# Ch 10. Water

[redacted]

AREA OF STUDY 1 HOW DO CHEMICALS INTERACT WITH WATER?

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<u>Key knowledge:</u>

**Water as a unique chemical**

- existence of water in all three states on Earth's surface, including the distribution and

proportion of available drinking water

- explanation of the anomalous properties of H2O (ice and water) with reference to hydrogen

bonding:

° trends in the boiling points of group 16 hydrides

° the density of solid ice compared with liquid water at low temperatures

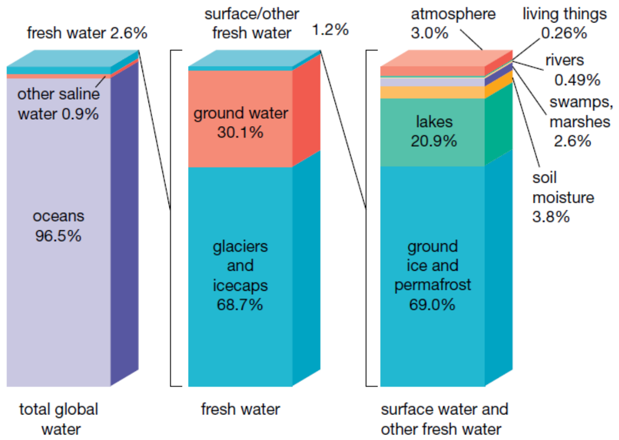
° specific heat capacity of water including units and symbols

- the relatively high latent heat of vaporisation of water and its impact on the regulation of the temperature of the oceans and aquatic life.

# 10.1 Introduction

- 70 % of Earth's surface is covered by water, but only a small percentage of this water is fit to drink
- Water moderates our climate and is essential for life
- Water exists in all three states: solid, liquid and as water vapour in the atmosphere
- Only 2.6% water on earth is fresh water
- From that, only 1.2% is surface/other fresh water

Thus, only 0.03 of all water on Earth must sustain all land-based life, including more than 7 billion people.




## 10.2 Water on Earth

**TABLE 10.1** Approximate global distribution of water by percentage and state

| | Location of water | State of water | Percentage of total water on Earth |
|---|---|---|---|
| Salt water 97.4% | Oceans | Liquid | 96.5% |
| | Other saline water | Liquid | 0.9% |
| Fresh water 2.6% | Glaciers and icecaps | Solid | 1.72% |
| | Ground water | Liquid | 0.753% |
| | Ground ice and permafrost | Solid | 0.0207% |
| | Lakes | Liquid | 0.00627% |
| | Soil moisture | Liquid | 0.00114% |
| | Atmospheric water vapour | Gas | 0.0009% |
| | Swamps and marshes | Liquid | 0.00078% |
| | Rivers | Liquid | 0.000147% |
| | Living things | Liquid and gas | 0.000078% |

### Water usage

- United Nations predicts that by 2025 an estimated 1.8 billion people will live in water-scarce regions
- Usage is exacerbated by population growth and climate change.

Therefore, strategies targeting the United Nations Sustainability Goals, including Goal 6 (Clean Water and Sanitation) and Goal 14 (Life Below Water) are encouraged.

### Water sources in Australia

The sources of water in Australia are from:
- water catchments — protected and open
- lakes
- rivers and creeks
- groundwater (bore water)
- desalinated water
- recycled water.

Uses of water:
- agriculture - 67 %
- urban use- 22%
- industrial use- 11%

### Urban water

Water in urban areas is sourced from a mains water supply (through a network of pipes), called reticulated water.

- Melbourne's source of water is mainly from surface water assisted by desalinated water;
- Perth uses both groundwater and desalinated water;
- Adelaide relies on water from rivers and desalinated water.

Read: Case studies- Melbourne water sources and Wurundjeri creation story of the Yarra river (pg 373 and 374)

### Sustainable Development Goal 6 — clean water and sanitation

- The sixth goal of the United Nations Sustainable Development Goals (SDGs) is to 'ensure availability and sustainable management of water and sanitation for all' by 2030.

Between 2015 and 2020:

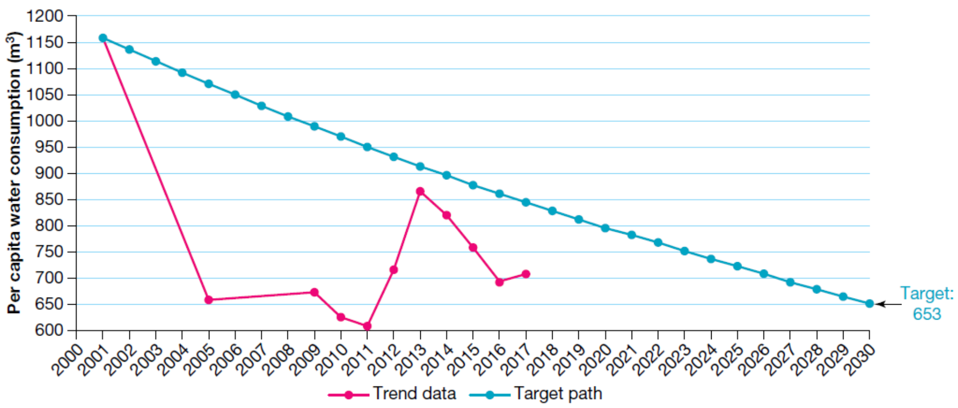
- 70.2 to 74.3 %- access to drinking water services
- 47.1 to 54.0 % - safely managed sanitation services
- 67.3 to 70.7 %- access to basic hygiene needs

In 2020, 771 million people were still without even basic drinking water, with half of these people (387 million) living in sub-Saharan Africa.

### Sustainable Development Goal 6 — clean water and sanitation- in Australia

Australia's 2020 progress report of SDGs only reported against two of the eight targets within Goal 6 (cost and consumption per capita — see table 10.3)

**FIGURE 10.7** Australia's performance against UN Target 6.4: water consumption per capita




*Source*: www.sdgtransformingaustralia.com/explore-by-goal/#/1247/1271//, based on QECD data on total water abstractions per capita.

### Sustainable Development Goal 14 — life below water

- Oceans take up 96.5 % of the world's water and represent 99 %of the living space of the planet
- Oceans assist absorbing heat (more than 90%) and carbon dioxide (~30%) from the environment

Increase in carbon dioxide emissions in atmosphere has led to:

- increase in ocean water temperatures, as oceans can no longer absorb excess $CO_2$, so it contributes to the greenhouse effect
- oceans can no longer act as a buffer to the high levels of carbon dioxide compared to pre-industrial levels
- increased atmospheric temperature results in increasing surface water temperature, which causes ocean currents to slow, water layers are formed, and $CO_2$ becomes saturated in these layers and can no longer be absorbed

## Ocean acidification

When oceans absorb CO2 , bicarbonate ions are produced. They dissociate and produce H+ ions

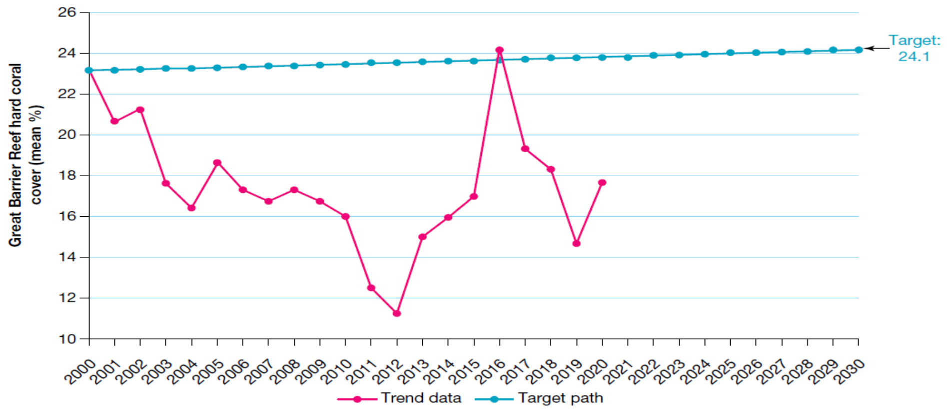
$$H_2O + CO_2 + CO_3^{2-} \rightarrow 2HCO_3^- \rightarrow H^+ + CO_3^{2-}$$

Increased H+ ions lead to reduced pH or increased acidity

## Eutrophication

- Eutrophication - takes place when the body of water is still and there is not enough oxygen in water. This leads to build up of nutrients, such as nitrogen and phosphorus, leaching from soils, typically resulting in excessive growth of algae.
- During the growth of algae and when plants die, their decomposition seriously depletes the level of dissolved oxygen in the water.
- As a result of this, animals, especially fish, and even plants may die due to a lack of oxygen required for respiration.
- Examples of eutrophication: The Coral reef
- 

**FIGURE 10.9** Australia's reporting of Target 14.2: hard coral cover shows a decrease of cover and is listed as off track for this target.




*Source:* www.sdgtransformingaustralia.com/explore-by-goal/#/1255/1376//, based on data from the Australian Institute of Marine Science (AIMS) Long-term Reef Monitoring Program.

***Activity***: Think about water

Describe and draw (2 min) the structure of the water molecule in terms of:

- Shape of molecule
- Type of intramolecular force
- How electrons are shared? – any lone pairs?
- Are the individual bonds polar?
- Is the molecule overall polar?
- Does the molecule have a permanent dipole?

***Homework:***

Read: Case studies- Melbourne water sources and Wurundjeri creation story of the Yarra river (pg 373 and 374)

Exercises pg 379 : 10.2 - all questions

**Intramolecular bonding-**

***COVALENT***

- shared e- between H and O
- Polar bonds
- V-shaped molecule

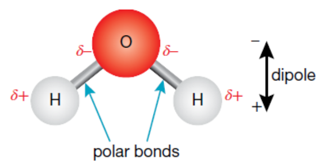
**Intermolecular bonding-**

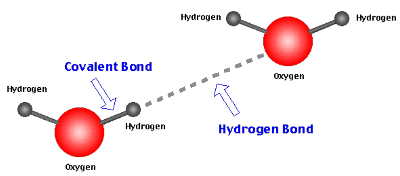
***H- bonding***

- electrostatic attraction between delta + partiel charge from a H atoms and delta- partial charge from O-atom of neighbouring water molecule
  - ➔ Large electronegativity = strong bond

***Dispersion forces***

- Weak bond



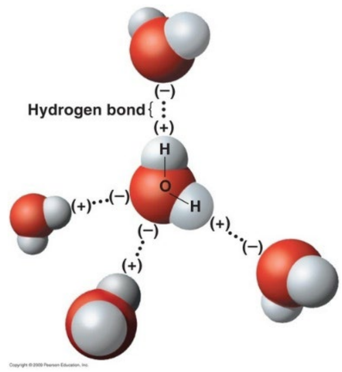




**TABLE 10.4** Summary of bonding within and between water molecules

| Type of bond | Description of bond | Where the bond is found relative to the molecular structure of water | Relative bond strength (in order from strongest to weakest) |
|---|---|---|---|
| Covalent bond | Intramolecular | Between hydrogen and oxygen within the water molecule | Strongest |
| Hydrogen bond | Intermolecular | Between the delta-positive hydrogen of one water molecule and the delta-negative oxygen atom of another water molecule | ↓ |
| Dipole–dipole bond | Intermolecular | Hydrogen bond is a type of dipole–dipole bond; only hydrogen bonding dipole–dipole bonds exist due to water only having hydrogen and oxygen atoms | ↓ |
| Dispersion force | Intermolecular | Present between all molecules; however, due to the small size of a water molecule, this force is extremely weak | Weakest |

## Melting and boiling points (M.P. and B.P.)

The melting and boiling temperatures of a compound depend on the strength of the intermolecular bonding between the molecules

**Boiling temperature** of a substance:

- is the temperature at which it changes from a liquid to a gas.
- energy must be provided in this **endothermic process**.
- the stronger the intermolecular bonds, the higher the boiling temperature.

**Melting temperature:**

- temperature at which state changes from solid to liquid
- energy must be provided in this **endothermic process**.

To change state from liquid to solid, energy must be removed — making this an **exothermic process.**

### Water states of matter

The density of water is greatest at 4 °C. As the temperature continues to decrease, the denser water at 4 °C sinks and eventually the temperature at the surface becomes 0 °C and freezes.

Ice forms in an open, hexagonal crystalline lattice that places the water molecules further apart than occurs in the liquid state.

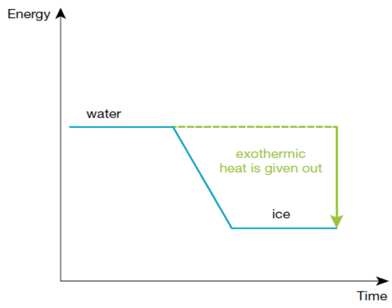



FIGURE 10.14 Arrangement of water molecules in its three different states

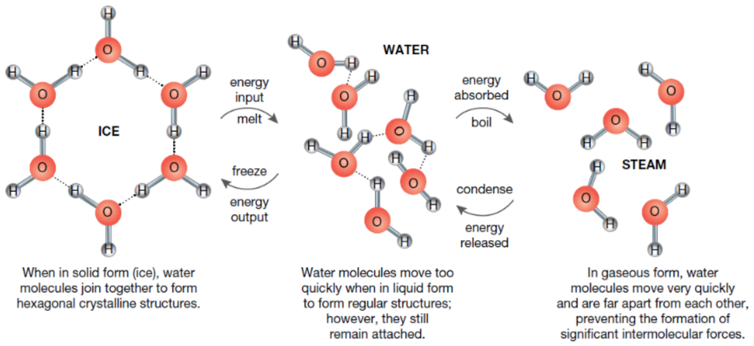



FIGURE 10.15 Each water molecule forms tetrahedral hydrogen bonds to four other water molecules.

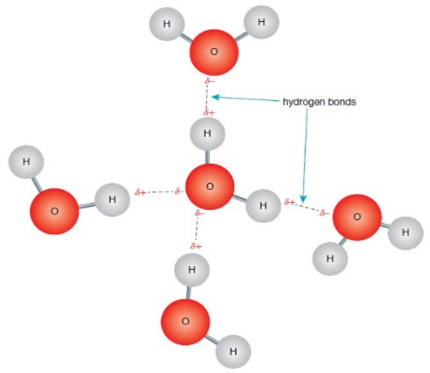



TABLE 10.5 Density of ice and water at selected temperatures

| Ice | | Liquid water | |
|---|---|---|---|
| Temperature (°C) | Density ($\rho$) (g mL) | Temperature (°C) | Density ($\rho$) (g mL) |
| −50 | 0.922 | 0 | 0.999 84 |
| −40 | 0.921 | 2 | 0.999 94 |
| −30 | 0.920 | 4* | 0.999 98 |
| −20 | 0.919 | 6 | 0.999 94 |
| −10 | 0.919 | 8 | 0.999 85 |
| 0 | 0.916 | 10 | 0.999 7 |
| | | 20 | 0.998 2 |
| | | 25 | 0.997 1 |
| | | 30 | 0.995 7 |

Water has its highest density at 3.98 °C.

## Density of water

| Density of a substance is the amount of mass that is contained in a certain volume of that substance.<br><br>**d = m/V**<br><br>d- density of the substance,<br>m is the mass (g or Kg)<br>V- volume (L, mL, or $m^3$) | **Practice #1**. Calculate the mass, in grams, of 150 mL water at 25.0 °C given that the density of water is 0.997 g $mL^{-1}$. |
|---|---|

Water's maximum density is at at 4 °C (see table 10.5).

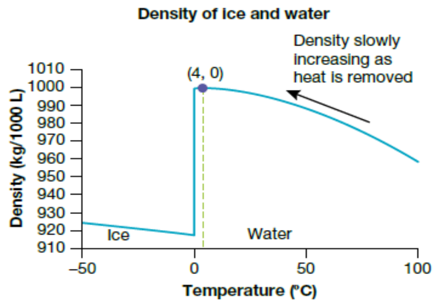
- As it approaches 0 °C (close to freezing), rises to the top because it is less dense than the surrounding water.
- Ice has a density that is significantly less than water.

That is why ice floats on water (l).

Since **d (ice) < d(water liquid)**

**V (ice) > V(water liquid)**

FIGURE 10.16 The density of water changes as it approaches freezing point.



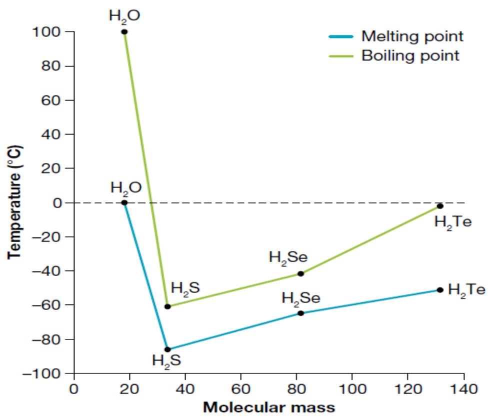

## Melting point and boiling point of group 16 hydrides

Except for water, the larger the molecule, the higher the MP and BP.

Water is an anomaly because of its H-bonding.

TABLE 10.6 Melting and boiling temperatures of group 16 hydrides

| Hydride | Formula | Molar mass (g mol–1) | Melting temperature (°C) | Boiling temperature (°C) |
|---|---|---|---|---|
| Water (hydrogen oxide) | $H_2O$ | 18 | 0 | 100 |
| Hydrogen sulfide | $H_2S$ | 34 | –86 | –61 |
| Hydrogen selenide | $H_2Se$ | 81 | –65 | –42 |
| Hydrogen telluride | $H_2Te$ | 129.6 | –51 | –2 |




Water has hydrogen bonding, and dispersion forces, and hence has the highest M.P. and B.P.

As you go down the group from $H_2S$ to $H_2Po$, there is dipole-dipole attraction present but the mass of the molecule also increases, therefore strength of dispersion forces increases (the greater the mass of molecule, the greater the strength of dispersion forces). More energy is needed to overcome the increasing dispersion forces, therefore MP and BP increase.

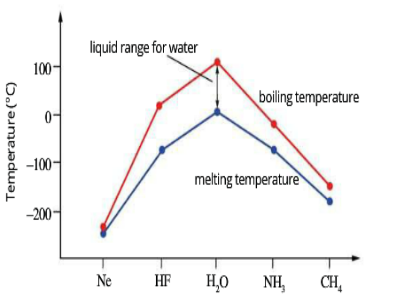



FIGURE 12.1.7 The melting and boiling points of water and other molecules of similar size.

When comparing water molecule with other molecules of similar sizes, water has significantly higher melting point and boiling point.

This is due to its relatively strong H-bonds between molecules

### Water expands on freezing

- When a sample of water freezes, the resulting ice crystal lattice has greater volume than the sample of water in liquid state  lower density in solid phase than liquid phase (unusual property)

- When water freezes, the molecules arrange in a way that one water molecule forms four H-bonds to four neighbouring water molecules  open arrangement of water molecules (more widely spaced)

Water is unusual in that its solid phase, ice, will float on its liquid phase.

***Homework:***

Exercises: 1, 2,3, 4,5, 6, 7,8. 8,10

Exam questions: 1,2,3,4

## 10.4 SPECIFIC HEAT CAPACITY

### Specific heat capacity

- The specific heat capacity of a substance measures the amount of energy (in joules) needed to increase the temperature of a certain amount (usually 1 gram) of a substance by 1°C

- Specific heat capacity is given the symbol C and is expressed in joules per grams per degrees Celsius; i.e. J $g^{-1}$ $°C^{-1}$

- SHC reflects the type of bonding in that substance. For covalent molecules, it will depend on strength of intermolecular forces

- Water has high SHC due to large amount of H-bonds. H-bonds are able to absorb and store large amounts of heat energy before they break.

**TABLE 10.7** Specific heat capacity of some common substances

| Substance | Specific heat capacity (c) (J $g^{-1}$ $°C^{-1}$) |
|---|---|
| Water | 4.18 |
| Ethanol | 2.5 |
| Vegetable oil | 2.0 |
| Soil (wet) | 1.5 |
| Aluminium | 0.90 |
| Concrete | 0.88 |
| Glass | 0.84 |
| Sand (dry) | 0.80 |
| Soil (dry) | 0.80 |
| Copper | 0.39 |
| Gold | 0.13 |
| Lead | 0.13 |

### Water heat capacity

- Water has specific heat capacity of 4.18 J $g^{-1}$ $°C^{-1}$ or 4.18 kJ $kg^{-1}$ $K^{-1}$
- Water has high SHC due to large amount of H-bonds.
- Water is an excellent insulator of heat.
- With a heat capacity almost five times higher than soil or rock (see table before), water retains heat five times more effectively than land, but may take five times longer than land to heat up.
- Water can absorb large amounts of heat energy with only a minimal increase in temperature.

**Calculations**

Heat energy = specific heat capacity x mass x temperature change

**q = C x m x ΔT**

Where:

q is the amount of heat energy (J)

C is specific heat capacity (J $g^{-1}$ $°C^{-1}$ or J $g^{-1}$ $K^{-1}$)

m is mass (g)

ΔT is temperature change (in °C, or K)

**SAMPLE PROBLEM 2 Calculating the heat energy to raise the temperature of water**

**Calculate how much heat energy (in kJ) is needed to raise 250.0 grams of water from 20.0 °C to 100.0 °C. The specific heat capacity of water is 4.18 J $g^{-1}$ $°C^{-1}$.**

| THINK | WRITE |
|---|---|
| 1. State the given information and identify the quantity required. | $m(H_2O) = 250.0$ g<br>$c(H_2O) = 4.18$ J $g^{-1}$ $C^{-1}$<br>$\Delta T(H_2O) = 100.0\,°C - 20.0°C = 80.0\,°C$<br>$q(H_2O) = ?$ |
| 2. Recall the formula to calculate energy is $q = mc\Delta T$. | $q = 250.0 \times 4.18 \times 80.0\,°C = 8.36 \times 10^4$ J |
| 3. Convert J to kJ by dividing by 1000. Check that significant figures and the unit are correct. | $q = \frac{8.36 \times 10^4}{1000} = 83.6$ kJ |

**Example 1:**

Calculate the heat energy, in kJ, needed to increase the temperature of 200 g of water by 15.0 °C

***Example 2:***

PRACTICE PROBLEM 2

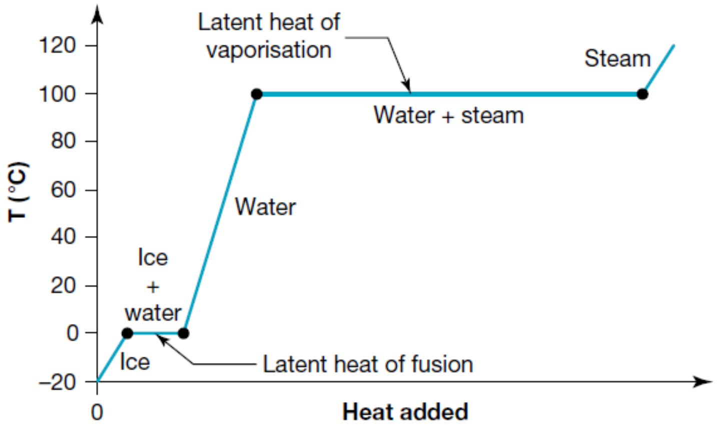
**Calculate the amount of heat energy (in kJ) required to warm 1000 grams of water from fridge temperature at 4.0 °C to room temperature, 25.0 °C.**

## 10.4.2. Latent heat

Latent heat is the energy absorbed by a substance in order to change state at its melting or boiling temp

Horizontal region of graph shows where latent heat is absorbed and there is no change in temp.

- Latent heat of fusion of a substance is the heat needed to change 1 mole of a substance from a solid to a liquid at its melting point. Water melts at 0 °C.
- Latent heat of vaporisation of a substance is the heat needed to change 1 mole of the substance from a liquid to a gas at its boiling point. Water boils at 100 °C.
- The symbol for latent heat is L. Common units are kJ $mol^{-1}$ and J $kg^{-1}$.
- The higher the latent heat of a substance, the greater the amount of energy it needs when it changes state.




**Latent heat of fusion of water is 6.0 kJ mol$^{-1}$**
6.0 kJ of energy is needed to change 1 mole of water from a solid to a liquid at 0°C
This energy is needed to disrupt the ice lattice by breaking some of the H-bonds between water molecules.
The molecules can move more freely in the liquid phase.

**Latent heat of vaporisation of water is 44.0 kJ mol$^{-1}$**
44.0 kJ is needed to change the state of 1 mole of water from a liquid to a gas at 100°C
This large quantity of energy is required to completely break the H-bonds between water molecules so they can separate and form a gas.
The molecules must be completely separated from each other when changing from liquid to gas and not just slightly moved apart as when moving from the crystal lattice in ice to liquid water.

## Significance of water's latent heat of vaporisation

- Cooling systems for living organisms
- Takes a relatively large amount of energy to vaporise sweat from body's surface
- As sweat evaporates, it extracts large quantity of heat which effectively cools the body

- Longevity of water supplies
- Evaporation losses from water storage facilities can be large but it would be larger if water's latent heat of vaporisation was lower

## Calculations:

Amount of heat energy required to change state = amount of substance (mol) x latent heat value (kJ mol–1)

**$q = n \times L$**

where
q is the amount of heat energy (kJ)
n is the amount (mol) of substance changing state
L is the latent heat value of fusion or vaporisation (kJ mol$^{-1}$)

**SAMPLE PROBLEM 3 Calculating the heat energy to melt ice**

**Calculate the heat energy (in kJ) required to fully convert 100 grams of ice to liquid water.**

| THINK | WRITE |
| --- | --- |
| 1. State the given information and identify the quantity required. | $m(H_2O) = 100$ g<br>$q(H_2O) = ?$ |
| 2. To use the latent heat formula, $q = nL_f$, first calculate the number of mole of water, $n$, where $n = \frac{m}{M}$ | $n(H_2O) = \frac{m}{M}$<br>$= \frac{100}{(2 \times 1.0 + 16.0)}$<br>$= 5.56$ mol |
| 3. Find $q = nL_f$. The latent heat of fusion for water can be found in table 10.8, $L_f = 6.01$ kJ mol$^{-1}$. Check significant figures and units are correct. | $q(H_2O) = 5.56 \times 6.01$<br>$= 33.4$ kJ |

***Example 1:***
Calculating the heat energy required to evaporate a given mass of water at its boiling temperature
Calculate the heat energy, in kJ required to evaporate 200 g of water at 100°C.

***Example 2:***
Calculate the heat energy (in kJ) required to evaporate 75.0 g of water at 100°C

### 10.4.3 Impacts on ocean temperature and ocean life

- Oceans act as a buffer to control global temperatures for the following reasons:
- Water has much higher latent heat values than other substances. This means that water evaporates more slowly than many other liquids.
- The ocean and the atmosphere continuously exchange heat, water vapour and carbon, forming the water cycle and weather patterns.
- Due to the high specific heat capacity of water, the oceans can release the heat over a long period of time.
- Short-term extremes in temperature can be evened out as the oceans absorb heat from the atmosphere in the tropics and then release it when ocean currents take this water to the polar regions.

### Impacts of human activities

- Burning of fossil fuels, agriculture and land clearing — are increasing the amount of greenhouse gases in the atmosphere resulting in increased heat being trapped within Earth's atmosphere through the enhanced greenhouse effect.
- As average global temperatures rise, the oceans are struggling to maintain stable atmospheric and sea temperatures.
- So far, 2016 was the warmest year on record for the world's average sea surface temperatures.

**Impacts of warming sea activities**

**Rainfall patterns**: This has serious implications, not only for ecosystems but also for human activity such as agriculture.
**Increased severity of storms**: increased sea surface temperatures increase the amount of evaporation from the oceans, leading to increased risk of heavier rainfall. With additional energy in the environment, storms are also more severe.
**Impacts on ecosystems and biological diversity**: different aquatic organisms have different optimal temperatures for survival and, changes in ocean temperatures have an impact on biological diversity.

Example: Plankton (at the bottom of the marine food chain) make up 90 % of the living mass in oceans. They regulate the climate as they absorb carbon dioxide and release oxygen via photosynthesis. With ocean temperatures rising, the plankton are migrating to colder waters and, the whole food chain must shift too.
This also affects food and job security for humans.

**Sustainable Development Goal 13 — Climate action**
The 13th goal of the United Nations Sustainable Development Goals (SDGs) is to 'take urgent action to combat climate change and its impacts' by 2030.
A major indicator in monitoring climate change is the total greenhouse gas emissions per year.

**Homework**
Questions: 1,2,3,4,5,6,7,8,9,10,11,12
Exam questions: 1,2,3,4,5

Summary chart- see textbook.

**Summary**
Exercises: All
Exam questions: All