Friday worksheet 1a – Specific heat capacity

$$E(J) = c_s(J/g/^oC) \times m(g) \times \Delta T\ (^oC)$$

Different substances do not absorb heat the same way.

For example, take an aluminium frying pan that weighs 200g being heated on a cooktop. The temperature of this aluminium frying pan will increase very quickly when compared to 200g of liquid water being supplied with the same amount of energy as the frying pan.

The energy required to change the temperature of one gram of a substance by one degree Celsius is known as the ***specific heat capacity (C_s)*** of the substance and has the units kj/kg/^{o}C or J/g/^{o}C. Specific heat capacity is *unique* to individual substances as shown in table 1. This is known as an *intensive property* and does not depend on the mass of substance.

Substance	Specific Heat (C_s) (J/g/^{o}C)
Water (l)	4.18
Water (s)	2.06
Water (g)	1.87
Aluminum (s)	0.897
Copper (s)	0.385
Gold (s)	0.129
Iron (s)	0.449

Table 1

As seen in table 1, one gram of water can absorb a great deal more energy before it goes up by one degree Celsius when compared with one gram of metals.

Heat capacity, on the other hand, depends on the mass of an object and is the amount of heat an object, of any given mass, can absorb before it's temperature changes by one degree Celsius. This value can change depending on the object's mass so heat capacity is referred to as an *extensive property* as it depends on the mass of the object.
The formula for heat capacity uses the specific heat capacity. $C_H = E/\Delta T$
where:
- C_H = *Heat capacity (J/^{o}C or kJ/^{o}C)*
- *E = energy supplied (J or kJ)*
- ΔT = *change in temperature (^{o}C or ^{o}K)*

In attempting to solve questions involving specific heat capacity, temperature change or energy input/output, the equation below will become the workhorse of your calculations.

$$E(J) = c_s(J/g/^oC) \times m(g) \times \Delta T\ (^oC)$$

Where:
c_s = the specific heat capacity of the given substance in J/g/^{o}C
m = mass of substance in grams
ΔT=change in temperature in ^{o}C.

Let's try some exercises.
1) What is the heat capacity , J/^{o}C, of a 20.0g sample of a solid unknown substance, if it was supplied

with 0.030 kJ of heat energy to change its temperature by 30.0°C

=>C_H = 30J/30.0 = 1.0 J/°C

2) Calculate the amount of energy, in joules, required to raise the temperature of 35.6g of water at 25.0 °C to 37.5°C.

The equation below will give us the amount of energy in joules needed to change a given mass of substance by a known amount of degrees.

$E = c_s \times m \times \Delta T$

=> E = 4.18 X 35.6 X 12.5 = 1860 J.

3) 200.0 mL of water at 25.0 °C is heated to a temperature of 50 °C. Calculate the amount of heat energy, in kJ, that was absorbed by the sample of water. Density of water at 25°C is 0.997g/mL.

Step 1 change the volume of 200 mL of water into grams of water using the density given.

=> 200.0 X 0.997 = 199.4g

Step 2 Apply the equation

=> E = 4.18 X 199.4 X 25.0 = 20837 = 20.8 kJ.

4) 1.00 kJ of heat energy was applied to 50.0g of pure solid iron and 1.00 kJ was also applied to 50.0g of water separately. Calculate the final temperature, in °C, if both the solid iron and the liquid water were both at 25°C and suggest why cooking utensils, such as frying pans, are made of metals.

Step 1 derive the formula for ΔT

=> $E / (c_s \times m) = \Delta T$

Step 2 calculate the ΔT for iron

=> 1000J/(0.449 J/g/°C X 50.0g) = 44.5°C

=> final temp = 69.5°C

Step 3 calculate the ΔT for water

=> 1000J/(4.18 J/g/°C X 50.0g) = 4.8°C

=> final temp = 29.8°C

Metals have a low specific heat capacity which cuaes them to heat up with little energy. This is god for cooking. Water on the other hand has a high specific heat capacity and so absorbs a great deal of energy before it changes temperature. This is why water is used as a coolant.

5) A 200g solid sample of an unknown pure metal was heated over a Bunsen burner.
1.54 kJ of energy was applied which increased the temperature of the metal from 23.0 °C to 43.0 °C. Identify the metal.

Step 1 find the specific heat capacity of the metal. This will identify the metal as it is unique for all substances.

=> transform the formula to make it equal to c_s

=> $E = c_s \times m \times \Delta T$

=> $E / (m \times \Delta T) = c_s$

=> 1540 J / (200 X 20.0) =c_s

=> 0.385 = c_2

=> The metal is copper.

Try the following.

1) 1.068 kJ of heat energy was applied to 50.0 g of an unknown solid metal. If the temperature of the metal increases from 21.0°C to 45.0 °C:

a. calculate the heat capacity, in J/°C

C_H = 1.068 / 24.0 = 44.5 J/°C

b. identify the metal.

Step 1 – Find the specific heat capacity of the unknown metal as this will identify the metal.

=> E = c_s X m X ΔT

=> E / (m X ΔT) = c_s

=> 1068 / (50.0 X 24.0) = 0.89 j/g/°C

=> it is close to aluminium so from our results we will identify the metal as aluminium.

2) What amount of energy, in kJ, is required to raise the temperature of a block of pure metal iron of mass 23.5g by 43.2°C?

=> E = c_s X m X ΔT

=> E = 0.449 X 23.5 X 43.2 = 456J = 0.456kJ

3) A cubic block of pure iron is immersed in a measuring cylinder and found to displace exactly 2.34 cm^3 of water. It is then taken out, dried and it's temperature measured at 23.1°C before been heated in a well, insulated oven. If a total amount of 0.345kJ of heat energy is applied to the iron metal calculate the final temperature of the iron block.

Density of Fe =7.86 g/cm^3

Step 1 find the mass of the iron block.

=> mass = volume X density = 2.34 cm^3 X 7.86g/cm^3 = 18.39g

Step 2 calculate ΔT

=> E /(c_s X m) = ΔT

=> 345J /(0.449 X 18.39) = 41.8

Step 3 Find the final temperature

=> 23.1 + 41.8 = 64.9°C

4) An amount of 877.8kJ of energy is added to a volume of water to raise its temperature from 20 °C to 50 °C . Calculate the mass, in kg, of water being heated.

E = c_s X m X ΔT

=> m = E /(c_s X ΔT)

=> mass(g) = 877,800J / (4.18 J/g/°C X30.0°C)

=> 7.00kg

5) What 2kg substance, from table 1 above, has its temperature raised by 20 °C if it is given 82.4 kJ of energy?

=>find the specific heat capacity of the substance.

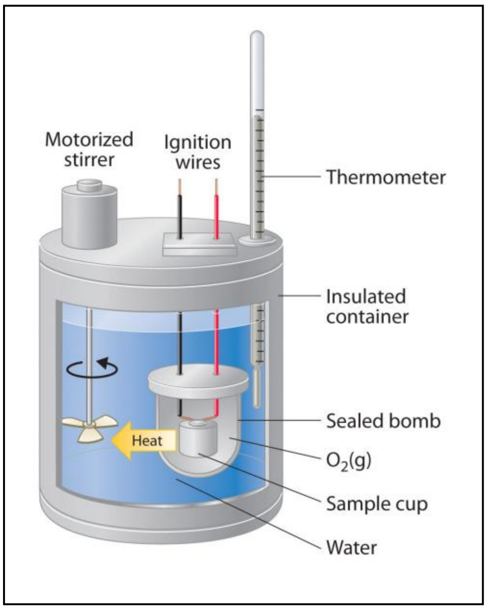
=> E = c_s X m X ΔT

=> E/ (m X ΔT) = c_s

=> 82,400J /(2000g X 20°C) = 2.06 J/g/°C

=> ice

6) A bomb calorimeter, shown on the right, is used to measure the amount of energy that is produced when a given amount of fuel burns completely in oxygen gas. It is a well, insulated instrument that traps heat in the surrounding water.



a) Circle which of the following is/are <u>most</u> critical in calculating the energy density of the fuel in kJ/g? Justify your choice.

i. Initial temperature of the water
ii. Type of insulation used in the calorimeter
iii. Final temperature of the water
iv. Volume of water
v. Room temperature
vi. Mass of fuel

Give one other piece of information that you think is necessary *Density of water*

Using the equation $E = c_s \times m \times \Delta T$ to find the energy delivered to the water by the fuel and so find the energy lost by a given mass of fuel. Once the energy in known then it is divided by the mass of fuel.

b) A 0.100g sample of pure ethanol is burnt in excess, oxygen. The calorimeter was filled with 101.0g of distilled water at 23.0°C and the ethanol ignited in the sealed bomb. Calculate the energy density of ethanol in kJ/g given the final temperature of the water reached 30.1°C.

Step 1 Calculate the energy given out by 0.100g of ethanol. Use the specific heat capacity of water and the initial and final temperatures of the water in the following equation

$E = c_s \times m \times \Delta T$

=> E(joules) = 4.18J/g/°C X 101.0g X 7.1°C = =2997J

Step 2 find energy density

=> 2997J/0.1 = 30kJ/g

c) A 300g cube of hot iron at 85°C is placed into a glass containing 200g of water at 25°C. What is the final temperature of the water? Assume no energy is lost and the transfer of heat from the iron and to the water 100% efficient.

Energy will be lost by the iron as it cools while the same amount of energy will be gained by the water as it warms up. Since energy is conserved the following expression applies.

Enegy lost from iron = energy gained by the water

Since both substances will achieve the same final temperature (T_f) we can write

=> Energy given out by iron(J) = 0.449 J/g/°C X 300g X (85°C – T_f)

=> Energy absorbed by water(J) = 4.18 J/g/°C X 200g X (T_f – 25°C)

=> 0.449 J/g/°C X 300g X (85°C – T_f) = 4.18 J/g/°C X 200g X (T_f – 25°C)

=> 134.7(85°C – T_f) = 836(T_f – 25°C)

=>11449.5 -134.7T_f = 836T_f – 20900

=>32350 = 970T_f

=> T_f = 32350/970 = 33.4°C