

THERMAL PROPERTIES

The internal energy of a system is the sum of kinetic energy and potential energy.

$$U = E_K + E_P$$

Where U is internal energy and is determined by the state of the system.

In solids, the majority of the internal energy is E_P , while in gases the majority of the internal energy is E_K .

Heat Capacity & Specific heat capacity

A change in temperature of a body indicates a change in internal energy.

Heat Capacity (C)

This is the heat energy needed of an object to raise its temperature by one Kelvin (or one degree).

The heat capacity of an object depends on:

- (i) the type of material the object is made of.
- (ii) the mass of the object.

The formula for heat capacity (C) is:

$$\textit{Heat Capacity} = \frac{\textit{Heat Energy}}{\textit{Temperature Rise}}$$

$$C = \frac{E}{\Delta T}$$

Units: J/°C or J/K

[N.B. - The heat capacity refers to the whole object]

Specific Heat Capacity (c)

The specific heat capacity of a substance is the heat energy needed to raise the temperature of 1kg of a substance by 1K (or one degree).

The formula for specific heat capacity (c) is:

$$\text{Specific Heat Capacity} = \frac{\text{Heat Energy}}{\text{Temperature rise} \times \text{Mass}}$$

$$c = \frac{E}{m \times \Delta T}$$

Units: $J/(kg^{\circ}C)$ or $J/(kgK)$

We can arrange the formula to get:

$$\text{heat energy} = \text{mass} \times \text{specific heat capacity} \times \text{temperature change}$$

$$E = mc\Delta T$$

[NB: This formula is used to calculate the heat energy required to heat up a substance]

The Relationship between Heat Capacity and Specific Heat Capacity

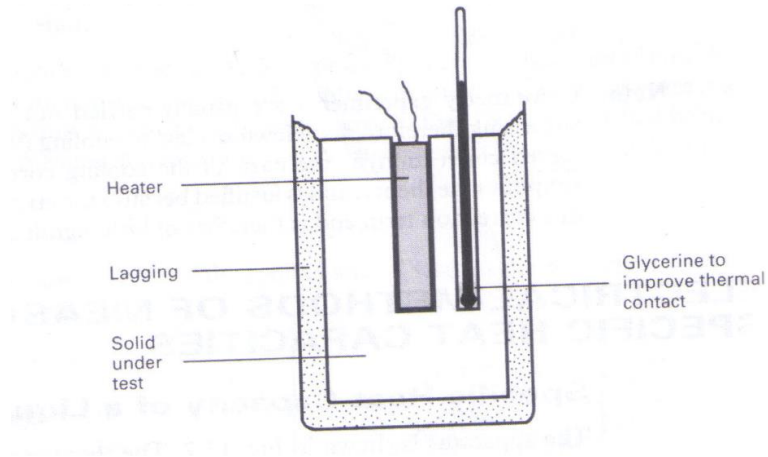
The heat capacity is when you are talking about the entire / whole object. The specific heat capacity refers to 1 kg of the object. There is a relation which exists between the heat capacity and the specific heat capacity of an object.

$$\text{heat capacity} = \text{specific heat capacity} \times \text{mass}$$

$$C = mc$$

Electrical Methods of Measuring Heat Capacity

Heat Capacity of Solids



We set up the experiment as shown in the diagram above. We then determine the mass of the material. We use a thermometer and measure the initial temperature of the material. Next we supply a known amount of energy to the material and we measure the temperature rise in the material.

We use a heater of known power supply and use the heater for approximately five (5) minutes. We can use the formula below to determine how much energy was sent to the material.

$$\text{heat energy supplied} = \text{power of heater} \times \text{time}$$

$$E = VI t$$

We then find the temperature change of the material by using

$$\text{temperature change } (\Delta T) = \text{initial temperature} - \text{final temperature}$$

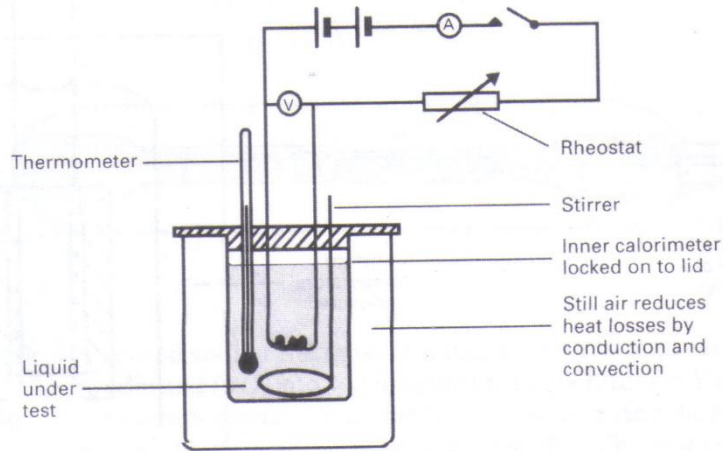
$$\Delta T = T_{\text{final}} - T_{\text{initial}}$$

Finally we use the formula below to calculate the specific heat capacity of the material

$$\text{specific heat capacity} = \frac{\text{heat energy supplied}}{\text{temperature change} \times \text{mass}}$$

$$c = \frac{VI t}{m \Delta T}$$

Heat Capacity of Liquids



The specific heat capacity of a liquid is c_l and inner calorimeter is c_c

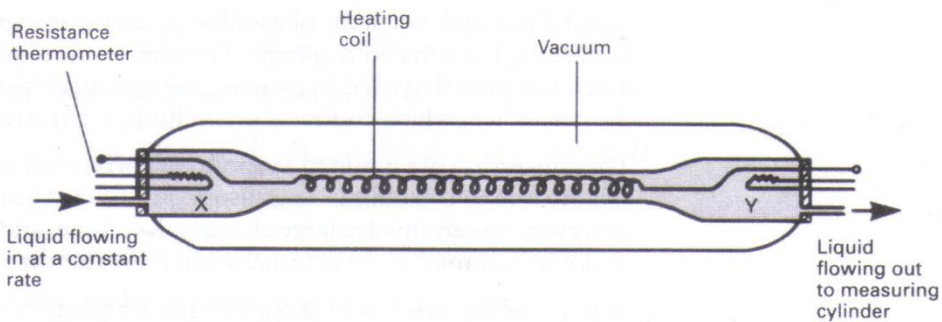
V is the voltage and I is current

We can use the equation

$$\text{Heat energy supplied by heater} = \text{heat energy to calorimeter} + \text{heat energy to liquid}$$

$$VIt = m_c c_c \Delta\theta_c + m_l c_l \Delta\theta_l$$

Continuous Flow Method for Specific Heat Capacity of Liquids (pg 241)



Method is due to Callender & Barnes (1899)

- Liquid passes through the continuous flow calorimeter at a constant rate until all conditions are steady.

- At this time measure mass of liquid (m_1), current (I_1), voltage (V_1), time (t) and temperature change ($\Delta\theta$).
- Alter the rate flow of liquid so that the mass in time (t) is m_2
- Measure V_2 and I_2 . Use same temperature change $\Delta\theta$, using original initial temperature of final temperatures.

We can find the heat energy by using

$$\text{Heat energy supplied by heater} = \text{heat energy gained by fluid} + \text{heat lost by surroundings}$$

Initially:

$$V_1 I_1 t = m_1 c \Delta\theta + Q \quad \dots (1)$$

After changing the rate of flow of the liquid and heating rate

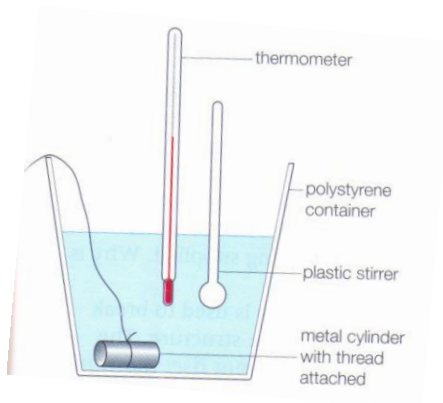
$$V_2 I_2 t = m_2 c \Delta\theta + Q \quad \dots (2)$$

If we subtract equation (2) and equation (1) we get

$$V_2 I_2 t - V_1 I_1 t = m_2 c \Delta\theta - m_1 c \Delta\theta$$

$$(V_2 I_2 - V_1 I_1) t = (m_2 - m_1) c \Delta\theta$$

Method of Mixtures



This is the most common practical used to find the specific heat capacities of solids and liquids. We usually add a hot solid (or a hot liquid) of known temperature to a cold liquid and determine the final temperature.

We assume that all the heat from the hot substance goes to the cooler one if we can reduce heat loss by using insulation.

We then use the formula below to determine the specific heat capacity of the substance

$$\textit{heat loss by solid} = \textit{heat gained by liquid}$$

$$m_{\text{solid}} \times c_{\text{solid}} \times (T_{\text{solid}} - T_{\text{final}}) = m_{\text{liquid}} \times c_{\text{liquid}} \times (T_{\text{final}} - T_{\text{liquid}})$$

Where:

m_{solid} = mass of the solid

c_{solid} = specific heat capacity of

m_{liquid} = mass of liquid

c_{liquid} = specific heat capacity of liquid

T_{solid} = initial temperature of solid

T_{liquid} = initial temperature of liquid

T_{final} = final temperature of mixture

Melting, Boiling & Latent Heat

When a substance undergoes a phase change, energy is absorbed or released, but there is no temperature change.

During melting & boiling the energy absorbed increases the mutual potential energy of all molecules. The average kinetic energy remains constant.

In terms of the first law of thermodynamics: melting, vaporization and sublimation are represented by the equation

$$L = \Delta U + \Delta W$$

where

L is the latent heat in order to phase change

ΔU is the increase in internal potential energy which accompanies the phase change.

(NB: no change in temperature means there is no change in kinetic energy)

ΔW is the external work done as a result of the phase change.

(positive for expansion and negative for contraction)

Latent Heat of Fusion (L)

The latent heat of fusion of a solid is the heat required to change a solid to a liquid without a temperature change.

latent heat of fusion = heat energy needed to melt all of it.

$$L = \Delta Q$$

Units: Joules (J)

Specific Latent Heat of Fusion (l)

The specific latent heat of fusion of a solid is the heat required to change 1kg of it, from a solid to a liquid without any temperature change.

specific latent heat of fusion = heat energy

mass

$$l = \frac{\Delta Q}{m}$$

Units: J/kg

We can rearrange this formula, to obtain a formula for heat energy:

heat energy = mass × specific latent heat

$$\Delta Q = ml$$

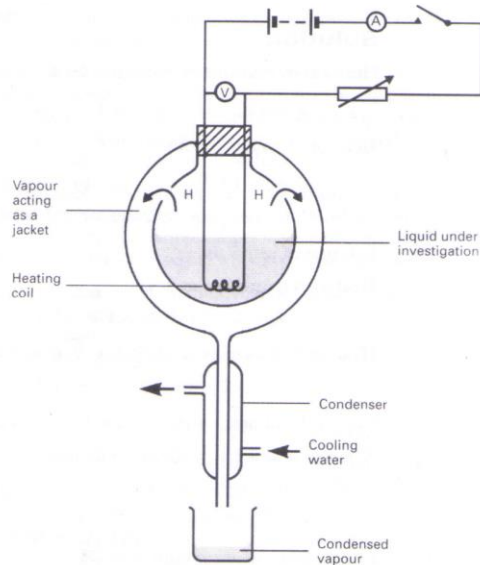
Latent Heat of Vaporization (L)

The latent heat of vaporization of a liquid is the heat required to change a liquid to a gas, without a temperature change.

Specific Latent Heat of Vaporization (l)

The specific latent heat of vaporization of a liquid is the heat required to change 1kg of it, from a liquid to a gas without any temperature change.

Experimental Determination of the Specific Latent Heat of Vaporization of a Liquid



- An example of continuous flow method which uses a self-jacket vaporization
- Liquid is heated to boiling point, vapour passes to the condenser through holes (H) in the inner walls of the vessels
- Boiling continues and eventually the temperatures at all parts become steady
- At this point, condense vapour is collected over a time (t), mass (m_1) is determined and the voltage (V_1) and current (I_1) is measured. Since the temperatures are constant this energy is used to vaporise the liquid and offset heat lost.

$$V_1 I_1 t = m_1 l + Q \quad \dots (1)$$

where l is latent heat of vaporization
 Q is heat lost to the surroundings

- When the voltage and current are changed to V_2 and I_2 , the new mass (m_2) of the vapour is measured in the same time (t). Since each part of the apparatus is the same temperature, we can state that

$$V_2 I_2 t = m_2 l + Q \quad \dots (2)$$

- Hence if we subtract equation 2 and equation 1 we get that

$$(V_2 I_2 - V_1 I_1) t = (m_2 - m_1) l$$

- In summary

$$l = \frac{V I t}{m}$$

Evaporation

High energy surface molecules leave liquids. Hence the average E_k of the remaining molecules is less so the liquid is cooler. The greater the rate of evaporation, the cooler the liquid will feel.

Evaporation is affected by the ambient temperature (temperature of surrounding). The second factor that affects evaporation is the specific heat capacity of the liquid.

Cooling

Molecules of a liquid have a variety of speeds. During evaporation, the molecules with higher E_k escape. As a result the average E_k of the remaining liquid is cooler due to the temperature of the liquid being reduced.

Example when a volatile liquid (methanol) comes in contact with your skin it feels cool. The reason for this is that specific heat capacity and latent heat are required for change of state. This energy is absorbed from the skin by the liquid. Hence the temperature of the skin drops.

Comparisons of Boiling and Evaporation

BOILING	EVAPORATION
<ul style="list-style-type: none"> ▪ occurs at a specific temperature called the boiling point ▪ occurs throughout the liquid ▪ produces steam ▪ boiling point raised by external pressure 	<ul style="list-style-type: none"> ▪ occurs at any temperature ▪ occurs at the surface of the liquid ▪ produces water vapour ▪ rate of evaporation increases with temperature and surface area ▪ rate increases with airflow over the liquid ▪ rate is decreased with increased pressure