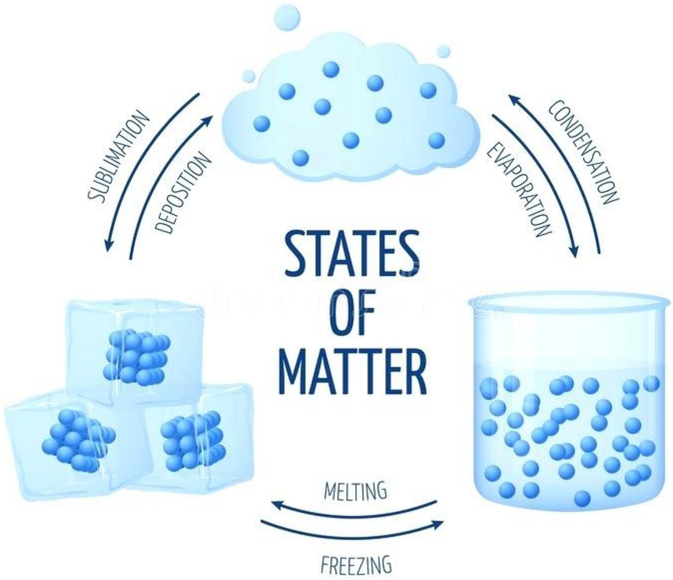
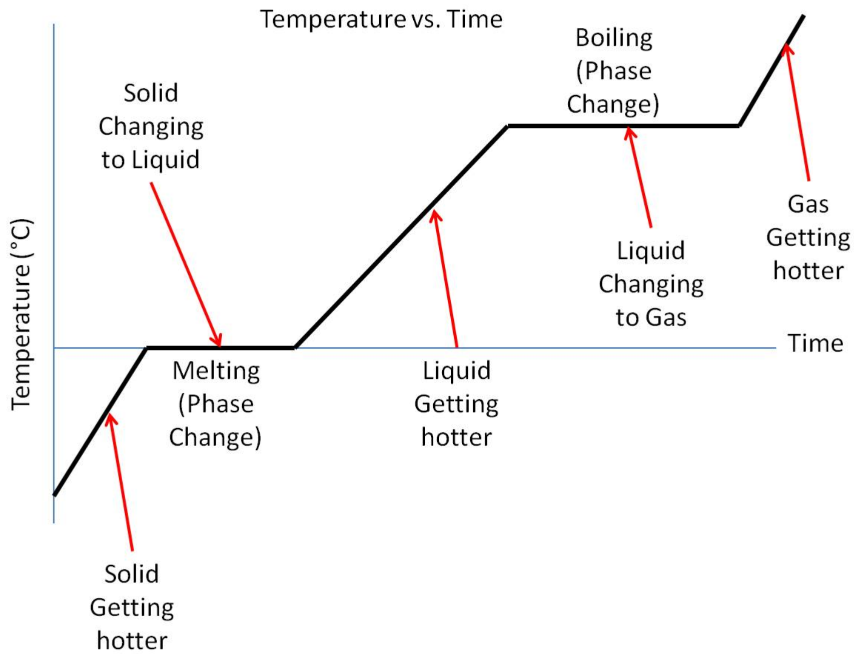
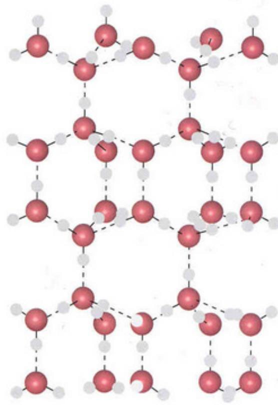
2. HIGH LATENT HEAT VALUES OF WATER



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

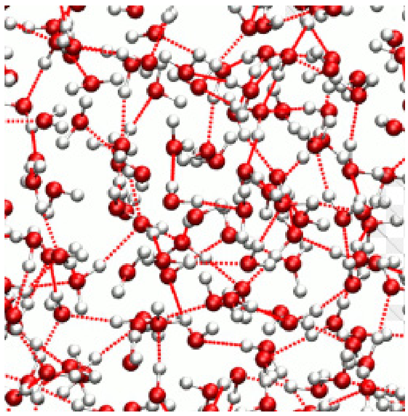
- Once the temperature reaches 0°C, the water will start to melt.
- At this point, the vibrations of the water molecules are large enough that the attractive forces holding the lattice together are no longer strong enough to hold the water molecules in fixed positions.
- During this time, the energy added to the system is absorbed by the intermolecular bonds and so **the temperature of the system doesn't increase**.
- Energy will continue to be absorbed by the intermolecular bonds until it's 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 and 100°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: $L_v(H_2O) = 2265\,kJ.kg^{-1}$

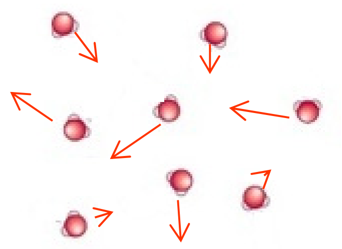
- It is the latent heat of vaporisation of water that makes it an **effective coolant**.

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.

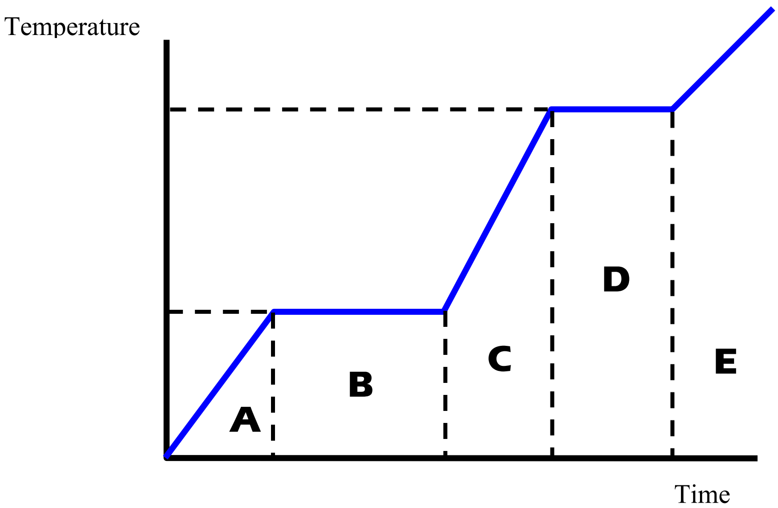


Figure 2

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 were 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?
The 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 vaporisation 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. Therefore, 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 required.

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 a 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 $4.184\ J/g/°C$. 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 $1.413\ J/g/°C$. 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.

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.

QUESTION 14
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 15
Which would heat up faster? A metal with high or low specific heat? Give a reason for your answer.

Solution

CALCULATING 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 16
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 17
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 18
Calculate the temperature change when $10.0\,kg$ of water loses $232\,kJ$ of heat.

Solution

QUESTION 19
$2.52 \times 10^4\,J$ of heat is added to $2.0\,kg$ of mercury to reach a final temperature of $130^o C$. What was the initial temperature of the mercury if its specific heat capacity is $0.14\,J/g/^oC$?

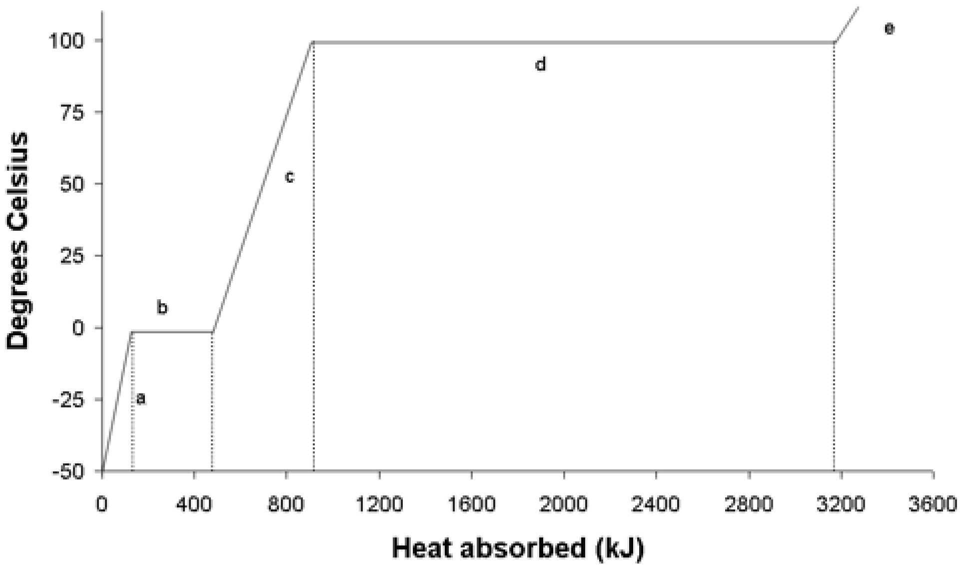
Solution

QUESTION 20
How much water at $50^o C$ is needed to just melt $2.2\,kg$ of ice at $0.0^o C$?

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 21
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.

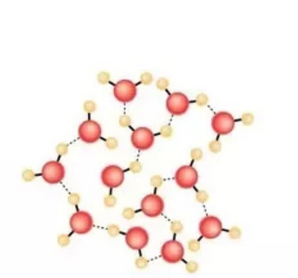


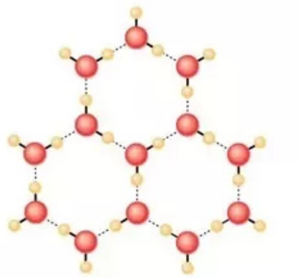
Solution

QUESTION 22
Determine the heat energy needed to convert $5.00\ kg$ of water at $60^o C$ to steam at $100^o C$.

Solution

3. EXPANSION ON FREEZING OF WATER

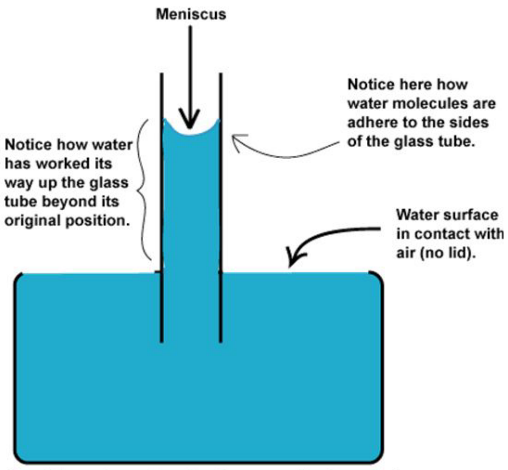




Water Liquid **Water Ice**

As water is cooled, the molecules slow down and arrange themselves regularly. The lattice is open and the molecules in ice are more widely spaced than in the liquid so ice has a lower density than liquid water.

4. HIGH CAPILLARY ACTION OF WATER



Capillary rise of water in a small glass tube.

Some liquids have the ability to rise up capillary tubes (tubes with small internal diameters) and to enter porous materials, despite the pull of gravity in the opposing direction. This is because the liquid particles are attracted to the surface of the tube as well as to one another through adhesive forces.

Water has the highest surface tension of all natural liquids and a relatively low density, so it will creep up a given capillary tube far higher than other natural liquids.

5. WATER IS AN EXCELLENT SOLVENT

TERMINOLOGY

Solute: The substance that is being dissolved.

Solvent: The liquid used to dissolve the solute.

Solution: The mixture produced when a solute has dissolved in a solvent.

A solution is one in which no more solute will dissolve at a particular temperature is referred to as a **saturated solution**.

Solutions formed using water as a solvent are called **aqueous** solutions.

The polar nature of water molecules enables it to dissolve a large number of polar covalent and ionic substances. For this reason, water is never found pure in nature.

In order for a substance to dissolve into water, three processes must occur.

1. The solute particles must separate from one another.
2. At least some of the water particles must separate to make room for the solute particles.
3. Solute and water particles must mix together.

Therefore, the solubility of a substance depends on the relative strengths of the intermolecular/interparticle forces between:

- Solute particles
- Water particles
- Solute and water particles

A substance will dissolve in water if the intermolecular/interparticle bonding between the solute and water is similar in strength to that between the water molecules or that between the solute particles. If this is not the case, there is no advantage in the substance dissolving.

If the intermolecular/interparticle bonding between the solute particles is stronger than that between the solvent particles, the solute will *not* dissolve.

Example: *Calcium carbonate and water.*

The strength of the attraction between Ca^{2+} and CO_3^{2-} ions is much stronger than the attraction that can form between these ions and water. Hence, $CaCO_3$ is insoluble.

If the intermolecular bonding between the solvent particles is stronger than that between the solute particles, the solute will *not* dissolve.

Example: *Hexane and water.*

The strength of the hydrogen bonding between water is much stronger than the attraction that it can form with hexane via dispersion forces. Hence, hexane is insoluble in water.

If the intermolecular bonding between the solute particles is similar to the strength of the bonding between the solvent particles, the solute is *likely* to dissolve.

Example: *Methanol and water.*

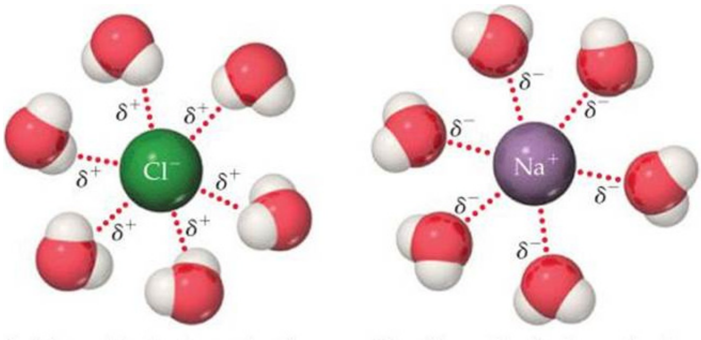
The strength of the hydrogen bonding in water and methanol is so similar that they can replace one another. Hence, methanol is soluble in water.

In general, a substance will dissolve in water if it is relatively small and is highly polar or can hydrogen bond with water.

SOLUBILITY OF IONIC COMPOUNDS

Ionic solids (or salts) contain positive and negative ions which are held together by the strong force of attraction between particles with opposite charges. When placed in water, many ionic solids dissociate. That is, the ionic lattice breaks apart allowing the ions to go into solution. This occurs since the positive end of the water molecules are attracted to the anions, and the negative ends of the water molecules are attracted to the cations.

The anions and cations become surrounded by water molecules in the solution and are held in solution by relatively strong ion-dipole interactions.



Ionic compounds *will* dissolve in water if the energy given off when the ions interact with water molecules compensates for the energy needed to break the ionic bonds and separate the water molecules.

If the ionic bonding in an ionic solid is particularly strong, then the ionic substance may not dissolve.

The solubility of ionic substance can be determined by using a solubility table.

Level of solubility	Ionic compounds containing ions of	Exceptions
Generally soluble	K^+, Na^+, NH_4^+	
	CH_3COO^-, NO_3^-	
	Br^-, Cl^-, I^-	Ag^+ and Pb^{2+} compounds.
	SO_4^{2-}	Pb^{2+}, Ba^{2+}, Ag^+ and Ca^{2+} compounds are slightly soluble.
Low solubility	CO_3^{2-}, PO_4^{3-}, S^{2-}	K^+, Na^+, NH_4^+ compounds
	OH^-	K^+, Na^+, NH_4^+, Ba^{2+}, Sr^{2+} compounds. $Ca(OH)_2$ is slightly soluble.

Note: The solubility of ionic substances *generally* increases with temperature but there are some exceptions!

QUESTION 24
Give a reason as to why some ionic compounds, such as silver chloride, are insoluble in water.

Solution