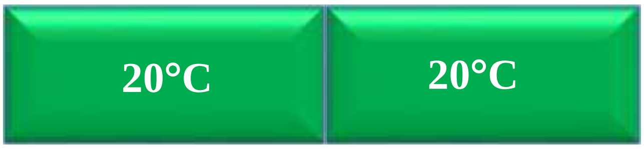
Section 1.1.2 – Transfer of Energy

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

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

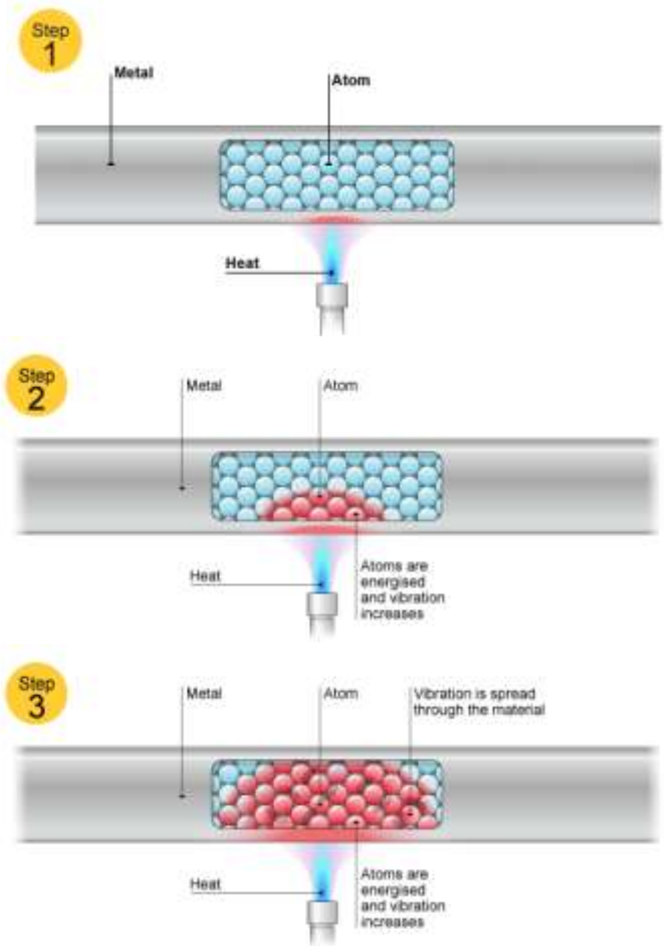
This is the primary method of **heat transfer in solids** and it works best of all in metals (because loosely bound or delocalised electrons). It is also an efficient method of conduction in liquids, but occurs hardly at all in gases. In gases, a low density of atoms or molecules inhibits conduction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

Conduction is a heat transfer that can occur for all **phases of matter** (solids, liquids, and gases). Conduction between two systems **only occurs when**:

- they are in contact.
- they are at different temperatures. Remember, two systems can be at different temperatures but have the same internal energy (and vice versa).

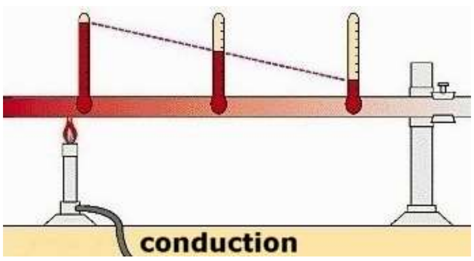
Due to their differing atomic and molecular structures, some materials and substances will be better at conduction than others are.

- 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.



Sample thermal conductivities

Thermal Conductivities of Selected Materials, W/m.K (values at 20°C, unless otherwise stated)					
Good Conductors		*Average conductors*		*Poor conductors (good insulators)*	
Diamond	2,000	Ice (0°C)	2.20	Brick, insulating	0.150
Silver	429	Concrete	1.70	Asbestos	0.090
Copper	400	Soil	1.50	Fiberglass	0.040
Aluminum	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



A temperature gradient along a conducting metallic rod.

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.

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

$$\boxed{\frac{Q}{t} \propto \Delta \mathrm{T}}$$

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 °C)

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

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°C is placed into a bucket of cold water of temperature 20°C. 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?

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

$$\frac{Q}{t} = \frac{400}{0.50} = 800\,J/s$$

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

Qn.2 What is the new heat flow rate between the two objects?

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

$$\Delta T_{original} = T_{horseshoe} - T_{water}$$
$$\Delta T_{original} = 800°\mathrm{C} - 20°\mathrm{C} = 780°\mathrm{C}$$

$$\Delta T_{new} = T_{horseshoe} - T_{water}$$
$$\Delta T_{original} = 450°\mathrm{C} - 60°\mathrm{C} = 390°\mathrm{C}$$

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

Therefore $\frac{Q}{t}$ will also change be a factor of $\frac{1}{2}$

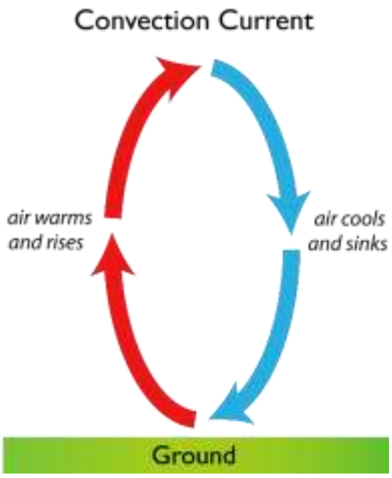
$$\frac{Q}{t} = \frac{1}{2} \times 800 = 400 J/s$$

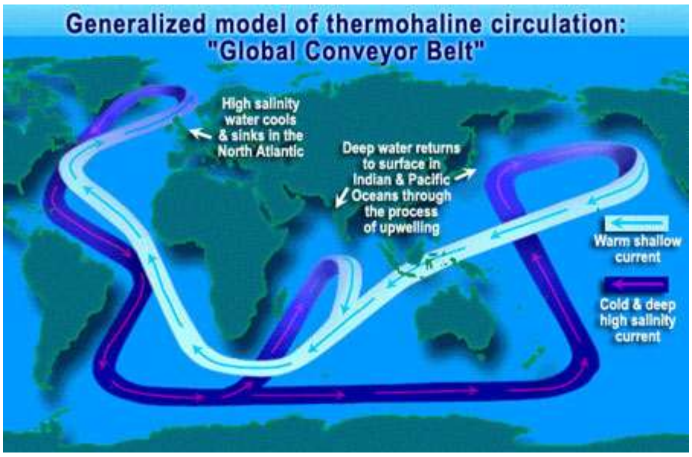
Convection

Heat transfer can also occur by the process of ***convection***. In this case, 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 **hot air rising:** on a hot day,

- Air is heated by the ground
- The hot air expands and becomes less dense, accordingly it rises
- Therefore energy is convected away from the ground
- The hot air 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.





As you might expect, 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*.

Radiation

The third and final process of energy transfer during heating and cooling is that of **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.

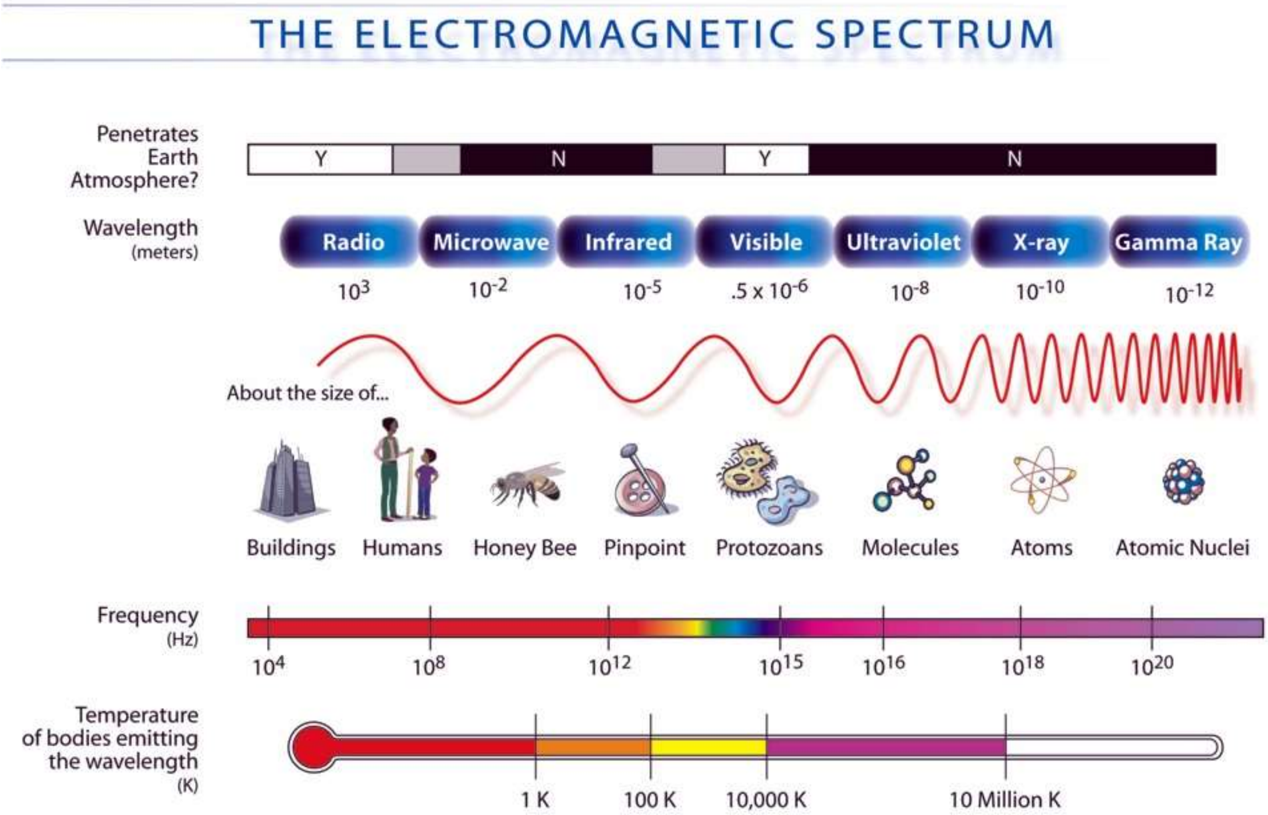
All objects above absolute zero emit some wavelength of **electromagnetic radiation**.

Example 3

Sun **Earth**

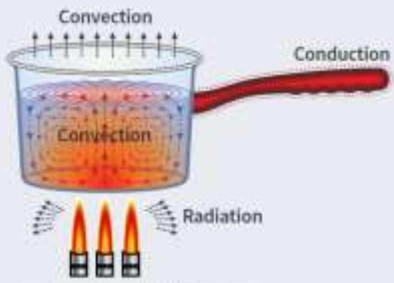
Surface Temperature:	6000 K	288 K
Radiation:	Short wavelength	Longer wavelength
	High frequency	Lower frequency
Energy:	High energy	Lower energy

NB: Any moving charges, even electrons located in atoms, will produce electromagnetic radiation.



Heat Transfer Comparison Table

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



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