Section 1.1.3 – Quantity of Heat

When two objects at different temperatures are placed in contact, the temperature of the colder object **increases** and the temperature of the hotter object **decreases**.

Heat energy is **transferred** from the hotter object to the colder object. We call this process **heating** (or **cooling**).

The quantity of energy transferred depends upon:

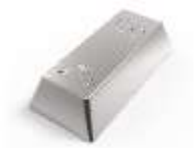
- the temperature of the objects
- the mass of the objects
- the material that each object is made of

Consider the following:
Combination A: 100g of water at 70°C mixed with 100g of water at 10°C $\rightarrow$ final temp of 40°C
Combination B: 100g of iron filings at 70°C mixed with 100g of water at 10°C $\rightarrow$ final temp of 16°C

Clearly the "nature" of the material impacts significantly upon the final temperature reached.

Specific Heat Capacity

Different materials have different **capacities** to hold heat. For example, consider a 1kg sample of water and a 1 kg sample of silver. If both samples were heated to 50°C and allowed to cool, which would reach room temperature first?



The silver sample of identical mass will cool much quicker than the water sample, as the water sample has a greater **capacity to hold heat**.

The term "***Specific heat capacity***" is defined as the amount of energy required to increase the temperature of 1 kg of the substance by 1 °C (or K).

NB: Water has a much higher specific heat capacity than silver. Accordingly, it takes more energy (and time) to heat a sample of water than silver. Water will also retain its heat better than silver and therefore takes longer to cool.

Sample specific heat capacities

Substance	Specific heat capacity ($J\ kg^{-1}\ K^{-1}$)
Helium	5193
Water	4200
Human body (average)	3500
Cooking oil	2800
Ethylene glycol (used in car 'antifreeze')	2400
Ice	2100
Steam	2000
Fertile topsoil	1800
Neon	1030
Air	1003
Aluminium	897
Carbon dioxide	839
Desert sand	820
Glass (standard)	670
Argon	520
Iron and steel (average)	450
Zinc	387
Copper	385
Lead	129

Water has a specific heat capacity of **4200 $Jkg^{-1}K^{-1}$.**

By definition this means that it will take 4200 Joules of energy to raise the temperature of 1 kilogram of water by 1 Kelvin (or 1°C).

Knowing the mass of a sample, its change in temperature and its specific heat capacity allows one to calculate the energy transferred.

$\boxed{Q = mc\Delta T}$

Where Q represents the energy transferred (J)
m represents the mass of the substance (kg)
c represents the substances specific heat capacity ($Jkg^{-1}K^{-1}$)
ΔT represents the change in temperature (K)

NB: Specific heat capacities are only valid for materials in **one single state.**
The above equation **cannot be used** to calculate the energy transfer during a change of state such as melting, vaporisation, condensation, freezing etc.

Example 1

Find the amount of energy needed to raise the temperature of 3.0 kg of iron from 10°C to 18°C.

Q = ?
m = 3.0 kg
c = 450 $Jkg^{-1}K^{-1}$
$\Delta T = 18 - 10 = 8$ K

$Q = mc\Delta T$
$= 3.0 \times 450 \times 8$
= **10800 J (1.1 x 10^4 J)**

NB: ΔT of 8°C is the same as 8K.

Example 2

Find the amount of heat lost (to the surroundings) when 2.0 kg of water at 80°C cools to 20°C.

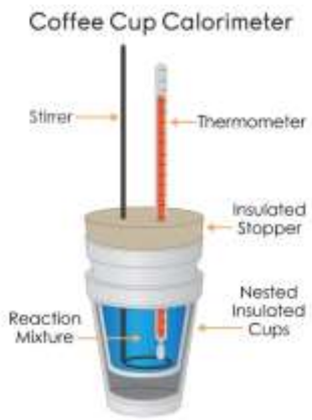
Q = ?	$Q = mc\Delta T$
m = 2.0 kg	$= 2.0 \times 4200 \times 60$
c = 4200 $Jkg^{-1}K^{-1}$	= **504000 J (5.0×10^5 J)**
$\Delta T = 80 - 20 = 60K$	

Example 3

A student supplies 1.40×10^4 J of heat energy to 500g of oil in a sealed container and the temperature rises from 10°C to 20°C.
Calculate the specific heat capacity (c) of the alcohol.

c = ?	$Q = mc\Delta T$
m = 0.5 kg	$\therefore c = Q/m\Delta T$
Q = 1.40×10^4 J	$= 1.40 \times 10^4/(0.5 \times 10)$
$\Delta T = 20 - 10 = 10K$	= **2800 $Jkg^{-1}K^{-1}$**

Calculating Specific Heat Capacity



To measure the specific heat capacity of a material we use a device called a **calorimeter**. The steps are as follows:

1. measure the mass of the material being tested
2. measure the mass of the water in the calorimeter
3. measure the initial temperature of the material being tested
4. measure the initial temperature of the water in the calorimeter
5. place the material into the water filled calorimeter
6. stir the contents until thermal equilibrium is reached

Use the conservation of energy to calculate the specific heat capacity of the material being tested.

Energy lost by hotter = Energy gained by colder $mc\Delta T$ (hotter) = $mc\Delta T$ (colder)

Example 4

A 75g block of aluminium at 100°C is placed in 200g of water at 10°C, in a calorimeter. The final temperature of the mixture is 16°C. Neglecting any heat energy gained by the calorimeter, what is the specific heat capacity of the aluminium?

Aluminium (hotter)	Water (colder)	
c = ?	c = 4200 $Jkg^{-1}K^{-1}$	
m = 0.075 kg	m = 0.200 kg	
$\Delta T = 100 - 16 = 84$ K	$\Delta T = 16 - 10 = 6$ K	**NB:** $\Delta T = T_{hot} - T_{cold}$

Energy lost by hotter = Energy gained by colder
$mc\Delta T$ (hotter) = $mc\Delta T$ (colder)

$0.075 \times c \times 84 = 0.200 \times 4200 \times 6$
$6.3 \times c = 5040$
$\therefore c = 5040/6.3$
$= 800\ Jkg^{-1}K^{-1}$

The specific heat capacity of the aluminium block is **800 (8.0 x 10^2) $Jkg^{-1}K^{-1}$.**

Example 5

A 100 g block of metal at 100°C is placed in a calorimeter containing 150g of water at 10°C. If the final temperature of the mixture is 15°C, what is the specific heat capacity of the metal?

Metal (hotter)	Water (colder)	
c = ?	c = 4200 $Jkg^{-1}K^{-1}$	
m = 0.100 kg	m = 0.150 kg	
$\Delta T = 100 - 25 = 85$ K	$\Delta T = 25 - 10 = 5$ K	**NB:** $\Delta T = T_{hot} - T_{cold}$

Energy lost by hotter = Energy gained by colder
$mc\Delta T$ (hotter) = $mc\Delta T$ (colder)

$0.100 \times c \times 85 = 0.150 \times 4200 \times 5$
$8.5 \times c = 3150$
$\therefore c = 3150/8.5$
$= 370.6\ Jkg^{-1}K^{-1}$

The specific heat capacity of the metal block is **370.6 (3.7 x 10^2) $Jkg^{-1}K^{-1}$.**

Example 6

A hot iron bar of mass 2.5 kg, at a temperature 120°C, is placed into a full 10 litre (10 kg) container of water at 20°C. Find the final temperature of the water. What assumptions have you made?

c_{iron} = 450 $Jkg^{-1}K^{-1}$
c_{water} = 4200 $Jkg^{-1}K^{-1}$

Iron bar (hotter)	Water (colder)	
c = 450 $Jkg^{-1}K^{-1}$	c = 4200 $Jkg^{-1}K^{-1}$	
m = 2.5 kg	m = 10.0kg	
T_i = 120°C	T_i = 20°C	
T_f = ?	T_f = ?	
$\Delta T_{hot} = (T_i - T_f)$	$\Delta T_{cold} = (T_f - T_i)$	**NB:** $\Delta T = T_{hot} - T_{cold}$
$= (120 - T_f)$	$= (T_f - 20)$	

Energy lost by hotter = Energy gained by colder
$mc\Delta T$ (hotter) = $mc\Delta T$ (colder)

$2.5 \times 450 \times \Delta T_{hot} = 10.0 \times 4200 \times \Delta T_{cold}$
$1125 \times (120 - T_f) = 42000 \times (T_f - 20)$
$(1125 \times 120) - (1125 \times T_f) = (42000 \times T_f) - (42000 \times 20)$
$135000 - (1125 \times T_f) = (42000 \times T_f) - 840000$
$135000 + 840000 = (42000 \times T_f) + (1125 \times T_f)$
$\therefore 975000 = 43125 \times T_f$
$\therefore T_f = 975000/43125$
= **<u>22.6°C</u>**

Assuming no heat is lost to the surrounding or transferred to the container.