5 Pressures, Density, LHC, SPH

1. Use the following units: degree Celsius (°C), Kelvin (K), joule (J), kilogram (kg), kilogram/metre3 (kg/m3), metre (m), metre2 (m2), metre3 (m3), metre/second (m/s), metre/second2 (m/s2), newton (N) and pascal (Pa)
2. Use the following unit: joules/kilogram degree Celsius (J/kg °C)
3. Know and use the relationship between density, mass and volume:
4. Practical: investigate density using direct measurements of mass and volume
5. Know and use the relationship between pressure, force and area
6. Understand how the pressure at a point in a gas or liquid at rest acts equally in all directions
7. Know and use the relationship for pressure difference
8. Explain why heating a system will change the energy stored within the system and raise its temperature or produce changes of state
9. Describe the changes that occur when a solid melt to form a liquid, and when a liquid evaporates or boils to form a gas
10. Describe the arrangement and motion of particles in solids, liquids and gases
11. Practical: obtain a temperature–time graph to show the constant temperature during a change of state
12. know that specific heat capacity is the energy required to change the temperature of an object by one degree Celsius per kilogram of mass (J/kg °C)
13. Use the equation: change in thermal energy = mass × specific heat capacity × change in temperature
14. Practical: investigate the specific heat capacity of materials including water and some solids
15. Explain how molecules in a gas have random motion and that they exert a force and hence a pressure on the walls of a container
16. Understand why there is an absolute zero of temperature which is –273 °C
17. Describe the Kelvin scale of temperature and be able to convert between the Kelvin and Celsius scales
18. Understand why an increase in temperature results in an increase in the average speed of gas molecules
19. Know that the Kelvin temperature of a gas is proportional to the average kinetic energy of its molecules
20. Explain, for a fixed amount of gas, the qualitative relationship between pressure and volume at constant temperature / pressure and Kelvin temperature at constant volume
    (P1)(V1) = (P2)(V2)

21. Use the relationship between the pressure and Kelvin temperature of a fixed mass of gas at constant volume
    (P1) / (T1) = (P2) / (T2)
22. Use the relationship between the pressure and volume of a fixed mass of gas at constant temperature
    (V1) / (T1) = (V2) / (T2)

Specific Heat Capacity

DEF:

- Specific Heat Capacity: Amount of energy necessary to raise a kg of substance by one C.
- Specific latent heat of fusion (melting): energy required to change the phase of 1kg of substance from a solid to liquid at a constant temperature
- Specific heat of vaporization (boiling): the energy required to change the phase of 1kg of liquid into gas at constant temperature
- temperature is random kinetic energy
- during the phase changing phase, the inter-particle potential energy increases to break the bonds and increase the separation between the molecules until the phase has changed
- heat capacity: energy required to change the temperature of a substance by 1 C.

08/27/21

Summary

Solving problems

In design:
Links + notes = systems model

Solving wicked physics problems:
Nodes = # steps **Links= #Tools/equations**
Systems model = result and happiness

Conversion factors

We often need to change units in which a physical quantity is expressed. We need to multiply the original measurement by a conversion factor, which is a ratio of units that is equal to 1.

For example:

$$\left(\frac{1\ min}{60\ s}\right) = 1 \qquad \left(\frac{1000\ g}{1kg}\right) = 1 \qquad \left(\frac{1m}{1000mm}\right) = 1$$

Because we are multiplying any quantity by 1, it leaves the quantity unchanged. However, it leaves the quantity with different units. You can create any conversion factor if you know an equivalence between quantities.

You can also **chain-link** multiple conversion factors at the same time.

For example:

$$4.5\ \frac{g}{cm^3} \times \left(\frac{1\ kg}{1000\ g}\right) \times \left(\frac{100cm}{1m}\right)^3 = \frac{4.5\ \times 100\ ^3}{1000}\ \frac{kg}{m^3} = 4500\ \frac{kg}{m^3}$$

Density

Density is the mass per unit volume of a substance. Density is a scalar property. Its SI unit is the *kilogram per cubic meter.* The dictionary also defines it as the *degree of compactness of a substance.*

We can calculate the density of a substance using the equation:

$$\rho = \frac{m}{V}$$

where ρ is the density, m is mass and V is the volume.

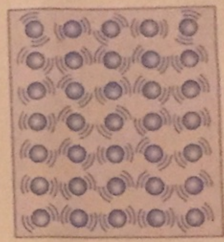
Solids	Density/g/cm³	Liquids	Density/g/cm³
aluminium	2.7	paraffin	0.80
copper	8.9	petrol	0.80
iron	7.9	pure water	1.0
gold	19.3	mercury	13.6
glass	2.5	**Gases**	**Density/kg/m³**
wood (teak)	0.80	air	1.3
ice	0.92	hydrogen	0.09
polythene	0.90	carbon dioxide	2.0

Some Densities

Material or Object	Density (kg/m³)	Material or Object	Density (kg/m³)
Interstellar space	10^{-20}	Iron	7.9×10^3
Best laboratory vacuum	10^{-17}	Mercury (the metal, not the planet)	13.6×10^3
Air: 20°C and 1 atm pressure	1.21	Earth: average	5.5×10^3
20°C and 50 atm	60.5	core	9.5×10^3
Styrofoam	1×10^2	crust	2.8×10^3
Ice	0.917×10^3	Sun: average	1.4×10^3
Water: 20°C and 1 atm	0.998×10^3	core	1.6×10^5
20°C and 50 atm	1.000×10^3	White dwarf star (core)	10^{10}
Seawater: 20°C and 1 atm	1.024×10^3	Uranium nucleus	3×10^{17}
Whole blood	1.060×10^3	Neutron star (core)	10^{18}

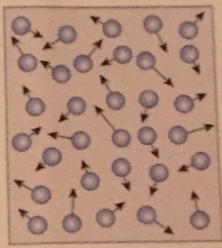
Simple density experiments

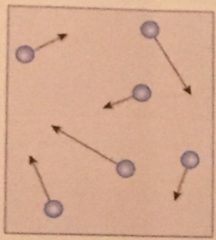
Summary



Solids: In a solid, the atoms (or molecules) are packed in a regular structure. The atoms cannot move out of their fixed positions, but they can vibrate. The atoms are held close together by strong forces, so it is difficult to change the shape of a solid.

Liquids: In a liquid, the atoms (or molecules) in a liquid are also close together. The forces between the atoms keep them in contact, but atoms can move from one place to another. A liquid can flow and change shape to fit any container. Because the atoms are close together, it is very difficult to compress a liquid.





Gas: In a gas, the atoms (or molecules) are separated by relatively large distances. The forces between the atoms are very small. The atoms in a gas are in constant, random motion A gas can expand to fill any volume and be compressed.

Property	Solid	Liquid	Gases
Definite shape	yes	no	no
Can be easily compressed	no	no	yes
Relative density	high	high	low
Can flow (fluid)	no	yes	yes
Expands to fill available space	no	no	yes

Specific heat capacity

Specific heat capacity of a substance is the energy required to change its temperature by 1 degree Celsius (or Kelvin) per unit mass.

$$c = \frac{\Delta Q}{m\Delta\theta} \qquad \left[\frac{J}{kg°C}\right]$$

$\Delta Q = mc\Delta\theta$

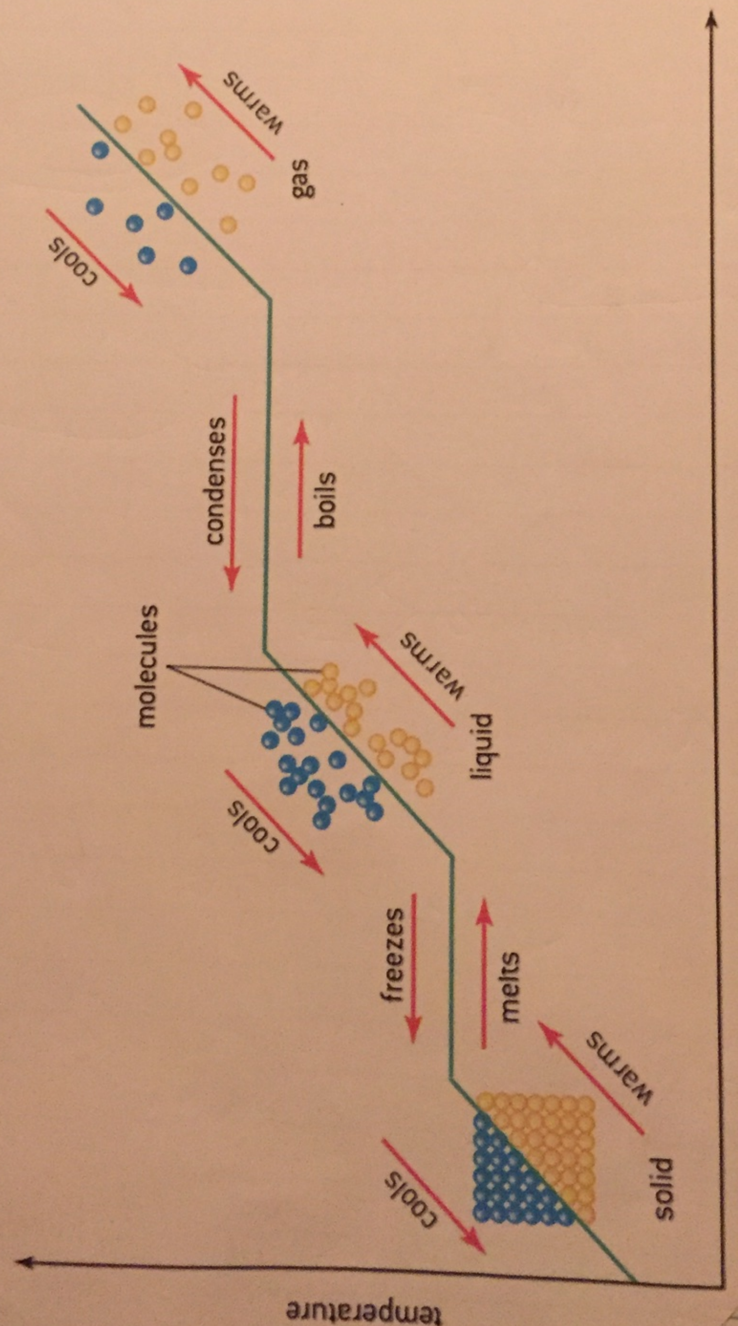
Substance	c / J kg^{-1} K^{-1}
aluminium	900 =
lead	128
iron	450
copper	385
silver	240
water	4200
ice	2200
ethanol	2430
marble	880

Specific latent heat of fusion (melting) is the energy required to change the phase of 1kg of substance from a solid to a liquid at constant temperature.

Specific latent heat of vaporisation (boiling) is the energy required to change the phase of 1kg o
liquid into gas at constant temperature.

$$L = \frac{\Delta Q}{m} \qquad \left[\frac{J}{kg}\right]$$

Substance	Specific latent heat of fusion / kJ kg^{-1}	Melting temperature / °C	Specific latent heat of vaporisation / kJ kg^{-1}	Boiling temperature / °C
water	334	0	2260	100
ethanol	109	−114	840	78
aluminium	395	660	10550	2467
lead	23	327	850	1740
copper	205	1078	2600	5190
iron	275	1540	6300	2800



Summary Notes

Particle Theory and Pressure in Gases

Big idea: The pressure of gases is explained by the movement of its particles.

- As gas particles move about, they **randomly** collide into each other and the walls of their container.
- When the gas particles collide with the wall of the container, they exert a force on it, creating an outward pressure.
- The pressure depends on the kinetic energy of the particles, and hence on their speed and momentum.
- The pressure also depends on how often the particles hit the walls and the number of collisions per unit time.

When you heat up a gas, the particles increase their average kinetic energy, hence the temperature of the gas increases.

Pressure – Temperature law: at constant volume, the pressure and the absolute temperature are directly proportional.

- If you put a fixed amount of gas in a bigger container, the pressure will decrease because there will be fewer collisions between the gas particles and the walls of the container. Additionally, when the volume is reduced, the particles will hit the walls of the container more frequently, which increases the forces over a smaller surface area, which increases the pressure.

Pressure – Volume law: at constant temperature, the pressure and volume of a gas are inversely proportional.

Evaporation is a special example of a change of state

- Evaporation happens when some particles escape from a liquid and become gas particles.
- Particles can evaporate from a liquid at temperatures much lower than the liquid's boiling point, but only the fastest particles (with the most kinetic energy) near the surface of the liquid.
- When the fastest particles escape, this decreases the average kinetic energy of the particles in the liquid, which means that the temperature of the remining liquid falls. Hence, evaporation cools a liquid.
- The cooling effect can be useful. For example, when you sweat, the water from your sweat on your skin evaporates, and it cools you down.
- A few factors that affect the rate of evaporation are the **surface area** of the liquid and the **initial temperature** of the liquid.

LEARNING OBJECTIVES - THIS SECTION IS FOR TRIPLE AWARD STUDENTS ONLY

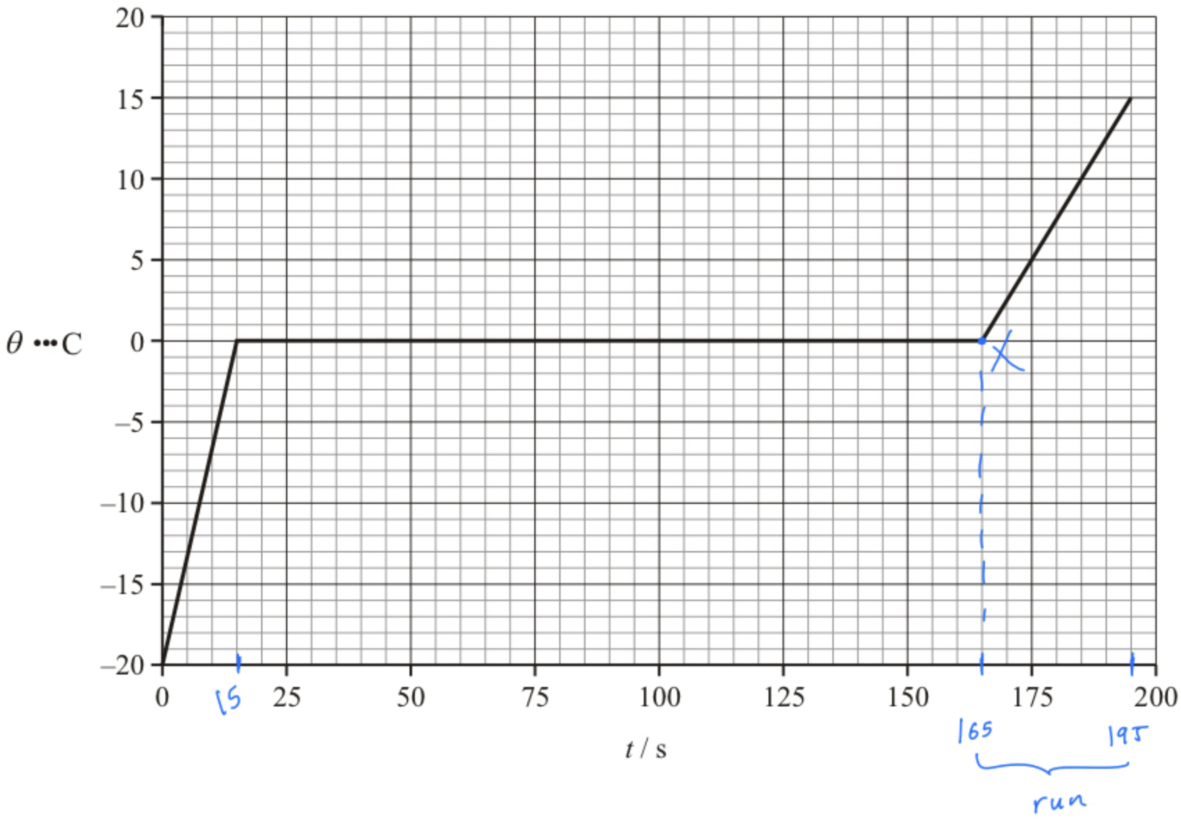
- Explain why heating a system will change the energy stored within the system and raise its temperature or produce changes of state
- Describe the changes that occur when a solid melt to form a liquid, and when a liquid evaporates or boils to form a gas
- Describe the arrangement and motion of particles in solids, liquids and gases
- *Practical: obtain a temperature–time graph to show the constant temperature during a change of state*
- know that specific heat capacity is the energy required to change the temperature of an object by one degree Celsius per kilogram of mass (J/kg °C)
- Use the equation: change in thermal energy = mass × specific heat capacity × change in temperature
- *Practical: investigate the specific heat capacity of materials including water and some solids*

Physics_-_SHCLH_triple.pdf

6. This question is about the change of phase (state) of ice.

A quantity of crushed ice is removed from a freezer and placed in a calorimeter. Thermal energy is supplied to the ice at a constant rate. To ensure that all the ice is at the same temperature, it is continually stirred. The temperature of the contents of the calorimeter is recorded every 15 seconds.

The graph below shows the variation with time t of the temperature θ of the contents of the calorimeter. *(Uncertainties in the measured quantities are not shown.)*



(a) On the graph above, mark with an X, the data point on the graph at which all the ice has just melted.

(1)

(b) Explain, with reference to the energy of the molecules, the constant temperature region of the graph.

To change phase, the inter-particle potential energy has to increase since the separation between molecules increases and bonds are broken, while the average kinetic energy remains constant during the process, hence the temperature remains constant.

(3)

The mass of the ice is 0.25 kg and the specific heat capacity of water is 4200 J kg^{-1} K^{-1}.

(c) Use these data and data from the graph to

(i) deduce that energy is supplied to the ice at the rate of about 530 W.

$\frac{\Delta\theta}{\Delta t}$ = gradient = $\frac{15\ °C}{30\ s}$ = 0.5 °C/s

$P = \frac{\Delta Q}{\Delta t} = mc\frac{\Delta\theta}{\Delta t} = 0.25 \times 4200 \times 0.5 = 525\ W$

(3)

(ii) determine the specific heat capacity of ice.

it takes 15 s for ice to go from −20°C to 0°C $\Delta\theta = 20°C$

$c = \frac{Q}{m\Delta\theta}$

$Q = P \cdot t = 530 \times 15 = 7950\ J$

525 W ok

$c = \frac{7950}{0.25 \cdot 20} = 1590\ \frac{J}{kg\ °C}$

(3)

(iii) determine the specific latent heat of fusion of ice.

time to melt ice = 150 s

$Q = P \cdot t = 530 \cdot 150 = 79500\ J$

525 W ok

$L = \frac{Q}{m} = \frac{79500}{0.25} = 318000\ J/kg$

(2)

(Total 12 marks)

7. This question is about specific heat capacity and specific latent heat.

(a) Define *specific heat capacity*.

S.H.C is the amount of energy required to change the temperature of 1 kg of mass by 1°c

(1)

(b) Explain briefly why the specific heat capacity of different substances such as aluminium and water are not equal in value.

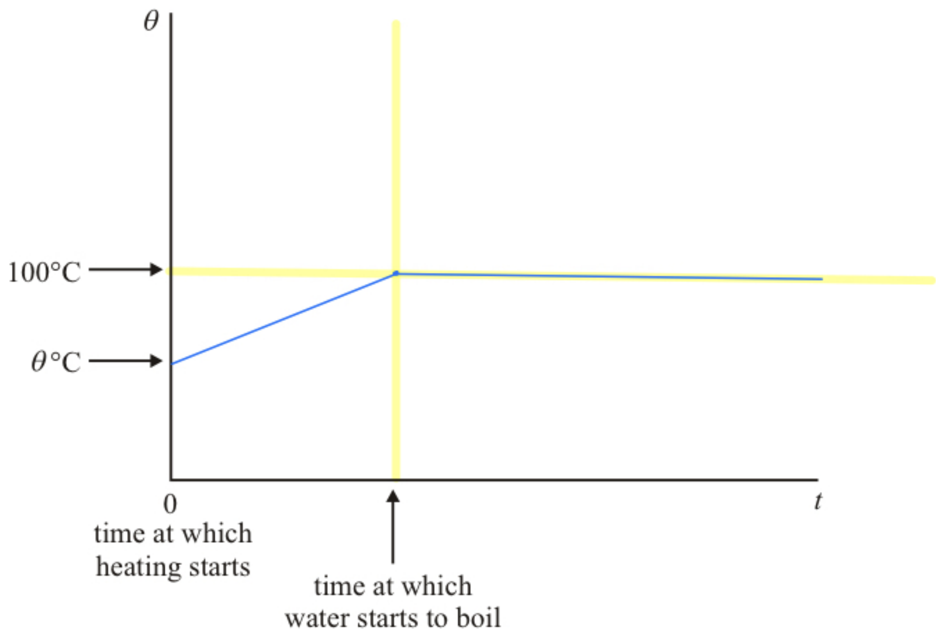
Changing the temperature means increasing the random kinetic energy of the molecules in a substance, which depends on several factors such as mass and number of molecules, free electrons, density. Hence different amounts of energy are required

(2)

A quantity of water at temperature θ is placed in a pan and heated at a constant rate until some of the water has turned into steam. The boiling point of the water is 100°C.

(c) (i) Using the axes below, draw a sketch-graph to show the variation with time t of the temperature θ of the water. (***Note**: this is a sketch-graph; you do not need to add any values to the axes.)*

(1)



(ii) Describe in terms of energy changes, the molecular behaviour of water and steam during the heating process.

From the initial temperature θ to the boiling point $100°c$, the KE of the molecules is increasing. When the water starts to change phase, there is no further change of KE since the inter-particle pE increases as the distance between molecules increases and bonds are broken, until molecules are far enough appart to become steam.

(5)

Thermal energy is supplied to the water in the pan for 10 minutes at a constant rate of 400 W. The thermal capacity of the pan is negligible.

(d) (i) Deduce that the total energy supplied in 10 minutes is 2.4×10^5 J.

$Q = P \cdot t = 400 \times 10 \times 60 = 240000 J$

(1)

(ii) Using the data below, estimate the mass of water turned into steam as a result of this heating process.

initial mass of water	= 0.30 kg
initial temperature of the water θ	= 20°C
specific heat capacity of water	= 4.2×10^3 J kg^{-1} K^{-1}
specific latent heat of vaporization of water	= 2.3×10^6 Jkg^{-1}

Energy to bring water to boiling point $Q = mc\Delta\theta$

$Q = 0.30 \times 4200 \cdot 80$

$Q = 100800 J$

Energy available to vaporise water $= 240000 - 100800 = 139200$

Hence $m = \frac{Q}{L} = \frac{139200}{2.3 \times 10^6} = 0.060$ Kg or 60g

(3)

(iii) Suggest **one** reason why this mass is an estimate.

Energy is lost to the surroundings

(1)
(Total 14 marks)

8. Gases and liquids

(a) Describe **two** differences, in terms of molecular structure, between a gas and a liquid.

1. The speed of gas molecules is far greater than the speed of liquid molecules

2. Average separation of molecules in gases is much greater than in liquids

3. Forces between gas molecules are much smaller than between liquid molecules

(2)

(b) The temperture of an ideal gas is a measure of the average kinetic energy of the molecules of the gas. Explain why the **average** kinetic energy is specified.

The molecules do not have the same speed, and their speed change each time they collide. Hence there is not an equal value of their KE

(2)

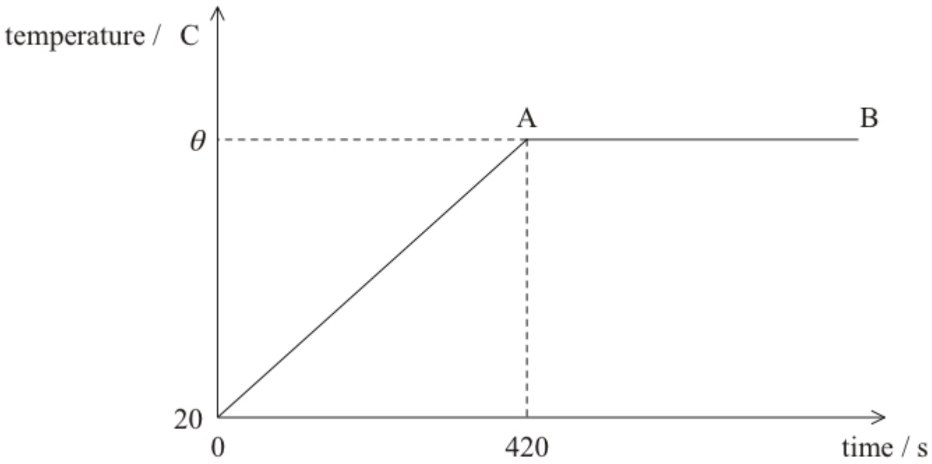
(c) Define *heat (thermal) capacity*.

the energy required to change the temperature ~~of 1kg~~ of a substance by 1°C

(1)

(d) Water is heated at a constant rate in a container that has negligible heat capacity. The container is thermally insulated from the surroundings.

The sketch-graph below shows the variation with time of the temperature of the water.



The following data are available:

initial mass of water = 0.40 kg
initial temp of water = 20°C
rate at which water is heated = 300 W
specific heat capacity of water = 4.2×10^3 J kg^{-1}°C^{-1}

(i) State the reason why the temperature is constant in the region A to B.

Water is changing phase, hence only the inter-particle PE increases while the KE remains constant

(1)

(ii) Calculate the temperature θ at which the water starts to boil.

time = 420s

$Q = P \cdot t = 300 \times 420 = 126000$ J

$\Delta\theta = \frac{Q}{mc} = \frac{126000}{0.40 \times 4200} = 75°C$ $\theta = 75 + 20$

$\theta = 95°C$

(5)

(e) All the water is boiled away 3.0×10^3 s after it first starts to boil. Determine a value for the specific latent heat L of vaporization of water.

$Q = P \cdot t = 300 \times 3.0 \times 10^3 = 900000$ J

$L = \frac{Q}{m} = \frac{900000}{0.40} = 2250000 \ \frac{J}{kg}$

(2)