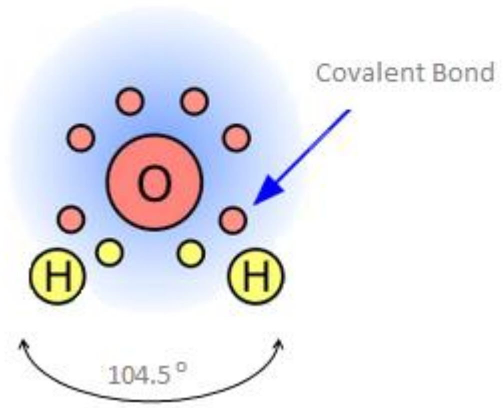
UNIT 2 CHEMISTRY

WHAT MAKES WATER SUCH A UNIQUE CHEMICAL?

STRUCTURE OF WATER

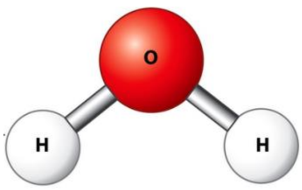
Water is a ***molecular compound*** with the molecular formula H_2O. The central oxygen atom has two lone pairs of electrons but also forms two single covalent bonds with two hydrogen atoms. The bonding and non-bonding pairs of electrons like to arrange themselves as far from each other as possible in order to minimise the amount of repulsion between them. Usually, four pairs of electrons around a central atom would result in a tetrahedral shape with an angle of 109.5° between them. However, since non-bonding pairs (lone pairs of electrons) exert a stronger repulsion force than bonding pairs, the covalent bonds are pushed closer together resulting in a distorted tetrahedral shape in which the $H-O-H$ angle is 104.5°.



The shape of the ***atoms and lone pairs*** is a distorted tetrahedral.

Source: www.chem1.com

To properly describe the shape of a water molecules, the lone pairs are ignored. It is the relative positions of the *atoms* that determines its shape.

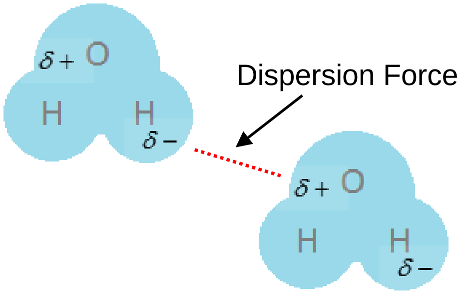


The position of the ***atoms*** makes the shape of the molecule **bent or V-shaped**.

There are few molecules that are more stable or difficult to decompose than water.

INTERMOLECULAR BONDING

- **Dispersion forces**

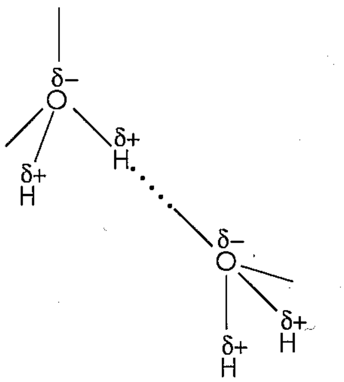


The electrons in water molecules are in constant motion so at any moment in time, electrons can accumulate at one side of the molecule. This makes one end of the molecule slightly negative and the other side slightly positive. This separation of charge is called an **instantaneous dipole**. The presence of this dipole distorts the electrons of a neighbouring molecule, producing an induced dipole. A weak electrostatic attraction then forms between the molecules which is called a dispersion force. Dispersion forces are relatively weak and become significant only when the molecules are very close.

- **Hydrogen bonding**

Hydrogen bonding is a special case of dipole-dipole bonding. It occurs between molecules when a particularly strong dipole exists within the molecules.

In water, the high electronegativity of the oxygen means that electrons are permanently more attracted to it. Because of this, the oxygen end of the molecule becomes slightly negative and the hydrogen ends become slightly positive. This separation of charge causes a permanent dipole to form. The positive end of one water molecule is then attracted to the negative end of a neighbouring molecule. This type of intermolecular force of attraction is called hydrogen bonding.



Hydrogen bonding is the strongest type of intermolecular bonding and is the reason behind many of the unique properties of water.

QUESTION 1
Water molecules are polar, with

A the oxygen side being slightly positive and the hydrogen side being slightly negative.

B the oxygen and hydrogen sides being slightly positive.

C the oxygen and hydrogen sides being slightly negative.

D the oxygen side being slightly negative and the hydrogen side being slightly positive.

QUESTION 2
The covalent bonds between H and O in a water molecule are polar because:

A O and H are equally electronegative.
B O is more electronegative than H.
C H is more electronegative than O.
D Water molecules are cohesive. e. hydrogen bonds form between H and O.

QUESTION 3
Hydrogen bond is best represented as the electrostatic attraction between:

A A hydrogen covalently bounded to an electronegative atom and another hydrogen atom

B A hydrogen covalently bounded to an electronegative atom and another electronegative atom

C Two electronegative atoms and a hydrogen atom

D Two hydrogen atoms

QUESTION 4
The hydrogen bonding in water is an example of:

A intermolecular bonding
B intramolecular bonding
C covalent bonding
D ionic bonding

QUESTION 5
Theoretically, a single water molecule can form how many hydrogen bonds at a time?

A 1
B 2
C 3
D 4

QUESTION 6
Which one of the following types of bonding would not be present in a sample of water?

A Ionic
B Covalent
C Dispersion
D Hydrogen

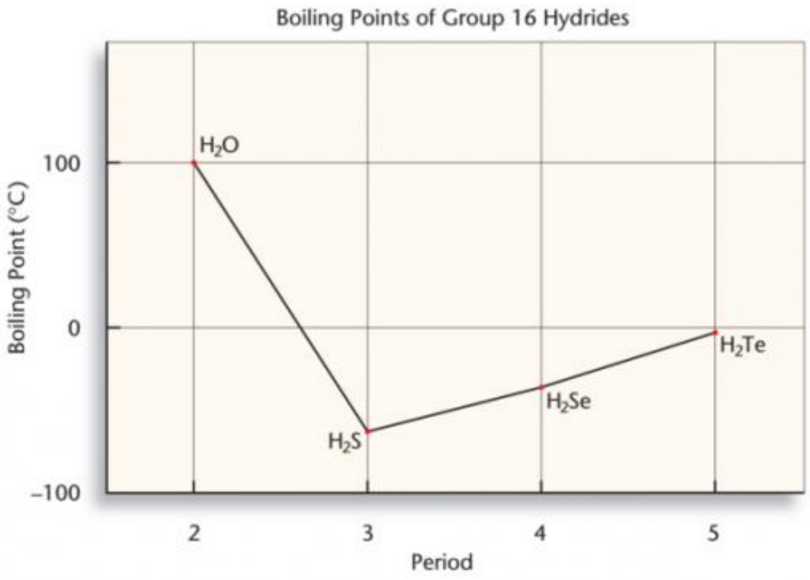
THE UNIQUE PROPERTIES OF WATER

Many of the properties of water are unusual when they are compared with those of other similar compounds of low molecular mass. In particular, water has:

- An unusually high melting and boiling point.
- A higher specific heat capacity and latent heat than almost any other liquid.

1. HIGH MELTING AND BOILING POINT

The graph below shows the boiling points of the Group 16 hydrides.

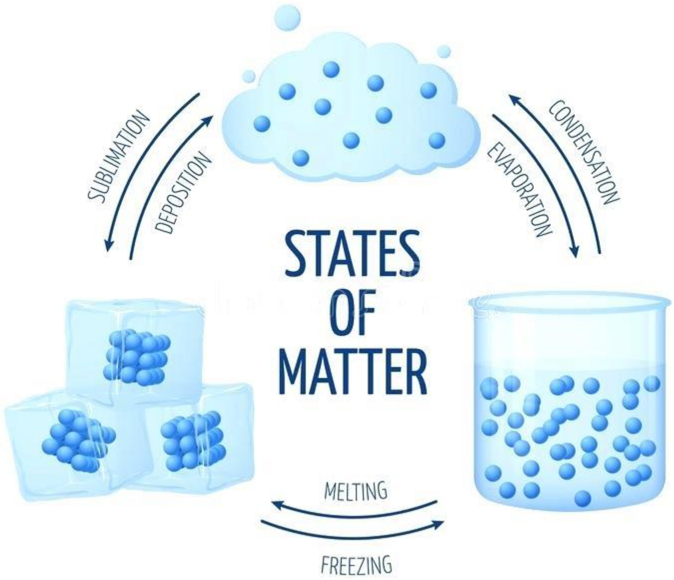


The strength of intermolecular bonding between water molecules is stronger than that between the molecules of any of the other hydrides and hence water requires more energy to change from a liquid to a gaseous state.

In ice, H_2O molecules are arranged in a regular way with each molecule surrounded by four others.

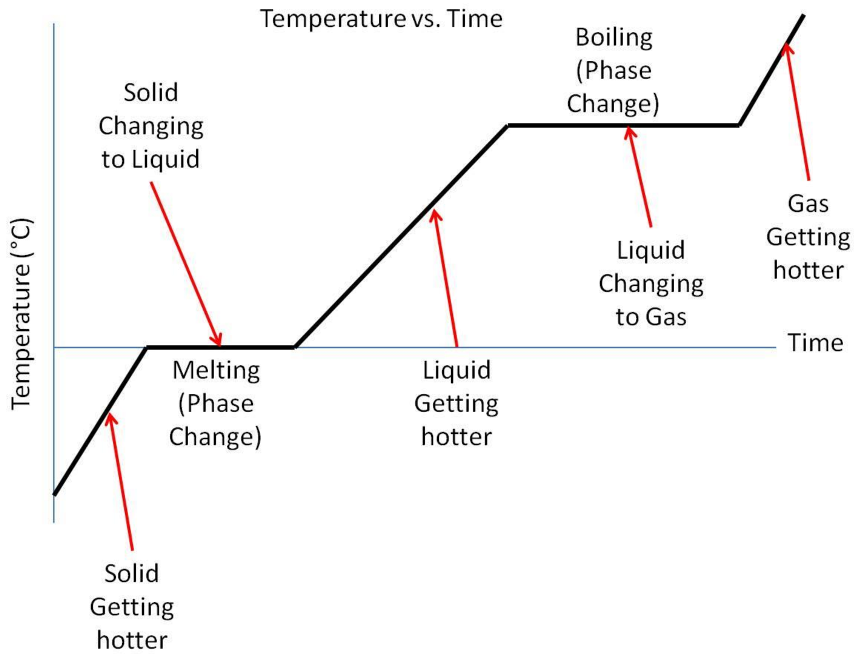
To melt ice, energy must be supplied to increase the kinetic energy of the H_2O molecules so they can break free of the lattice. Water's relatively high melting point implies that large amounts of energy are required as the hydrogen bonds between water molecules are relatively strong.

2. HIGH LATENT HEAT VALUES OF WATER

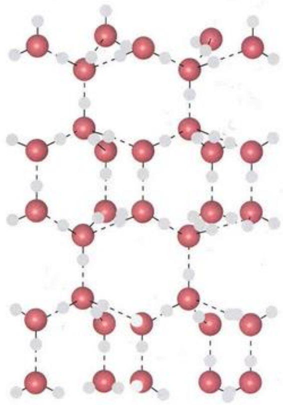


Latent heat is the energy required to change the state of a substance. The latent heat values of water are considerably higher than those of other common molecular substances. This is due to the hydrogen bonding between water molecules. The small size of the water molecules allows the hydrogen bonding to be very effective in attracting the molecules to each other and therefore larger amounts of energy are needed to cause changes in state.

MOLECULAR CHANGES DURING THE HEATING OF WATER



Temperature change: -40°C → 0°C



- Below zero degrees Celsius, water exists as a solid.
- The water molecules are in fixed positions in a molecular lattice.
- As the temperature is increased from -40°C → 0°C, the added energy makes the molecules vibrate more vigorously. This increase in kinetic energy is reflected in the increasing temperature of the water.

Temperature: 0°C

- Once the temperature reaches 0°C, the water will start to melt.
- At this point, the vibrations of the water molecules are large enough that the attractive forces holding the lattice together are no longer strong enough to hold the water molecules in fixed positions.
- During this time, the energy added to the system is absorbed by the intermolecular bonding and so **the temperature of the system does not increase**.
- Energy will continue to be absorbed by the intermolecular bonding until it has been weakened to such an extent that individual particles are free to move as a liquid. At this point, the water has melted.
- The heat absorbed during this transition period is called the **latent heat of fusion**.

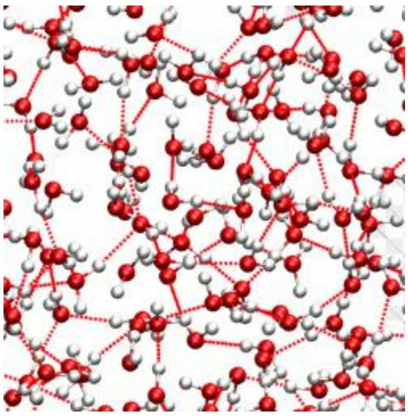
  Specific Latent Heat of Fusion for Water: $L_f(H_2O) = 334 kJ.kg^{-1}$

Note:

The specific latent heat of solidification is the amount of energy *released* as a substance changes from a liquid to a solid.

For water, the specific latent heat of solidification is still 334 kJ kg^{-1}. The sign does not change since the definition of specific latent heat of solidification is the amount of energy released, which will be a positive value.

Temperature change: 0°C → 100°C



- Between 0 and100°C, water exists as a liquid. The water molecules move freely around each other, however the intermolecular forces of attraction are still strong enough for some attraction to occur between them.
- As the temperature is increased from 0°C → 100°C, the molecules gain kinetic energy and move more vigorously. This increase in kinetic energy is reflected in the increasing temperature of the water.

Temperature: 100°C

- Once the temperature reaches 100°C, the water will start to boil.

- At this point, the movement of the water molecules are energetic enough that the attractive forces between them are totally overcome. During this time, the energy added to the system is absorbed by the intermolecular bonding and so **the temperature of the system does not increase**.

- Energy will continue to be absorbed by the intermolecular bonding until it has been weakened to such an extent that individual particles are free to move independently from each other as a gas. At this point, the water has boiled.

- The heat absorbed during this transition period is called the latent **heat of vapourisation**.

  Specific Latent Heat of Vapourisation for Water: $L_v(H_2O) = 2265\,kJ.kg^{-1}$

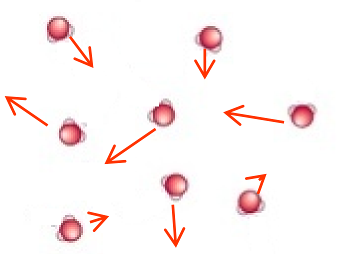
- It is the latent heat of vaporisation of water that makes it an **effective coolant**.

Note:

The specific latent heat of condensation is the amount of energy *released* as a substance changes from a gas to a liquid.

For water, the specific latent heat of condensation is still 2265 kJ kg^{-1}. The sign does not change since the definition of specific latent heat of condensation is the amount of energy released, which will be a positive value.

Temperature change: 100°C →



- Above 100°C, water exists as a gas.

- The water molecules move in a totally independent and disorganised manner. The intermolecular forces of attraction are totally overcome so that there is no effective attraction between the water molecules.

- As the temperature is increased above 100°C, the molecules will continue to gain kinetic energy and move more vigorously. This increase in kinetic energy is reflected in the increasing temperature of the steam.

Summary:

- Once water reaches 0°C, every kilogram of water will require 334 kilojoules of energy in order to make the transition from a solid state to a liquid state.

- Once water reaches 100°C, every kilogram of water will require 2265 kilojoules of energy in order to make the transition from a liquid state to a gaseous state.

- During these phase changes, the temperature of the system will not change.

QUESTION 7
Which of the following transformations take place with the absorption of heat?

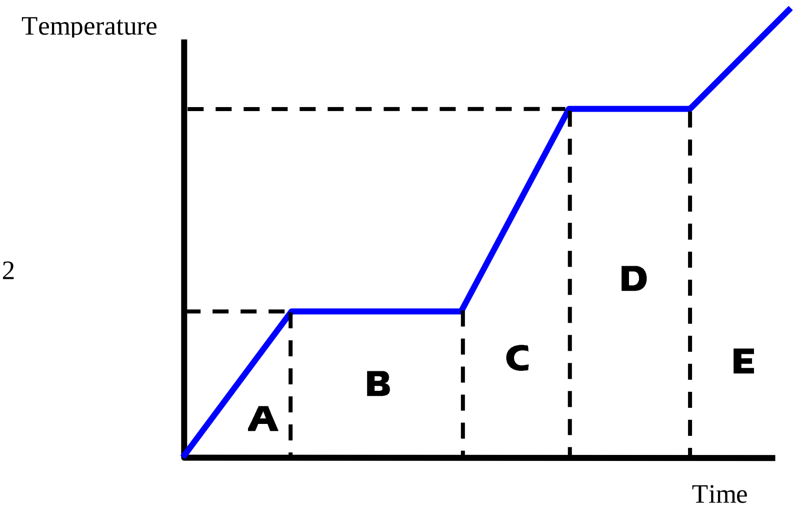
A vaporisation
B freezing
C the transition from a gas to a liquid
D the transition from a liquid to a solid

QUESTION 8
Water is liquid at room temperature. The most important reason for this is the:

A High boiling point of water
B High melting point of water
C High heat of vaporization of water
D Cohesive forces due to hydrogen bonds in water

QUESTION 9
The figure below shows how the temperature of a solid changes when it is heated steadily until it has turned into a gas.

Figure 2



Explain what is occurring at each section of the curve from "A" to "E".

Solution

QUESTION 10
A student graphed the temperature of gaseous naphthalene against time while it was cooling. The following three regions are observed:

- During the first 2 minutes, the temperature dropped from 90°C to 80°C.
- In the next 6 minutes, the temperature remained at 80°C.
- In the final 4 minutes, the temperature fell from 80°C to 60°C.

The melting point of naphthalene is?

A Above 90°C
B 90°C
C 80°C
D 60°C or below

QUESTION 11
How much energy is needed to turn 2 kg of water, at 100^0C into steam at 100^0C? Specific latent heat of vaporisation of water is $2265\,kJ.kg^{-1}$.

Solution

QUESTION 12
The specific latent heat of fusion of water is $334\,kJ.kg^{-1}$. Calculate the energy needed to change $2.0\ g$ of ice into water at $0^o C$.

Solution

QUESTION 13
How does water's high heat of vaporization help you feel cooler when you sweat?

Solution

3. HIGH SPECIFIC HEAT CAPACITY

Heating a substance requires energy. This energy increases the internal energy of the substance by increasing the kinetic energy of its molecules and so the temperature of the substance rises.

The amount of heat energy needed to change the temperature of a substance depends on:

- What the substance is.
- How much of it is being heated.
- The change in temperature of the substance.

The amount of energy needed to increase the temperature of a substance is related to the bonding within it. The stronger the bonding, the larger the amount of energy needed in order to make the particles vibrate more quickly and hence increase its temperature. Therefore, different substances will require different amounts of energy in order to undergo the same temperature change.

A useful way of comparing the amount of energy needed to increase the temperature of different substances is to compare their specific heat capacities.

The specific heat capacity of a substance is the amount of energy needed to change the temperature of **1 g** of the substance by **1°C**.

The higher the specific heat capacity of a substance, the greater the amount of energy that needs to be added in order to increase 1 g of that substance by 1°C.

For example: Water and Ethanol

- Water has a specific heat capacity of $4.184\ J / g / {}^{\circ}C$. Therefore, 4.184 J of energy is needed to raise the temperature of 1 gram of water by 1°C.

- Ethanol has a specific heat capacity of $1.413\ J / g / {}^{\circ}C$. Therefore 1.413 J of energy is needed to raise the temperature of 1 gram of ethanol by 1°C.

The differences in the heat capacities of water and ethanol clearly shows that water requires more energy per gram to increase its temperature. It also means that if the same amount of energy was applied to one gram of water and one gram of ethanol, there would be a greater increase in the temperature of the ethanol.

When a set amount of energy is added to different materials,
their temperatures will increase by different amounts.

Substances with higher heat capacities will:

- Require more energy to heat up.
- Will take longer to cool down.
- Will store energy more effectively.

Note:

Compared to other molecular substances of similar sizes, water has a high specific heat capacity. This is due to the hydrogen bonding that exists between water molecules. The small size of the water molecules allows the hydrogen bonding to be very effective in attracting the molecules to each other. The strength of these hydrogen bonds means that large amounts of energy need to be absorbed before the hydrogen bonds have weakened enough for the water molecules to increase their kinetic energy (movement). It is only then that the temperature will increase.

HEAT GAIN & LOSS

The heat energy gained or lost by a substance during a temperature change can be calculated using the formula:

$$E = mc\Delta T$$

Where E = Energy (J)
c = Specific Heat Capacity ($J/g/°C$)
m = Mass of substance heated/cooled (g)
ΔT = Temperature Change ($°C$ or K)

QUESTION 14
How much energy is required to raise the temperature of 100 ml of water by 10°C?

Solution

$$\begin{aligned} E &= mc\Delta T \\ &= 100 \times 4.18 \times (10) \\ &= 4180\, J \\ &= 4.2\, kJ \end{aligned}$$

QUESTION 15
What change in temperature will result from 2.0 kg of water being supplied with 20.0 kJ of energy?

Solution

$$E = mc\Delta T$$

$$\begin{aligned} \Delta T &= \frac{E}{mc} \\ &= \frac{20,000}{2000 \times 4.18} \\ &= 2.4°C \end{aligned}$$

QUESTION 16

Calculate the temperature change when $10.0\ kg$ of water loses $232\ kJ$ of heat.

Solution

QUESTION 17

$2.52\times10^4\ J$ of heat is added to $2.0\ kg$ of mercury to reach a final temperature of 130^oC. What was the initial temperature of the mercury if its specific heat capacity is $0.14\ J/g/^oC$?

Solution

QUESTION 18

How much water at 50^oC is needed to just melt $2.2\,kg$ of ice at 0.0^oC?

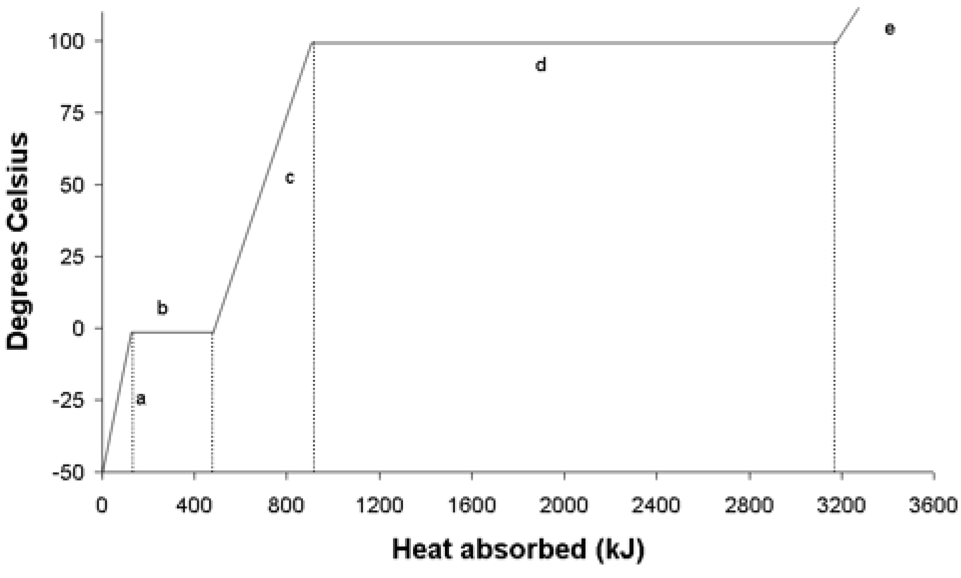
Specific Latent Heat of Fusion for Water: $L_f(H_2O) = 334 kJ.kg^{-1}$

Specific Latent Heat of Vapourisation for Water: $L_v(H_2O) = 2265 kJ.kg^{-1}$

Solution

QUESTION 19

The figure below shows how the temperature of a solid changes when it is heated steadily until it has turned into a gas. Use this graph to calculate the amount of ice used to produce this graph.



Solution

QUESTION 20
What will heat up faster? Substances with a high or low specific heat capacity?

Solution

QUESTION 21
Does polystyrene have a high or low specific heat capacity? Give a reason for your answer.

Solution

QUESTION 22
If equal masses of two metals are heated to a temperature of 100 °C, which would cause a more severe burn – the one with the higher specific heat or the one with the lower specific heat?

Solution

QUESTION 23
Which would heat up faster? A metal with high or low specific heat? Give a reason for your answer.

Solution