figure 1**).



**Figure 1. Formation of the thymine dimer.**

 More information for figure 1

The diagram illustrates the formation of a thymine dimer in DNA due to UV radiation. On the left, two parallel strands of DNA are shown with their bases labeled: adenine (A), thymine (T), cytosine (C), and guanine (G). These bases are paired across the two strands, showing the typical A-T and C-G pairings. In the middle of the image, a sun icon emits UV radiation toward the DNA, indicated by a wavy arrow labeled "UV radiation." To the right, the DNA strand shows a disruption where two adjacent thymine bases have formed a dimer, labeled as "Thymine dimer," causing a kink in the DNA structure.



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1. Predict the possible consequence of the thymine dimer formation on the complementary base pairing in the DNA.
2. Predict the impact of the thymine dimer induced by exposure to UV on the stability of the DNA double helix.
3. Describe the possible impact of this mutation on gene expression.

1. The formation of a thymine dimer, induced by UV exposure, disrupts the normal complementary base pairing in DNA. This disruption can lead to errors during DNA replication and transcription processes.
2. Complementary base pairing stabilises the DNA double helix/the formation of thymine dimers disrupts the regular hydrogen bonding pattern in the DNA double helix. It introduces a bulky and distorted region, causing a local distortion in the DNA molecule. As a result, the DNA helix becomes destabilised in that specific region, affecting its overall stability.
3. Gene expression is the process by which the genetic code in the DNA is translated into a protein. The presence of thymine dimers interferes with transcription by creating physical blocks on the DNA template, hindering the progression of transcription. This can lead to the termination of transcription. It can also induce errors during transcription which might result in the production of an abnormal protein.

## Task 2

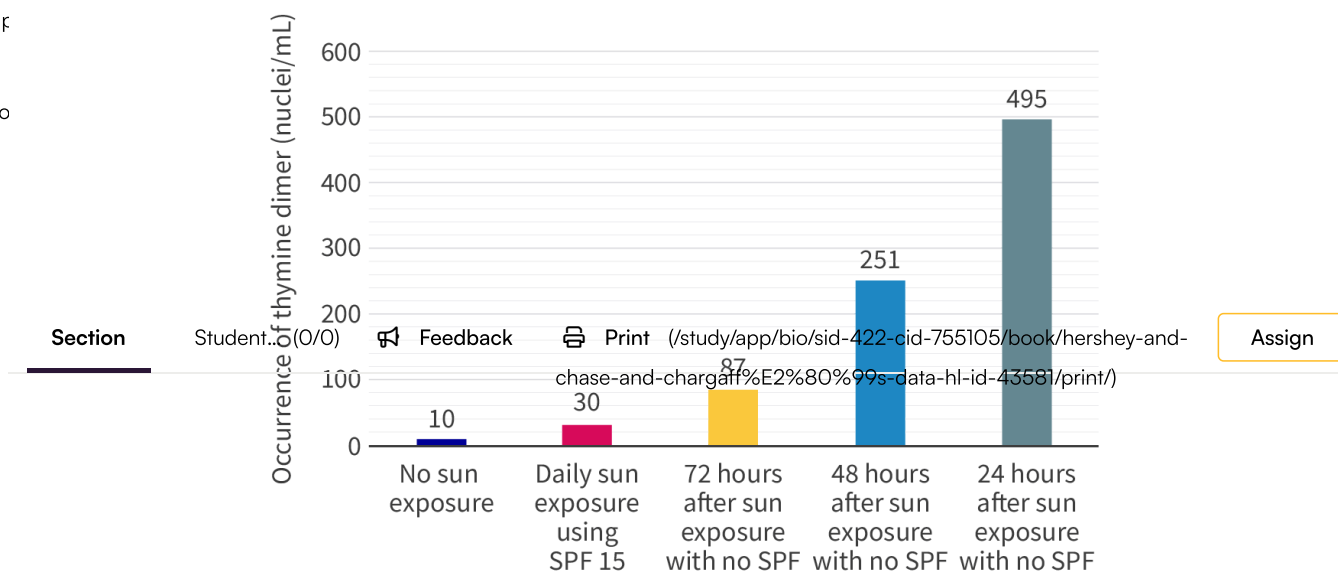
A study has been conducted to determine whether using sunscreen with a sun protection factor (SPF) of 15 protects human skin against UV-induced DNA damage as determined by the formation of thymine dimers. Study **Figure 2** and answer the following questions.



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**Figure 2.** Effect of SPF 15 on the formation of thymine dimers.

More information for figure 2

The bar chart illustrates the occurrence of thymine dimers in nuclei per milliliter under various sun exposure conditions and the use of SPF 15. The Y-axis represents the occurrence of thymine dimers, ranging from 0 to 600 nuclei/mL. The X-axis lists different conditions: 'No sun exposure' with a value of 10 nuclei/mL, 'Daily sun exposure using SPF 15' with 30 nuclei/mL, '72 hours after sun exposure with no SPF' with 87 nuclei/mL, '48 hours after sun exposure with no SPF' with 251 nuclei/mL, and '24 hours after sun exposure with no SPF' with 495 nuclei/mL. The bars show a trend where the levels of thymine dimers increase significantly as the time after sun exposure without SPF increases.

[Generated by AI]

1. Distinguish the formation of thymine dimers between the two scenarios: one where daily sunscreen with SPF 15 is used, and another where no protection is used and the skin is exposed to the sun for 24 hours.
2. Based on this study, discuss the degree to which SPF 15 sunblock provides protection against DNA damage.
3. Suggest a reason why the formation of thymine dimers may decrease after exposure to the sun for 72 hours.

1. The occurrence of thymine dimer formation shows a significant rise following 24 hours of unprotected sun exposure. A study indicated that the number of nuclei containing thymine dimers per millilitre (nuclei/mL) increased to 495 after 24 hours of sun exposure, whereas it was only 30 nuclei/mL when SPF 15 sunblock was used daily during exposure.
2. Compared to the negative control group with no sun exposure, the application of SPF 15 sunblock during daily sun exposure resulted in an increase from 10 nuclei/mL to 30



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nuclei/mL. This indicates that SPF 15 protection did not completely prevent the formation of thymine dimers. However, when compared to the group exposed to the sun without any protection, which had 495 nuclei/mL after 24 hours, the use of SPF 15 was significantly effective in reducing the number of thymine dimer nuclei.

- One possible reason for the decrease in thymine dimer formation after 72 hours of sun exposure could be the activation of DNA repair mechanisms. Our cells have repair systems specifically designed to recognise and correct DNA damage, including the repair of thymine dimers. These repair mechanisms can be activated in response to prolonged exposure to UV radiation. Over time, the repair processes work to remove or repair the thymine dimers, leading to a reduction in their overall formation.



## Practical skills

### Tool 3: Mathematics — Graphing

One of your objectives is to analyse, evaluate and synthesise experimental procedures, primary and secondary data and recognise patterns and predictions. This skill can be enhanced by practicing solving questions in unfamiliar situations. Database questions are often based on research papers, graphs and data and the key is to read the question thoroughly. Do not be confused by any long or unfamiliar terms as the question will not be about the terms but rather about what you can conclude from the data.

Learning command terms is very important. When you describe trends, use terms such as: gradual increase/decrease, significant increase/decrease, fluctuations, error bars overlap. Be as descriptive as possible when you answer such questions.

A1. Unity and diversity: Molecules / A1.2 Nucleic acids

# Reflection

Section

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Feedback



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Assign



## Teacher instructions

The goal of this section is to encourage students to reflect on their learning and conceptual understanding of the subject at the end of this subtopic. It asks them to go back to the guiding questions posed at the start of the subtopic and assess how confident they now are in answering them. What have they learned, and what outstanding questions do they have? Are they able to see the bigger picture and the connections between the different topics?

Students can submit their reflections to you by clicking on 'Submit'. You will then see their answers in the 'Insights' part of the Kognity platform.



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## Reflection

Now that you've completed this subtopic, let's come back to the guiding questions introduced in [The big picture \(/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43236/\)](#).

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

With these questions in mind, take a moment to reflect on your learning so far and type your reflections into the space provided.

You can use the following questions to guide you:

- What main points have you learned from this subtopic?
- Is anything unclear? What questions do you still have?
- How confident do you feel in answering the guiding questions?
- What connections do you see between this subtopic and other parts of the course?

 Once you submit your response, you won't be able to edit it.

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Submit

### Rate subtopic A1.2 Nucleic acids

Help us improve the content and user experience.



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