Section 1.1.5 – How thermal energy moves

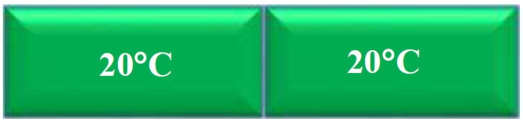
VCAA Study Design Dot Points

- describe temperature with reference to the average translational kinetic energy of the atoms and molecules within a system:
  - distinguish between conduction, convection and radiation with reference to heat transfers within and between systems

Heat

Heat, symbol Q, is thermal energy that **flows/transfers** from one system to another. Consider two objects that are in thermal contact with one another:

Scenario 1
The two objects are at the **same temperature**.
There will be **no net transfer of heat** between them.



NB: Heat is measured in Joules since it is a form of energy

Scenario 2
The two objects are at the **different temperatures**.
There will be a **net transfer of heat from the hotter object (higher temperature) to the colder object (lower temperature)**. The greater the difference in temperature of the two objects, the faster the transfer of heat.

Eventually, as result if heat flow, the two objects will reach the **same equilibrium temperature**. This is known as **thermal equilibrium**.

There are three different processes through which energy can be transferred during heating and cooling:

- Conduction
- Convection
- Radiation

Conduction

Conduction between two systems can only occur when:

- they are in **physical contact**, and
- they are at **different temperatures**

In conduction, heat energy transfer occurs by a process of **molecular or atomic collision**.

If you heat up one end of a bar of iron, the energy is transferred from the hot end to the cold by atoms or molecules bumping into one another (ie. a transfer of kinetic energy). This can be seen in **Figure 1** below.

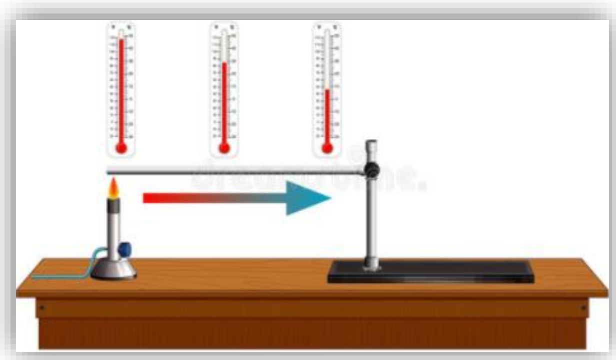


Figure 1 *Conduction of heat in metallic bar*

While there is a transfer of energy from hot to cold, the molecules themselves do not change their respective positions.

This is the primary method of **heat transfer in solids** and it works best of all in **metals** (because loosely bound or delocalised electrons). It is also an efficient method of conduction in liquids, but
occurs hardly at all in gases. In gases, a low density of atoms or molecules inhibits conduction very effectively

Something that is **good at conducting** heat is called a good **thermal conductor**.
Something that is **bad at conducting** heat is called a good **thermal insulator**.

A table of typical conductivities is provided in **Table 1**.

Thermal Conductivities of Selected Materials, $W/m.K$ (values @20℃, unless otherwise stated)					
Good Conductors		**Average Conductors**		**Poor Conductors (good insulators)**	
Diamond	2000	Ice (@0℃)	2.20	Brick	0.150
Silver	429	Concrete	1.70	Asbestos	0.090
Copper	400	Soil	1.50	Fiberglass	0.040
Aluminium	220	Glass	1.00	Glass wool	0.040
Iron	80	Water	0.60	Styrofoam	0.033
Lead	35	Epoxy	0.59	Air (dry)	0.026
Stainless steel	14	Body fat	0.20	Silica aerogel	0.004
Granite	3	Snow	0.16	Vacuum	0

***Table 1** Conductivity Table*

Example 1
An individual builds a fire, and then moves around the burning logs with a poker. Heat is conducted from the burning logs to the poker, making the end of the poker become red-hot if it is left in the fire too long.

Rate of Conduction

The heat flow rate between two objects due to conduction is directly proportional to their difference in temperature.

$$\frac{Q}{t} \alpha \Delta T$$

Where Q is the net heat transferred (J)
t is the time taken for transfer (s)
ΔT is the magnitude of difference in the temperature between the two objects (K or ℃)

NB: $\frac{Q}{t}$ is described as the **heat flow rate**, and is measured in J/s.

Accordingly, if the difference in temperature between two objects is doubled, then so too the rate of heat transfer is doubled.

Example.2

A red-hot iron horseshoe of temperature 800℃ is placed into a bucket of cold water of temperature 20℃. In doing so 400 J of heat is transferred from the horseshoe to the water every 0.50 seconds.

Qn.1 What is the heat flow rate between the two objects?

$\frac{Q}{t} = ?$
$Q = 400J$
$t = 0.50\ s$

$$Heat\ flow\ rate = \frac{Q}{t} = \frac{400}{0.50} = 800\ J/s$$

At a few minutes, the horseshoe now has a new temperature of 450℃ and the water a new temperature of 60℃.

Qn.2 What is the <u>new</u> heat flow rate between the two objects?

$\frac{Q}{t} = ?$
$\frac{Q}{t}\ \alpha\ \Delta T$

$$\Delta T_{original} = T_{horseshoe} - T_{water}$$
$$\Delta T_{original} = 800℃ - 20℃ = 780℃$$

$$\Delta T_{new} = T_{horseshoe} - T_{water}$$
$$\Delta T_{new} = 450℃ - 60℃ = 390℃$$

ΔT has changed by a factor of ($\frac{390}{780}$) = ($\frac{1}{2}$)

$\frac{Q}{t}\ \alpha\ \Delta T$

Therefore, $\frac{Q}{t}$, the heat flow rate will also change by a factor of $\frac{1}{2}$

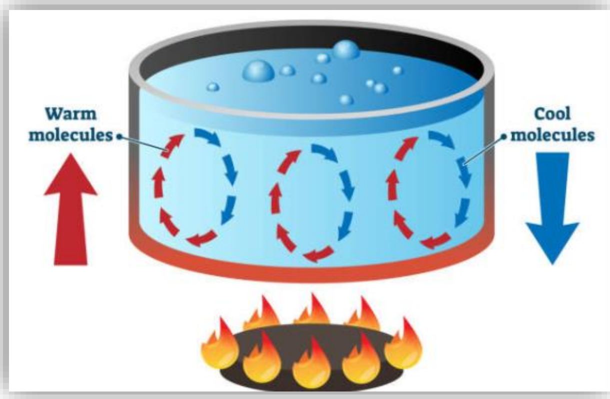
$\therefore\ \frac{Q}{t} = \frac{1}{2} \times 800\ J/s = 400\ J/s$

Convection

A **hotter** substance will generally **rise** above a **cooler** substance due to **convection**. Heat energy is transferred by a movement of molecules between regions of **different temperatures**. Convection occurs in **fluids** (gasses and liquids) where particles are free to move around.

The classic example is water being heated in a pot, as shown below in **Figure 2**.

- The fluid (water) is being heated from the bottom of the pot
- The hot fluid (water) expands and becomes less dense, accordingly it rises
- Therefore energy is convected away from the ground
- The colder fluid (water) is denser, so sinks and pushes up the hotter fluid (water)
- The hot fluid (water) cools down as it rises by transferring heat to its cooler surroundings, increasing in density and falling back down to the bottom.
- If the heating persists, particles continue rising and falling in what we call convection cells.



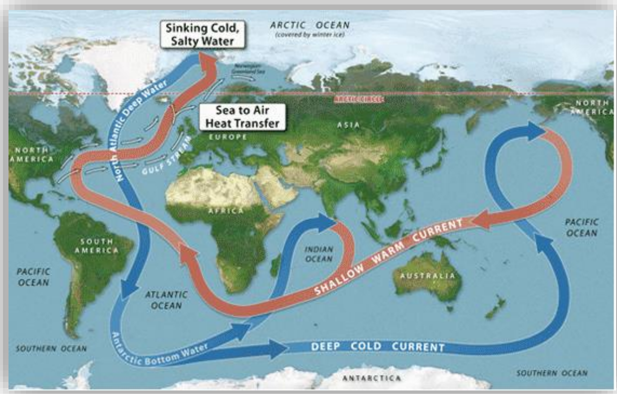


Figure 2 *Convection in a pot of water* ***Figure 3*** *Convection & the global conveyor belt*

This an important method of heat transfer in gases, and convection currents are responsible for everything from sea breezes at shore to major wind patterns around the globe.

Example.3
Ocean currents transport heat from the equator to the poles through a heat and saline-driven process called thermohaline circulation. Refer to **Figure 3** above.

Radiation

Unlike conduction or convection, radiation does not require any medium. In fact radiation can be transmitted in a vacuum. Radiation is an electromagnetic wave. Thermal radiation is emitted by all objects with a temperature above absolute zero. Refer to **Figure 4**.

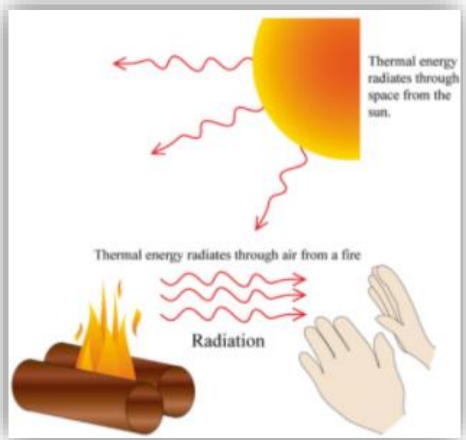


Figure 4 *Thermal radiation*

Accelerated charged particles emit **electromagnetic radiation.** Charged particles inside atom (ie. electrons and protons) accelerate due to the random motion associated with thermal energy.

Some of the **translational kinetic energy** inside the atom is transformed into **electromagnetic radiation**. This emission of radiation results in the **decrease** of the internal energy and temperature of the emitting substance.

When radiation meets an object one of three things can occur:

- **Transmission** – radiation travels through the material
- **Reflection** – radiation "bounces off" the material
- **Absorption** – the particles in the material receive the energy from the radiation

	In what situations it occurs	What it is	Medium required?	Matter transferred?	Energy transferred?
Conduction	When two systems are physically touching and within systems	Particles collide with each other across the contact surface or within the system, transferring their thermal energy.	✓	×	✓
Convection	In fluids	Particles move around the fluid, carrying their energy with them.	✓	✓	✓
Radiation	In all systems, but is more significant for hotter objects	Charged particles transform thermal energy into electromagnetic radiation (thermal radiation) as they accelerate.	×	×	✓

Exam Styled Questions

Question 1 (3 marks)
If all objects in a room are at room temperature, why does a metal tap feel colder than a timber benchtop?
Explain your answer.

All materials conduct heat. Materials that conduct heat well are known as heat conductors; for example, the metal tap. **1 mark**

Materials that do not conduct heat well are known as insulators; for example, the timber benchtop. **1 mark**

As heat is being lost from a person's hand to the metal tap at a faster rate than the timber benchtop, the tap is perceived as colder. **1 mark**

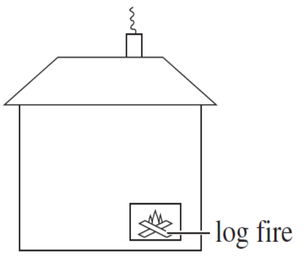
Question 2 (3 marks)
Discuss the methods of heat transfer when a tin can of cold water is placed over a Bunsen burner flame for a period of time.

The flame from the Bunsen burner produces radiation which heats the tin can. **1 mark**

The tin can then transfers heat to the water through conduction. **1 mark**

The hot water then rises to the top in the convection process, replacing it with cooler water and setting up convection currents. **1 mark**

Question 3 (1 mark)
A log fire is used to heat a large rumpus room, as shown in the diagram below.



By which of the following processes is the room heated when the log fire is burning?

A. radiation only
B. convection only
C. radiation and convection
D. radiation and conduction

C

Fire emits radiation. Convection currents are set up in the rumpus room.

Question 4 (1 mark)
Mia stirs her coffee with a metal spoon and notices that the spoon becomes warmer.
The method of heat transfer occurring is

A. evaporation
B. conduction
C. convection
D. radiation

B

The metal spoon is a solid, so the main method of heat transfer in the spoon is conduction.
