TOPIC A1
UNITY AND DIVERSITY: MOLECULES

SUBTOPIC A1.1
WATER

A1.1.0 The big picture

A1.1.1-3 Structure of water

A1.1.4-5 Interactions with water

A1.1.6 Living things and water

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A1.1 Teacher view

Water

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A1. Unity and diversity: Molecules / A1.1 Water

The big picture

? Guiding question(s)

- What physical and chemical properties of water make it essential for life?
- What are the challenges and opportunities of water as a habitat?

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.

From the inner workings of our cells to the life-sustaining climate of our planet, every aspect of our existence depends on water. Useful and unusual properties emerge from water's simple formula, H_2O – two hydrogen atoms attached to an oxygen atom by a covalent bond.

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This subtopic will focus on the chemical structure of water (*Molecules* level of organisation) and how its properties have shaped the nature of all life on Earth – and possibly beyond (*Unity and diversity* theme).

Look at **Figure 1**. How is water interacting with and affecting the person in the image? What makes water act in these ways?

Figure 1. A swimmer's interaction with water depends on water's physical properties.

Credit: technotr, Getty Images (https://www.gettyimages.co.uk/detail/photo/female-swimmer-royalty-free-image/176102617)

In **Figure 1**, a thin layer of water covers the swimmer as she emerges from the water. She propels herself forwards by pulling water backwards. The water counteracts the force of gravity, supporting her.

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Although we are used to how water behaves, the properties of water that explain these observations are unusual and interesting. You'll learn the reasons for all these properties of water in this subtopic.

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Prior learning

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

- There are 118 chemical elements, each with a specific number of protons leading to defining properties. These elements are the fundamental building blocks of matter.
- The structure of atoms includes protons and neutrons in the central nucleus and electrons in outside orbitals.
- The outermost electrons are known as valence electrons. Pairs of valence electrons can be shared between atoms forming covalent bonds. Valence electrons can be lost by an atom, creating a cation, or gained by an atom, creating an anion.

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Structure of water

A1.1.1: Water as the medium for life A1.1.2: Hydrogen bonds A1.1.3: Cohesion of water molecules

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Learning outcomes

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

- Explain that water is the substance in which cells first developed and life's processes still occur.
- Explain how a difference in electronegativity between two atoms results in a polar covalent bond.
- Draw two or more water molecules and hydrogen bonds between them with a notation to indicate polarity.
- Explain that water molecules are attracted to each other and that this property, cohesion, has important impacts on organisms.

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Water cycles through the ground, the atmosphere and the bodies of living things. It is also a link between biotic and abiotic molecules. Water is needed by every living thing on Earth. Understanding the chemical structure of water will help you understand why it acts the way it does, whether in everyday situations such as drinking a glass of water, or on a less familiar scale, as seen in **Video 1**. The insect relies on the water remaining as drops, otherwise it would drown through its spiracles. But what properties of water molecules cause the drop to retain its form?

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Video 1. A Wood Ant (Formica rufa) Drinks a Droplet of Water.

More information for video 1

A video displays how a red wood ant drinks water. A large drop of water is on a broken branch of a tree.

In the video, a red wood ant approaches the large water drop. It has two antennae and six legs.

The ant supports itself with four legs near the droplet and places two legs on the broken edge of the branch as it drinks the water. As the video progresses, the ant moves to the upper surface of the branch and returns to drink water from the same droplet.

Further along, the ant moves on all sides of the branch and around the droplet, sometimes displaying its reflection in the water droplet.

This video highlights how ants drink water from the water's surface without drowning.

Student view

Water has always been essential to life

Although there are competing hypotheses about how the first cells originated (see subtopic A2.1 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43202/)), all agree that water was essential. Evidence suggests that liquid water has existed on Earth for more than four billion years. Water was required for:

1. Effective interaction of the naturally formed molecules of life, allowing growth and copying of these molecules.
2. Formation of compartments, which allowed the development of internal chemistry different from the surrounding environment.

Whatever the specifics may have been, living things have never stopped needing water, which remains abundant on Earth as a solid, liquid and gas. Living things are made up of one or more cells, and each cell contains cytoplasm, a water-based fluid. The chemical reactions that cells perform, known as metabolism, can only occur when the starting materials are in the watery environment of the cell (see subtopic C1.1 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43208/)). The plasma membrane, the barrier between the inside and outside of a cell, only functions in a watery environment (see subtopic B2.1 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43205/)).

Water was essential to the development of the first cells and remains essential as the medium, or facilitator, in which life's processes take place due to its solvent properties, which are covered in the next section.

The chemical structure of water

A water molecule is formed from one oxygen atom covalently bonded to two hydrogen atoms. However, the pair of electrons in each covalent bond is not shared equally between the oxygen and a hydrogen atom. This is because of a property called electronegativity, which measures how strongly the nucleus of an atom attracts the electrons it shares with another atom.

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Electronegativity is influenced by:

- **The number of protons in the nucleus.** Protons are positively charged and therefore attract the negatively charged electrons.
- **The number of orbital levels in the atom.** More orbital levels will decrease the pull on the shared electrons because they will be further away from the nucleus, and because the other negatively charged electrons will shield them from the positive charge of the nucleus.

Oxygen is more electronegative than hydrogen. Therefore, overall, the oxygen atom attracts the shared electrons more strongly than does the hydrogen atom. The uneven sharing of electrons is a polar covalent bond.

A water molecule is a polar molecule. As the shared electrons spend more time with the oxygen atom, the oxygen side of the atom has a partial negative charge, making it the negative pole. The hydrogen side has a partial positive charge, making it the positive pole. Note the geometry of the water molecule: the hydrogen atoms are at an angle (104.5°), not in a straight line. This is because the pairs of electrons repel each other, so they move as far apart as possible in three dimensions.

When drawing water, the element symbol is used to represent the atoms and a solid line is used to show a covalent bond. The superscript + and – symbols show the charge of the atom, and the small delta (δ) shows that the charge is partial. For example, the oxygen in water would be $O^{\delta-}$. The correct drawing for water is shown in **Figure 1**.

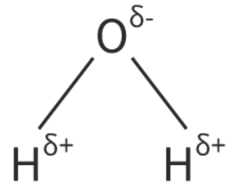

Figure 1. The polarity of water.

More information for figure 1

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The diagram represents the polarity of a water molecule. It features a central oxygen atom labeled "Oδ-" to denote the partial negative charge. The oxygen atom is positioned at the top center of the diagram. Two hydrogen atoms are bonded to the oxygen atom with covalent bonds represented by solid lines. Each hydrogen atom is labeled "Hδ+" to indicate the partial positive charge. The hydrogen atoms are located on the lower corners of the diagram, forming a V-shape with the oxygen atom. This configuration visually represents the molecular structure and charge distribution of water, reflecting its polar nature.

[Generated by AI]

Bonding between water molecules

The partially positive hydrogen side of one water molecule is attracted to the partially negative charge on the oxygen side of other water molecules. An intermolecular force, known as a hydrogen bond, holds the molecules together (**Figure 2**). Because the charges are partial, the bond is weak and is indicated by a dashed line in drawings. In water, hydrogen bonds break and reform rapidly between different molecules, whereas the polar covalent bonds break much less frequently.

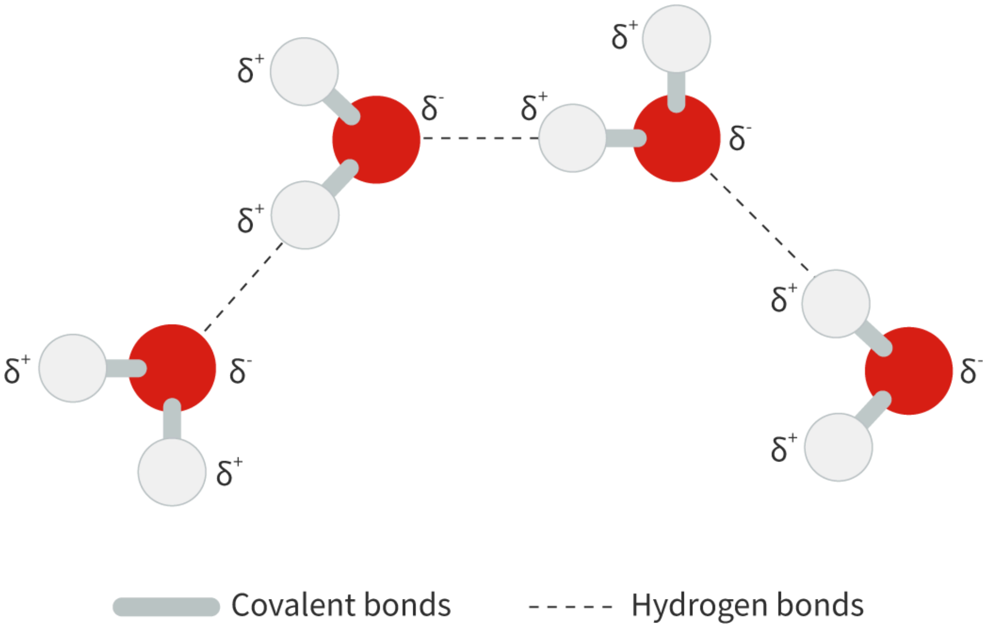

Figure 2. Hydrogen bonds between water molecules.

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More information for figure 2

The diagram illustrates four water molecules, depicted as a red circle (oxygen) connected to two smaller grey circles (hydrogens) by solid grey lines representing covalent bonds. These form a slight angle, typical of the structure of water molecules. Each oxygen atom is labeled with a partial negative charge (δ−), while each hydrogen atom has a partial positive charge (δ+). Dotted lines, labeled as hydrogen bonds, connect these water molecules. These lines indicate the attraction between the hydrogen atom of one water molecule and the oxygen atom of another, highlighting the intermolecular hydrogen bonding. Overall, this diagram demonstrates how the structure of water molecules allows them to form hydrogen bonds with each other. There is a key at the bottom indicating that solid lines represent covalent bonds and dashed lines represent hydrogen bonds.

[Generated by AI]

The structure of water leads to formation of chemical bonds: polar covalent bonds within water molecules and hydrogen bonds between them.

Study skills

When discussing bonding in water, be very clear about the difference between the bonds within a water molecule (polar covalent bonds) and intermolecular forces between water molecules (hydrogen bonds).

Cohesion and its consequences

Cohesion occurs when ‘like’ molecules are mutually attracted. Water is highly cohesive because of the hydrogen bonds between molecules.

Cohesion pulls water molecules together. The force of cohesion may counteract gravity, for example when water is pulled up into a domed droplet shape instead of being pulled flat. Vascular plants use the cohesion of water to transport water

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up thin tubes called xylem, reaching to the top of the plant, sometimes tens of metres above ground (**Figure 3**).

In the leaves of a tree, water evaporates from the surface of inner cell walls into air spaces in the leaf. As water molecules evaporate, they are replaced by water from within the cells. As more water molecules move from the xylem into the leaf, tension, a force to pull water against gravity, is transmitted down a continuous column of water molecules all the way to the root.

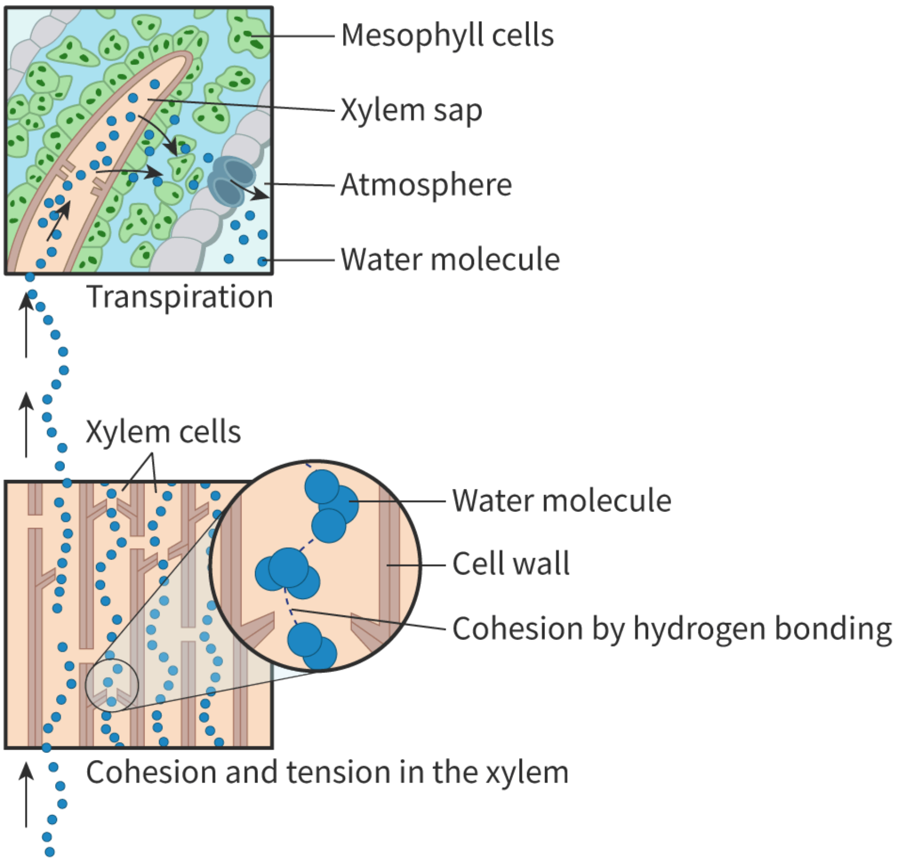

Figure 3. Cohesion is important in transporting water through xylem in vascular plants.

More information for figure 3

The image consists of two main parts, illustrating the processes of transpiration and cohesion in the xylem. At the top of the diagram, transpiration is depicted. The outer edge contains small blue shapes labeled 'water molecules.' Moving inward, there are large grey-blue shapes labeled 'atmosphere.' Next, there are green rounded shapes labeled 'mesophyll cells' on a blue background. At the center, a long brown oval labeled 'xylem sap' contains small blue shapes. Arrows point from the xylem sap to the mesophyll cells, indicating flow.

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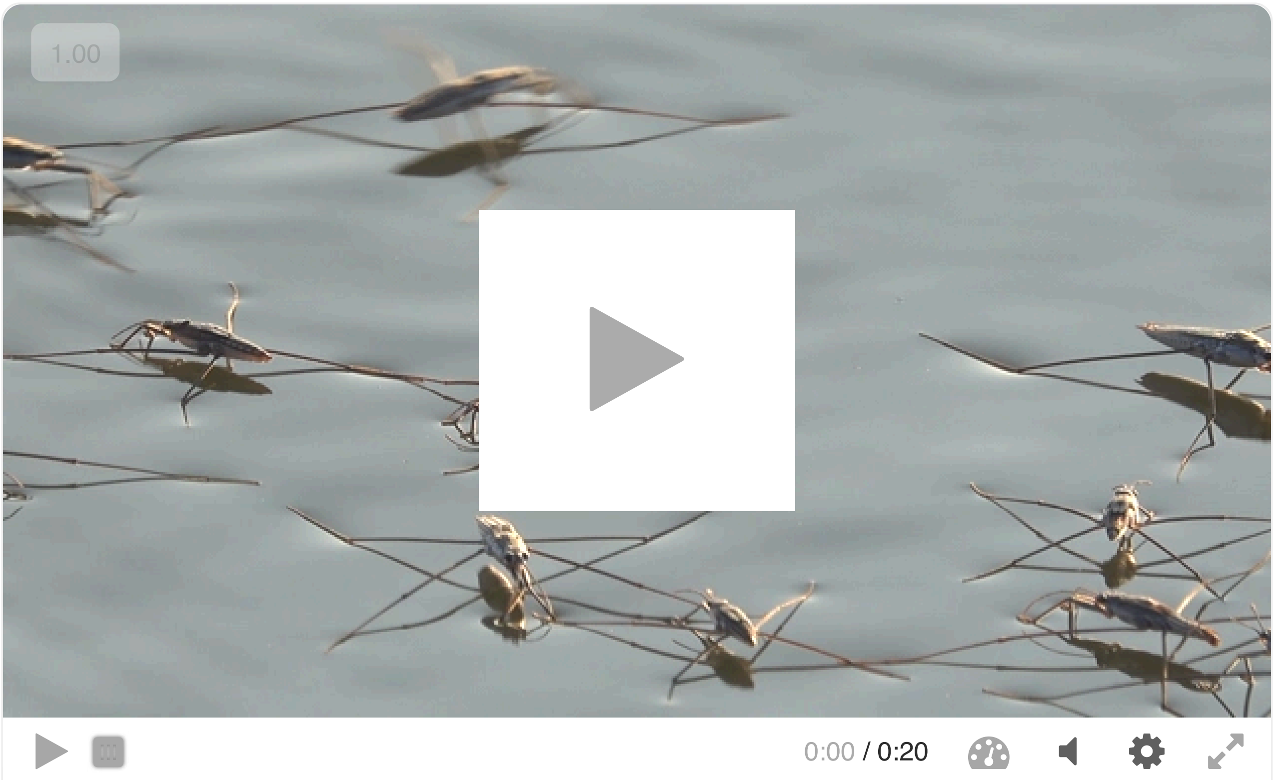
The lower part of the diagram illustrates cohesion and tension in the xylem. It consists of five columns of xylem walls, shown as vertical lines with gaps and branches. Between these columns are blue dots, labeled 'xylem cells.' A zoomed view shows each dot consisting of three smaller blue dots, labeled 'water molecules,' connected by dotted lines indicating 'cohesion by hydrogen bonding.'

[Generated by AI]

Due to the hydrogen bonds, water resists increase of its surface area, whether by gravity or by disruption from other objects. Some insects use the unusual strength of water's surface tension to create a habitat. Recall the ant drinking a droplet of water in **Figure 2**. Water striders (*Gerris lacustris*, also called pond skaters) live on the surface of relatively calm and unpolluted bodies of water – see **Video 2**. Calm water is needed to provide a stable and undisrupted surface; however, many pollutants, including detergents, interfere with surface tension and cause the water striders to sink.



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Video 2. A Group of Water Striders on the Surface of Liquid Water.

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More information for video 2

A video displays a group of water striders on a water body. The striders float on the surface of the water without immersing themselves. They have six legs, with the middle and hind legs being long and widely spread on the water.

The striders' legs do not break the water's surface, allowing them to stay afloat due to surface tension. They move rapidly by skating across the water.

This video helps users understand how the physical adaptations of water striders, such as hydrophobic legs and body structure, enable them to utilize surface tension to walk on water without sinking.

Try this activity to test your understanding of this section.

Activity

- **IB learner profile attribute:** Knowledgeable
- **Approaches to learning:** Thinking skills — Applying key ideas and facts in new contexts
- **Time required to complete activity:** 10 minutes
- **Activity type:** Individual and pair activity

1. Draw or describe what you know about the structure of hydrogen and oxygen atoms, the two elements that are combined in water. Remember that atoms do not have an overall charge. Then, reveal the images hidden below and compare with yours.

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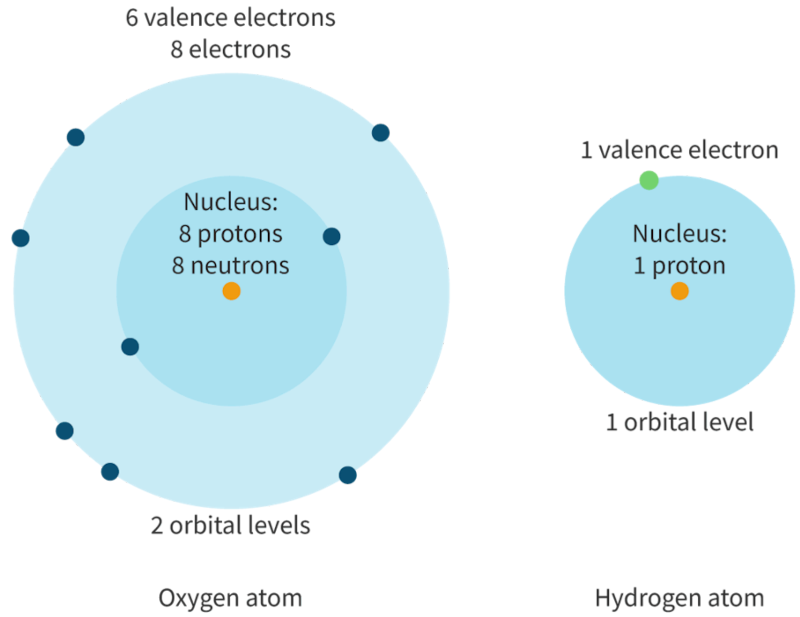

Structures of oxygen and hydrogen atoms, illustrating neutrons, protons and electrons.

2. The chemical formula for water is H_2O. This indicates that a molecule of water contains two hydrogen atoms and one oxygen atom, sharing electrons so that oxygen has eight valence electrons and each hydrogen has two.

   Draw and describe the structure of water molecules including how the electrons are arranged. Explain the type of bonding within a water molecule.

   Then look at **Interactive 1** and complete it by moving the hydrogen atoms to form a water molecule. Compare this arrangement of electrons to your drawing.

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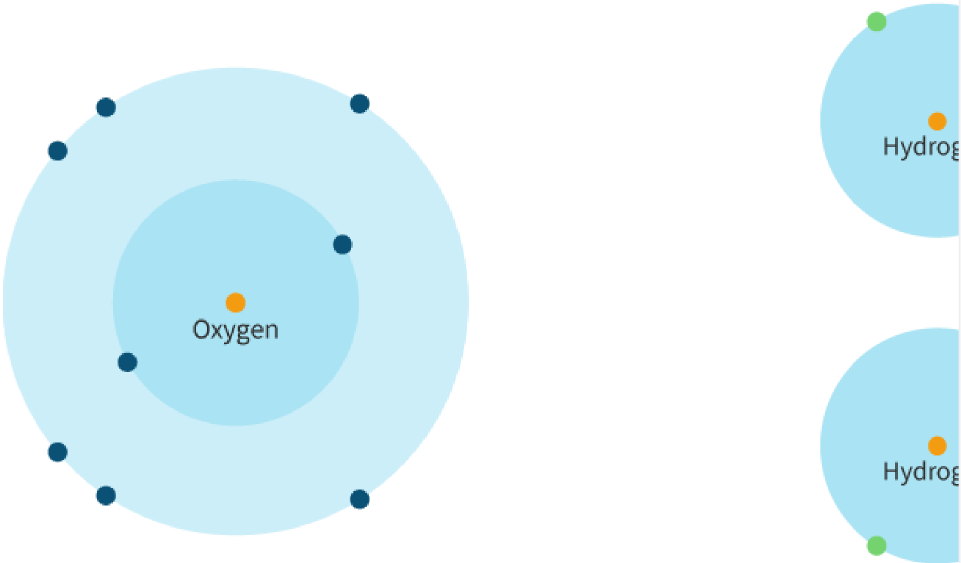

Check

Interactive 1. The Atomic Structure of Water.

More information for interactive 1

An interactive illustration displays the atomic structure of an oxygen molecule and two hydrogen molecules. An oxygen atom is positioned on the left, and two hydrogen atoms are placed on the right: one at the top and one below it. Users are expected to position the hydrogen atoms near the oxygen atom to form a water molecule.

The oxygen atom contains a nucleus in the center and two orbital levels. The first orbital level has two electrons, and the second has six electrons, featuring two on the top left, two on the bottom left, one on the top right, and one on the bottom right. The nucleus is depicted in orange and electrons are depicted in blue. The caption “Oxygen” is provided below the nucleus structure.

Each hydrogen atom has a central nucleus and one orbital level containing a single electron. The top hydrogen atom has its electron on the top left, and the bottom hydrogen has its electron on the bottom left. The caption “Hydrogen” is provided below the nucleus structure in each structure.

Users need to drag and drop the correct hydrogen atoms next to the oxygen

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atom in the drop boxes to form shared electron pairs. The “Check” icon at the bottom left allows users to check their answers. The right answer is indicated with a slider. If the inputted answers are wrong, the “Retry” icon at the bottom left allows users to retry the activity.

This illustration helps users understand the structure of oxygen and hydrogen atoms in water and how they share electrons.

Read below for the solution:

The top hydrogen atom should be positioned at the bottom right of the oxygen atom.

The bottom hydrogen atom should be positioned at the top right of the oxygen atom.

3. Think, pair, share. Work in pairs to draw the hydrogen bonds between at least ten water molecules. Make sure you include the small delta (δ^+ and δ^-) symbols to show the polar covalent bonds that exist in water molecules. Discuss the properties of water associated with hydrogen bonds. Share your findings.

5 section questions

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Interactions with water

A1.1.4: Adhesion of water to materials A1.1.5: Solvent properties of water

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Learning outcomes

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

- Explain how the properties of water affect its roles as a means of transport.
- Explain how the solvent properties of water are linked to its role as a medium for metabolism.

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- Explain how the cohesive and adhesive properties of water are linked to its role as a medium for transport in plants and animals.

Every organism on Earth relies on chemical reactions that can only happen in water. Each species has evolved strategies for interacting with water that meet the opportunities and challenges of their habitat. Tardigrades are microscopic animals (**Figure 1**) renowned for their amazing ability to survive nearly complete drying (desiccation). But this is unusual. Most organisms will not survive desiccation. Why is water so important to the maintenance of life?

Figure 1. An electron micrograph of a tardigrade.

Credit: STEVE GSCHMEISSNER/SCIENCE PHOTO LIBRARY, Getty Images (https://www.gettyimages.co.uk/detail/photo/tardigrade-sem-royalty-free-image/1155265546)

Water as a means for transport

Opposite charges attract, which means water isn't just attracted to itself (cohesion), but also to any other polar or charged material. The attraction between water and other materials is known as adhesion. Water's ability to adhere, or 'stick to' objects is so well known we have a term for it: to get wet.

Capillary action occurs when water is pulled through narrow tubes and space as a result of cohesion and adhesion (**Video 1**), which are two different properties. Cohesion is attraction between water molecules, whereas adhesion is attraction between water and other substances. Capillary action occurs when adhesion is greater than cohesion. This also provides us with a meniscus (**Figure 2)**, which is important for reading a graduated cylinder.

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Video 1. Water Moves Through Capillary Action, as a Result of Cohesive and Adhesive Interactions.

More information for video 1

An interactive video demonstrates the capillary action of water. A tissue is slowly dipped into a shallow plate containing blue-colored water, with only the edge of the tissue touching the water.

As soon as the tissue comes in contact with the surface of the water, the blue water slowly travels upward through the tiny spaces within the tissue. This movement is slow but steady and continues without any external force. As the water rises, it creates a visible blue trail on the tissue.

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This video helps users understand how water travels against gravity due to the combined effects of adhesion and cohesion.

Figure 2. Meniscus of water in a burette.

Source: "Meniscus of water in burette (https://commons.wikimedia.org/wiki/File:Meniscus_of_water_in_burette.JPG)" by Akaniji is licensed under CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0/)

Capillary action occurs in sands and soils, drawing moisture above the water line. This is why soil doesn't dry out around plant roots. As water is absorbed, it is also replaced by capillary action.

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Plants also use capillary action to move water into cell walls. For example, as water moves through the xylem, the cellulose fibres that compose the cell wall pull water into the spaces between them. When water evaporates from the surface of cells inside a leaf, capillary action draws out more water and prevents the cells from drying out.

Water as a medium for metabolism

Molecules that are attracted to water are called hydrophilic. Hydrophilic molecules are generally polar or have areas with uneven distribution of positive and negative charge, and many of them can dissolve in water. For example, when making tea with sugar, both the sugar and a variety of molecules from the tea leaves dissolve into the water, changing the colour and taste. Other molecules, such as oils and fats, are largely non-polar or hydrophobic, meaning they do not have much chemical attraction to water molecules. Water and other polar solvents tend to dissolve polar materials, while non-polar substances tend to dissolve in non-polar solvents such as benzene. Like dissolves like.

Inside every living cell, a complex assortment of chemical reactions, known as metabolism, takes place. The substrates of these reactions and the enzymes that catalyse them are usually dissolved in the aqueous solution known as cytoplasm. The cytoplasm is a complex and shifting mixture of many thousands of different types of dissolved molecules. The way these molecules interact within the water-based cytoplasm allows cells to control their composition, respond to the environment, and maintain all the functions of life. For example, many enzymes require a certain level of water in their structures to maintain their natural conformation, allowing them to deliver their full functionality. The enzyme amylase binds with starch in an aqueous medium to break it down into simple sugars.

Cells also rely on hydrophobic molecules for certain functions. For example, the hydrophobic portion of the cell membrane is essential in forming a barrier between the inside and outside of the cell. Further, proteins in the membrane help give different cells specific properties. For example, aquaporins are

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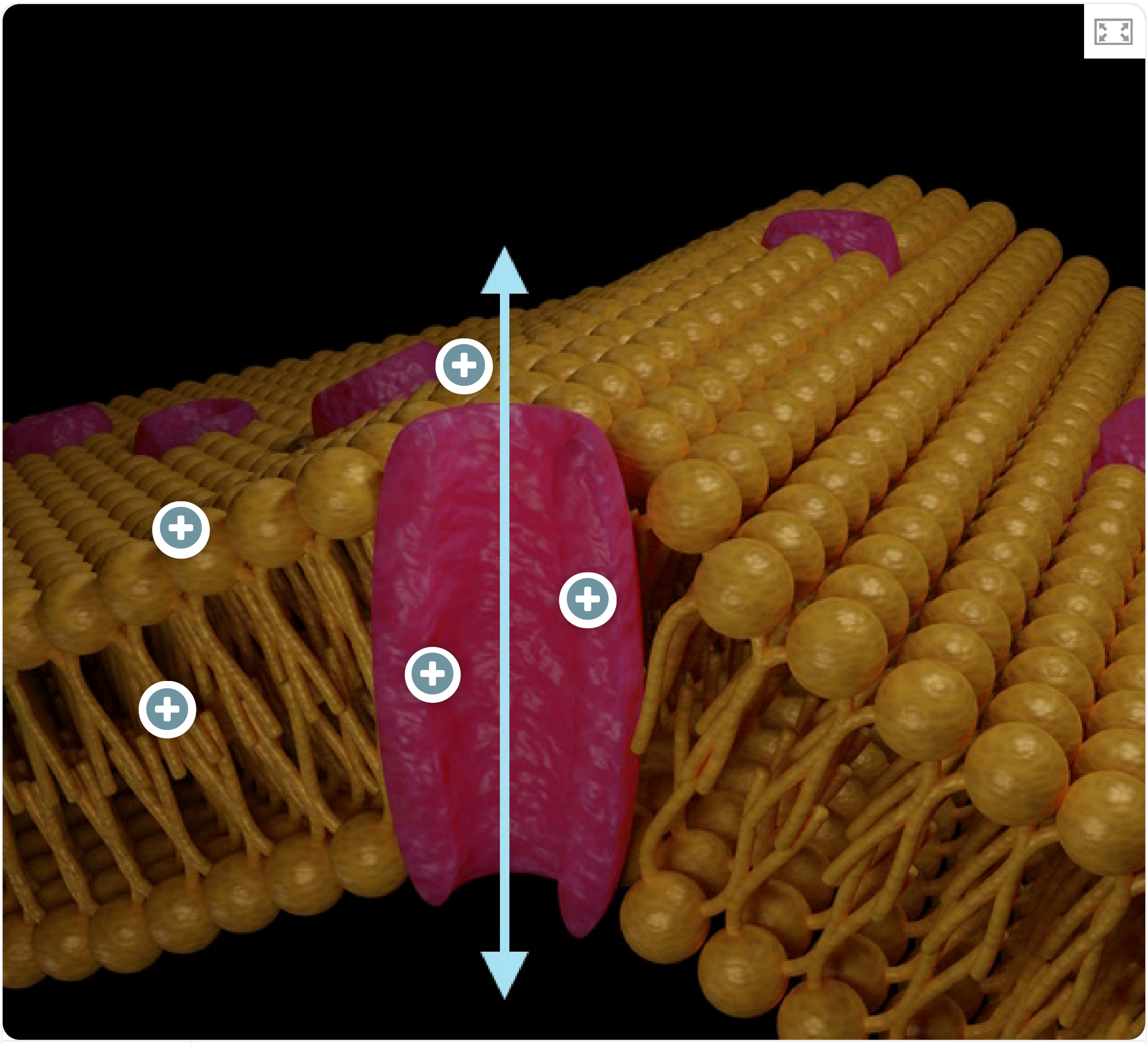
transmembrane proteins (**Interactive 1**) anchored in place by their hydrophobic exterior while providing a hydrophilic interior that allows water to move efficiently into or out of the cell. Membrane proteins are covered in more detail in subtopic B2.1 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43205/).



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Interactive 1. An Aquaporin in a Membrane. The Functions of Molecules May Depend on Their Hydrophobic or Hydrophilic Nature.

More information for interactive 1

This illustration presents an isometric perspective of a segment of a cell membrane, depicting a phospholipid bilayer. Aquaporin, a kind of protein molecule, is embedded within this lipid bilayer at various regions. The lipid bilayer consists of rows of lipids with yellow spherical heads facing outward on both sides and their respective yellow tail strands facing inward. The head and tail represent the hydrophobic and hydrophilic portion of the lipid layer.

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An aquaporin, cut in half, is shown with a close-up view.

Various hotspots, numbered one to five are shown at various locations in the illustration. The hotspots are represented with plus signs. Read the following to know what each hotspot indicates:

Hotspot 1: It is indicated on the upper part of a double-headed arrow passing through the aquaporin vertically. As the users click on the plus sign, the term “Water flow” is shown.

Hotspot 2: It is indicated on the head part of a lipid molecule. Upon clicking, the term “Hydrophilic heads in the membrane” is shown.

Hotspot 3: It is indicated on the outermost region of the aquaporin. Upon clicking, the term “Hydrophobic exterior of the aquaporin barrel” is shown.

Hotspot 4: It is indicated within the innermost region of the aquaporin. Upon clicking, the term “Hydrophilic interior of the aquaporin pore” is shown.

Hotspot 5: It is indicated on the tail part of a tail molecule. Upon clicking, the term “Hydrophobic lipid tails” is shown.

All the terms are provided within a white rectangular box with a close sign at the top right corner. Users can view the text and close the box.

Making connections

Water is not only the medium in which the chemical reactions of metabolism take place. It is also a substrate in catabolic reactions and a product in anabolic reactions.

See subtopic C1.1 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43208/) for more details.

The ability of water to dissolve sugars, salts, amino acids and more also provides multicellular organisms like plants and animals with a medium for transporting materials from cell to cell. Animals may use blood or haemolymph, which is water-based, to transport nutrients, hormones and wastes to specialised organs. The liquid portion of blood, known as plasma, uses water as a solvent. The plasma directly transports easily dissolved materials, such as glucose, which are generally small and hydrophilic. However, some materials that need to be transported, such as oxygen gas, are non-polar and do not dissolve well in water. Therefore, some

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animals have evolved specialised means of binding and transporting these materials. For example, the protein haemoglobin, which binds and carries oxygen gas, is found in enormous quantities in red blood cells that are carried throughout the body in the blood plasma.

In **Video 2**, the ionic compound, sodium chloride, also known as table salt, dissolves into water as it is stirred.

Video 2. Table salt, like many ionic compounds, dissolves well in water.

More information for video 2

This video demonstrates how sodium chloride (table salt) dissolves in water. In the video, a glass is filled with water. Approximately a quarter of a teaspoon of salt is added to the water. A stirrer is then inserted into the glass to mix the salt thoroughly into the water. The water is initially milky but it turns colourless as the salt completely dissolves in it.

Dissolved minerals are carried through the soil to the roots of plants along with the water. Tiny root hairs absorb the minerals and water, which are then transported through the xylem as described in section A1.1.1 (/study/app/bio/sid-422-cid-755105/book/structure-of-water-id-43194/). Further, plants transport dissolved sugars and other organic molecules in their sap. Phloem sap is a complex mixture

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of organic and inorganic substances; sugars and amino acids are the most predominant metabolites in phloem sap. Sucrose is the main sugar in phloem sap and it is transported as a soluble solute in water.

Making connections

Linking question: How do multicellular organisms solve the problem of access to materials for all their cells?

In subtopic B3.2 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43215/), the transport of materials and the adaptations that support transport are explored in plants and animals.

Use the tasks in this activity to check your understanding of the properties of water.

Activity

- **IB learner profile attribute:** Knowledgeable
- **Approaches to learning:** Communication skills — Clearly communicating complex ideas in response to open-ended questions
- **Time required to complete activity:** 15 minutes
- **Activity type:** Pair activity

Discuss the following questions with your partner in relation to the properties of water:

1. Would you expect the feet of water striders to be polar or non-polar, and why?
2. How and why does water act differently on a freshly waxed car compared with an unwaxed car?
3. What factors affect how far capillary action can move water against gravity?

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4. How might your body transport materials, like oxygen gas and lipids (fats), that are not very soluble in water?

Research the answers to check your thinking. What are three other natural phenomena you can find that relate to these properties of water?

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Living things and water

A1.1.6: Physical properties of water

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Learning outcomes

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

- Describe the properties of water including buoyancy, viscosity, thermal conductivity and specific heat capacity.
- Contrast, using examples, how the physical properties of water and air have consequences for animals that live in these two habitats.

The physical properties of water provide both opportunities and challenges for organisms. Female ringed seals find a natural snow cave or dig a birth lair where a single pup stays during a five- to eight-week nursing period (**Figure 1**). How do the properties of water and air explain why the pup stays in the lair?

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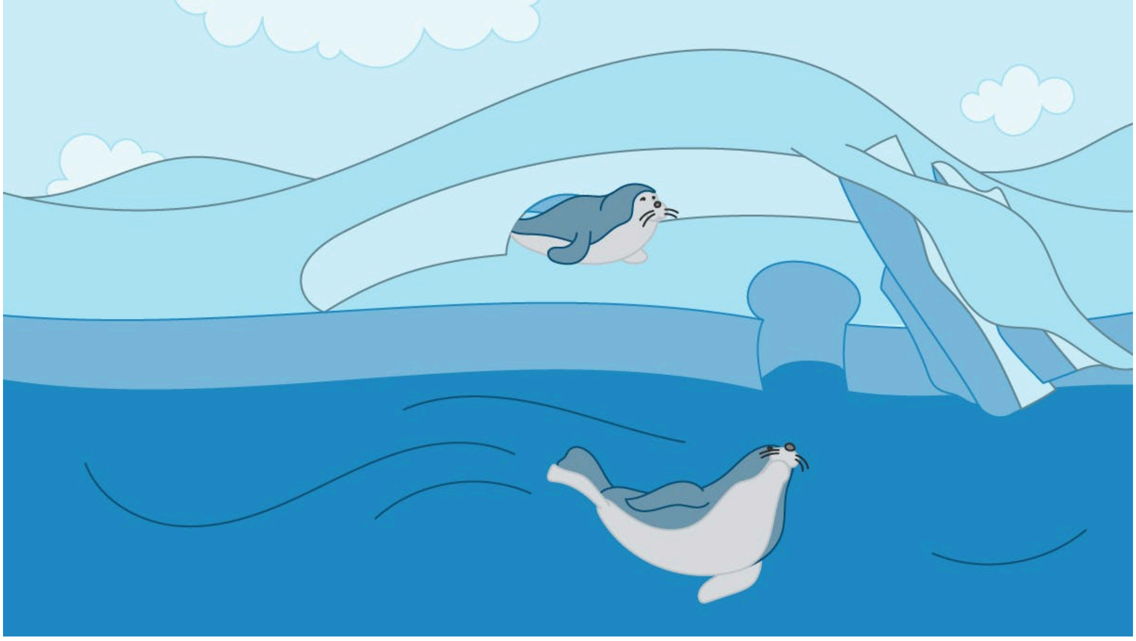

Figure 1. An insulated lair used by ringed seals.

Physical properties of water

Water has a variety of physical properties that impact living things.

1. **Buoyancy** is a force that counteracts the force of gravity. The high density of liquid water creates high buoyancy, allowing less dense materials to float. Air, being much less dense than water, is much less buoyant as well. Water is less dense as a solid (ice) than as a liquid, which is unusual. This is due to the pattern of hydrogen bonding that develops as water solidifies. Therefore, ice floats in liquid water. Very cold liquid water is most dense, so it sinks to the bottom of ponds preserving a layer of liquid water when the surface freezes, so that life can continue.
2. **Viscosity** is resistance to flow and is related to how much energy is needed to change the shape of a liquid. Water has low viscosity compared with other liquids, but greater viscosity than air.
3. **Thermal conductivity** is the ability of a substance to transfer heat when there is a temperature difference. Water has a high thermal conductivity compared with other liquids (except liquid metals). Air has a much lower thermal conductivity than water.
4. **Specific heat capacity** is how much energy is needed to raise the temperature of a substance. Water has a high specific heat capacity. Air has a much lower specific heat capacity than water. This is because of the hydrogen

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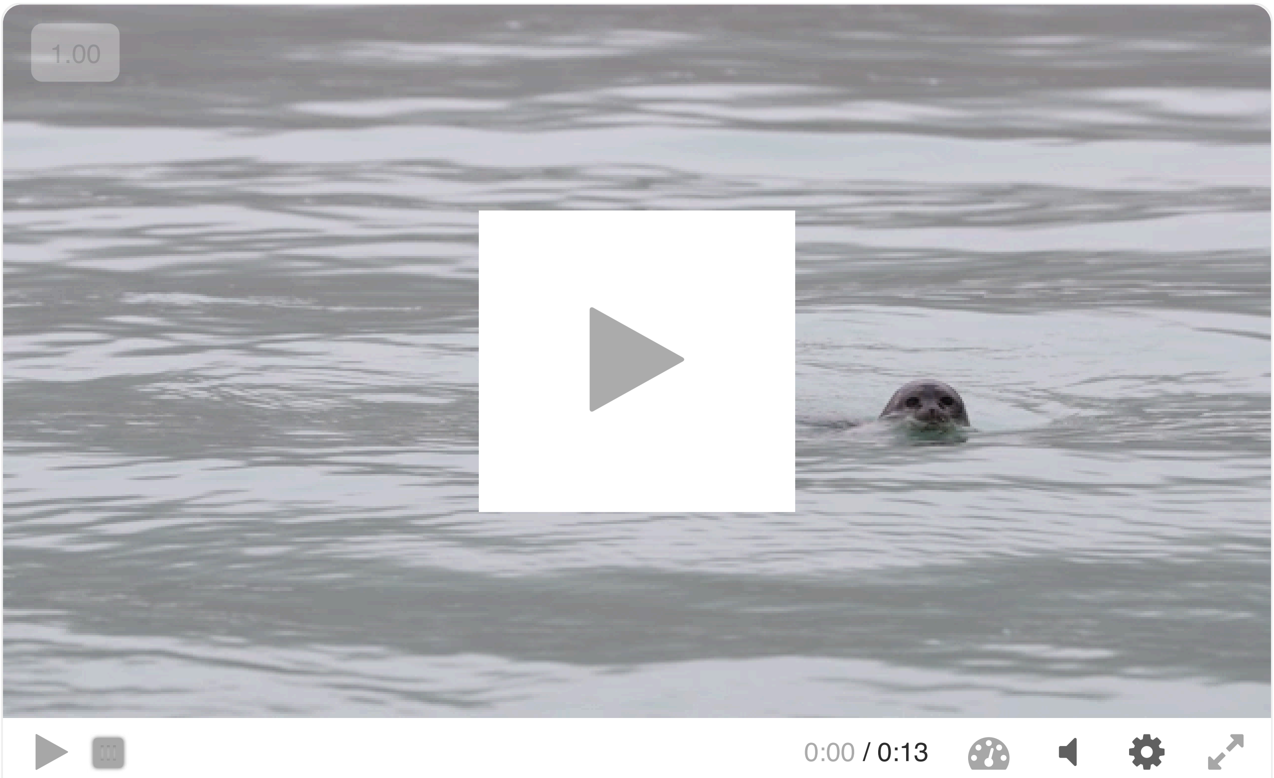
bonds between water molecules. These intermolecular forces must be overcome to increase the temperature of water. The additional energy needed gives water a high specific heat capacity compared with air and land.

We will look at two examples of animals that live both in and out of the water.

The ringed seal (*Pusa hispida*) lives almost exclusively in and on water, in the cold seas and on the ice of the Arctic Basin. Ringed seals swim efficiently, with their hydrodynamic, torpedo-like shape reducing drag due to the viscosity of water, their powerful flippers exerting force against water to propel them and their low-density blubber increasing the buoyant force (**Video 1**).



Rights of use

Video 1. The Hydrodynamic Shape of the Seal Allows Efficient Swimming.

More information for video 1

This interactive explores how the physical properties of water shape the movement and survival strategies of aquatic animals, with a focus on the ringed seal (Pusa hispida). A black and white video shows a ringed seal gliding effortlessly along the water's surface. Its streamlined, torpedo-shaped body

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is highlighted. Occasional glimpses of the seal's mouth and head as it moves with the waves reinforce its adaptation to a fluid environment.

In contrast, ringed seals appear somewhat heavy and awkward on solid ice because the air is not as buoyant, and their flippers and overall shape, while excellent for efficient movement in liquid water, are less useful on the solid ice (**Figure 2**).

Figure 2. Ringed seal on the ice.

Credit: Paul Souders, Getty Images (https://www.gettyimages.co.uk/detail/photo/ringed-seal-pup-on-iceberg-nunavut-territory-canada-royalty-free-image/534972450)

Ringed seals have physical and behavioural adaptations to retain body heat in the cold climate. The high thermal conductivity of liquid water tends to take the heat from the seal's body. The low thermal conductivity of the blubber insulates the body of the seal and reduces heat loss. Further, the seals build lairs under the snow where the air, with its low specific heat capacity, can be easily warmed. The snow, a combination of solid water and air pockets, has a much lower thermal conductivity than liquid water and is therefore a good insulator (see subtopic D4.3

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(/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43218/) – the change in the conditions causes a shift in climate). Young seals, born with little blubber, can only survive in the warm and insulated lairs (see **Figure 3**).

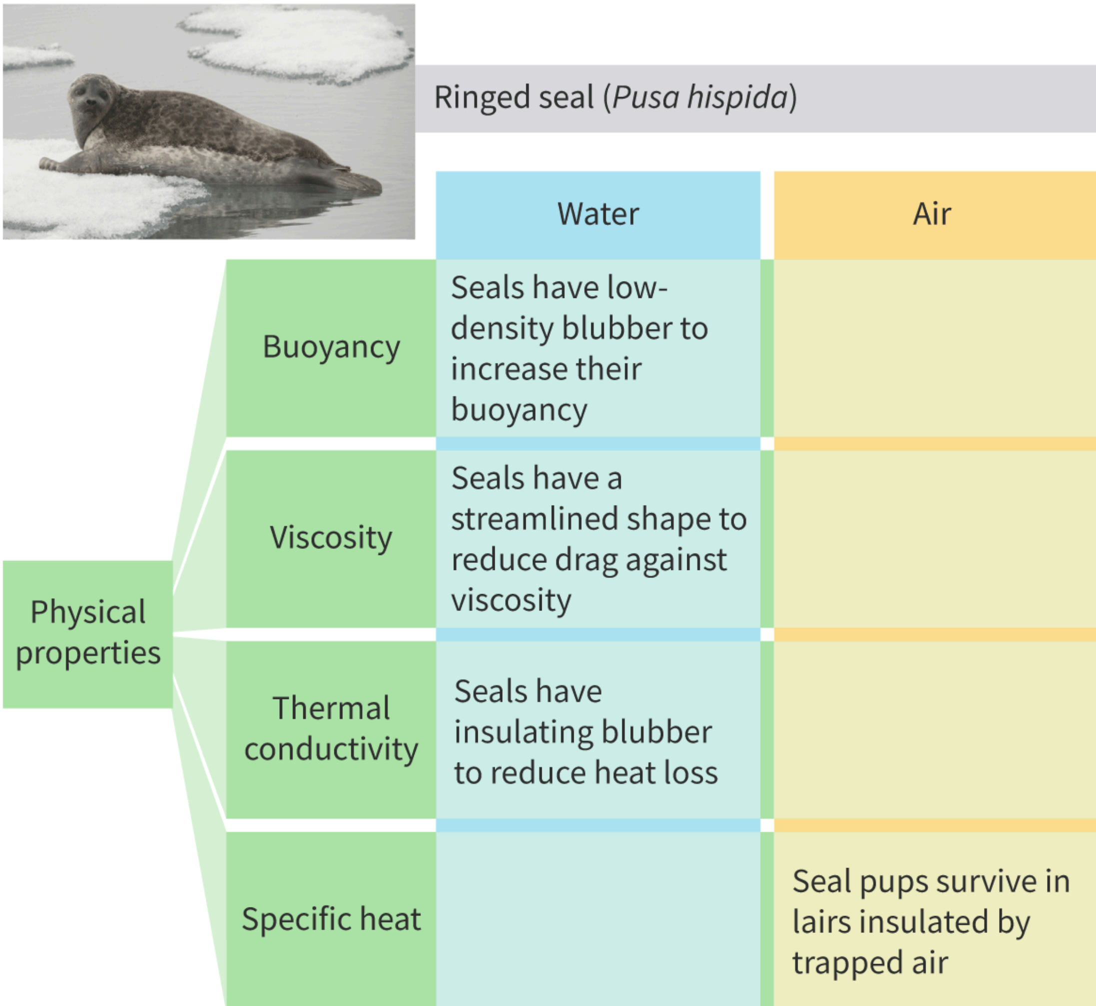

Figure 3. Ringed seals and properties of water.

Photo credit: Mary Ann McDonald, Getty Images (https://www.gettyimages.co.uk/detail/photo/ringed-sea-royalty-free-image/1253677980?phrase=ringed%2Bseal4099)

More information for figure 3

This diagram illustrates how ringed seals use the physical properties of water and air to adapt to cold environments. The diagram is divided into two columns representing water and air, intersected by four rows that represent different physical properties: buoyancy, viscosity, thermal conductivity, and specific heat. Under the water column, the buoyancy row describes that seals have low-density blubber to increase their buoyancy. In the viscosity row, seals have a streamlined shape to reduce drag. For thermal conductivity, the insulating blubber of seals is highlighted as reducing heat loss. In the air column, the

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specific heat row explains that seal pups survive in lairs insulated by trapped air. These adaptations are visually mapped to show the relationship between the seals' physical properties and their environmental interactions.

[Generated by AI]

The black-throated loon (*Gavia arctica*) also lives in the cold Arctic, spending time in the water, on land and in the air (**Figure 4**). The shape of the bird is both hydro- and aerodynamic, allowing it to minimise drag while swimming in the more viscous water as well as generate lift during flight in the less buoyant air. Lift is a mechanical force acting through the centre of pressure and perpendicular to the direction of flow, which pushes an object, in this case the loon, upward in flight. Drag is a resistant force, which slows movement down. To maintain body heat, the loon uses an insulating layer of air and down feathers, with low thermal conductivity, and excludes water from these layers using oiled exterior feathers that are hydrophobic and tightly interconnected so that water does not penetrate (see **Figure 5**).

Credit: Grigorii_Pisotckii, Getty Images (https://www.gettyimages.co.uk/detail/photo/gavia-arctica-black-throated-diver-against-the-sky-royalty-free-image/597939344)

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Credit: Ashley Cooper, Getty Images (https://www.gettyimages.co.uk/detail/photo/great-northern-diver-royalty-free-image/520996990)

Figure 4. A black throated loon has different methods to move efficiently through the air and the water.

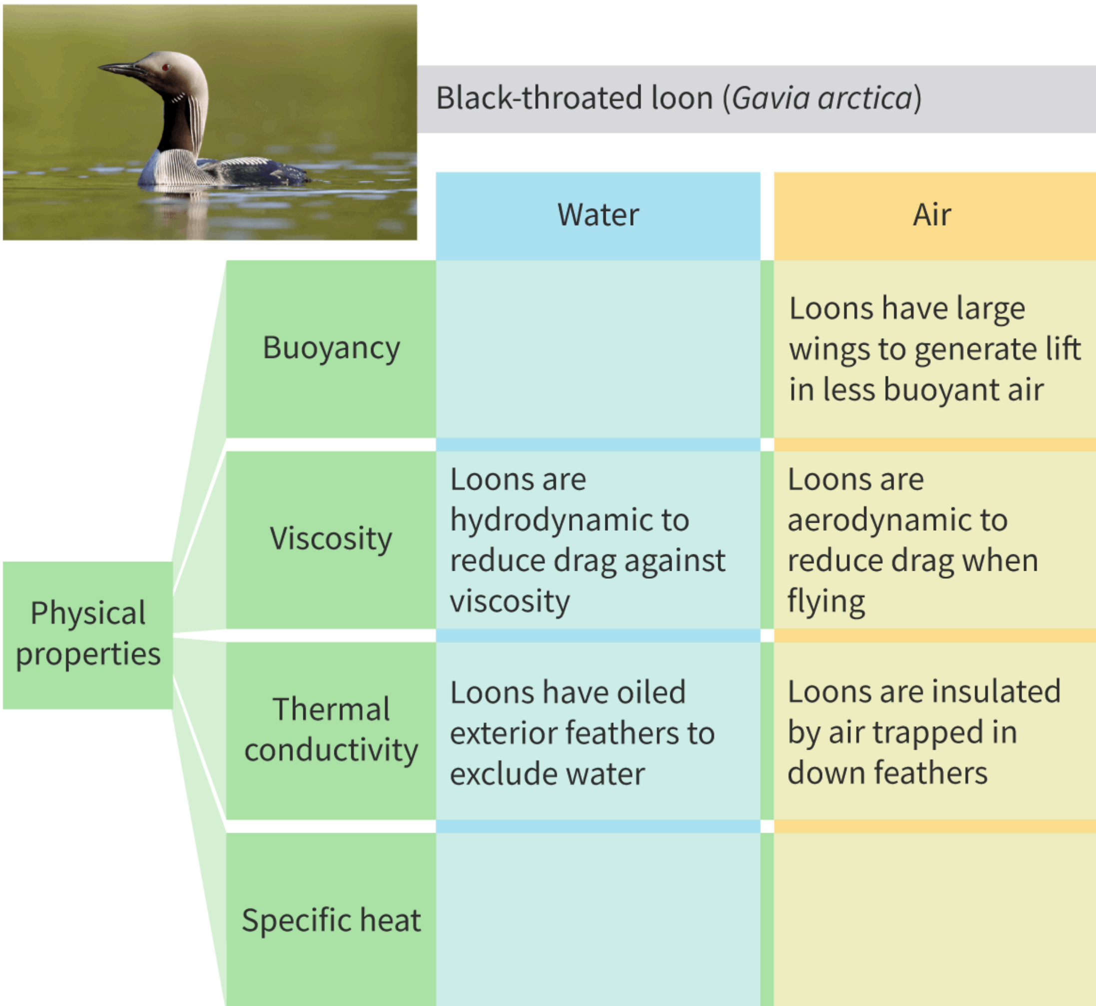

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Figure 5. Black-throated loons and properties of water.

Credit: Jean Voiculescu, Getty Images (https://www.gettyimages.co.uk/detail/photo/close-up-of-duck-swimming-in-lake-royalty-free-image/1396338772)

More information for figure 5

The image is a diagram explaining how a black-throated loon (Gavia arctica) adapts to its environment using the physical properties of water and air. The diagram is divided into two main columns labeled 'Water' and 'Air', showing how the loon uses various properties across four categories: buoyancy, viscosity, thermal conductivity, and specific heat.

On the left side, under 'Water': - **Buoyancy:** No specific text is provided here for water. - **Viscosity:** Loons are hydrodynamic to reduce drag against viscosity. - **Thermal conductivity:** Loons have oiled exterior feathers to exclude water. - **Specific heat:** No specific text is provided here for water.

On the right side, under 'Air': - **Buoyancy:** Loons have large wings to generate lift in less buoyant air. - **Viscosity:** Loons are aerodynamic to reduce drag when flying. - **Thermal conductivity:** Not mentioned for air. - **Specific heat:** Loons are insulated by air trapped in down feathers.

The text and structure indicate the loon's adaptations to efficiently move through and survive in its aquatic and aerial environments, highlighting its various physical and physiological adaptations.

[Generated by AI]

The polar habitats (see section (:sectionlink:124009)D4.3.4 (/study/app/bio/sid-422-cid-755105/book/causes-and-consequences-of-climate-change-id-43578/)) are losing land and sea ice due to climate change. Although the seals and loons are well adapted to the Arctic habitat, they may struggle to survive as conditions change. For example, many ringed seals have not been able to find ice to build insulated lairs and have lost their pups to cold on the bare ground.

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Theory of Knowledge

What kinds of explanations do natural scientists offer?

Natural scientists offer a variety of types of explanations. For example, in biology, the explanations range from the molecular, as in the chemical structure of water, to cells (water potential), to organisms (osmoregulation), to ecosystems (adaptations to the environment).

Explanations in biology also centre around key themes, such as unity and diversity, form and functions, interaction and interdependence, and continuity and change. These explanations can include the 'what', 'how' and 'why' of biological observations.

Within natural science such as biological observations, which is more important: what can be explained or what cannot be explained?

In this activity you will research an animal and its relationship with water.

Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Research skills — Using search engines and libraries effectively
- **Time required to complete activity:** 30 minutes
- **Activity type:** Individual activity

Choose a local species of animal or one in which you are particularly interested. Read about the habitat and life cycle of the species and pay special attention to its relationship with water.

Research and outline the adaptations that the species has in relation to at least three of the following properties of water: cohesion, adhesion, surface tension, solvent properties, buoyancy, viscosity, thermal conductivity and specific heat capacity.

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Be sure to cite your sources. Present your ideas to your class.

5 section questions

Origin of water (HL)

Higher level (HL)

Learning outcomes

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

- Outline that the origin of water on Earth is understood to be extraplanetary, delivered by multiple collisions of water-rich asteroids.
- Describe how the moderate temperature and gravity of Earth allow water to be retained.
- Explain the concept of the 'Goldilocks zone' in relation to the search for extraterrestrial life.

Scientists have long wondered whether liquid water would be essential to life that may have evolved elsewhere in the universe. If so, the presence of liquid water limits where life may exist and helps direct the search for life beyond the Earth. Referring to section A1.1.1–3 (/study/app/bio/sid-422-cid-755105/book/structure-of-water-id-43194/), what properties of water might make it necessary to even extraterrestrial life? Evidence strongly suggests that water exists on other planets, both within our planetary system and in other places. Read more about water in the Solar System

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here (https://www.usgs.gov/news/tour-water-solar-system). Which planets or moons in our Solar System are considered good candidates for the search for life beyond Earth? Why?

Origin of water on Earth

When the planet Earth first formed, between four and five billion years ago, it was far too hot to have liquid water on its surface. Scientific evidence suggests that water was delivered to Earth through many collisions with water-rich asteroids (**Figure 1**), also known as comets. The rate of asteroid collisions has varied over Earth's history, but smaller objects like meteoroids fall to Earth dozens of times a day on average.

Figure 1. An artist's impression of a large asteroid striking the Earth.

Credit: RomoloTavani, Getty Images (https://www.gettyimages.co.uk/detail/photo/asteroid-impact-on-earth-meteor-in-collision-with-royalty-free-image/1367201304)

Reasons for retention of water on Earth

Gravity is the attraction between any two objects with mass. Larger objects, like planets, exert a greater gravitational force. As the Earth began to cool, water was able to condense and the force of Earth's gravity helped to retain water on the Earth's surface. In geological terms, life

Student view

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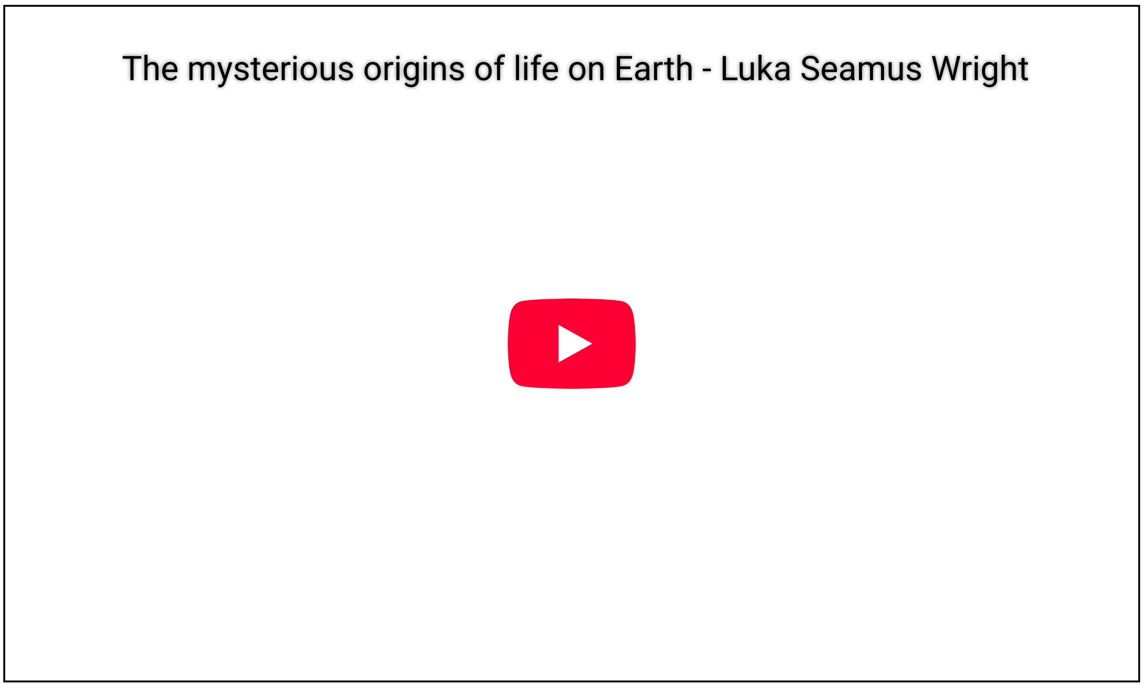
began to evolve not long after liquid water appeared in meaningful amounts (**Video 1**). The Earth has remained at a moderate temperature, with water neither boiling away nor frozen solid. The presence of liquid water as a solvent and medium for metabolism is considered necessary for life as we know it to exist.



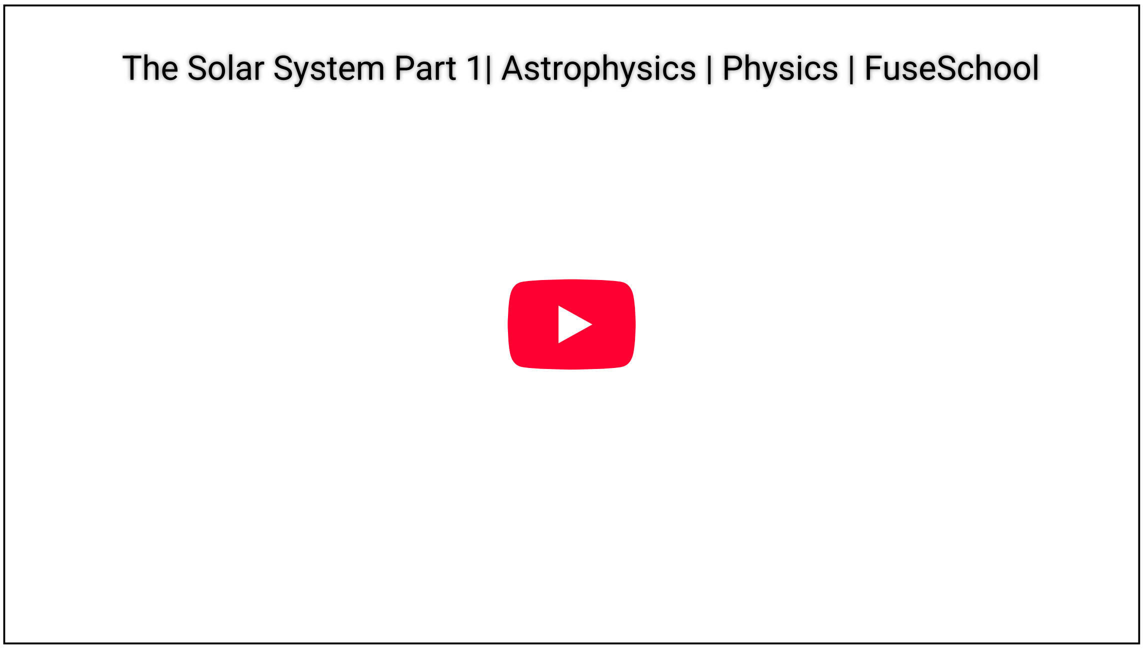
Video 1. Life evolved once liquid water was available on Earth.

The search for extraterrestrial life

Astrobiologists search for and study life as it may exist anywhere in the universe. Most astrobiologists believe extraterrestrial life will be found only in the presence of liquid water on other planets or natural satellites.

The habitable zone (https://exoplanets.nasa.gov/search-for-life/habitable-zone/), or Goldilocks zone, refers to the orbital distance from a star that will result in liquid water. The planet Earth is in the Goldilocks zone (**Video 2**) because its distance from its star (the Sun) is neither too hot nor too cold to prevent liquid water – it is just the right distance. This is reminiscent of the children's story 'Goldilocks and the Three Bears' in which a little girl scorns extremes in the temperature of food among other things, and seeks the 'happy medium'. The search for other planets in the Goldilocks zone is a key focus for astrobiologists.

Student view



Video 2. An explanation of the Goldilocks zone.

An example of a planet that might once have had large amounts of liquid water on its surface can be found in our own planetary system, the Solar System. Images from the Mars probe show impressions of ancient lakes and rivers that long ago evaporated and were lost to space (**Figure 2**).

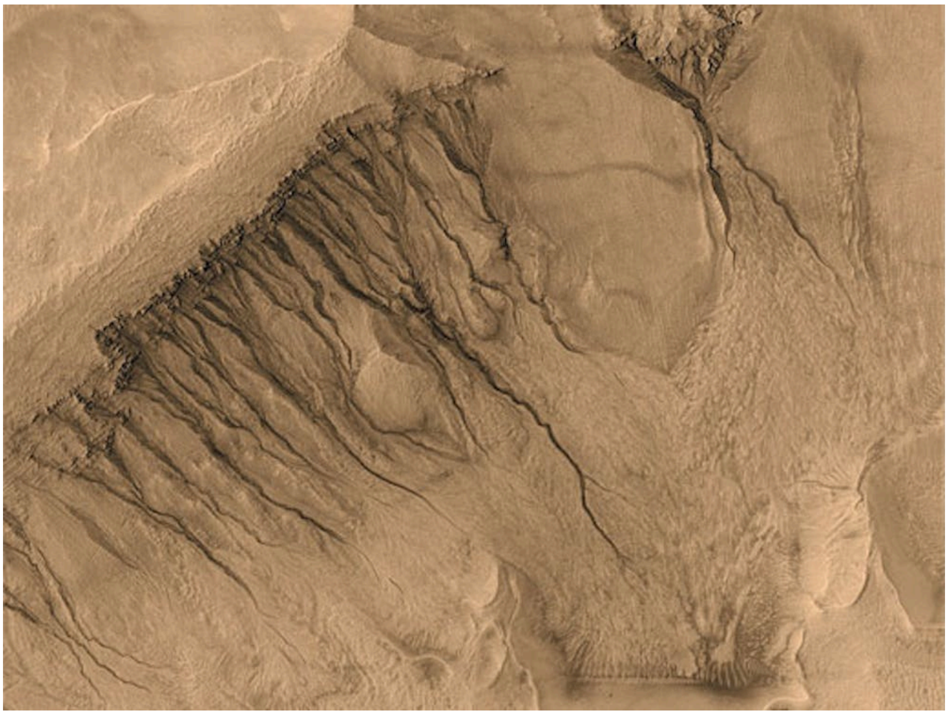


Figure 2. Evidence of past liquid water on the surface of Mars.

Source: "Unusual Gullies and Channels on Mars (https://commons.wikimedia.org/wiki/File:Unusual_Gullies_and_Channels_on_Mars.jpg)" by NASA is in the public domain

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The tasks in the following activity will check your understanding of the definition of life.

Activity

- **IB learner profile attribute:** Risk-taker
- **Approaches to learning:** Thinking skills — Providing a reasoned argument to support conclusions
- **Time required to complete activity:** 40 minutes
- **Activity type:** Group activity

Astrobiologists make assumptions about what the most likely features of life will be and where it will most likely be found. For example, they may assume that water is needed as the solvent that allows the chemical reactions of life to occur. Science fiction writers and even some biologists try to think outside these assumptions.

In small groups, visit the Wikipedia site for 'Hypothetical types of biochemistry (https://en.wikipedia.org/wiki/Hypothetical_types_of_biochemistry)'. Each member of the group should choose an example to read from the sections on non-water solvents, other speculations and/or non-planetary life.

After you've read for five minutes, discuss as a group how you would define life.

Finally, discuss as a group whether you think life as you defined it would be common, rare or non-existent outside the Earth, and why.

5 section questions

Student
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Summary and key terms

- Water is the substance in which cells first developed and remains necessary for the processes of life to occur.
- The difference in electronegativity between hydrogen and oxygen leads to polar covalent bonds within water molecules and hydrogen bonds between them.
- Water molecules are cohesive, which leads to surface tension. Some animals, like water striders, can live on the surface of water.
- Water can dissolve many substances including substrates, such as sugar, and enzymes, such as amylase, needed in metabolism. The solvent properties also allow organisms to make water-based solutions to transport dissolved substances.
- Water is adhesive to polar and charged substances which are known as hydrophilic.
- Water is buoyant and viscous compared with air.
- Water has high thermal conductivity and high specific heat capacity compared with air.
- The ringed seal and black-throated loon have hydrodynamic shapes for swimming. The ringed seal has blubber for insulation, while the loon uses a layer of dry air and downy feathers.
- Most of the water on Earth is believed to have been delivered by asteroids.
- The moderate temperature of the Earth keeps water liquid and gravity allows water to be retained.
- The concept of the ‘Goldilocks zone’, or habitable zone, is the orbital area around a sun where a planet or natural satellite might have liquid water.

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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. _____ is the sum of a cell's chemical reactions, which must take place in liquid water.
2. A water molecule is held together by _____ bonds, while different water molecules are temporarily connected by _____ bonds.
3. Water's attraction to itself is called _____, while water's attraction to other polar or charged substances is called _____.
4. Polar and charged substances are called _____ or 'water-loving', while non-polar substances are called _____.
5. Water counteracts the force of gravity on submerged objects due to _____. While the energy necessary for water to change shape is its _____.
6. Water helps moderate climate because it has a high _____, while it also has a high _____ which makes it hard for Arctic animals to stay warm.
7. [HL] Most of the water on Earth is believed to have been brought by _____. Liquid water occurs on _____ that are in the _____ around a star.

Metabolism | viscosity | polar covalent | planets | buoyancy | cohesion | Goldilocks zone | thermal conductivity | hydrophobic | hydrophilic | adhesion | hydrogen | asteroids | specific heat capacity

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Interactive 1. Water: Key Terms and Concepts Quiz.

A1. Unity and diversity: Molecules / A1.1 Water

Checklist

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/checklist-id-43199/print/) Assign

What you should know

After studying this subtopic you should be able to:

- Explain that water is the substance in which cells first developed and life's processes still occur.
- Explain how a difference in electronegativity between two atoms results in a polar covalent bond.
- Draw two or more water molecules and hydrogen bonds between them with a notation to indicate polarity.
- Explain that water molecules are attracted to each other and that this property, cohesion, has important impacts on organisms.
- Explain how the properties of water affect its roles as a metabolic medium and a means of transport.
- Explain how the solvent properties of water are linked to its role as a medium for metabolism.
- Explain how the cohesive and adhesive properties of water are linked to its role as a medium for transport in plants and animals.
- Describe the properties of water including buoyancy, viscosity, thermal conductivity and specific heat capacity.
- Contrast, using examples, how the physical properties of water and air have consequences for animals that live in these two habitats.

Higher level (HL)

- Outline that the origin of water on Earth is understood to be extraplanetary, delivered by multiple collisions of water-rich asteroids.

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- Describe how the moderate temperature and gravity of Earth allow water to be retained.
- Explain the concept of the 'Goldilocks zone' in relation to the search for extraterrestrial life.

A1. Unity and diversity: Molecules / A1.1 Water

Investigation

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/investigation-id-43200/print/) Assign

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking skills – Providing a reasoned argument to support conclusions
- **Time required to complete activity:** 1 hour
- **Activity type:** Individual activity

Your task

In this investigation, you will observe some phenomena involving water and explain your observations by applying your learning about the properties of water. Be careful and cautious when doing any hands-on activities. Avoid using more materials than needed. If you use food colouring, reseal the container immediately after use to prevent spills.

Gather any of the following materials that you have available:

1. A faucet with running water
2. A bowl of water
3. A plate or tray
4. Three cups

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5. Paper towels
6. A coin
7. An ice cube
8. A dropper (if not available, a folded paper towel can be used)
9. A balloon
10. Food colouring
11. Ground black pepper
12. A paper clip or staple
13. Liquid soap

Demonstration 1

Place two cups next to each other. Fill one cup half full of water. Add a drop of food colouring if available. Roll or fold a paper towel into a strip or tube (**Figure 1**) and place one end in the water, with the other end hanging into the empty cup. Make observations every few minutes.

What physical or chemical properties of water cause these results? Explain what is happening at the molecular level.

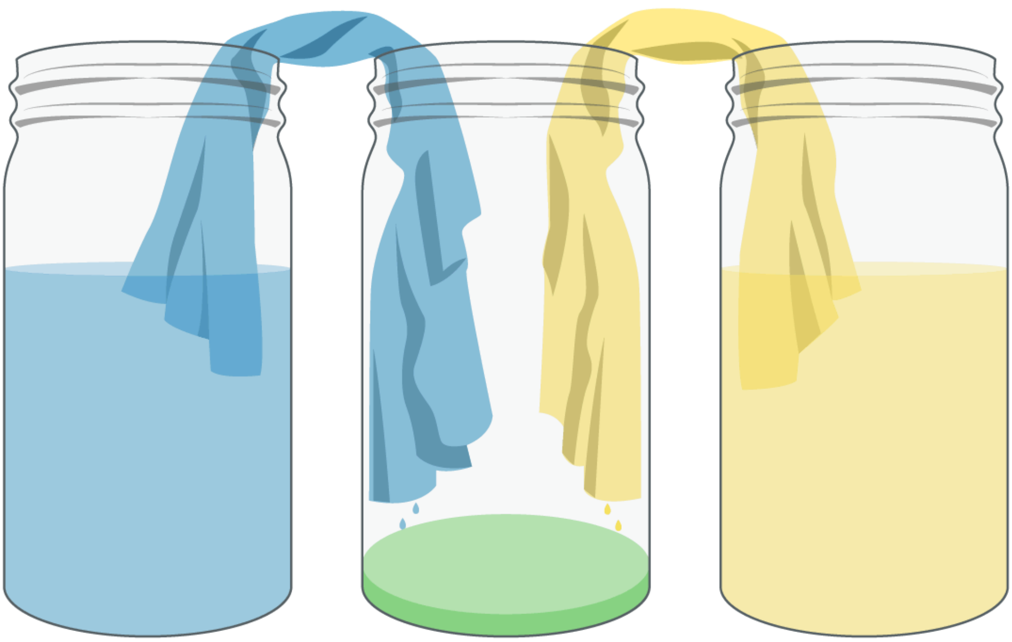

Figure 1. Capillary action.

More information for figure 1

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The diagram shows three jars arranged side by side. The left jar is half-filled with a blue liquid, and a paper towel is dipped into it, extending into the middle jar. The right jar is half-filled with a yellow liquid, with a paper towel also dipping into the middle jar. Both towels absorb their respective liquids, as indicated by their colors—blue and yellow—and they drip into the middle jar, where the mixed liquid appears green. This demonstrates capillary action, where fluids move through a porous medium.

[Generated by AI]

Demonstration 2

Wet the back of one of your hands and leave the other dry. Hold your hands next to each other and blow air onto your hands.

How do the hands feel different? What physical or chemical properties of water cause these results? Explain what is happening at the molecular level.

Demonstration 3

Place a coin on a plate or tray. Before you begin, guess how many drops of water will fit on the coin before it spills over. Hold the dropper or a wet paper towel folded to a point a centimetre or two above the coin. Squeeze the water out one drop at a time and count the number of drops that can fit on the coin (**Figure 2**). Optional, if supervision and materials are available: Repeat the process using ethanol and compare the results.

What physical or chemical properties of water cause these results? Explain what is happening at the molecular level.

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Figure 2. Water on a coin showing surface tension.

Credit: kevinruss, Getty Images (https://www.gettyimages.co.uk/detail/photo/singel-penny-with-water-droplet-royalty-free-image/133896288)

Demonstration 4

Take a bowl partly filled with water. Gently place a paper clip or staple on the surface of water so that it floats (**Figure 3**). Then push it beneath the surface and release it. Repeat this process using an ice cube instead of the paper clip.

What physical or chemical properties of water cause these results? Explain what is happening at the molecular level.

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Figure 3. A paper clip floating on top of water.

Credit: Science Photo Library, Getty Images (https://www.gettyimages.co.uk/detail/photo/paperclip-floating-on-water-royalty-free-image/687787161)

Demonstration 5

Take a bowl partly filled with water. Sprinkle a small quantity of ground black pepper onto the surface of the water. Place a drop of liquid soap onto your finger or the corner of a paper towel. Gently touch the surface of the water with the soap (**Video 1**).

What physical or chemical properties of water cause these results? Explain what is happening at the molecular level.

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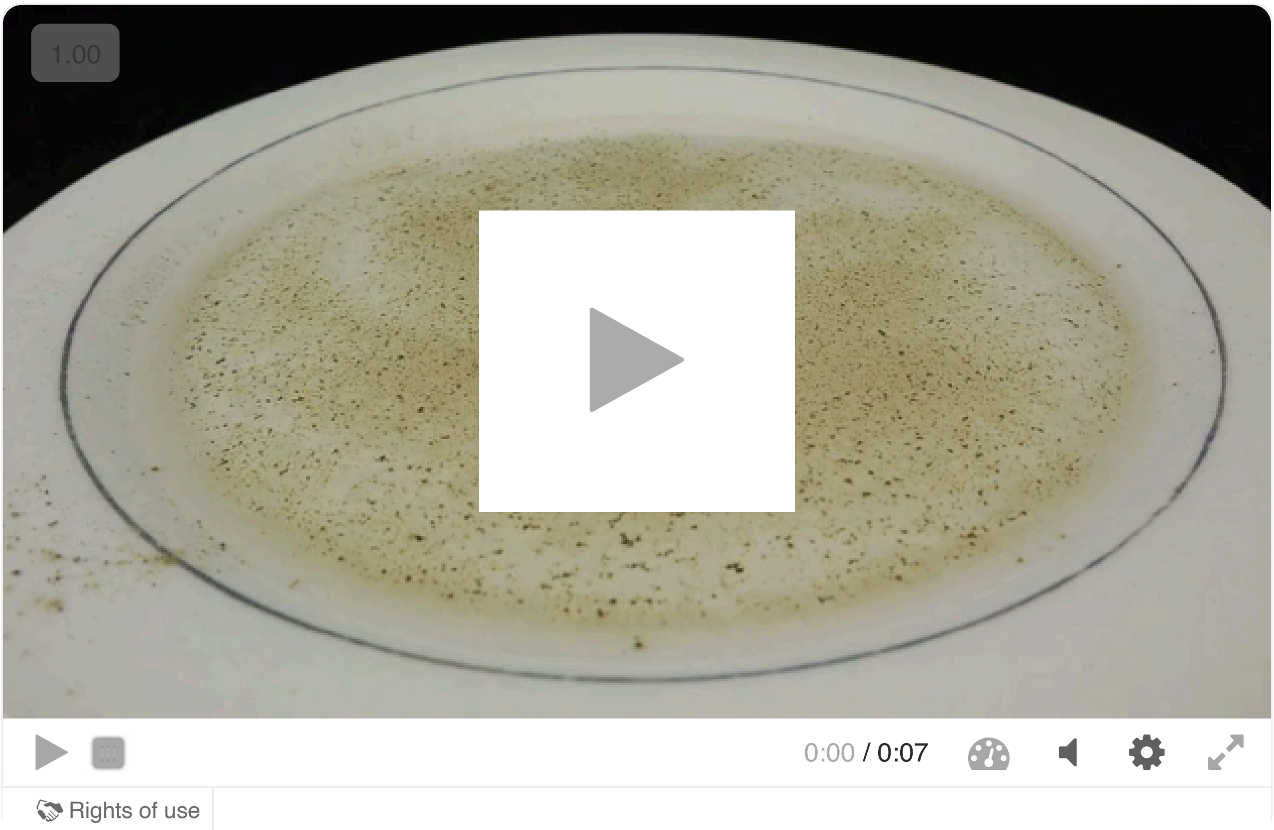

Video 1. The Effect of Soap on Water With Black Pepper.

More information for video 1

A video demonstrates how water with black pepper reacts to soap. A small plate contains water sprinkled with ground black pepper. The pepper particles float on the water's surface.

As the video progresses, a person wearing gloves touches the center of the plate with a finger that has a drop of soap on it. When the soap touches the water, the pepper particles move away from the finger to the sides of the plate, leaving water with very few solid pepper particles.

As the video continues further, the person removes his or her finger from the plate, but the pepper particles do not return to their original positions. Instead, they remain dispersed in the pattern created by the soap's interaction with the water.

This video highlights key concepts such as surface tension, the role of surfactants (soap), and the behavior of particles in a liquid medium.

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Demonstration 6

Take an inflated balloon. Rub the balloon vigorously back and forth on your hair to generate static electricity. Without putting the balloon down, turn the water tap on slightly so that a thin stream of water is falling from the tap. Hold the balloon to the side of the water stream without letting the balloon be splashed (**Figure 4**). Observe the stream of water as the balloon is moved closer and further away.

What physical or chemical properties of water cause these results? Explain what is happening at the molecular level.

Figure 4. A stream of water pulled toward the negative static electric charge on a balloon.

Credit: Dorling Kindersley: Lol Johnson, Getty Images (https://www.gettyimages.co.uk/detail/photo/water-bending-experiment-royalty-free-image/1377686264)

Student view

How do these phenomena relate to the challenges and opportunities facing organisms? Discuss your findings with the class.

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Extension

Choose one demonstration. Consider how changing one factor might affect the results of the demonstration. Design an experiment to test your hypothesis. Do not carry out the experiment unless directed by your teacher after a safety review.

A1. Unity and diversity: Molecules / A1.1 Water

Reflection

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/reflection-id-46831/print/) 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.

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-43193/).

- What physical and chemical properties of water make it essential for life?
- What are the challenges and opportunities of water as a habitat?

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

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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 A1.1 Water

Help us improve the content and user experience.

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