9749 H2 Physics Topic 9 DUNMAN HIGH SCHOOL

First Law of Thermodynamics Year 5 (2024)

Guiding Questions

- How can temperature and heat be understood from both macroscopic and microscopic perspectives?
- How does the energy transferred between a system and its environment relate to heat transfer and mechanical work done?

Content

- Specific heat capacity and specific latent heat
- Internal energy
- First law of thermodynamics

Learning Outcomes

Candidates should be able to:

(a) define and use the concepts of specific heat capacity and specific latent heat

(b) show an understanding that internal energy is determined by the state of the system and that it can be expressed as the sum of a random distribution of kinetic and potential energies associated with the molecules of a system

(c) relate a rise in temperature of a body to an increase in its internal energy

(d) recall and use the first law of thermodynamics expressed in terms of the increase in internal energy, the heat supplied to the system and the work done on the system.

Introduction

The first law of thermodynamics is central to understanding thermodynamic processes which involve heat and mechanical work. This law extends the principle of conservation of energy in Newtonian mechanics, by introducing the concept of internal energy.

Thermodynamics and its applications are relevant to our daily lives. Many researchers still actively investigate the behaviour of gases using computer simulation and other techniques. Environmental problems connected with Earth's atmosphere, such as the depletion of ozone layer, are motivations for such work. A better understanding of the behaviour of gases might lead to an improved characterisation and possible solutions to these problems.

The application of thermodynamics pervades modern society e.g. car engines, air conditioners and power stations. However, an inevitable consequence of this energy conversion is the discharge of heat. This unwanted release of thermal energy into the environment is known as thermal pollution. One approach to reduce this is the development of alternative sources of energy, e.g. solar power. Another approach is to make things more efficient. Reducing the demand for energy should also be a personal and policy priority.

(a) define and use the concepts of specific heat capacity and specific latent heat

Specific heat capacity

> The specific heat capacity of a substance is defined as the heat per unit mass required to cause unit change in temperature.

If the heat Q supplied to a mass m of the substance can cause its temperature to rise by ΔT, then the specific heat capacity of the substance c is expressed mathematically as

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

The unit of c is J kg^{-1} K^{-1}.

For example, if c of a substance is 100 J kg^{-1} K^{-1} then 100 J of thermal energy is required to increase the temperature of 1 kg of the substance by 1 K.

Rearranging the above equation gives $Q = mc\Delta T$

The heat capacity of an object C is heat required to cause a unit change in its temperature, i.e., $C = \frac{Q}{\Delta T}$, with a unit of J K^{-1}.

Rearranging give $Q = C\Delta T$. Comparing with the equation above, $C = mc$, i.e. the heat capacity of an object is the product of the specific heat capacity of the material and the mass of that object.

Example 1

An air gun pellet, mass m and specific heat capacity c, hits a steel plate at speed v. During the impact, 50% of the pellet's kinetic energy is converted to thermal energy in the pellet. What is the rise in temperature of the pellet?

A $\frac{v^2}{2c}$ **B** $\frac{v^2}{4c}$ **C** $\frac{mv^2}{2c}$ **D** $\frac{mv^2}{4c}$

Ans: ( )

Example 2

A piece of brass of mass of 1.0 kg undergoes three different processes involving change of energy:

P: it is lifted vertically 2.0 m
Q: it is heated from 15 ^{o}C to 20 ^{o}C
R it is accelerated from rest to 10 m s^{-1}

Given that the specific heat capacity of brass is 380 J K^{-1} kg^{-1}, the processes, arranged in order of increasing energy change, are

A PQR **B** QPR **C** QRP **D** PRQ

Ans: ( )

Specific latent heat

The specific latent heat of a substance is defined as the heat per unit mass required to change its phase without changing its temperature.

For the change of phase between solid and liquid, it is known as the specific latent heat of **fusion**, and it occurs at the substance's melting point.

For the change of phase between liquid and gas, it is known as the specific latent heat of **vaporisation**, and it occurs at the substance's boiling point.

If the heat Q supplied to a substance can cause a change in phase of a mass m of the substance, then the specific latent heat of the substance L is expressed mathematically as

$$L = \frac{Q}{m}$$

The unit of L is J kg^{-1}.

`Rearranging the above equation gives $Q = mL$

You may refer to Annex A and Annex B for the experimental determination of specific heat capacity and specific latent heat respectively.

Example 3

A liquid is maintained at its boiling point by means of an electric heater.
The constant rate at which liquid boils away is measured for two different powers of the heater as shown:

power of heater	rate of loss of mass of liquid
P_1	m_1
P_2	m_2

For each power of the heater, P_1 or P_2, the rate of heat loss h to the environment is the same.
Which expression is correct for the specific latent heat of vaporisation of the liquid?

A $\dfrac{P_1}{m_1}$ **B** $\dfrac{1}{2}\left(\dfrac{P_1}{m_1}+\dfrac{P_2}{m_1}\right)$ **C** $\dfrac{(P_1-P_2)}{(m_1-m_2)}$ **D** $\dfrac{(P_1+P_2)}{(m_1+m_2)}$

Ans: ( )

Example 4

In a heating experiment, energy is supplied at a constant rate to a liquid in a beaker of negligible heat capacity. The temperature of the liquid rises at 4.0 K per minute just before it begins to boil. After 40 minutes all the liquid has boiled away. For this liquid, what is the ratio

$$\frac{\text{specific heat capacity}}{\text{specific latent heat of vaporisation}}?$$

A $\dfrac{1}{10}\,\text{K}^{-1}$ **B** $\dfrac{1}{40}\,\text{K}^{-1}$ **C** $\dfrac{1}{160}\,\text{K}^{-1}$ **D** $\dfrac{1}{640}\,\text{K}^{-1}$

Ans: ( )

(b) show an understanding that internal energy is determined by the state of the system and that it can be expressed as the sum of a random distribution of kinetic and potential energies associated with the molecules of a system

> The internal energy of a substance is determined by the state of the system and that it can be expressed as the sum of a random distribution of kinetic and potential energies associated with the molecules of a system.

The thermodynamic state of a system is defined by specifying values of a set of measurable properties sufficient to determine all other properties. For fluid systems, typical properties are pressure, volume and temperature.

The internal kinetic energy depends on the temperature and is the total energy of the atoms and molecules due to their translational, rotational and vibrational motion.

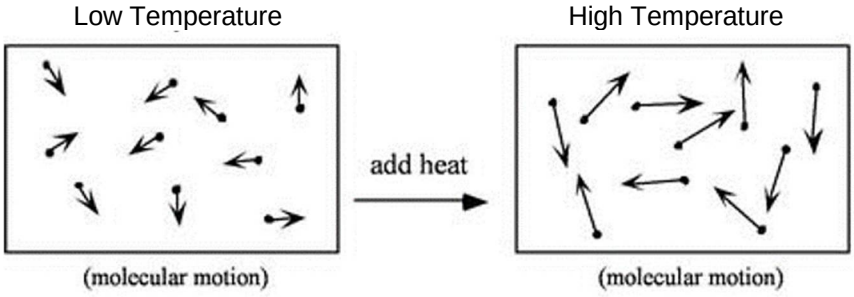
The internal potential energy depends on the separation and is the total energy of the atoms and molecules due to intermolecular forces.

When the internal energy of a system changes, the change depends only on the initial and final states of the system, and *not on how the change was brought about*. This is equivalent to saying that the internal energy of a system depends only on the state that it is in, and not on how it reached that state.

(Note: A system is said to have changed its 'state' if any observable properties of the system, such as its temperature, pressure, volume, or phase, have changed.)

(c) relate a rise in temperature of a body to an increase in its internal energy

When a body absorbs heat, the random motion of the atoms or molecules increases (i.e., the internal kinetic energy increases). Macroscopically, this is seen as an increase in temperature of the body. At the same time, the heat may be used to separate the atoms or molecules further, thus increasing the internal potential energy. Hence, when the temperature of a body rises, the internal energy of the body also increases.



[Random motion is the physical basis for internal energy.]

For an ideal gas, the microscopic potential energy of the molecules is zero because the intermolecular forces are negligible. Therefore, the internal energy U consists solely of the random kinetic energy of the molecules.

Recall: the average translational kinetic energy of a molecule is given by

$$\langle KE \rangle = \frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} kT \ .$$

Thus, the internal energy U of an ideal gas with N molecules can be mathematically expressed as

$$N\langle KE\rangle = \frac{3}{2}NkT = U$$

A change in temperature of $\Delta T\left(=T_f - T_i\right)$ would result in a corresponding change in internal energy expressed as

$$\begin{aligned}\Delta U &= U_f - U_i \\ &= \tfrac{3}{2}NkT_f - \tfrac{3}{2}NkT_i = \tfrac{3}{2}Nk\Delta T \\ &= \tfrac{3}{2}nRT_f - \tfrac{3}{2}nRT_i = \tfrac{3}{2}nR\Delta T \\ &= \tfrac{3}{2}p_fV_f - \tfrac{3}{2}p_iV_i\end{aligned}$$

You may refer to Annex C for the kinetic theory of melting, boiling and the cooling effect of evaporation.

Example 5

The air in an aircraft when travelling has

8 MJ of kinetic energy as a result of the motion of the aircraft,
30 MJ of kinetic energy as a result of the random movement of the air molecules,
75 MJ of potential energy as a result of the altitude of the aircraft,
–3 MJ of potential energy as a result of intermolecular attraction between air molecules.

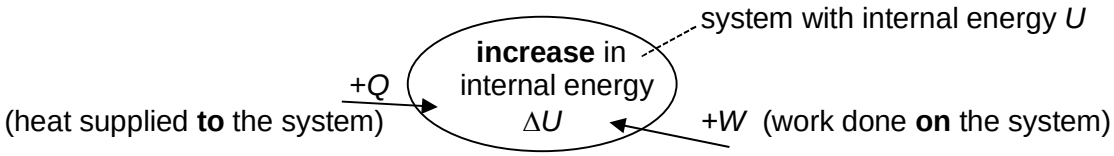
What is the **internal energy** of the air in the aircraft?

A 27 MJ **B** 33 MJ **C** 35 MJ **D** 110 MJ

Ans: ( )

(d) recall and use the first law of thermodynamics expressed in terms of the increase in internal energy, the heat supplied to the system and the work done on the system.

The internal energy of a fixed mass of ideal gas only depends on its temperature.



Applying the principle of conservation of energy for the system, we have

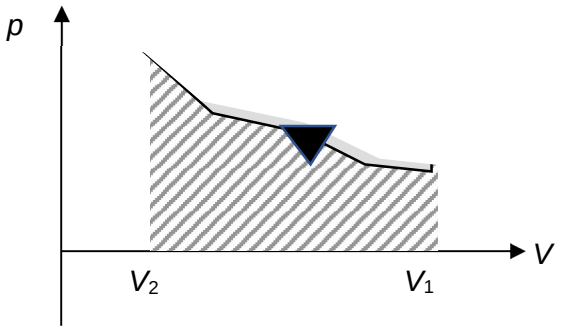
The **first law of thermodynamics** states that the **increase in internal energy** of a system is the **sum** of the **heat supplied to** the system and the **work done on** the system.

$$\Delta U = Q + W$$

Symbol	Sign	Meaning	Remarks
ΔU	positive	increase in internal energy	For an ideal gas, a change in internal energy directly corresponds to a change in temperature.
	negative	decrease in internal energy	
Q	positive	heat supplied to the system	Even if Q is zero, there can still be temperature change.
	negative	heat removed from the system	
W	positive	work done on the system	work done on the system = –work done by the system
	negative	work done by the system	

More details on the work done on the system (W):

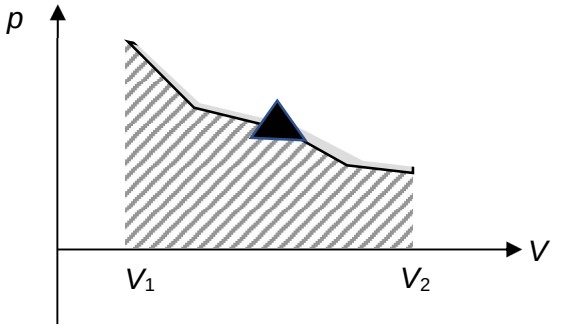
Work done on the system (W) depends on whether the system contracts or expands.



$$W = -\int_{V_1}^{V_2} p\, dV$$

If $V_2 < V_1$, volume decreases, then W is positive.

Work is done **on** the system, adding energy to it.



If $V_2 > V_1$, volume increases, then W is negative.

Work is done **by** the system, resulting in energy leaving the system.

If the volume of the system changes at constant pressure p, the **work done on the system** is

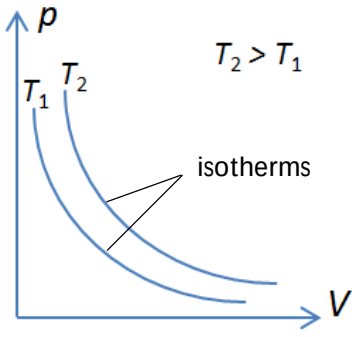
$$W = -p(V_2 - V_1)$$

Thermodynamic Processes and p-V Graphs:

If the state of a system changes, then it is undergoing a process. The succession of states through which the system passes defines the path of the process.

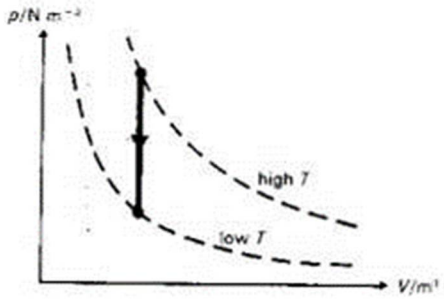
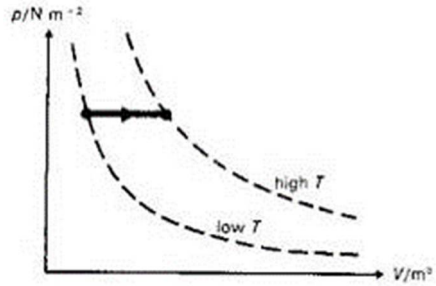
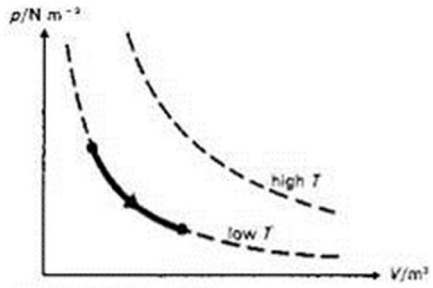
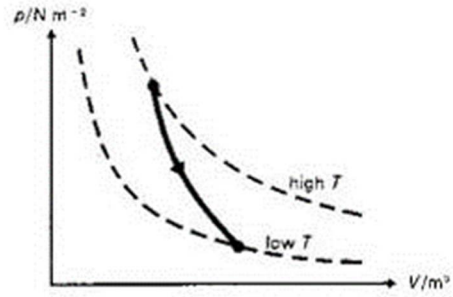
The state of a system can be represented by a point on a p-V graph, with specific values for p (pressure) and V (volume).

For an ideal gas, given the equation $pV = nRT$, the temperature (T) is determined once specific values for p and V are known.



At constant temperature, the product pV remains constant, so the p-V graph is a hyperbola known as an **isotherm**. The larger the value of pV, the higher the temperature. Therefore $T_2 > T_1$.

The following four thermodynamic processes are the most common for an ideal gas:

Process	Characteristics	Graph
isochoric/ isovolumetric	• $V = \text{constant}$ • $W = 0$ • Therefore $\Delta U = Q$	
isobaric	• $p = \text{constant}$ • $W = -p\Delta V$	
isothermal	• $T = \text{constant}$ • $pV = \text{constant}$ (ideal gas) • $W = \pm$area under the path (+ if compression, − if expansion) • $\Delta U = 0$ (ideal gas); $Q = -W$ • slow process	
adiabatic	• all variables change • $Q = 0$ • $W = \pm$area under the path (+ if compression, − if expansion) • $\Delta U = W$ • fast process	

Recall,

$$U = \frac{3}{2}nRT = \frac{3}{2}pV$$

In a p-V graph,

(i) for any change between two states, ΔU is the same, regardless of the path.

(ii) for any change which starts and ends with the same state, $\Delta U = 0$.

Example 6

(a) State in words the first law of thermodynamics.

(b) An *adiabatic* change is one in which no heat is supplied or extracted.

(i) Write down an expression for the first law when related to an adiabatic change in the state of an ideal gas in which the gas does 600 J of work.

(ii) Deduce the change in the internal energy of the gas.

(iii) What can you deduce about the temperature of the gas?

Answer:

Example 7

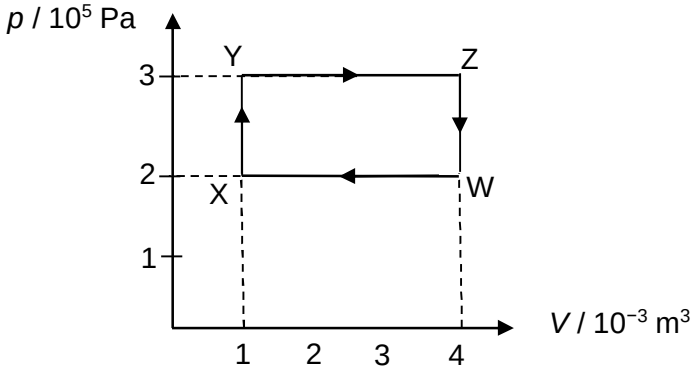
A fixed mass of an ideal gas absorbs 1000 J of heat and expands under a constant pressure of 20 kPa from a volume of 25×10^{-3} m^3 to a volume of 50×10^{-3} m^3. What is the change in internal energy of the gas?

A −1000J **B** −500 J **C** zero **D** +500 J

Ans: ( )

Example 8 (N89/1/3) (modified)

A gas undergoes the cycle of pressure and volume changes W→X→Y→Z→W shown in the diagram.



What is the net work done *by* the gas?

A −900 J **B** −300 J **C** 300 J **D** 900 J

Ans: ( )

Example 9

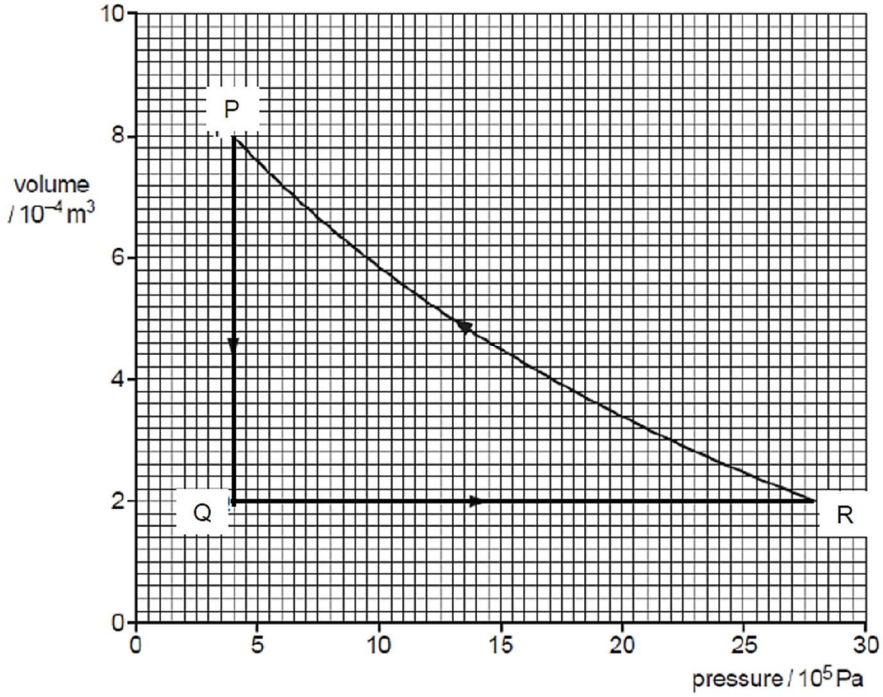
One mole of an ideal gas is contained within a cylinder by a frictionless piston and is initially at temperature T. The pressure of the gas is kept constant while it is heated and its volume doubles. If R is the molar gas constant, the work done by the gas in increasing its volume is

A $RT \ln 2$ **B** $\frac{1}{2}RT$ **C** RT **D** $\frac{3}{2}RT$

Ans: ( )

Worked Example 10 (J94/II/5)

A fixed mass of helium gas undergoes a cycle PQRP of changes as shown.



Complete the table to show all the energy changes.

Change	Work done on gas/ J	Heat supplied to gas/ J	Increase in internal energy/ J
P → Q		0	
Q → R		+320	
R → P		0	

Solution:

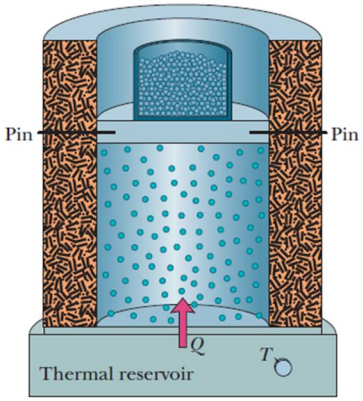
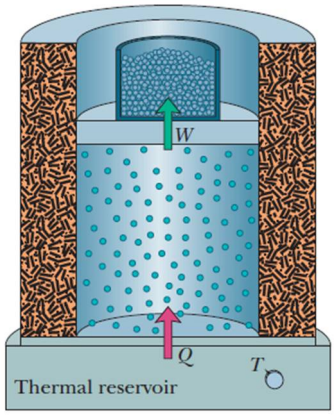
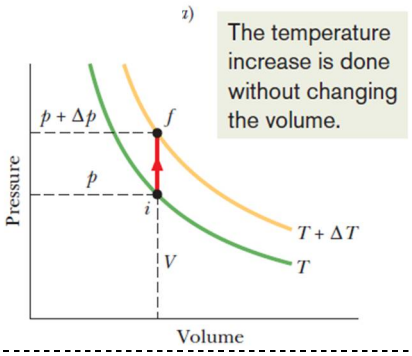
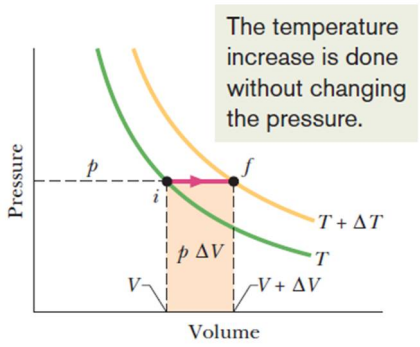
Notice that the given graph is a *V-p* graph, not *p-V* graph. Hence

Change	Work done on gas/ J	Heat supplied to gas/ J	Increase in internal energy/ J
P → Q		0	
Q → R		+320	
R → P		0	

Example 11 (2017/H2/P3/Q7(c)(iii)) (2015/H2/P3/Q7(d)(ii)

Use the first law of thermodynamics to suggest why the specific heat capacity of an ideal gas would be larger when the heating takes place at constant pressure rather than constant volume.

Solution

heating at constant volume	heating at constant pressure
	
	
$\Delta U = Q_v + W = mc_v\Delta T$ --- (1)	$\Delta U = Q_p + W = mc_p\Delta T - p\Delta V$ --- (2)

ΔU for a constant-pressure process, as described by Eq. (2), is the same as that given by Eq. (1), even though the volume is not constant. The internal energy of an ideal gas depends **only** on temperature. Therefore, the change in internal energy during any process is determined solely by the temperature change.

If Eq. (1) is valid for an ideal gas for one particular kind of process, it must be valid for an ideal gas for every kind of process with the same ΔT. So, we may replace ΔU in Eq. (2) by $mc_v\Delta T$:

$$mc_v\Delta T = mc_p\Delta T - p\Delta V \text{ --- (3)}$$

For n mole of ideal gas, $pV = nRT$, so for constant pressure heating, $p\Delta V = nR\Delta T$.

Eq. (3) becomes:

where M is the molar mass of the ideal gas.

We can write:

where r is the gas constant per unit molar mass.

This shows that the specific heat capacity at constant pressure (c_p) is greater than the specific heat capacity at constant volume (c_v) by an amount equal to the gas constant per unit molar mass r.

The reason is that, at constant pressure, part of the heat added to the system is used to do work (expansion), in addition to increasing the internal energy. Hence, more heat is required to achieve the same temperature change at constant pressure, making c_p larger than c_v.

Annex A: Determination of specific heat capacity

For the determination of c of a material in liquid form, the principle of its determination requires the measurement of Q, m and ΔT. For a liquid, a container is required. The mass of the liquid, m, and its container, m_c, can be measured with a balance. The specific heat capacity of the container, c_c, must be known. The heat supplied by an electric heater having a constant current I driven by a constant p.d. V for a time t, can be expressed as

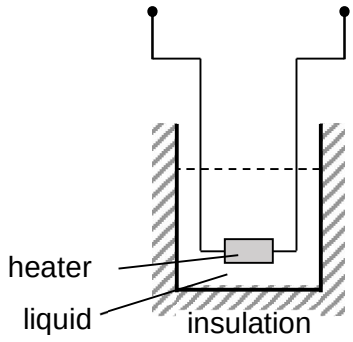
$$Q = IVt$$

This amount of heat would raise the temperature of the liquid and its container by ΔT, which can be found by noting the temperature of the liquid θ_1 before heating and the temperature θ_2 after being heated for time t. So

$$\Delta T = \theta_2 - \theta_1$$

Mathematically,

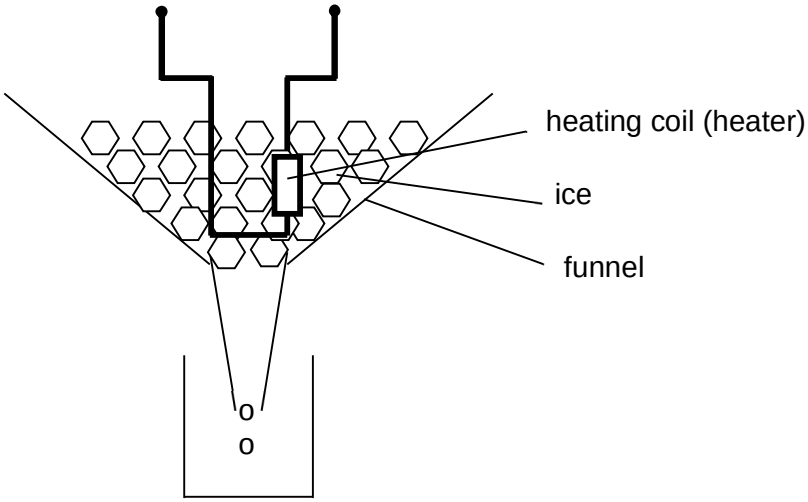
$$\begin{aligned} Q &= mc\Delta T + m_c c_c \Delta T \\ &= \left(mc + m_c c_c\right)\Delta T \\ \Rightarrow mc &= \frac{Q}{\Delta T} - m_c c_c \\ \Rightarrow c &= \frac{IVt}{m\left(\theta_2 - \theta_1\right)} - \frac{m_c c_c}{m} \end{aligned}$$



Note: The heat lost to the surroundings would cause a systematic error in the determination of c, since the measured amount of heat Q would *not* be completely absorbed by the liquid and its container to increase their temperature. This systematic error may be reduced by insulation.

Annex B: Determination of specific latent heat

For the determination of the specific latent heat of fusion of a solid, *L* (e.g., ice), a heating coil (connected to a power supply) is placed in a large funnel and surrounded by lumps of melting ice as shown in the diagram to the right.



The principle of its determination requires the measurement of *Q* and *m*. *m*, the mass of ice that melts in time *t*, should only be collected for measurement when the stream of drops of water from the melted ice has become steady.

The heat supplied by an electric heater having a constant current I driven by a constant p.d. *V* for a time *t*, can be expressed as

$$Q = IVt$$

Without the heater, ice would still melt due to heat absorbed from the surroundings. If the mass of ice melted in time *t* is m_1, without the heater; and the mass of ice melted in the same time due to heat supplied by both the heater and the surroundings is m_2, then

$$m = m_2 - m_1$$

From the above equations, the specific latent of fusion of ice can be determined by

$$L = \frac{Q}{m} = \frac{IVt}{m_2 - m_1}$$

To modify for determining the specific latent heat of vaporisation of a liquid, the mass of liquid *m* vaporised by the heat supply must be condensed before being collected for measurement. Again, collection of the liquid condensed should be done only when the stream of drops of liquid has become steady.

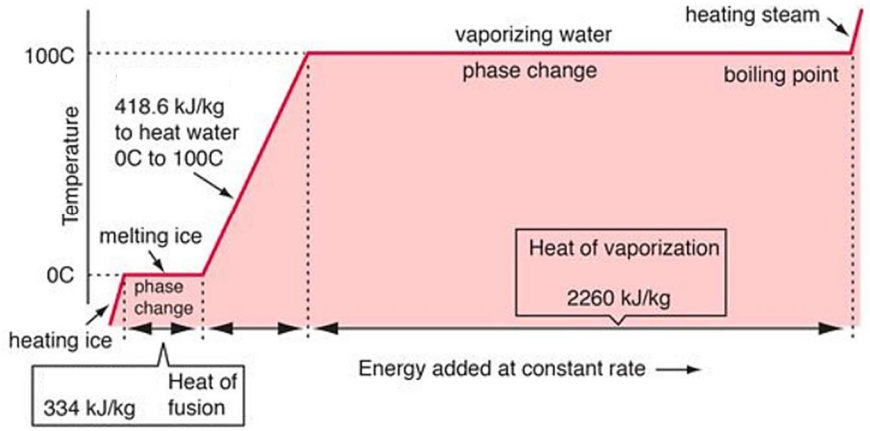
Note: The heat lost to the surroundings would cause a systematic error in the determination of *L*, since the measured amount of heat *Q* would *not* be completely absorbed by the substance to change its state. This systematic error may be reduced by insulation.

Annex C: Kinetic Theory interpretation of melting, boiling (which takes place without a change in temperature) and the cooling effect of evaporation

From the kinetic theory, *mean random kinetic energy* of the molecules is directly proportional to the temperature of a substance.

- In **melting**, the heat supplied is used by the molecules to do work against the intermolecular attractions, allowing them to move freely within the substance rather than being restricted to fixed positions by the bonds. This transition changes the state from solid to liquid. The volume of the substance in the liquid state may be slightly larger than in the solid state, indicating that the molecules are slightly further apart. The heat supplied increases the potential energy of the molecules, but the mean (average) random kinetic energy of the molecules remains the same during the melting process. Therefore, there is no change in temperature, which remains at the melting point of the substance."

- In **boiling**, the molecules move much further apart as the substance changes from a liquid to a gaseous state. This involves a significant increase in their total potential energy and considerable work done against atmospheric pressure. Consequently, the potential energy of the molecules increases. However, the mean random kinetic energy of the molecules remains the same during the boiling process, resulting in no change in temperature, which remains at the boiling point of the substance.



Why is the specific latent heat of vaporisation higher than specific latent heat of fusion for the same substance?

In boiling, the specific latent heat of vaporization is higher because the molecules move much further apart (approximately 10 times further). The heat supplied is used to:

- Do work in moving the molecules further apart against the intermolecular attractions.
- Do work against atmospheric pressure.

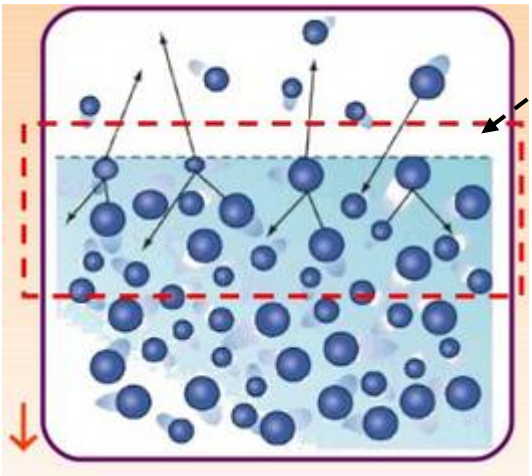
In melting, the increase in the separation of the molecules is very slight. The increase in their total potential energy, as well as the work done against atmospheric pressure, is much less compared to the boiling process. This accounts for the relatively lower specific latent heat of fusion.

Cooling effect accompanies evaporation:

This can be explained in two ways:

Simple Explanation: Evaporation is a process that occurs at all temperatures. Since there is no external heat source for this process, the latent heat of vaporization required for evaporation must come from the remaining liquid and its surroundings. This loss of heat from the liquid causes the remaining liquid to cool.

Kinetic Model Explanation: In the kinetic model, evaporation is the process by which molecules in the liquid state vaporize to become gas molecules. This occurs near the surface of the liquid, where molecules with relatively higher random kinetic energies can escape from the liquid surface to become vapor. The loss of these high-energy molecules decreases the *mean* random kinetic energy of the remaining molecules in the liquid, resulting in a decrease in the liquid's temperature.



Definition List:

Internal energy	The internal energy of a system is determined by the state of the system and that it can be expressed as the sum of a random distribution of kinetic and potential energies associated with the molecules of a system.
Specific heat capacity	The quantity of heat required *per unit* mass *per unit* temperature rise.
Heat Capacity	The quantity of heat required per unit temperature rise.
Latent Heat	It is the heat required by matter for a change in phase.
Latent heat of fusion	The quantity of heat required when the substance changes from solid state to liquid state without a change in temperature.
Latent heat of vaporization	The quantity of heat required when the substance changes from liquid state to gaseous state (vapour) without a change in temperature.
Specific latent heat of fusion	The quantity of heat required *per unit mass* when the substance changes from solid state to liquid state without a change in temperature.
Specific latent heat of vaporization	The quantity of heat required *per unit mass* when the substance changes from liquid state to gaseous state (vapour) without a change in temperature.
First Law of Thermodynamics	The First Law of Thermodynamics states that the increase in the internal energy of a system is equal to the sum of the heat supplied to the system and the work done on the system.
Isobaric process	An isobaric process is a thermodynamic process in which the pressure p of the system remains constant.
Isothermal process	An isothermal process is a thermodynamic process in which the temperature T of the system remains constant throughout.
Isochoric process	An isochoric process, also known as an isovolumetric process, is a thermodynamic process in which the volume V of the system remains constant.
Adiabatic process	An adiabatic process is a thermodynamic process in which there is no heat exchange between the system and its surroundings. In other words, during the process, there is no transfer of heat into or out of the system. Note: An adiabatic process typically occurs when changes happen *suddenly* or *rapidly*.

Tutorial Questions

1. 10.0 g of ice at –10°C are introduced into 100 g of water at 50°C contained in a copper calorimeter with a mass of 50.0 g. Calculate the final temperature reached.

   specific latent heat of fusion of ice = 0.34×10^6 J kg^{-1}
   specific heat capacity of ice = 2.09×10^3 J kg^{-1} K^{-1}
   specific heat capacity of copper = 380 J kg^{-1} K^{-1}
   specific heat capacity of water = 4200 J kg^{-1} K^{-1} [38.1°C]

2. 1.00 kg of vegetables, having a specific heat capacity 2200 J kg^{-1} K^{-1}, at a temperature of 373 K are plunged into a mixture containing some ice and 1 kg of water at 273 K. After all the ice has melted, the final temperature of the entire mixture is 300 K. Calculate the mass of ice originally present. Assume no heat loss to the container and the surroundings.

   specific latent heat of fusion of ice = 3.34×10^5 J kg^{-1} [0.105 kg]

3. A thermally insulated vessel containing liquid water and water vapour is connected to a vacuum pump which removes water vapour continuously. When the temperature reaches 0.00°C, the vessel contains 110 g of liquid water. What mass of ice has been formed when no liquid remains?

   specific latent heat of fusion of water = 3.40×10^5 J kg^{-1}
   specific latent heat of vaporisation of water = 2.52×10^6 J kg^{-1} [96.9 g]

4. A lead bullet is fired with a muzzle velocity of 320 m s^{-1} and becomes immediately embedded in clay. Estimate the fraction of the mass of the bullet which melts, assuming that all the heat generated remains as internal energy in the lead.

   Given: the muzzle temperature of the bullet is 30°C, melting point of lead is 330°C, the specific heat capacity of lead is 130 J kg^{-1} K^{-1} and the specific latent heat of fusion of lead is 2.1×10^4 J kg^{-1}. [0.58]

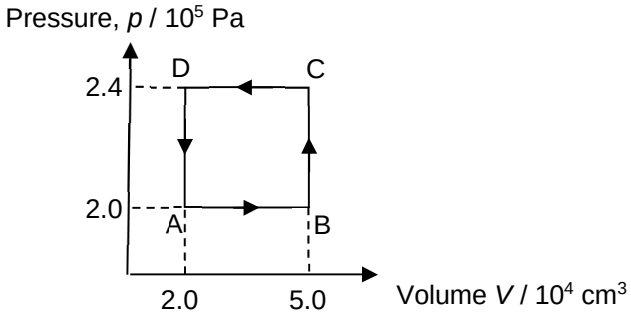
5. Cooling water enters the heat exchanger in the turbine hall of a nuclear power station at 6.0°C and leaves at 14.0°C. The rate of heat removal by the water is 6.7×10^9 J per minute. The specific heat capacity of water is 4200 J kg^{-1} K^{-1}. Determine the mass of water flow per unit time. [3320 kg s^{-1}]

6. (a) Using the concept of internal energy, compare the internal energy per unit mass of water and water vapour at the same temperature.
   (b) Explain, using a simple kinetic model for matter,
      (i) why the temperature of a pure substance does not change when it experiences a change of state.
      (ii) the specific latent heat of vaporisation of water (= 2.26×10^6 J kg^{-1}) is greater than the specific latent heat of fusion (= 3.34×10^5 J kg^{-1}).
   (c) Explain, using First Law of Thermodynamics,
      (i) the temperature of a fixed mass of gas increases when it is compressed in a cylinder using a piston,
      (ii) the temperature of an insecticide spray canister drops when it is used.

7. At a temperature of 100°C and a pressure of 1.01×10^5 Pa, 1.00 kg of steam occupies 1.67 m^3 but the same mass of water occupies only 1.04×10^{-3} m^3. The specific latent heat of vaporization of water at 100°C is 2.26×10^6 J kg^{-1}. For a system consisting of 1.00 kg of water changing to steam at 100°C and 1.01×10^5 Pa, determine
   (a) the heat supplied to the system, [2.26×10^6 J]
   (b) the work done by the system, [1.69×10^5 J]
   (c) the increase in internal energy of the system. [2.09×10^6 J]

8. An ideal gas of volume 1.5×10^{-3} m^3 and at pressure 1.0×10^5 Pa is supplied with 70 J of heat. The volume increases to 1.7×10^{-3} m^3, the pressure remaining constant. Calculate the change in internal energy of the gas. [+50 J]

9. Consider a system that is taken along the paths shown in the *p*-*V* diagram below. The internal energy of the system at A and at C is 30 kJ and 90 kJ respectively.

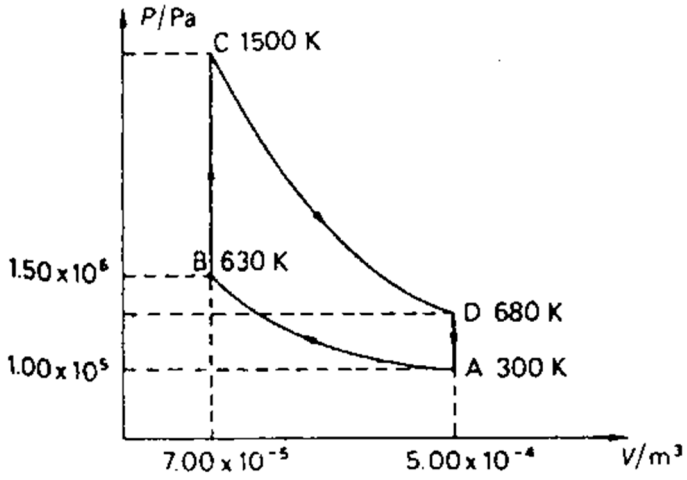


(a) Calculate the internal energy of the system at point B, if 51 kJ of heat is absorbed by the system in going from A to B.

(b) Find the amount of heat that enters the system along the path from B to C.

[75 kJ, 15 kJ]

10. The figure below shows some details concerning the behaviour of a fixed mass of a gas (assumed to be ideal) in a petrol engine.



(a) Use the equation of state for an ideal gas to find the number of moles in the fixed mass of gas.

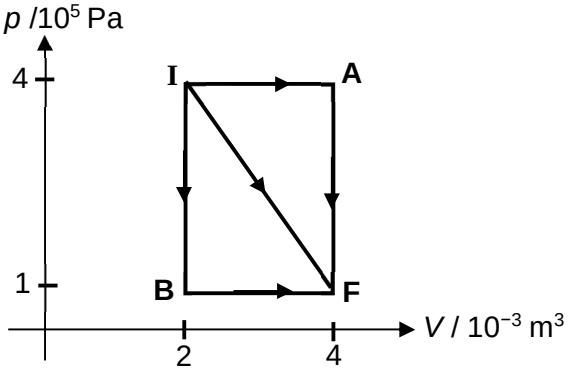
(b) In the change from state B to state C, the temperature of the gas rises from 630 K to 1500 K. The molar heat capacity of the gas at constant volume is 21 J mol^{-1} K^{-1}. Calculate the heat supplied in this change.

(c) How much work is done by the gas in the change from state B to C?

(d) In the change from state C to D, the gas expands to its original volume. The temperature at state D is 680 K. Calculate the pressure at state D.

[0.0201 mol, 367 J, 0 J, 2.27×10^5 Pa]

11. A gas expands from **I** to **F** along the three paths indicated in the figure below.



(a) Calculate the work done on the gas along the path

(i) **IAF** [–800 J]

(ii) **IF** [–500 J]

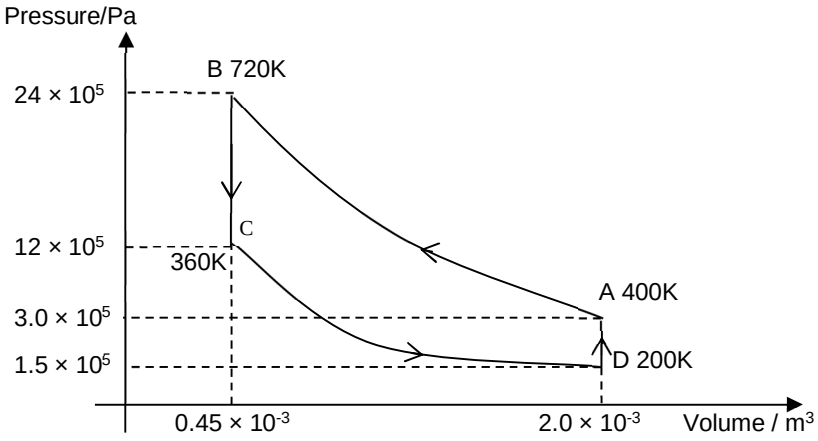
(iii) **IBF** [–200 J]

(b) When the gas expands from **I** to **F** along the diagonal path, the energy added to the gas by heating is 418 J.

(i) What is the change in internal energy of the gas? [–82 J]

(ii) How much energy must be added to the gas by heating along the indirect path **IAF** to give the same change in internal energy? [718 J]

12. A fixed mass of gas in a heat pump undergoes a cycle of changes of pressure, volume and temperature as illustrated in the graph below. The gas is assumed to be ideal.



The table below shows the increase in internal energy which takes place during each of the changes A to B, B to C and C to D. It also shows that in both sections A to B and C to D, no heat is supplied to the gas.

	Increase in internal energy /J	*Heat supplied to gas* /J	*Work done on gas* /J
A to B	1200	0	
B to C	–1350		
C to D	–600	0	
D to A			

- END -