21.0 Thermal Energy

AQA A2 Specification

Lessons	Topics
1 & 2	**Thermal energy** Calculations involving change of energy. For a change of temperature; $Q = m\, c\, \Delta\theta$ where c is specific heat capacity. For a change of state; $Q = m\, l$ where l is specific latent heat.

Thermal energy

What is thermal energy?

- internal energy.
- It is equal to the sum of the random distribution of the kinetic and potential energies of the object's molecules.
- Molecular kinetic energy increases with temperature.
- Potential energy increases if an object changes state from solid to liquid or liquid to gas.

If the internal energy is represented by the potential energy and kinetic energy in the bonds of any material, why do gases not have potential energy?

In a gas, the molecules are so far apart that there are no intermolecular interactions. So there is no potential energy. Therefore the energy is entirely kinetic

Heat

Heat is energy that flows from a high temperature object to a lower temperature object

- When something absorbs heat its internal energy (or the energy of its atoms/molecules) increases
- When something releases heat its internal energy decreases

What is the SI unit of heat?

Joule, J

What two things occur when an object absorbs or releases heat energy?

- The temperature will change (which is why they expand/contract, due to changes in molecular motion)
- The object (or part of it) will change phase (solid, liquid, gas)

Temperature

What is temperature?

Temperature is a measure of the degree of hotness of a substance.

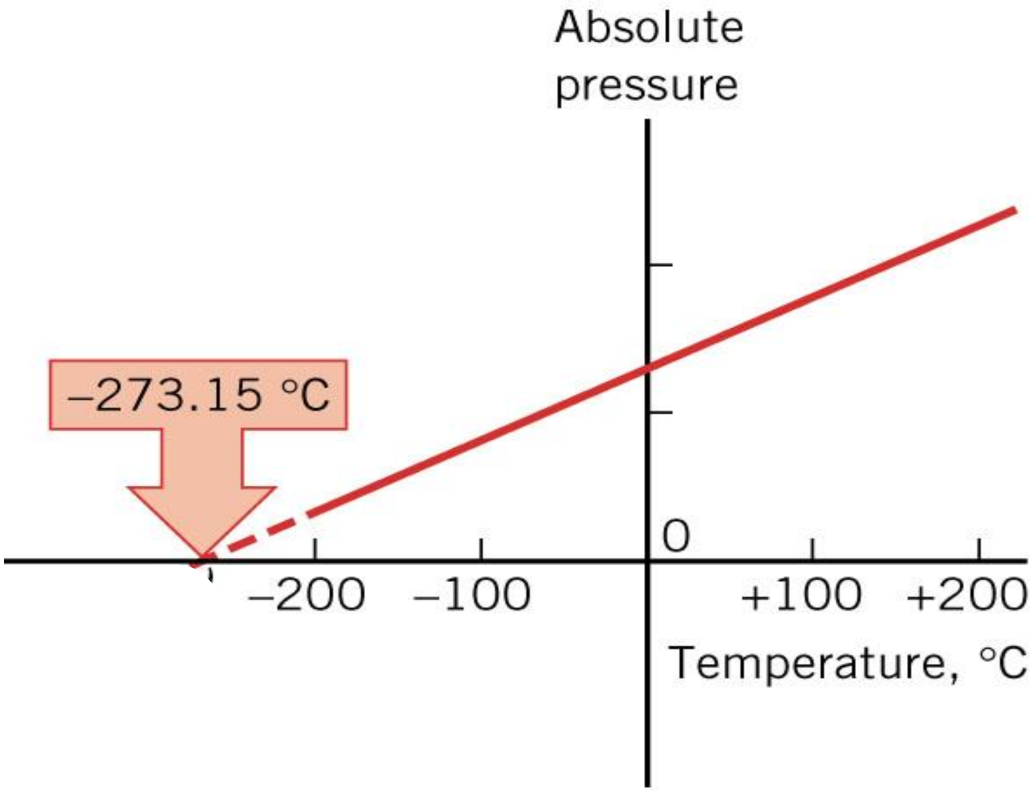
Heat energy normally moves from regions of higher to lower temperature.

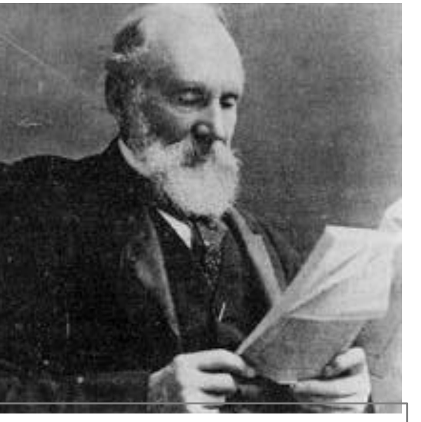
What is the condition for thermal equilibrium?

Two objects are said to be in **thermal equilibrium** with each other if there is not net transfer of heat energy between them.

This will only occur if both objects are at the same temperature.

Absolute Zero (0K)





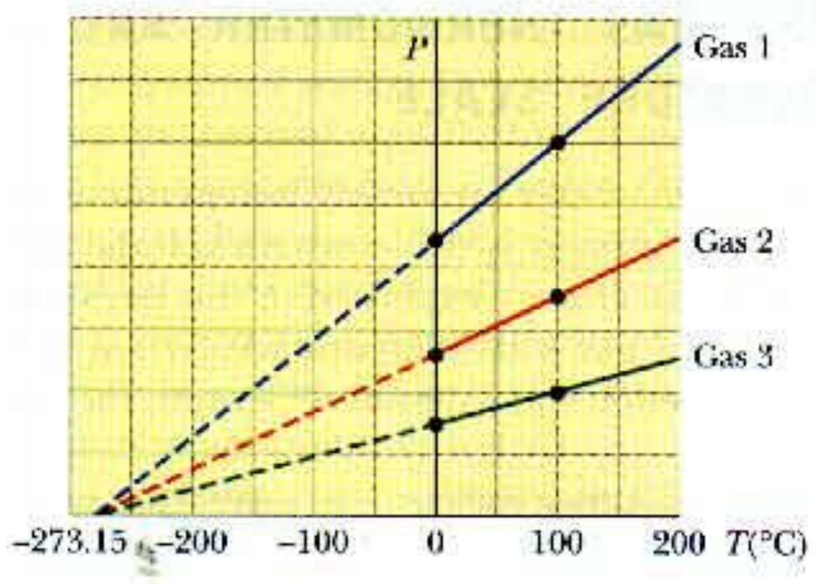
William Kelvin,
b. 1824, Belfast

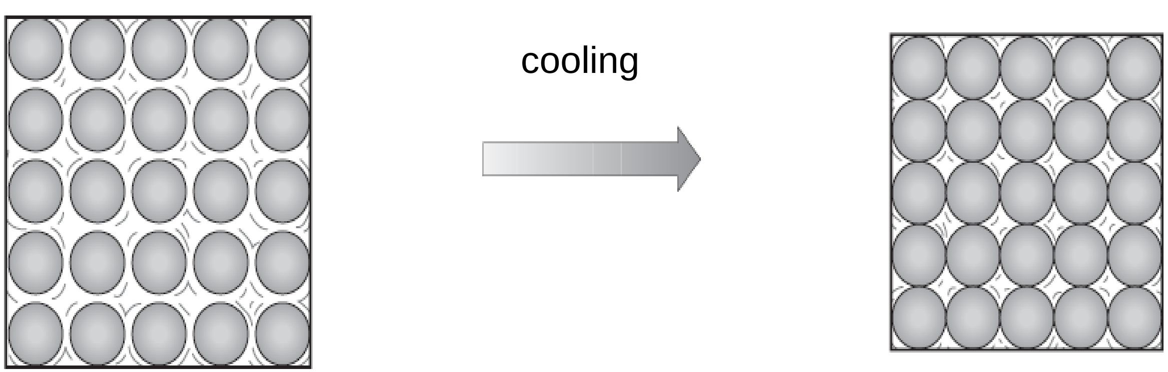
Absolute zero is the lowest possible temperature where objects have minimal KE

Absolute zero

The graph opposite shows that the pressure of all gases will fall to zero at absolute zero which is approximately - 273^{o}C.

What effect will this have on atomic spacing?





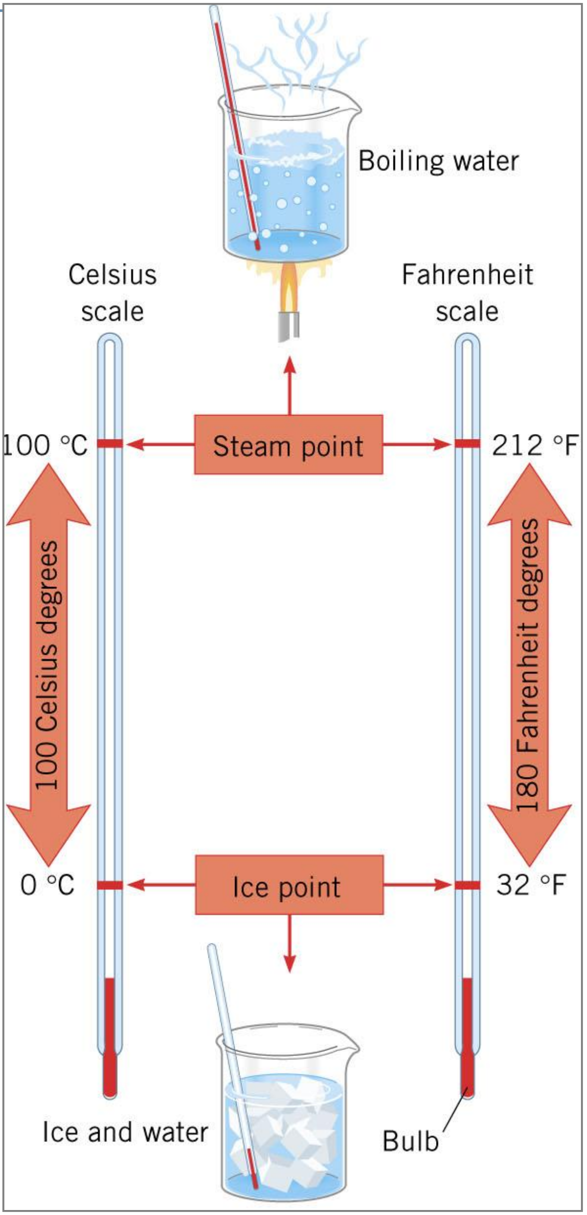
hot solid

cool solid

Temperature Scales

A temperature scale is defined by two fixed points which are standard degrees of hotness that can be accurately reproduced.

What fixed points might be used?



Celsius Scale (symbol: θ – unit: °C)

Fixed points:

ice point, 0°C: the temperature of pure melting ice

steam point, 100°C: the temperature at which pure water boils at standard atmospheric pressure

The *Absolute* scale

Fixed points:

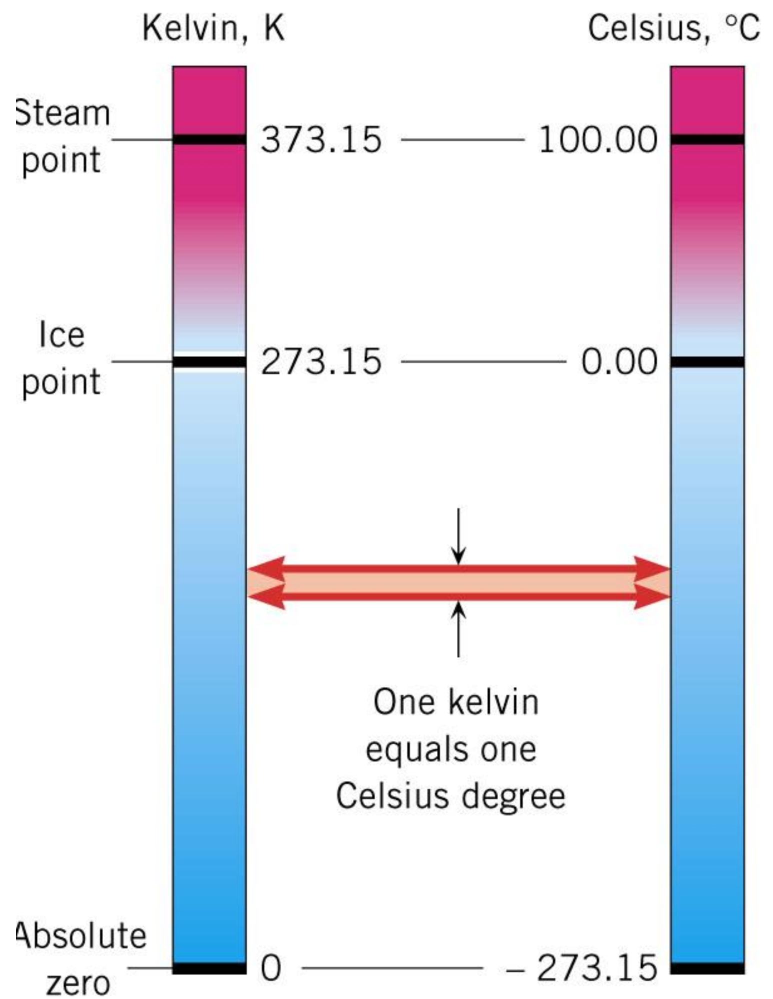
absolute zero, 0K: the lowest possible temperature. This is equal to – 273.15°C

triple point of water, 273.16K: the temperature at which pure water exists in thermal equilibrium with ice and water vapour. This is equal to 0.01°C.

Converting between scales

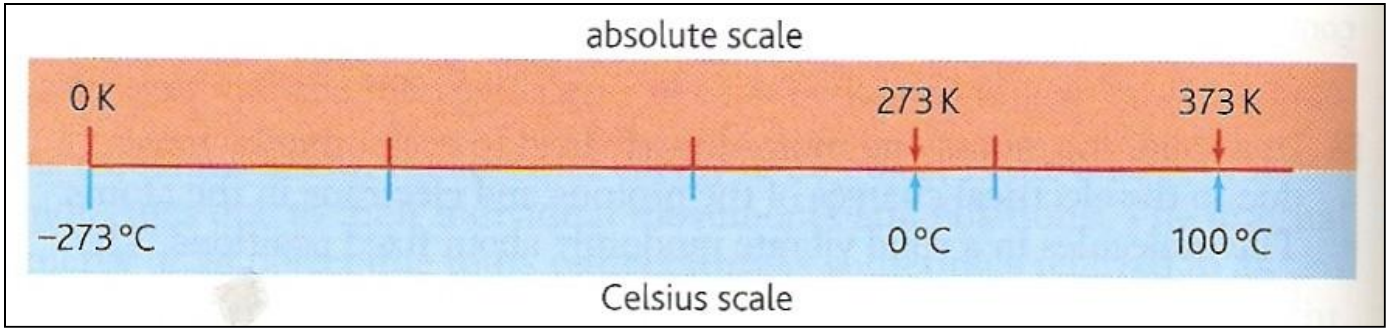
A change of one degree celsius is the same as a change of one kelvin.

Therefore:
°C = K - 273.15 OR ***K = °C + 273.15***



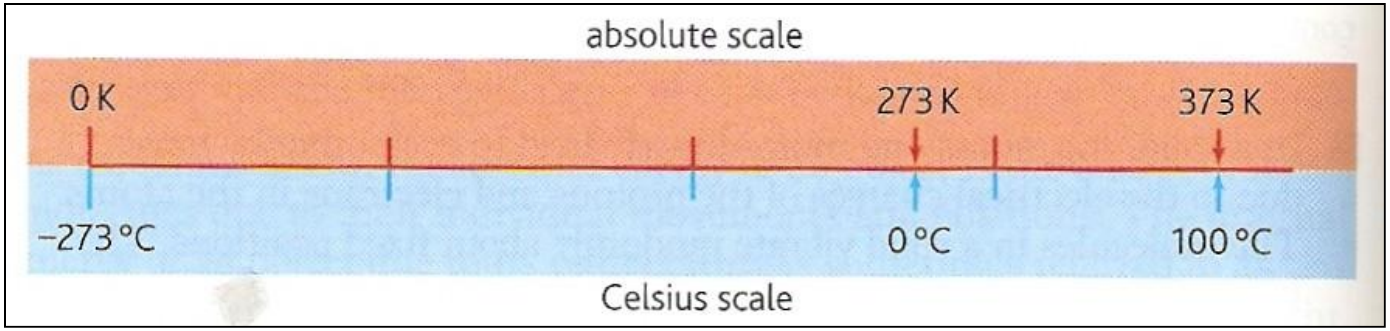
Complete (use 273K = 0 ºC):

Situation	Celsius (ºC)	Absolute (K)
Boiling water	100	
Vostok Antarctica 1983	- 89	
Average Earth surface		288
Gas flame	1500	
Sun surface		6000

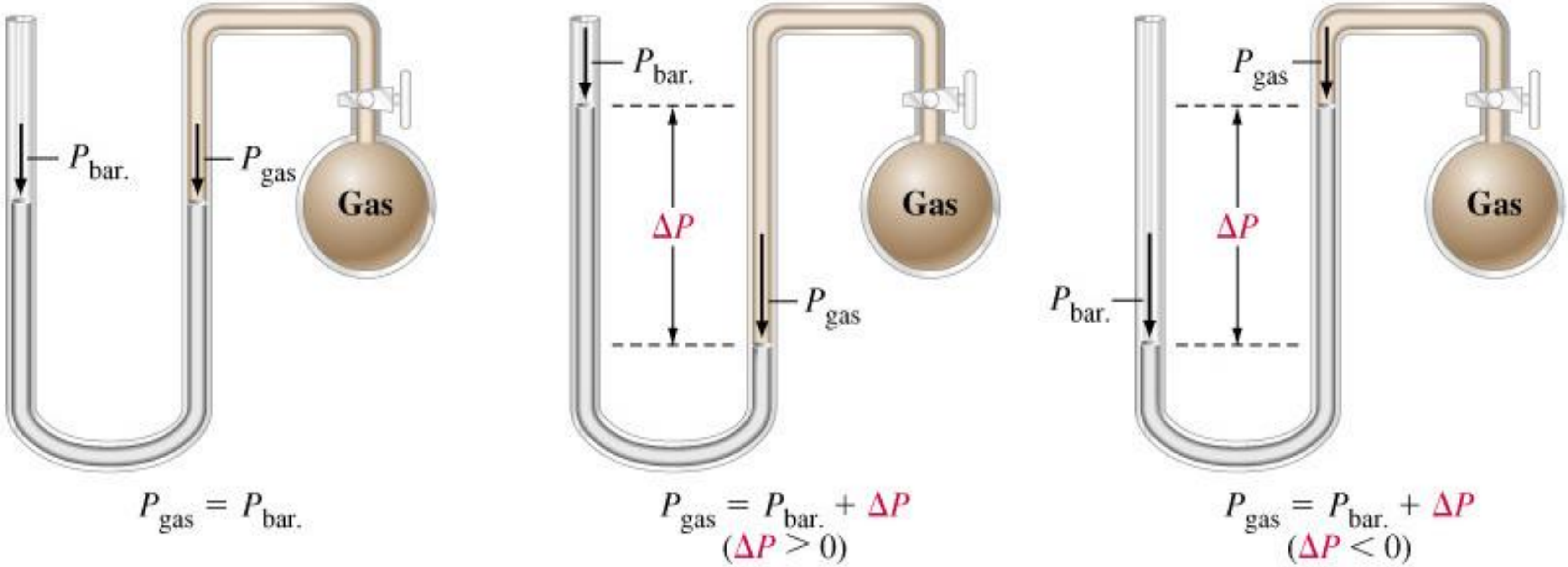


Answers:

Situation	Celsius (ºC)	Absolute (K)
Boiling water	100	373
Vostok Antarctica 1983	- 89	184
Average Earth surface	15	288
Gas flame	1500	1773
Sun surface	5727	6000



Manometers



(a) Gas pressure equal to barometric pressure **(b)** Gas pressure greater than barometric pressure **(c)** Gas pressure less than barometric pressure

11.2 Heating

If we heat some material so that its temperature rises, the amount of energy we must supply depends on three things:

- the mass *m* of the material we are heating
- the temperature change $\Delta\theta$ we wish to achieve
- the material itself.

Some materials are easier to heat than others. It takes more energy to raise the temperature of 1 kg of water by 1 °C than to raise the temperature of 1 kg of alcohol by the same amount.

We can represent this in an equation. Th e amount of energy *E* that must be supplied is given by:

$$E = mc\Delta\theta$$

where *c* is the **specifi c heat capacity** of the material.

11.2 The specific heat capacity of a substance

The specific heat capacity of a substance is the energy required per unit mass of the substance to raise the temperature by 1 K (or 1 °C).

Table **1** shows some values of specific heat capacity measured at 0 °C.

Substance	c / J kg^{-1} K^{-1}
aluminium	880
copper	380
lead	126
glass	500–680
ice	2100
water	4180
sea water	3950
ethanol	2500
mercury	140

Examples of SHC

Substance	SHC ($Jkg^{-1}K^{-1}$)	Substance	SHC ($Jkg^{-1}K^{-1}$)
water	4 200	helium	5240
ice or steam	2 100	glass	700
air	1 000	brick	840
hydrogen	14 300	wood	420
gold	129	concrete	880
copper	385	rubber	1600
aluminium	900	brass	370
mercury	140	paraffin	2130

Complete

Substance	Mass	SHC ($Jkg^{-1}K^{-1}$)	Temperature change	Energy (J)
water	4 kg	4 200	50 ^oC	
gold	4 kg	129		25 800
air	4 kg		50 K	200 000
glass		700	40 ^oC	84 000
hydrogen	5 mg	14 300	400 K	
brass	400 g	370	50^oC to K	14 800

Answers

Substance	Mass	SHC ($Jkg^{-1}K^{-1}$)	Temperature change	Energy (J)
water	4 kg	4 200	50 ^oC	840 000
gold	4 kg	129	50 ^oC	25 800
air	4 kg	1 000	50 K	200 000
glass	3 kg	700	40 ^oC	84 000
hydrogen	5 mg	14 300	400 K	28.6
brass	400 g	370	50^oC to 223K	14 800

Question

Calculate the heat energy required to raise the temperature of a copper can (mass 50g) containing $200cm^3$ of water from 20 to 100^oC

$E = m\,c\,\Delta\theta$

For the copper can:

E = 0.05 x 385 x (100 – 20) **= 1 540 J**

For the water:

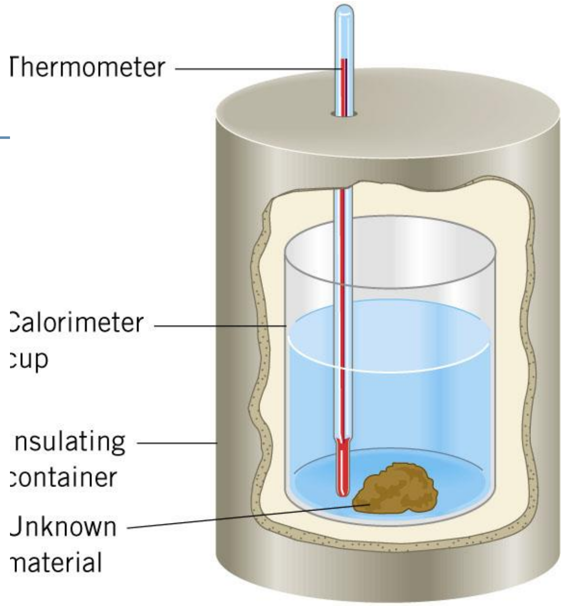
Density of water = 1 g cm^{-3}.

Therefore mass of water = 200g.

E = 0.200 x 4200 x 80 **= 67 200 J**

TOTAL HEAT ENERGY = 68 740 J

Calorimetry



A method to measure specific heat capacity that is based on:

The principle of conservation of energy

The known specific heat capacity for water (1000 cal/kg·°C or 4186 J/kg·°C)

The Process:

- A heated object is placed into a thermally isolated container containing a known amount of water

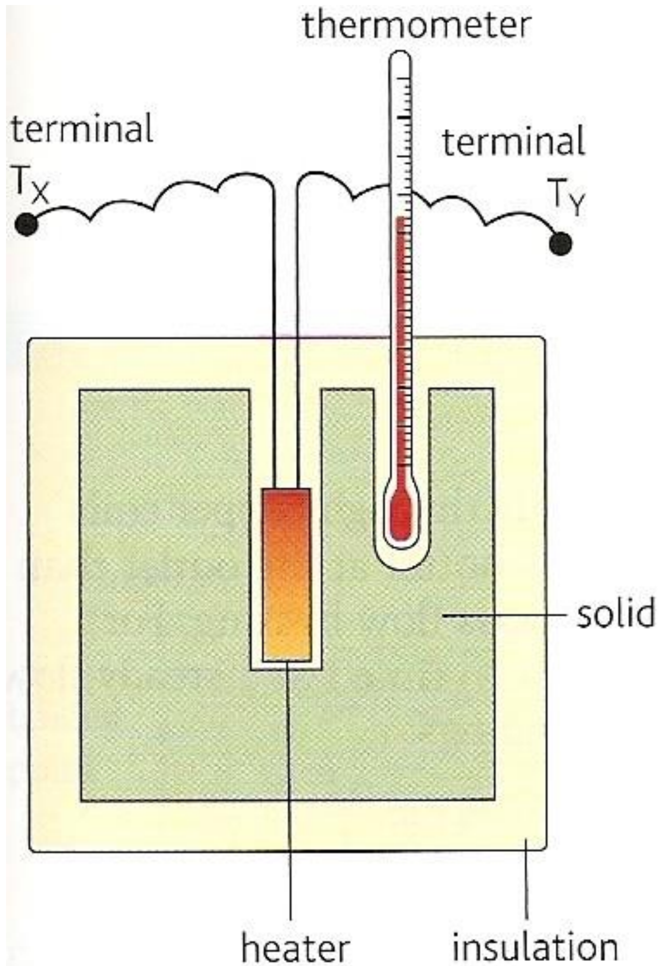
$$Q_{net} = Q_{gained\ by\ water} + Q_{gained\ by\ object} = 0$$

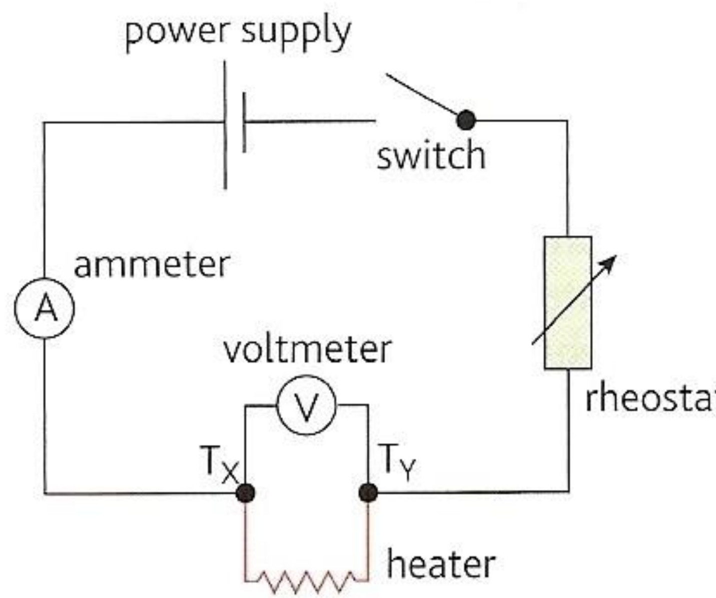
- Object and liquid reach thermal equilibrium:

$$Q_{gained\ by\ water} = Q_{lost\ by\ object}\ \{= - Q_{gained\ by\ object}\}$$

- The final temperature of the object/water is used to determine the specific heat of the object

Measuring SHC (metal solid)





Measuring SHC (metal solid)

- Metal has known mass, m.
- Initial temperature θ_1 measured.
- Heater switched on for a known time, t during which the average p.d., V and electric current I is measured.
- Final maximum temperature θ_2 measured.
- Energy supplied = VIt = $mc(\theta_2 - \theta_1)$
- Hence: $c = VIt / m(\theta_2 - \theta_1)$

Example calculation

Metal mass, ***m***. = 500g = 0.5kg

Initial temperature θ_1 = 20^{o}C

Heater switched on for time, ***t*** = 5 minutes = 300s.

p.d., ***V*** = 12V; electric current ***I*** = 2.0A

Final maximum temperature θ_2 = 50^{o}C

Energy supplied = ***VIt*** = 12 x 2 x 300 = 7 200J

= $mc(\theta_2 - \theta_1)$ = 0.5 x ***c*** x (50 – 30) = 10***c***

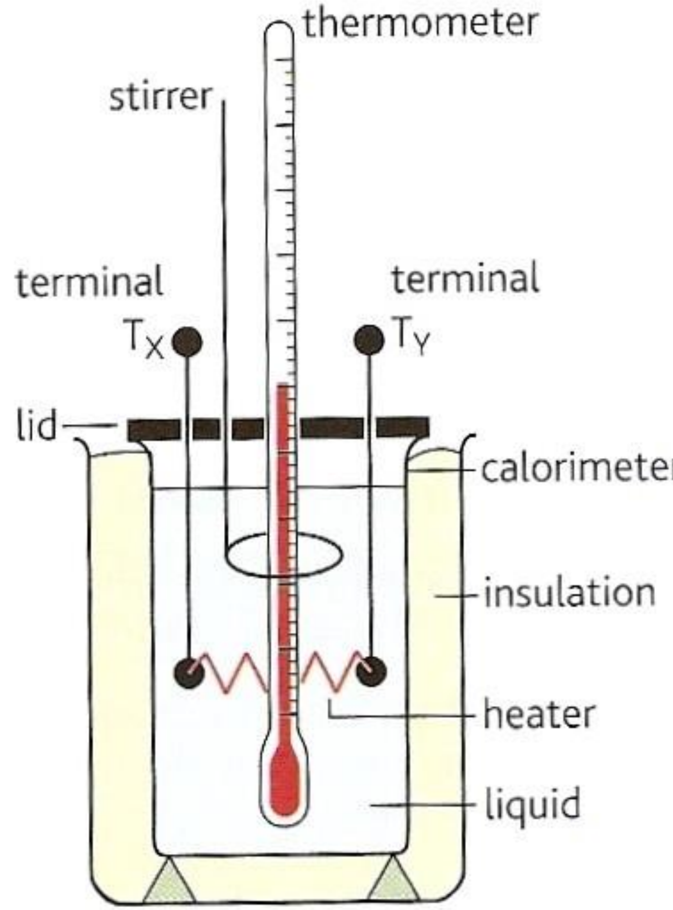
Hence: ***c*** = 7 200 / 10

= 720 J kg $^{-1}$ ^{o}C $^{-1}$

Measuring SHC (liquid)

This uses a similar method to measuring the SHC of a metallic solid.

What additional factor must we consider?



The heat absorbed by the liquid's container (called a calorimeter).

Electrical heater question

What are the advantages and disadvantages of using paraffin rather than water in some forms of portable electric heaters?

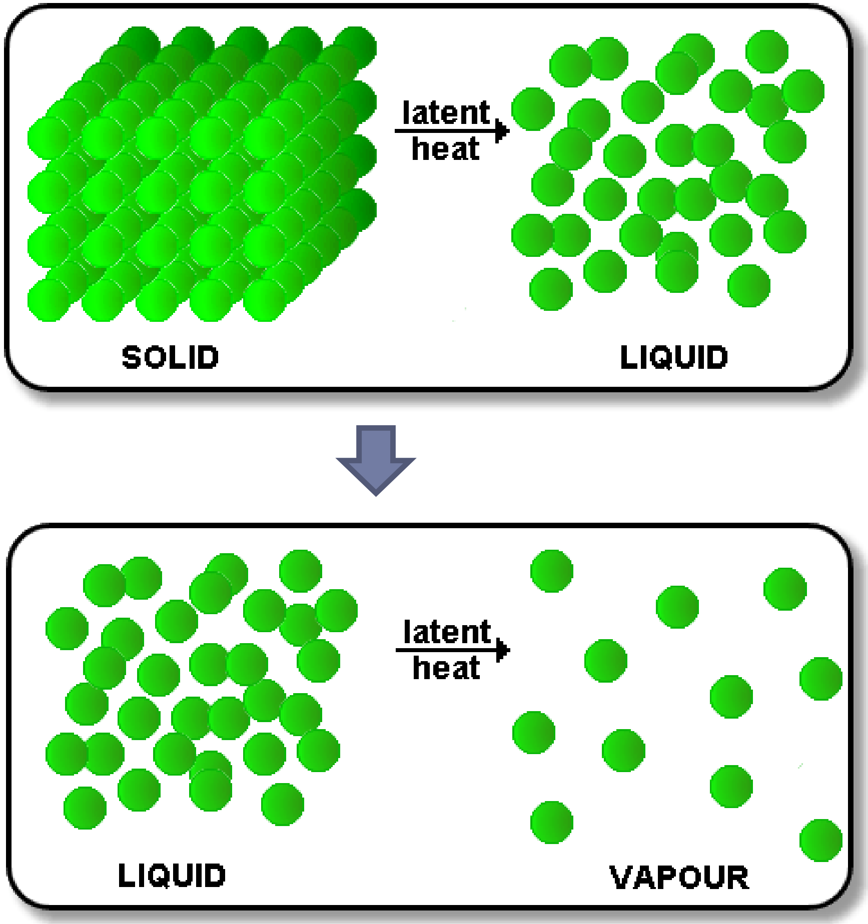
Advantages:
Electrical insulator – safer
Does not corrode metal container
Lower SHC – heats up quicker

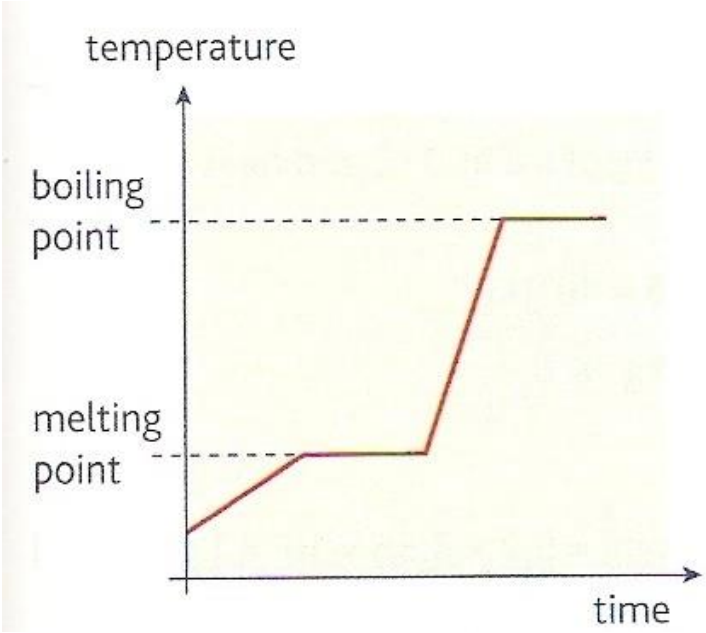
Disadvantages:
Lower SHC – cools down quicker

11.3 Latent heat

This is the energy required to change the state of a substance. e.g. melting or boiling.

Draw a temperature – time graph to show the melting and vapourisation of water

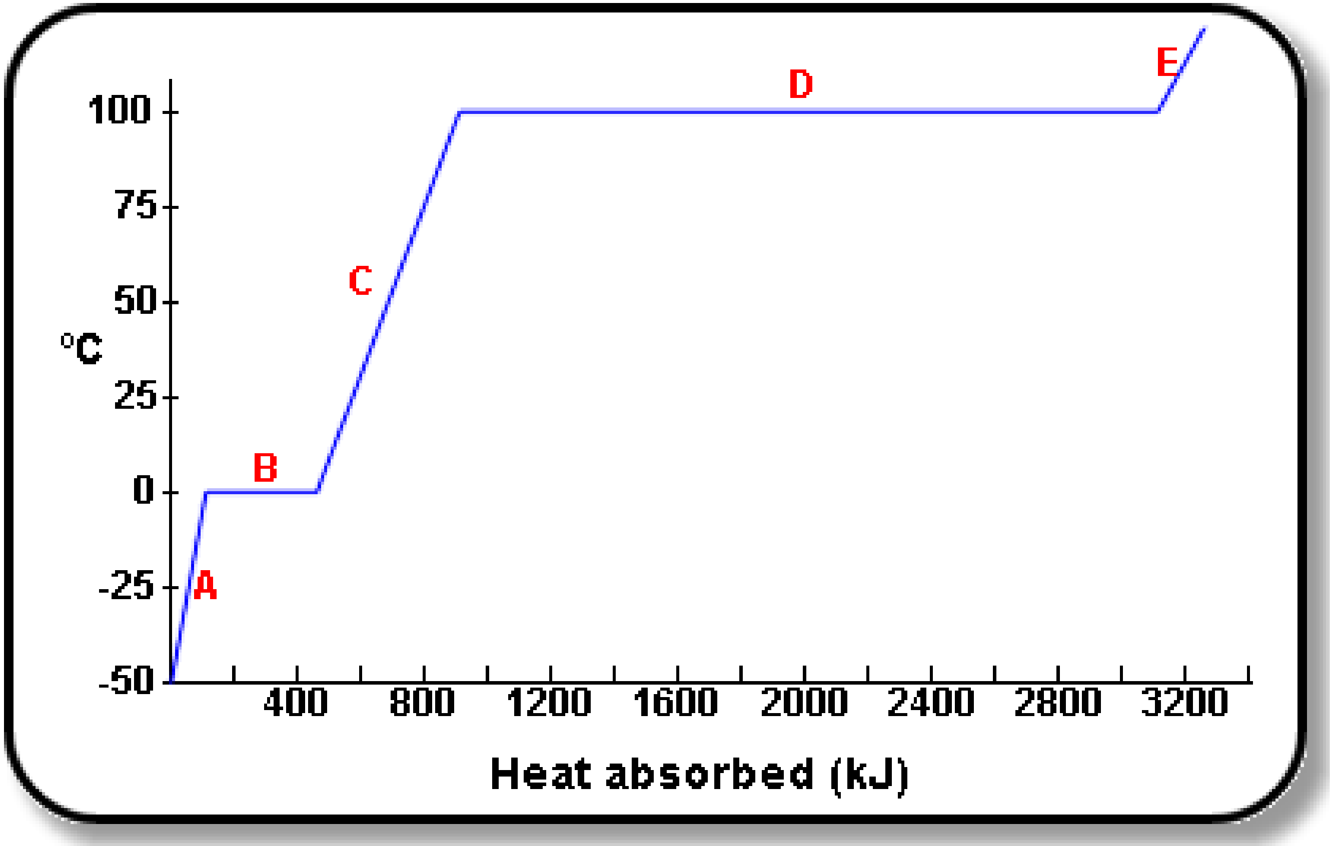




Task

The diagram shows the uptake of heat by 1 kg of water, as it passes from ice at -50 ºC to steam at temperatures above 100 ºC

Copy and label the diagram. Identify what is happening at each stage



Answer

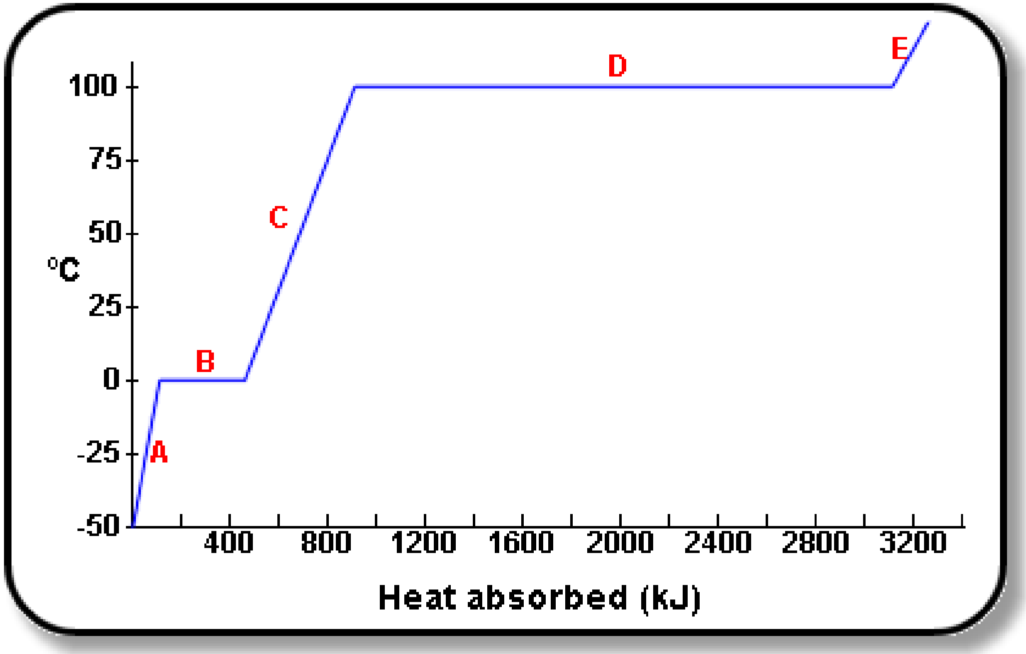
A: Rise in temperature as ice absorbs heat.

B: Absorption of latent heat of fusion.

C: Rise in temperature as liquid water absorbs heat.

D: Water boils and absorbs latent heat of vaporization.

E: Steam absorbs heat and thus increases its temperature.



Specific latent heat, *l*

What is specific latent heat ?

The specific latent heat, *l* of a substance is the energy required to change the state of unit mass of the substance without change of temperature.

$$\Delta Q = m\,l$$

where:

ΔQ = heat energy required in joules

m = mass of substance in kilograms

l = specific latent heat in J kg^{-1}

Examples of SLH

Substance	State change	SLH (Jkg^{-1})
ice → water	solid → liquid **specific latent heat of fusion**	336 000
water → steam	liquid → gas / vapour **specific latent heat of vaporisation**	2 250 000
carbon dioxide	solid → gas / vapour **specific latent heat of sublimation**	570 000
lead	solid → liquid	26 000
solder	solid → liquid	1 900 000
petrol	liquid → gas / vapour	400 000
mercury	liquid → gas / vapour	290 000

Complete

Substance	Change	SLH (Jkg^{-1})	Mass	Energy (J)
water	melting	336 000	4 kg	
water	freezing	336 000	200 g	
water	boiling	2.25 M		9 M
water	condensing	2.25 M	600 mg	
CO_2	subliming	570 k	8 g	
CO_2	depositing	570 k	40 000 µg	

Answers

Substance	Change	SLH (Jkg^{-1})	Mass	Energy (J)
water	melting	336 000	4 kg	**1.344 M**
water	freezing	336 000	200 g	**67.2 k**
water	boiling	2.25 M	**4 kg**	9 M
water	condensing	2.25 M	600 mg	**1 350**
CO_2	subliming	570 k	8 g	**4 560**
CO_2	depositing	570 k	40 000 μg	**22.8**

Question

Calculate

(a) the heat energy required to change 100g of ice at – 5°C to steam at 100°C.

(b) the time taken to do this if heat is supplied by a 500W immersion heater.

Sketch a temperature-time graph of the whole process.
Stage 1: ice at – 5°C to ice at 0°C

Answer (a)

Stage 1: Warm the water to 0 °C

$\Delta Q = m\ c\ \Delta\theta$

$= 0.100\ kg \times 2100 J\ kg^{-1}\ {}^{o}C^{-1} \times (0 - (-5))\ {}^{o}C$

$= 0.100 \times 2100 \times 5$

$= 1\ 050\ J$

Stage 2: ice at 0°C to water at 0°C

$\Delta Q = m\ l$

$= 0.100 \times 336\ 000$

$= 33\ 600\ J$

Stage 3: water at 0°C to water at 100°C

$\Delta Q = m\ c\ \Delta\theta$

$= 0.100 \times 4200 \times 100$

$= 42\ 000\ J$

Stage 4: water at 100°C to steam at 100°C

$\Delta Q = m\ l$

$= 0.100 \times 2\ 250\ 000$

$= 225\ 000\ J$

Stage 5:

Add them together:

1 050J
+ 33 600J
42 000J
225 000J
301 650J

Answer (b)

The heater supplies 500J per second to water. Assume no heat loss to the surroundings:

Stage 1: Warm the water to 0 °C
1 050J / 500W = 2.1 seconds

Stage 2: ice at 0°C to water at 0°C
33 600J / 500W = 67.2s

Stage 3: water at 0°C to water at 100°C
42 000J / 500W = 84s

Stage 4: water at 100°C to steam at 100°C
225 000J / 500W = 450s

Stage 5:

301 650J / 500W
= 603.3s

(c) Sketch graph