TOPIC 1 Hydrogen bonds and water

TN1

Basic concepts

Hydrogen bonds are important in the structure and function of biological molecules. They form between hydrogen and oxygen atoms on adjacent molecules, and between hydrogen and nitrogen atoms. Hydrogen bonds are weaker than covalent bonds.

The properties of water are vital to organisms. The special properties of water are linked to hydrogen bonding between water molecules (and between water molecules and other molecules).

The two strands of the DNA double helix are held together by hydrogen bonds between specific bases. Hydrogen bonds give strength to cellulose and chitin, which are two of the commonest biological molecules.

How Science Works

This topic allows students to apply knowledge to novel contexts.

Points for class discussion

- Water has unique properties that are essential for life on Earth. These properties are linked to the formation of hydrogen bonds.
- Hydrogen bonds are much weaker than covalent bonds, but are important in many biological molecules.
- Water molecules stick together and to many other molecules.
- Water is liquid at normal physiological and (most) environmental temperatures; ice floats on water.
- Water is a good solvent; most biological reactions take place in solution in water.
- Water has a high specific heat.
- Hydrogen bonds are critical to the structure and function of many biological molecules, particularly DNA.

Required knowledge

It is assumed that students have basic knowledge of GCSE chemistry and have been taught about the structure of carbohydrates and DNA.

Note: Details of transcription and translation are not appropriate to AS level.

Materials

For this topic, students only require rulers and photocopies of the worksheets.

Lesson structure

1 The lesson should start with class discussion about:
- hydrogen bonds and their importance to organisms
- the special properties of water related to hydrogen bonds
- the formation of hydrogen bonds in DNA being significant for all organisms
- the strength of two of the commonest biological molecules being related to the formation of hydrogen bonds

2 **Ws1** should be distributed. Students could work either individually or in small groups.

Hydrogen bonds and water

3 **Ws2** should be distributed. The tasks on this sheet require the application of knowledge and interpretation of data. These are skills that students should develop on an individual basis. **Ws2** is suitable for use as a homework sheet.

4 **Conclusion** The lesson could end with a discussion about how things as weak as hydrogen bonds have such a huge impact on life. We wouldn't have oceans or fresh water (at the temperatures on Earth) without H bonds. Our bodies wouldn't retain or get rid of heat as efficiently if there were no H bonds between water molecules.

Many of the commonest and strongest molecules in living organisms owe their strength to H bonding — each one weak but together immensely strong.

DNA is held together by H bonds — and, as the students will find out later, H bonding allows DNA replication and protein synthesis to occur in cells. Without H bonding there would be no transmission of information from one generation to the next — or even from cell to cell. Everything they will learn about genetics (and, indirectly, evolution) hinges upon complementary H bonding/specific base pairing — A to T and C to G.

Hydrogen bonds and water

There is emphasis here on the application of knowledge. Command words such as 'explain' and 'suggest' are used frequently. 'Explain' is used if there is only one reasonable answer, even if the content is novel. 'Suggest' implies that there may be more than one reasonable answer.

Answers to questions on Ws1

1 (a) Carbohydrate molecules have OH groups; **(1)**
(b) Amino acids have O-containing groups;
They also have N-containing groups; **(2)**

2 Layer of less dense ice forms/floats on the surface but water beneath remains liquid;
So organisms can survive beneath the ice; **(2)**

3 Surface film held together by weak hydrogen bonds, so is not very strong;
Can only support organisms with a low body mass; **(2)**

4 Columns of water in the xylem;
Water evaporates from the top and pulls the column up;
This brings water up the xylem tubes from the roots;
Together with mineral ions dissolved in water; **(2) max**

5 Triglycerides are made of fatty acids (and glycerol);
Fatty acids are long-chain molecules/do not have (effectively) oxygen or nitrogen-containing groups/ionic or polar groups;
So are not soluble in water/cannot form hydrogen bonds with water; **(3)**

It could also be argued that the molecules are too large to be soluble.

6 Sweat is mainly water;
The water evaporates;
This requires a lot of heat energy;
Needed to break H bonds;
This energy is taken from the skin/blood, so has a cooling effect; **(3) max**

7 Large animals contain a lot more water;
Water has to lose a lot of heat energy to cool down;
Larger animal cools more slowly/holds heat better; **(2) max**

Hydrogen bonds and water

With regard to DNA, the emphasis here is on structure, rather than function. This lays a foundation for later parts of the course. At AS, students should be aware of the structure of nucleic acids, the relationship between base sequence in nucleic acids and amino acid sequence in proteins, and the differences between the structures of nucleic acids.

Answers to questions on Ws2

1 (a) Two dashed lines between thymine and adenine;
Three dashed lines between cytosine and guanine; **(2)**
(b) Formed between hydrogen and oxygen, and between hydrogen and nitrogen on adjacent molecules;
Where the relevant atoms are close together; **(2)**

2 (a) Higher temperature, so more heat energy;
This breaks weak hydrogen bonds between the strands;
Does not break the covalent bonds within each individual strand; **(2) max**
(b) Three hydrogen bonds between G and C, compared with two between A and T;
The more G to C base pairs there are, the more hydrogen bonds there are holding the DNA strands together;
The more hydrogen bonds holding DNA together, the more heat energy is needed to break the strands apart; **(3)**

3 (a) Lines through/next to oxygen atoms forming links between monomers; **(1)**
(b) Chitin contains nitrogen, cellulose does not;
Chitin has longer side chains containing N and O; **(2)**
(c) Asterisks where oxygen and nitrogen occur; **(1)**
(d) Many places where hydrogen bonds could form between adjacent molecules;
(Each hydrogen bond is weak but) added together, they bind the molecules together strongly; **(2)**

TOPIC 1

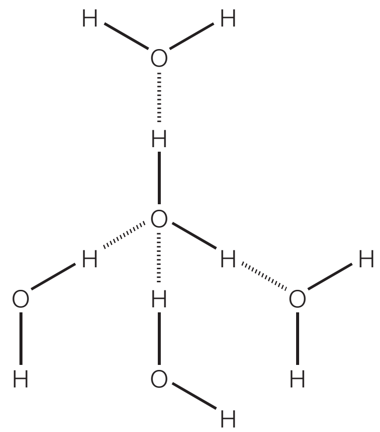
Hydrogen bonds and water

WS1

Read the following passage.

Hydrogen bonds can form between hydrogen and oxygen atoms on neighbouring molecules and between hydrogen and nitrogen atoms on neighbouring molecules. Hydrogen bonds are 'weak'. They are about one-tenth as strong as the covalent bonds that hold together the atoms in molecules.

Water molecules are held together by hydrogen bonds that form between hydrogen and oxygen atoms on neighbouring water molecules. It is the hydrogen bonds that give water its special properties.



Hydrogen bonding between water molecules is the reason that water is a liquid at normal physiological temperatures. Most molecules of a similar (or even larger) size are gases at these temperatures — for example, carbon dioxide. Hydrogen bonding also leads to water having its greatest density at 4°C.

Water molecules show cohesion — they stick together. This causes the surface tension 'film' on water. It also leads to the formation of 'columns' of water in the xylem vessels of plants. The xylem consists of continuous, water-filled tubes that lead from the roots to the leaves of plants.

Hydrogen bonding makes water a good solvent for many biological molecules that have polar or ionic groups on them.

Compared with most other liquids, water has a high specific heat. This means that it absorbs a lot of heat energy for every 1°C it increases in temperature. It also means that it has to lose a lot of heat energy for every 1°C fall in temperature.

Use the information from this passage and your own knowledge to answer the following questions.

1 Explain why hydrogen bonds can form between:
(a) neighbouring carbohydrate molecules **(1)**

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(b) neighbouring amino acids (2)

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2 In aquatic environments where winter temperatures fall below freezing, it is important to many organisms that water is at its most dense at 4°C. Suggest why. (2)

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3 Many small insects and water plants live on the surface film of the water in ponds and lakes. Suggest why only small organisms can do this. (2)

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4 Water evaporates from leaves and is replaced by water from xylem in the leaves. Evaporation of water from the leaves causes water and mineral ions to rise up from the roots. Suggest how. (2)

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Hydrogen bonds and water

5 Lipids, for example triglycerides, are not soluble in water. Explain why. (3)

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6 Sweating helps us to cool down when we are too hot. Explain how. (3)

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7 In very cold environments, large animals have fewer problems in maintaining a constant body temperature than small animals.

This difference is due partly to their different water contents. Explain why. (2)

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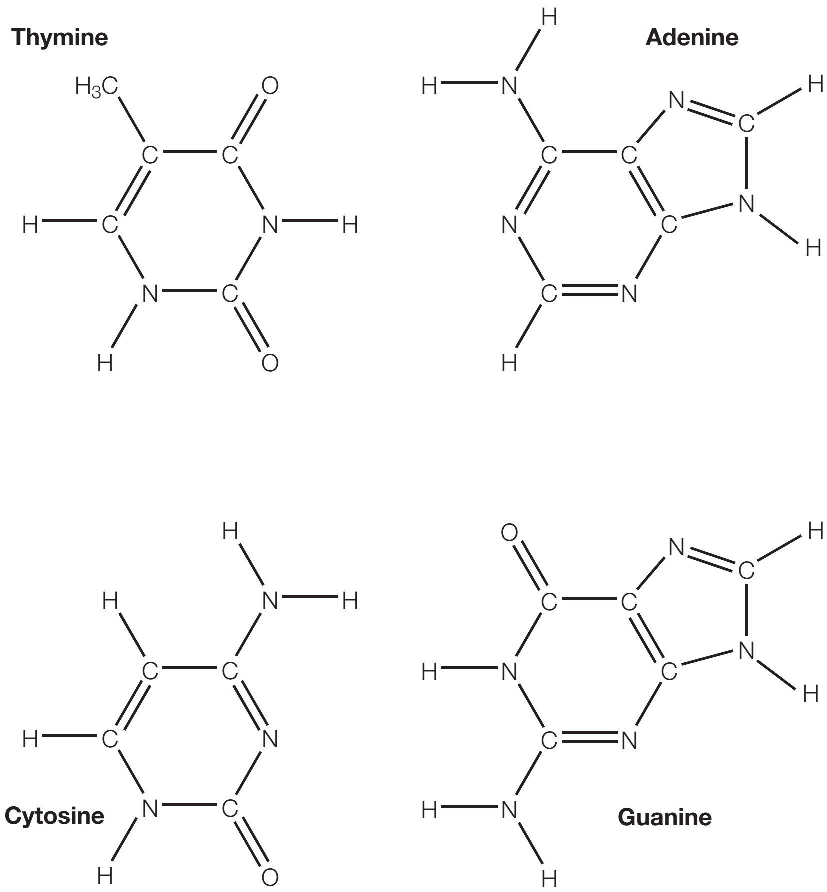
Hydrogen bonds and water

Hydrogen bonds and DNA

Hydrogen bonds hold the two strands of the DNA double helix together. They form between adenine and thymine, and between cytosine and guanine. Hydrogen bonds form between a hydrogen atom on one base and either an oxygen atom or a nitrogen atom on the complementary base, in positions where the hydrogen and oxygen or nitrogen are close enough.

1 (a) Draw dashed lines on the diagram to show where hydrogen bonds form between T and A and between C and G. **(2)**



(b) Explain why hydrogen bonds form where you indicated. **(2)**

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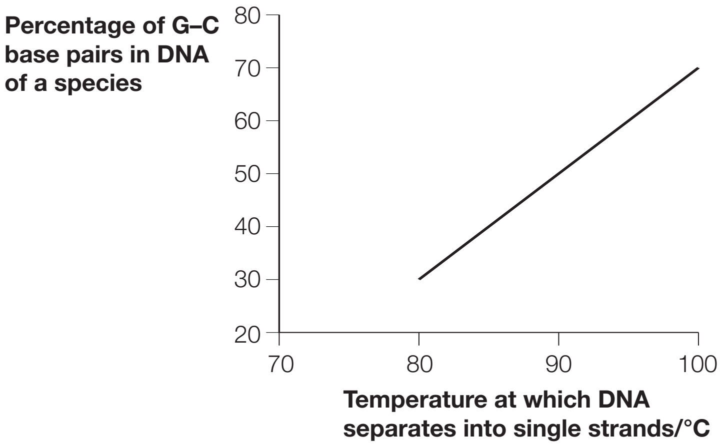
Hydrogen bonds and water

2 Analysis of DNA from different species has shown that the percentage of G–C base pairs varies between species. The percentage of G–C affects how easily the double helix is separated into single strands by heat. The graph below shows this relationship.



Graph showing the relationship between percentage of G–C base pairs in DNA and the temperature at which DNA separates into single strands

(a) How does raising the temperature cause the DNA double helix to separate into single strands? **(2)**

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(b) Suggest an explanation for the relationship shown in the graph. **(3)**

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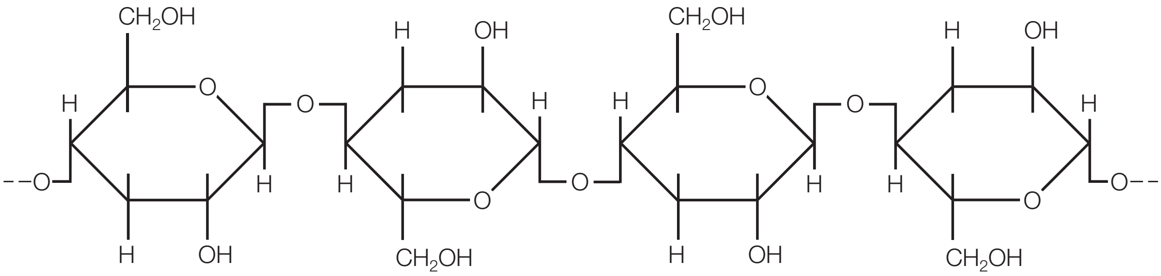
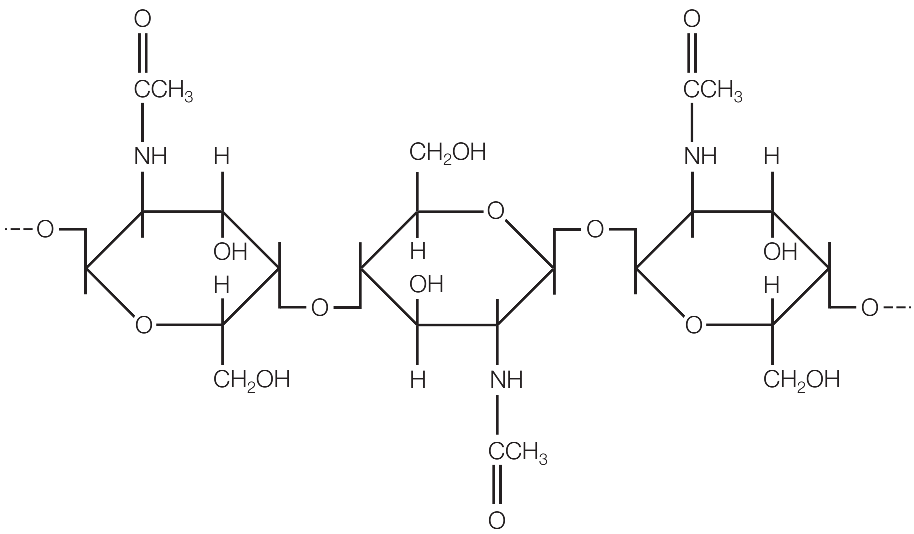
Hydrogen bonds, cellulose and chitin

3 Cellulose is probably the commonest biological molecule. It is the major component of the cell wall of plant cells. Chitin forms part of the cell wall of fungi and the exoskeletons (hard outer coverings) of some invertebrates — for example, insects. Both molecules are long polymers. There are hydrogen bonds between neighbouring cellulose molecules and between neighbouring chitin molecules. The diagram shows part of a cellulose molecule and part of a chitin molecule.



Cellulose



Chitin

(a) On the diagrams of cellulose and chitin, draw lines to show where the monomers are joined. **(1)**

(b) Describe the differences between the monomers of cellulose and chitin. **(2)**

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(c) On the diagrams of cellulose and chitin, use asterisks (*) to indicate parts of the molecules where hydrogen bonds could form. (1)

(d) Individual hydrogen bonds are weak but the hydrogen bonds between cellulose molecules and between chitin molecules make these substances very strong. Suggest how. (2)

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