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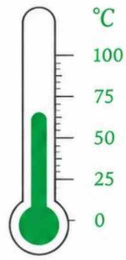
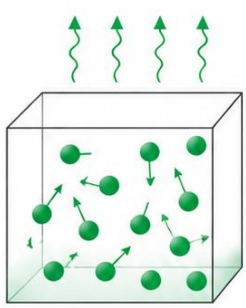
Smarter practice. Stronger understanding

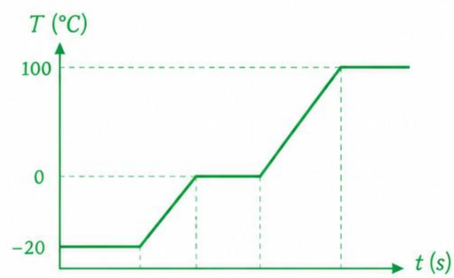
WORKBOOKS

UNDERSTAND | APPLY | PRACTISE | IMPROVE

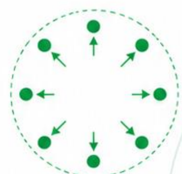


Thermal Physics





$\Delta E = mc\Delta T$

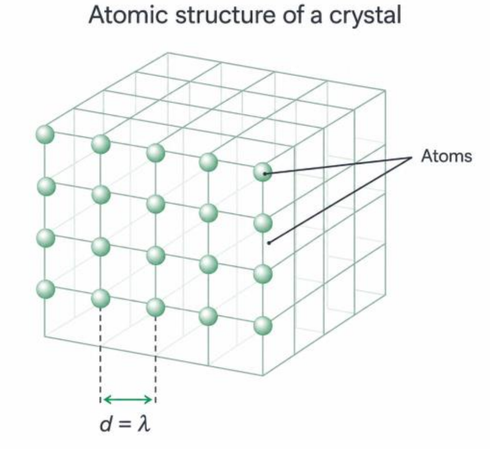


OWNER DETAILS

NAME: | GROUP: | TEACHER:

5-A-Day

1. Two objects, A and B are at different temperatures where $T_A > T_B$. Describe what you believe will happen if these two objects came into contact.
2. Object A is a cube of side 8cm. The cube is placed into a hot oven. **Explain** what might happen to the structure of the material as it is heated.
3. The density of object A is $3200 kg/m^3$. Calculate the mass of object A.
4. Object A is made of atoms of iron, each of mass 9.3×10^{-26}kg. Calculate the number of iron atoms in object A.
5. Challenge – Assume all iron atoms are 'touching' to form a cube (shown below). Estimate the diameter of an iron atom.



5-A-Day

1. Define the term density.
2. Calculate the mass of $3m^3$ of iron with a density of $7800kg/m^3$.
3. A temperature of 3^oC is measured. State this temperature in Kelvin.
4. Iron melts at around 1500^oC. Explain how the structure of iron changes as it begins to melt.
5. State, if any, the differences in energies between solid iron and liquid iron.

5-A-Day

1. Sketch a graph of the heating of ice at -10^{o}C into steam.
2. Explain how the molecular arrangement and motion of the substance change as it is heated.
3. Define the term internal energy.
4. Explain how potential, kinetic and internal energy of the substance change as it is heated.
5. When in its gas phase, a molecule with mass ‘m’ travels at speed ‘v’ and collides with a surface and rebounds with ‘–v’. The collision takes time ‘t’. Give an expression for the force exerted on the surface by the container.

5-A-Day

1. Define the term 'specific heat capacity'
2. The SHC of water is 4200J/kg/K. Calculate the change in temperature of 5kg of water when 20kJ of heat is transferred to the water.
3. An electrical heater is used to increase the temperature of a metal. Draw a labelled diagram, including the electrical circuit, to show this setup.
4. The potential difference of the heater is 20V and the current through the heater is 1.3A. Calculate the heat transferred to the metal after 4 minutes of heating.
5. The 1kg metal block experiences a temperature change of 6.5K. Calculate the SHC of the metal.

5-A-Day

1. Define the term 'specific latent heat'.
2. Give the units of SLH and SHC.
3. Explain how the internal energy of a substance change as it melts.
4. 25 kJ of energy is transferred to boiling water, causing 11 g of water to evaporate. Calculate the SLH of vaporisation for water.
5. The 11 g of water vapour is condensed and the resulting water is cooled to 0 °C. It then takes 2 minutes to freeze. Calculate the average rate at which thermal energy must be removed while it freezes.

5-A-Day

1. $2x10^{19}$ molecules of an ideal gas are kept at constant temperature in a sealed vial. Calculate the number of moles in the vial.
2. The vial is a cylinder of diameter 16mm and length 12cm. The vial is measured to have a temperature of 25^{o}C. Calculate the pressure of the gas inside the vial.
3. The gas is now heated using a flame so that the temperature increases to 35^{o}C. Calculate the new pressure in the vial.
4. The gas inside the vial is helium. Helium is monatomic and has a specific heat capacity at constant volume of 3120 $Jkg^{-1}K^{-1}$. Each helium atom has a mass of 6.6×10^{-27} kg
5. Use this data to find the molar mass (kg/mol) of helium.

5-A-Day

1. 4×10^{22} molecules of a gas are kept at 12°C in a container of $2m^3$. Calculate the pressure exerted on the container by the gas.
2. A valve on the container is opened and a third of the molecules escape. The container eventually returns to the original temperature. Calculate the new pressure in the container.
3. Explain the effect, if any on the speed of the molecules at this new pressure.
4. In an experiment, the sealed and rigid container is dropped into the ocean with a variety of sensors. The temperature of the water is 4°C. Explain how the pressure and speed of the gas molecules change as a result.
5. Calculate the ratio of the pressure calculated in Q2 to the pressure when placed into the ocean.

5-A-Day

1. Calculate the internal energy of a single atom of helium at 30^{o}C.
2. What assumptions were made in your previous calculation?
3. Calculate the internal energy of 50 g of helium at 30 °C, treating it as a monatomic ideal gas.
4. Calculate the rms speed of a single helium atom at this temperature.
5. The helium is kept in a canister, two thirds of the gas is released. The canister is crushed so that the product of pressure and volume remains the same. Give an expression for the new rms speed of the helium atoms.

5.1.2 Solid, liquid and gas

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) describe solids, liquids and gases in terms of the spacing, arrangement and motion of atoms or molecules

(b) explain the simple kinetic model for solids, liquids and gases

(c) explain Brownian motion using the kinetic model of matter, including the demonstration with smoke particles suspended in air

(d) define internal energy as the total of the randomly distributed kinetic and potential energies associated with the molecules in a system

(e) define absolute zero (0 K) as the lowest possible temperature, where a substance has minimum internal energy

(f) explain that the internal energy of a body increases as its temperature rises

(g) explain changes in internal energy during a change of state, and that temperature remains constant during the phase change

Temperature

(a) thermal equilibrium

(b) absolute scale of temperature (i.e. the thermodynamic scale) that does not depend on a property of any particular substance

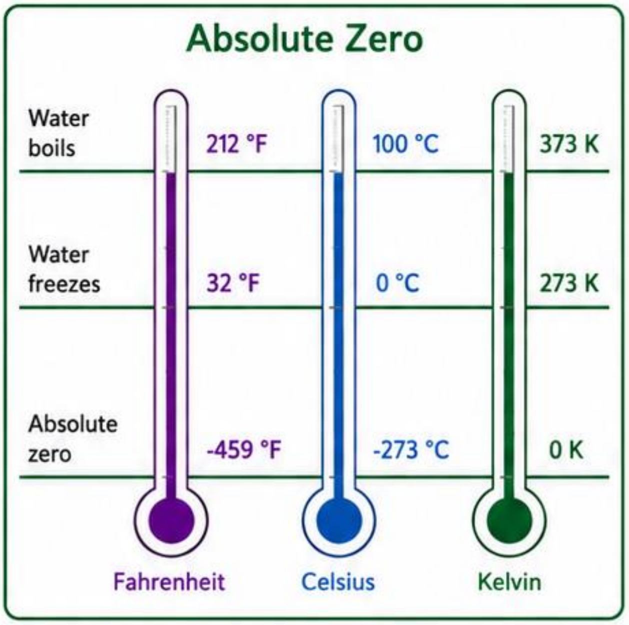
(c) temperature measurements both in degrees Celsius (°C) and in kelvin (K)

(d) $T(K) \approx \theta(°C) + 273.$

What is the difference between heat and temperature?

What is meant by equilibrium?

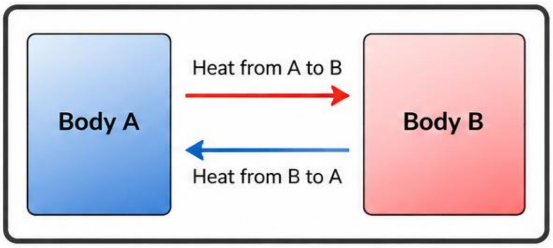
What conditions are required for heat energy to be exchanged between objects/places?



What is meant by absolute temperature and why is this used in calculations?

Thermal equilibrium

When two bodies are in **thermal equilibrium**, there is **no net transfer** of thermal energy between them.



Thermal equilibrium
No net transfer of thermal energy

Conditions for thermal equilibrium

- The bodies are in thermal contact.
- There is no net transfer of thermal energy between them.
- They have the same temperature.

Equal temperatures

If two bodies are in thermal equilibrium, their temperatures are equal.

$$T_A = T_B$$

Temperature is the measure

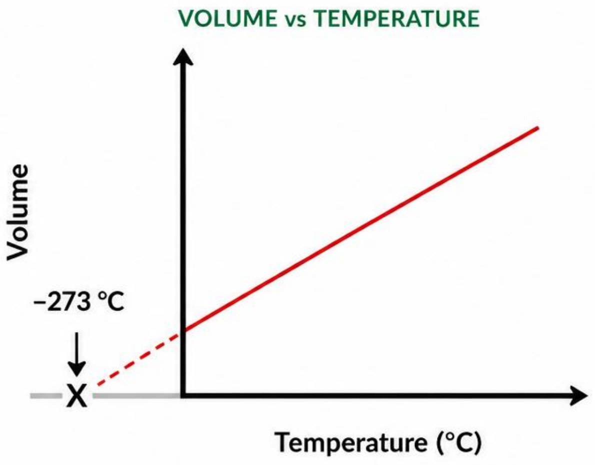
Temperature is a measure of the average kinetic energy of the particles in a body.

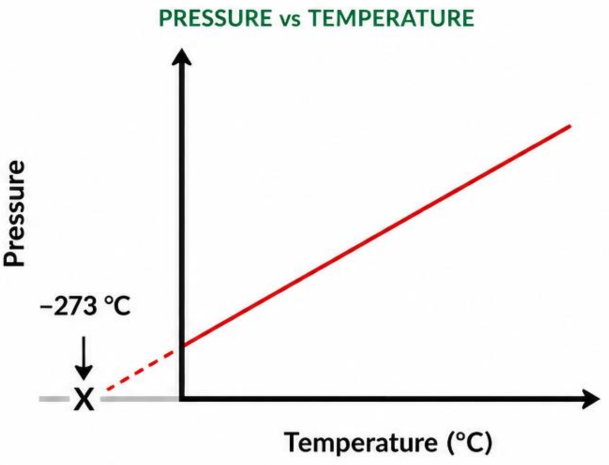
Same temperature $\Longleftrightarrow$ Same average kinetic energy

Key idea: Heat always flows from a hotter body to a colder body until thermal equilibrium is reached.
At thermal equilibrium, both bodies are at the same temperature and there is no net transfer of energy.

Absolute Zero

If volume or pressure is plotted against temperature in °C, the line extrapolates to −273 °C. This is **absolute zero**, the lowest possible temperature (0 K).





Key idea: At −273 °C (0 K), the extrapolated volume or pressure of an ideal gas would be zero. This is absolute zero — the lowest possible temperature.

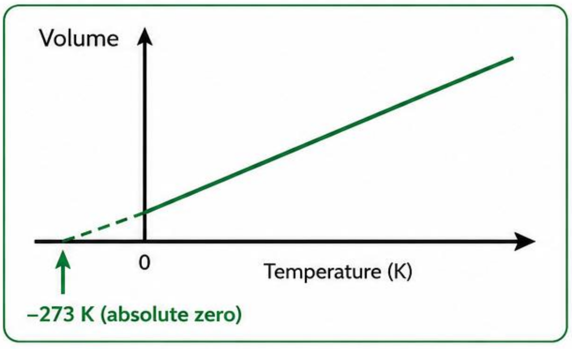
Thermal expansion of a gas

If the pressure of a gas is kept constant, its volume increases as its temperature increases.

If the temperature decreases, its volume decreases.

Volume – temperature graph

At constant pressure, the volume of a fixed mass of gas is directly proportional to its absolute (Kelvin) temperature.



Explanation

Gases consist of particles that are far apart and move freely and randomly.

- As temperature increases, the particles gain kinetic energy and move faster.
- They hit the container walls more often and with greater force.
- At constant pressure, the gas expands, so the volume increases.
- Extrapolating the straight-line graph back to zero volume gives −273 K, the absolute zero.

Key idea: At constant pressure, the volume of a fixed mass of gas is directly proportional to its absolute temperature.

Converting between °C and K

Kelvin: $$°K = °C + 273$$

Convert the following temperatures from °C into Kelvin

1. 0
2. 37.0
3. -120.5

Convert the following temperatures from Kelvin into °C

1. 30
2. 241
3. 120

Describe the thermal energy transfer, if any, of a metal block at 300 K placed into water at 15 °C

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The temperature of a body at 100 °C is increased by $\Delta\theta$ as measured on the Celsius scale. How is this temperature change expressed on the Kelvin scale?

A $\Delta\theta$

B $\Delta\theta + 273$

C $\Delta\theta - 273$

D $\Delta\theta + 373$

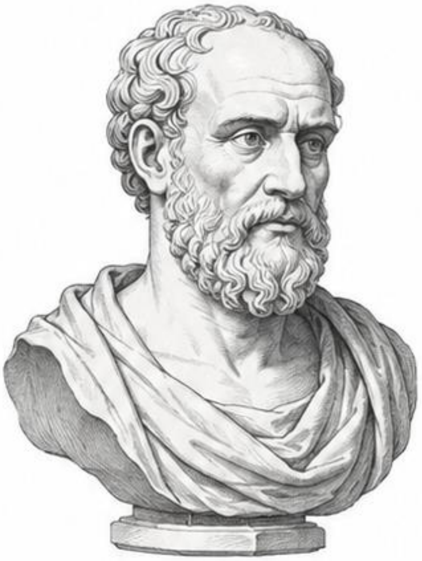
5.1.2 Solid, liquid and gas

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) solids, liquids and gases in terms of the spacing, ordering and motion of atoms or molecules

(b) simple kinetic model for solids, liquids and gases



Democritus

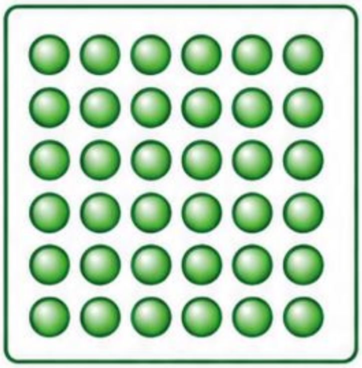
"Nothing exists except atoms and empty space"

430bc

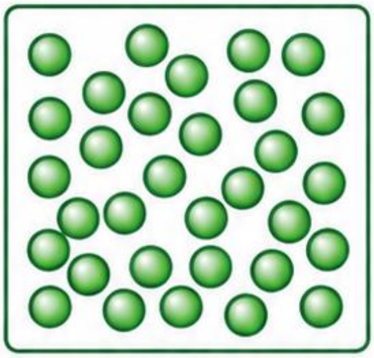
Ernst Mach

"I don't believe that atoms exist!"

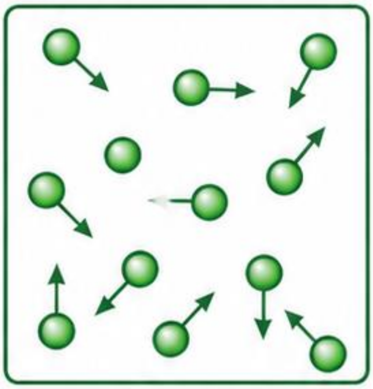
1897



Solid



Liquid



Gas

Use this simulation to investigate Brownian motion

https://www.physicsuk.co.uk/tools/brownian-motion-einstein-diffusion-lab

Explain the term Brownian motion. Underline the key terms required with each explanation of Brownian motion.

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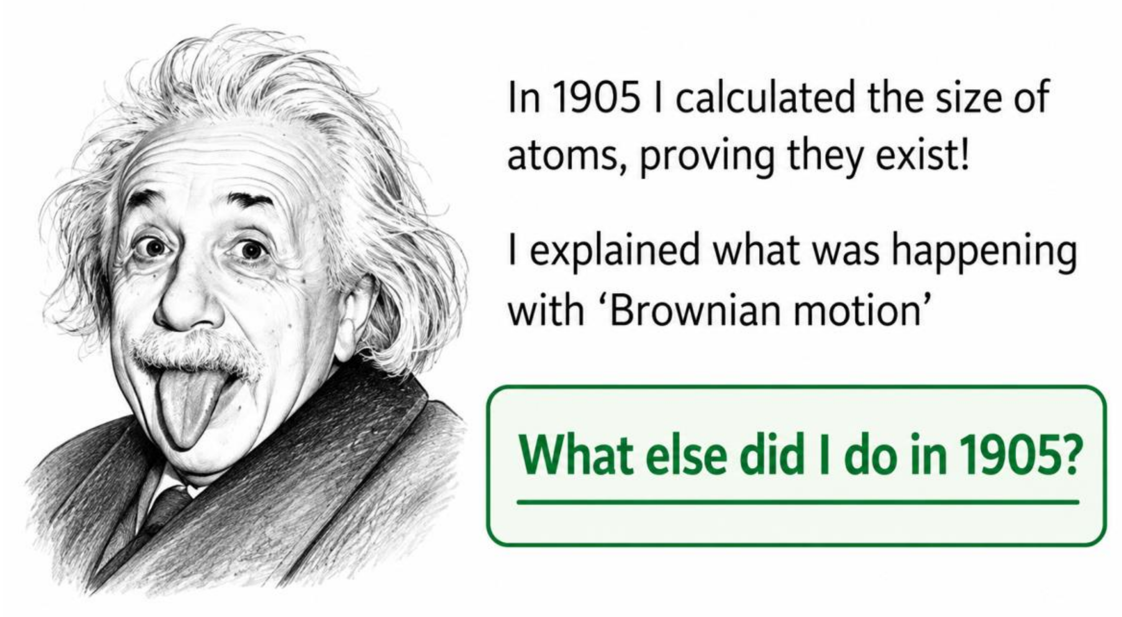

1 The freezing point of ethanol is 159 K.
What is 159 K in °C?

A −432 °C
B −114 °C
C 114 °C
D 432 °C

Your answer ☐ **[1]**

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2 Which of the following shows temperatures in ascending order?

A 273K, 57°C, 52K, 12°C
B 12K, 14°C, 286K, 29°C
C 29K, 12°C, −2K, −32°C
D 255K, −15°C, 273K, 15°C

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3 Explain how the motion of water molecules at 12°C change when they are placed in contact with a metal container at −15°C.

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Energies of thermodynamic systems

(d) internal energy as the sum of the random distribution of kinetic and potential energies associated with the molecules of a system

(e) absolute zero (0 K) as the lowest limit for temperature; the temperature at which a substance has minimum internal energy

(f) increase in the internal energy of a body as its temperature rises

(g) changes in the internal energy of a substance during change of phase; constant temperature during change of phase.

Define the term ‘internal energy’

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A metal ball is heated to $50^{o}C$ and then placed in water at $12^{o}C$. Explain how you would expect the energies of each object to change.

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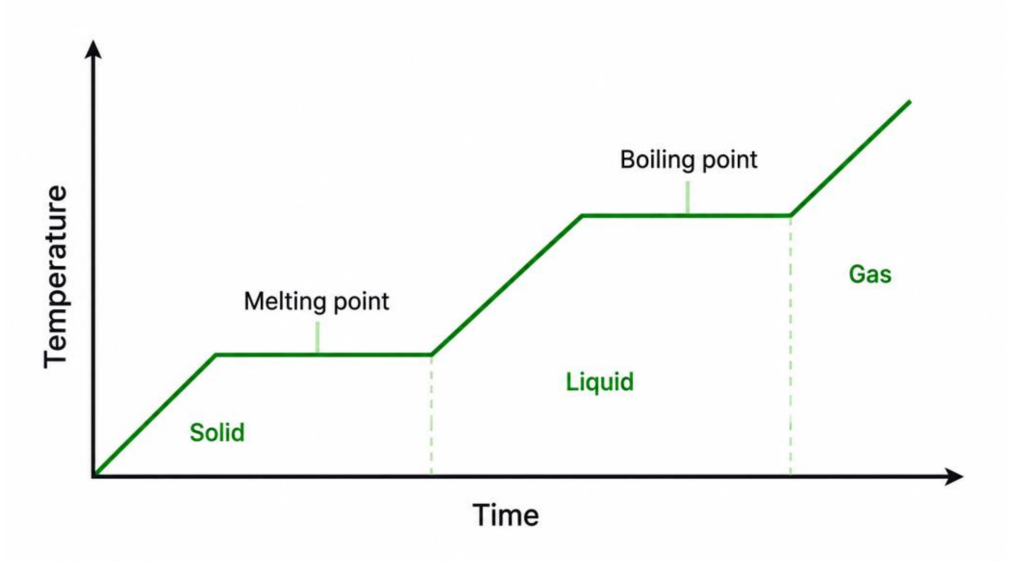

Explain how the internal, kinetic and potential energies change as the above object is heated with time.

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5.1.3 Thermal properties of materials

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) specific heat capacity of a substance; the equation $E = mc\Delta\theta$

(b) (i) an electrical experiment to determine the specific heat capacity of a metal or a liquid

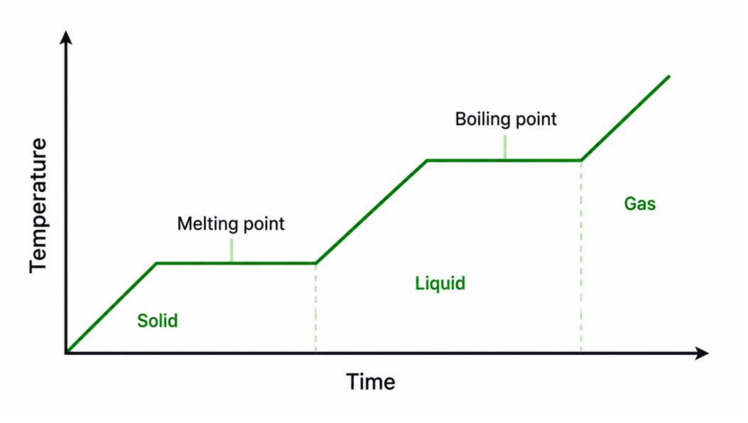
(ii) techniques and procedures used for an electrical method to determine the specific heat capacity of a metal block and a liquid

(c) specific latent heat of fusion and specific latent heat of vaporisation; $E = mL$

(d) (i) an electrical experiment to determine the specific latent heat of fusion and vaporisation

(ii) techniques and procedures used for an electrical method to determine the specific latent heat of a solid and a liquid.

Specific heat capacity



Explain any changes you would expect to see if the material that was being heated required more or less energy to change the temperature.

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Define the term 'specific heat capacity'.

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What equation can be used for this?

1 A Bunsen burner is used to heat a 300 g metal block. The specific heat capacity of the metal is 900 J kg^{-1} K^{-1}. If 6.0 kJ of thermal energy is transferred to the metal, calculate the temperature change of the metal.

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2 A bucket containing 11.5 kg of water at 10 °C is taken into a house and left until it reaches thermal equilibrium with the warmer surroundings. If 504 kJ of energy is absorbed by the water, calculate the temperature of the room.

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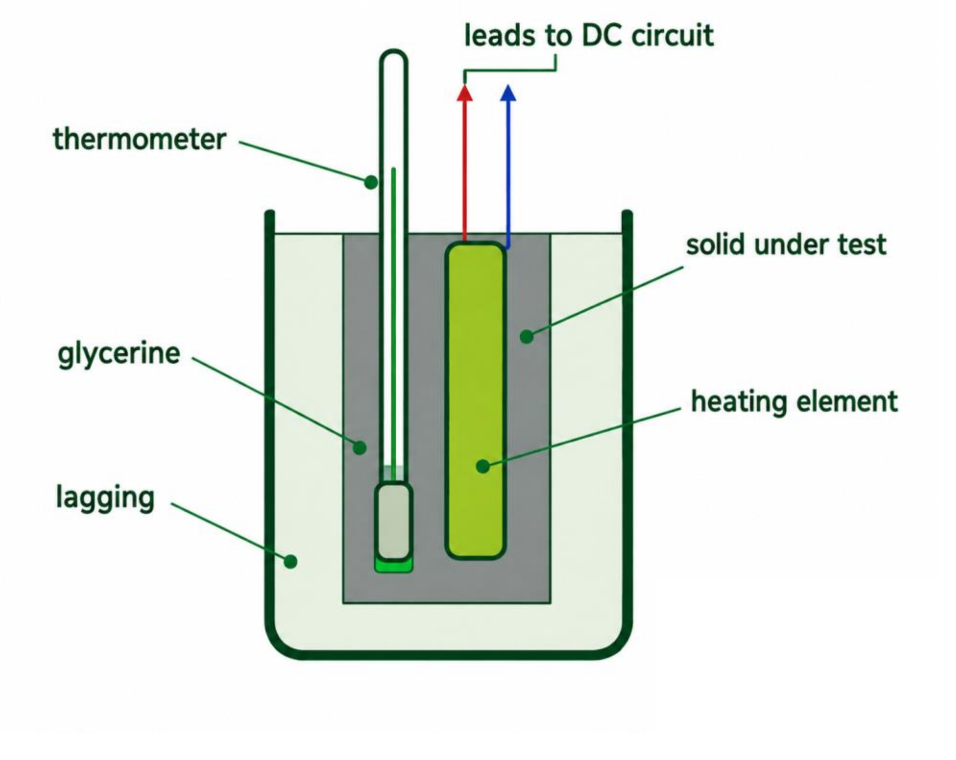
A 60 W immersion heater takes 2.5 minutes to heat 0.5 kg of water from 21°C to 25°C, what is the specific heat capacity of the water.



With the aid of a labelled diagram, explain how an experiment can be carried out to determine the specific heat capacity of a metal.

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1. A metal is heated using an electric heater. Select the correct statement.

A) A metal with half the original mass will experience four times the temperature increase.

B) Doubling the amount of heat transferred to the metal will double the mass of the metal.

C) The increase in temperature of the metal is due to the increasing potential energy between the molecules.

D) Doubling both the current and voltage will increase the temperature change by a factor of four.

2. A current of 1.2A is measured through a heater when the potential difference is 12V. The heater is used to raise the temperature of a 250g mass. Which of the following would be the gradient of a temperature-time graph for the mass.

A)$\frac{c}{58}$

B) 0.017c

C) $\frac{58}{c}$

D) 58

A metal mass of 100 g is heated up in a Bunsen flame to 600 °C and then dropped into 0.4 kg of water. The temperature of the water rises from 20 °C to 40 °C. The system is completely thermally isolated.

What is the value of the ratio $\frac{Specific\ heat\ capacity\ of\ metal}{Specific\ heat\ capacity\ of\ water}$?

A $\frac{2}{15}$

B $\frac{1}{7}$

C $\frac{4}{15}$

D $\frac{7}{1}$

The temperature of water entering a heater is 12ºC. The rate of flow of water through the heater is $3.6 \times 10^2\ cm^3\ min^{-1}$ and the output temperature of the water is 20ºC.

What is the power of the heater?

(Density of water = $1000\ kg\ m^{-3}$, specific heat capacity of water $4200\ J\ kg^{-1}\ K^{-1}$)

A 0.20 kW

B 0.50 kW

C 12 kW

D 20 kW

1(a) Lasers are often used to form precision-welded joints in titanium. To form one such joint it is first necessary to increase the temperature of the titanium to its melting point. Fig. 5.1 shows the joint and the volume of titanium to be heated.

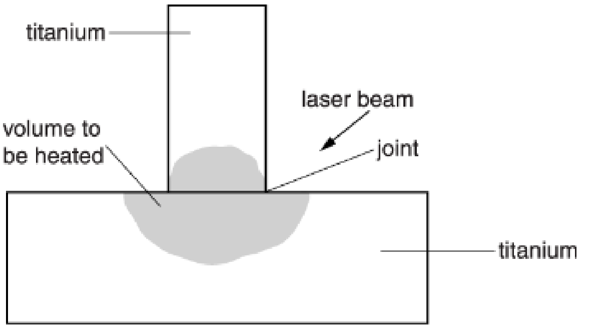


Fig. 5.1

The photon beam from the laser is focused onto the shaded volume of the joint and is converted into thermal energy in the titanium.

The wavelength of the photons is 1.1×10^{-6} m.

Show that the energy of a photon in the beam is 1.8×10^{-19} J.

[1]

(b) Photons are emitted from the laser at a constant rate of $6.3 \times 10^{19}\ s^{-1}$.

Estimate the time taken to raise the temperature of the shaded volume of titanium shown in Fig. 5.1 to melting point. Use the data below for your calculations.

initial temperature = 20 °C
melting point of titanium = 1700 °C
density of titanium = 4.5×10^3 kg m^{-3}
specific heat capacity of titanium = 520 J kg^{-1} K^{-1}
shaded volume of titanium being heated = 8.1×10^{-12} m^3.

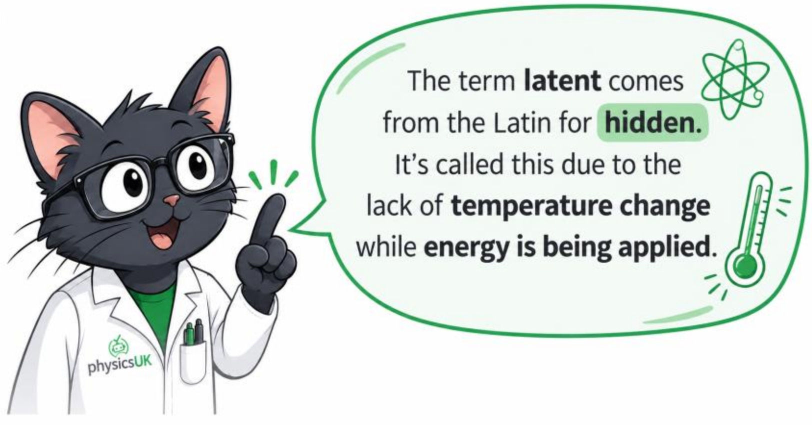
time = ________________________________ s **[3]**

200g of water with a SHC of 4200J/kg/K is held at 27^{o}C. A 12V, 7A system is used to heat the water for 2 minutes. Calculate the increase in temperature of the water.

$2x10^{28}$ particles each with a mass of $3.2x10^{-26}$kg are held in a container. The container is subjected to 12kJ of energy and increases in temperature by 0.8K. Calculate the SHC of the substance.

2kg of a metal at 70^{o}C with a SHC of 1210J/kg/K is placed into 5kg of water(4200) at 30^{o}C. Calculate the final temperature of the metal when it reaches thermal equilibrium.

Specific latent heat



Provide an exam style definition for 'specific latent heat'. Include an equation in your answer.

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Explain the difference in the terms latent heat of fusion and latent heat of vaporisation.

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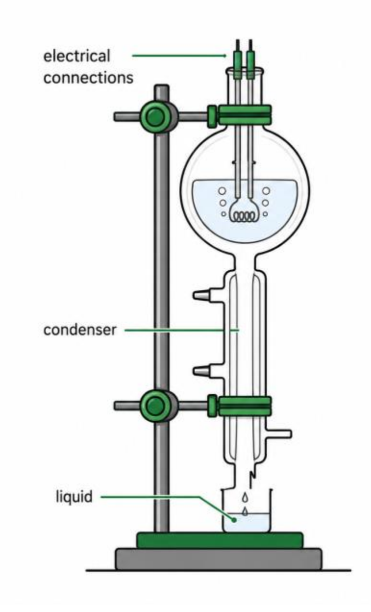
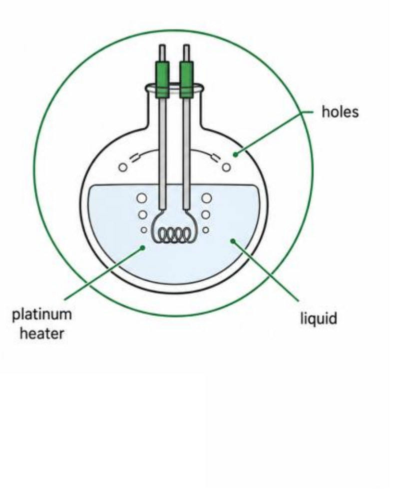
SLH vaporisation experimentally





A heating element is used to heat a liquid to a vapour. The vapour condenses and the mass of vaporised liquid can be recorded.

The maths doesn't change!

Write a detailed method of how this equipment would be used to measure the specific latent heat of vaporisation.
Include the equations/graph required and the equipment you would need to use.

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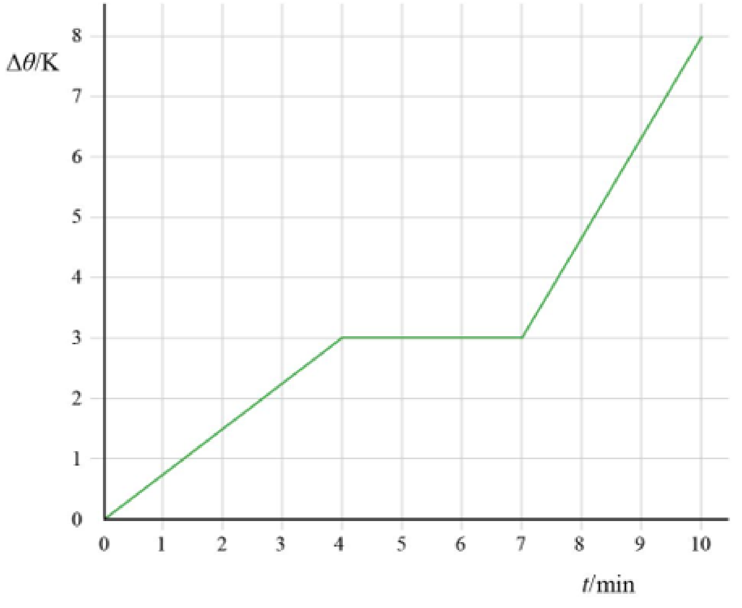
The graph shows the variation of temperature change $\Delta\theta$ with time t for 1 kg of a substance initially solid at room temperature. The substance is heated at a uniform rate of 2000 J min^{-1}.



What can be deduced from this graph?

A After 4 min of heating, the substance is all liquid.

B After 10 min of heating the substance is all gaseous.

C The specific heat capacity of the substance is greater when liquid than when solid.

D The specific latent heat of fusion of the substance is 6000 J kg^{-1}

A plastic bottle containing a litre of water at 20°C is placed inside a freezer, whose temperature is maintained at -18°C.

The plastic bottle limits the transfer of energy to a mean value of 800 joule per minute for two hours and has negligible specific heat capacity.

For water, the specific heat capacity is 4200 J $kg^{-1}K^{-1}$ and specific latent heat of fusion 3.3×10^4 J kg^{-1}.

What is the temperature of the water at the end of the two hours?

A 0°C

B -0.36 °C

C -3.0°C

D -18 °C

1 The unit of specific heat capacity (c) is $\mathrm{J\,kg^{-1}\,K^{-1}}$. What is its equivalent in terms of SI base units?

A $\mathrm{kg^{-1}\,m^2\,K^{-1}}$ **B** $\mathrm{m\,s^{-1}\,K^{-1}}$
C $\mathrm{m\,s^{-2}\,K^{-1}}$ **D** $\mathrm{m^2\,s^{-1}\,K^{-1}}$
E $\mathrm{m^2\,s^{-2}\,K^{-1}}$ [O & C 90]

2 A piece of aluminium of mass 0.20 kg and specific heat capacity $1.2\ \mathrm{kJ\,kg^{-1}\,K^{-1}}$ is heated to a steady temperature t and is then quickly but carefully placed in 0.22 kg of water contained in a copper calorimeter of water equivalent 0.02 kg. The temperature of the water rises from 16 to 21 °C. Calculate the temperature t, given that the specific heat capacity of water is $4.2\ \mathrm{kJ\,kg^{-1}\,K^{-1}}$.

[OU]

3 Energy is supplied at the rate of 15 W to 0.50 kg of a liquid in a container of negligible heat capacity until the temperature of the liquid is constant. When the heat supply is stopped the liquid initially cools at the rate of $1.2\ \mathrm{K\,min^{-1}}$.

The specific heat capacity of the liquid, in $\mathrm{J\,kg^{-1}\,K^{-1}}$, is

A 1500 **B** 1800 **C** 2160 **D** 2500

[AEB 95]

4 (a) Define *specific heat capacity*.

(b) A metal electric kettle was part-filled with 0.50 kg of cold water at 20 °C and then switched on. The water reached boiling point 2.5 minutes later. Subsequently, the empty kettle was filled with 1.00 kg of cold water at 20 °C. When switched on again, the time taken to reach boiling point was 4.3 minutes.

Assume heat losses to the kettle's surroundings to be negligible.

(i) Suggest why the time to boil 1.00 kg of water was not twice that required for 0.50 kg.

(ii) The specific heat capacity of water is $4.2\ \mathrm{kJ\,kg^{-1}\,K^{-1}}$. Calculate the power dissipated by the element of the kettle.

[C 95]

5 The element of a 2.5 kW electric kettle takes 200 s to raise the temperature of 1 kg of water from 20 °C to 100 °C. Assuming that the specific heat capacity of water is $4\ \mathrm{kJ\,kg^{-1}\,K^{-1}}$, the mean rate of energy loss to the kettle and the surroundings, in kW, is

A 0.45 **B** 0.80 **C** 0.90 **D** 1.6

[AEB 94]

6 A metal ball-bearing of specific heat capacity c, moving with speed v, is brought to rest. All its kinetic energy is converted into thermal energy which it absorbs, causing a temperature rise $\Delta\theta$. What was the value of v?

A $\frac{1}{2}c\Delta\theta$ **B** $2c\Delta\theta$
C $\sqrt{c\Delta\theta}$ **D** $\sqrt{2c\Delta\theta}$ [C 95]

7 To remove heat energy at a rate of 1 kW from the target of an X-ray tube, 0.24 kg of water has to be used each second. The specific heat capacity of water is $4200\ \mathrm{J\,kg^{-1}\,K^{-1}}$. What is the temperature difference, in K, between the water inflow and outflow?

A 17 **B** 10 **C** 1.0 **D** 0.01

[NEAB 92]

8 Under certain conditions, the rate of cooling of a given body is directly proportional to the difference between its temperature and that of its surroundings. The rate of cooling of the body is $12\ \mathrm{K\,min^{-1}}$ when its temperature is 100 °C, and $6\ \mathrm{K\,min^{-1}}$ when the temperature is 60 °C. The surrounding temperature, in °C, is

A 10 **B** 20 **C** 30 **D** 40

[AEB 92]

9 A block of ice at 0 °C, mass 1.5 kg, absorbs thermal energy from its surroundings at a steady rate of 50 W. The specific latent heat of fusion is $3.0 \times 10^5\ \mathrm{J\,kg^{-1}}$. The time, *in hours*, for the ice to melt is

A 150 **B** 100 **C** 3.75
D 2.50 **E** 1.67 [O & C 94]

10 Which one of the following is the correct unit for specific latent heat of vaporisation?

A $\mathrm{J\,kg^{-1}}$ **B** $\mathrm{W\,kg^{-1}}$
C $\mathrm{J\,kg^{-1}\,K^{-1}}$ **D** $\mathrm{J\,K^{-1}}$ [AEB 94]

11 In a method to measure the specific latent heat (specific enthalpy change) of vaporisation, an electric heater boils a liquid in a well-insulated container. When the current is 2.6 A and the potential difference 8 V, the mass of liquid decreases by 104 g in 8 minutes.

Calculate the energy transfer to the liquid and its specific latent heat of vaporisation. [L 95, p]

12 An ice cube of mass 0.010 kg at a temperature of 0 °C is dropped into a glass containing 0.10 kg of water at a temperature of 15 °C. What is the maximum estimated fall in temperature which can be produced by doing this?

A 1.5 K **B** 8 K **C** 13.5 K **D** 15 K

specific heat capacity of water = $4200\ \mathrm{J\,kg^{-1}\,K^{-1}}$
specific latent heat of ice = $3.4 \times 10^5\ \mathrm{J\,kg^{-1}}$

[NEAB 94]

6 (a) Describe

(i) the motion of atoms in a solid at a temperature well below its melting point

....

.... [1]

(ii) the effect of a small increase in temperature on the motion of these atoms

....

.... [1]

(iii) the effect on the internal energy and temperature of the solid when it melts.

....

....

.... [2]

(c) (i) The air in a greenhouse has a volume of $15\,m^3$, a density of $1.2\,kg\,m^{-3}$ and a specific heat capacity of $990\,J\,kg^{-1}\,K^{-1}$. Immediately after sunset, the soil is transferring thermal energy to the air at an average rate of 12W. Estimate the increase in temperature of the air in the greenhouse one hour after sunset as a result of this energy transfer from the soil.

increase in temperature = ...K [3]

(ii) Suggest two possible reasons why the actual increase in temperature of the air is likely to be much lower than this estimate.

....

....

.... [2]

(b) Fig. 6.1 shows the apparatus used to determine the specific heat capacity of a metal. A block made of the metal is heated by an electrical heater that produces a constant power of 48W. In order to reduce heat loss from the sides, top and bottom of the block, it is covered by a layer of insulating material.

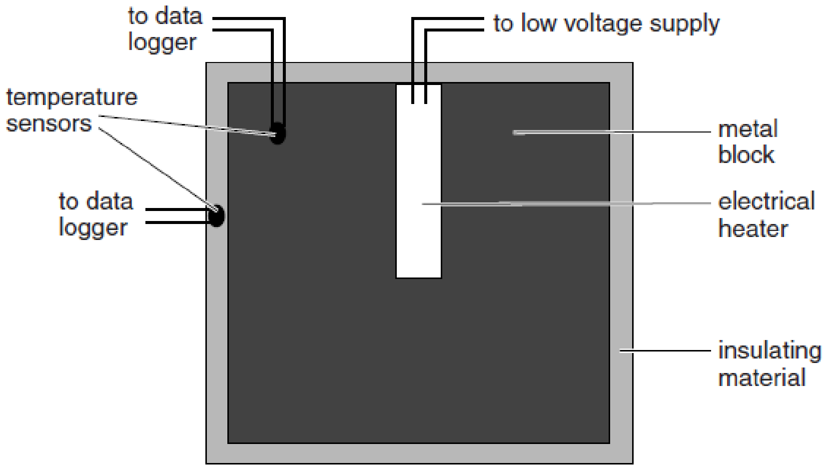


Fig. 6.1

Temperature sensors connected to a data logger show that the block and insulation are initially at the room temperature of 18 °C. The heater is switched on and after 720 seconds the sensors show that the temperature of the block is 54 °C and the average temperature of the insulating material is 38 °C.

(i) Use the information given above and the data shown below to determine the specific heat capacity of the metal block.

mass of metal block = 0.98 kg
power of heater = 48 W
specific heat capacity of the insulating material = 850 J kg^{-1} K^{-1}
mass of the insulating material = 0.027 kg

specific heat capacity = ... J kg^{-1} K^{-1} [4]

(ii) A second experiment is done without the insulating material and with the block again starting at 18 °C. Discuss whether the value of the specific heat capacity calculated from the second experiment is likely to be lower, the same or higher than the value calculated in **(i)**.

5.1.4 Ideal gases

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) amount of substance in moles; Avogadro constant N_A equals 6.02×10^{23} mol^{-1}

(b) model of kinetic theory of gases

(c) pressure in terms of this model

(d) (i) the equation of state of an ideal gas $pV = nRT$, where n is the number of moles

(ii) techniques and procedures used to investigate PV = constant (Boyle's law) and $\frac{P}{T}$ = constant

(iii) an estimation of absolute zero using variation of gas temperature with pressure

(e) the equation $pV = \frac{1}{3}Nm\overline{c^2}$, where N is the number of particles (atoms or molecules) and $\overline{c^2}$ is the mean square speed

(f) root mean square (r.m.s.) speed; mean square speed

(g) the Boltzmann constant; $k = \frac{R}{N_A}$

(h) $pV = NkT$; $\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$

(i) internal energy of an ideal gas.

Avogadro and mole calculations

The mole was defined by International Bureau of Weights and Measures as "the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon-12." Thus, by that definition, one mole of pure carbon-12 has a mass of exactly 12 g.

Avogadro’s number

A **mole** of a substance or a **mole** of particles is defined as 6.022×10^{23} particles, which may be atoms, **molecules**, ions, or electrons

$$N_A = 6.02\text{x}10^{23}$$

N:

n:

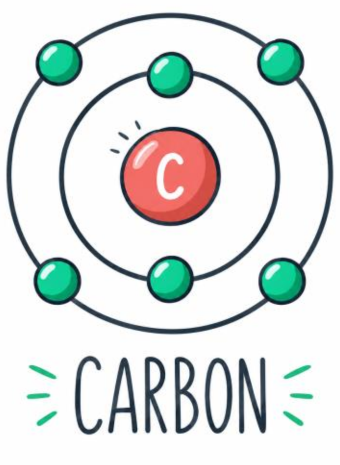
N_A:

Equation for number of moles which links number of molecules to Avogadro's number.

n =

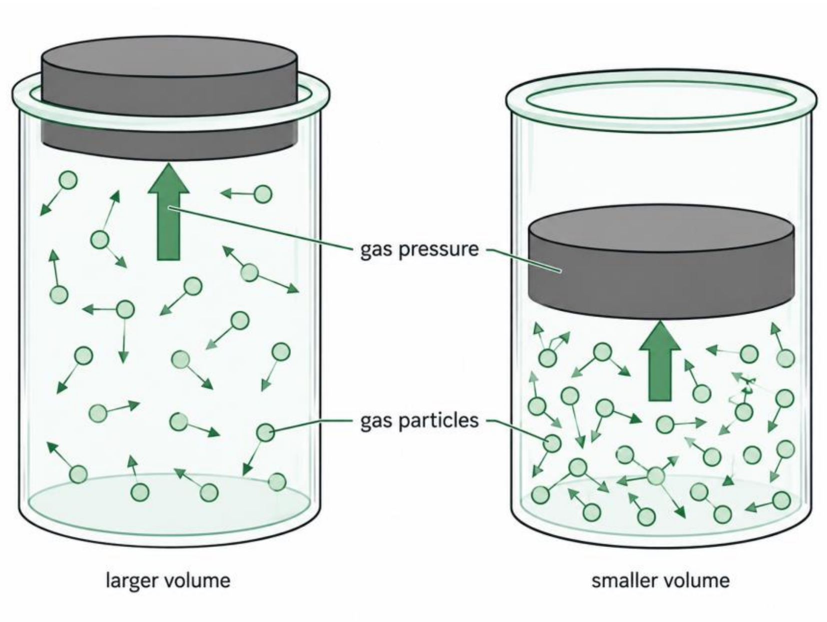
Calculate the number of moles in 2×10^{25} atoms of carbon-12.

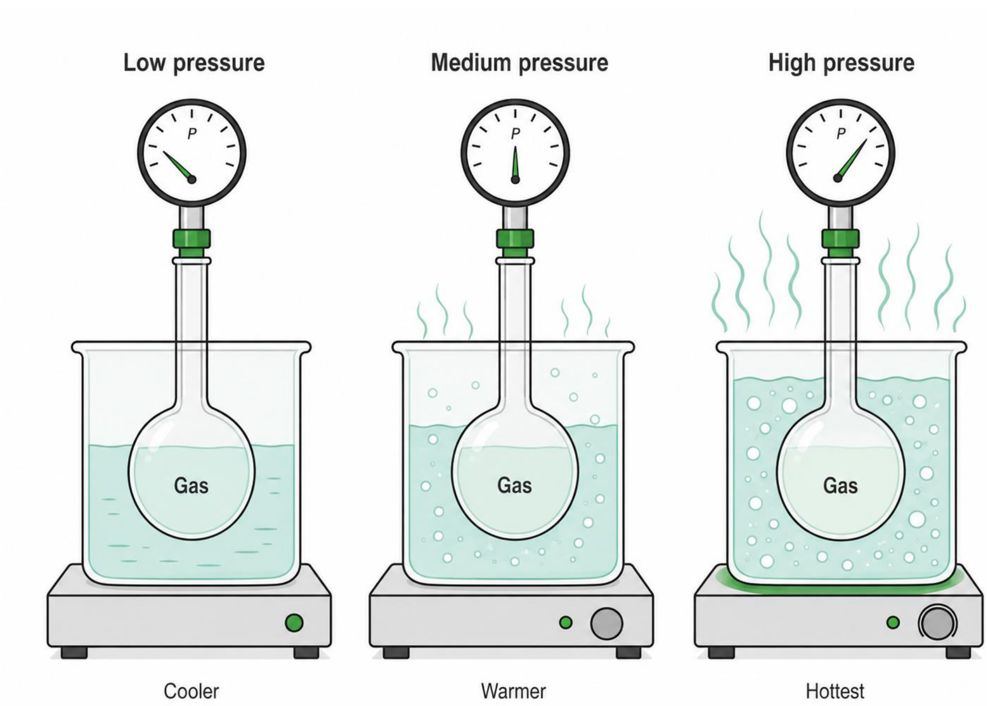
The molar mass of carbon-12 is 12g/mol. Calculate the mass of carbon-12 present.



Pressure, volume and temperature

Below, explain how you would expect pressure, volume and temperature to change in these scenarios.





With the aid of equations and graphs to show relationships, explain the differences between Boyle, Charles and Gay-Lussac's gas laws.

Ideal gas equation

$$PV = nRT$$

How many moles of gas is represented by $3x10^{48}\ particles$?

$$n = \frac{N}{N_A}$$

How many moles of gas are contained in a jar of volume $0.5m^3$ if the pressure is 12Pa at 201K?
How many particles is this?

4kPa of pressure is applied to $0.4mm^3$ of gas. When doing this the temperature becomes 200K. How many particles are in the gas?

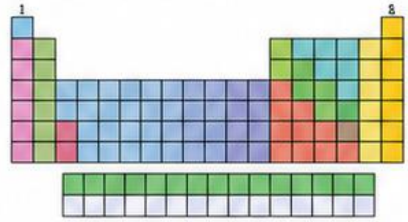
Mass calculations

You will often need to calculate the mass of a substance from the number of moles and its molar mass.

This also links to ideal-gas calculations for gases such as helium.

What is an element?

An element is a pure substance in which all atoms have the same number of protons.



Helium	Carbon	Iron
He	C	Fe
2	6	26
4.0026	12.011	55.845

Molar mass is the mass of 1 mole of a substance, measured in g mol^{-1}. For example, helium has a molar mass of about 4.0 g mol^{-1}, while iron has a molar mass of about 55.8 g mol^{-1}.

1. Calculate the mass of 12 moles of carbon.

2. A 1.5 kg sample of iron is given. Calculate the number of moles present.

3. Helium gas is stored in a 120 cm^3 container at 22 °C. The pressure is 180 kPa. Calculate the mass of helium in the container.

4. A helium balloon is at room temperature (about 300 K). The balloon bursts if its volume reaches 0.016 m^3 and the pressure reaches 110 kPa. Calculate the mass of helium needed to reach this condition.

19 (a) A fixed mass of nitrogen changes phase from liquid to gas at a constant temperature.

Explain the change in the total internal energy of nitrogen.

....

....

....

.... **[2]**

(b) In a factory, nitrogen gas is added to packets of food to keep it fresh for longer.
In 1.0 hour, the factory uses $15\,\text{m}^3$ of nitrogen at pressure 100 kPa and temperature 23 °C.

(i) Show that the number of moles *n*, of nitrogen used per hour is about 600.

[3]

(ii) Calculate the mass of nitrogen gas used in one hour.

molar mass of nitrogen = $0.028\,\text{kg}\,\text{mol}^{-1}$

mass = ... kg **[1]**

(iii) The volume of nitrogen being used cannot be changed.

State how the rate of mass of nitrogen used can be reduced.

....

.... **[1]**

(iv) The nitrogen at the factory is stored as a liquid.
The liquid expands at constant temperature to form gas in a short section of pipe.

When the air temperature is 0 °C, a thick layer of ice forms on the outside of the pipe from water vapour in the air. In 1.0 hour, the mass of ice formed is 1.3 kg at a temperature of 0 °C.

Use the data below and your answer to **(b)(ii)**, to estimate the specific latent heat of vaporisation L of nitrogen.

- specific latent heat of fusion of ice = $3.34 \times 10^5\,\mathrm{J\,kg^{-1}}$
- specific latent heat of vaporisation of water = $2.26 \times 10^6\,\mathrm{J\,kg^{-1}}$

L = ... $\mathrm{J\,kg^{-1}}$ **[4]**

a The **ideal gas equation** may be written as

$$pV = nRT$$

State the meaning of the terms n and T.

n ....

T .... **[2]**

b A bicycle tyre has a volume of 2.1×10^{-3} m^3. On a day when the temperature is 15 °C the pressure of the air in the tyre is **280 kPa**. Assume that air behaves as an ideal gas.

i Calculate the number of moles n of air in the tyre.

A scuba diver uses air in which the percentage of nitrogen is reduced by adding helium to form a substance known as Trimix. A 1.2×10^{-2} m^3 rigid steel scuba diving tank contains 45 mol of air at a temperature of 20 °C.

i Calculate the pressure in the tank.

Nitrogen fills a **0.010 m^3** container. The pressure of the gas is **6.2×10^5 Pa**. If there are **3 mol** of gas, what is the temperature of the gas?

The volume of a fixed mass of an ideal gas is V. The gas exerts pressure p and has thermodynamic temperature T. The temperature of the gas is now increased to $2T$. The new pressure exerted by the gas is $3p$.

What is the new volume of the gas in terms of V?

A $\frac{1}{6}V$

B $\frac{2}{3}V$

C $\frac{3}{2}V$

D $6V$

Your answer ☐

Assumptions of an ideal gas

Use the space below to research the assumptions made of an ideal gas. Your research should be focussed around the OCR A specification.

What does this tell us about the internal energy of an ideal gas?

Kinetic theory and pressure

- Using the kinetic theory of gases and Newton's laws, explain how a gas exerts pressure on a container.
- This should be a qualitative and quantitative explanation.
- Use this to derive the equation $PV = \frac{Nmc^2}{3}$

Boltzmann's constant

$2m^3$ of gas is at a pressure of 15kPa. Calculate the number of particles present in this gas at a temperature of 28^oC.

$$PV = nRT$$

$$PV = \frac{R}{N_A} NT$$

Here we discover that there are two constants being used combine to make a new constant. We call this Boltzmann's constant. Give the correct value below.

Calculate the number of moles in a gas containing 4.5×10^{30} particles.
What volume would this gas occupy at $40^{o}C$ and 10kPa?

Calculate the number of particles occupying a volume of $10m^3$ when at a temperature of $2^{o}C$ and 5kPa.

A $0.22m^3$ oven contains particles of mass $4.5 \times 10^{-26}kg$. Calculate the mass of gas in the oven when baking a cake at $175^{o}C$ at standard pressure 100kPa.

Internal energy of gases

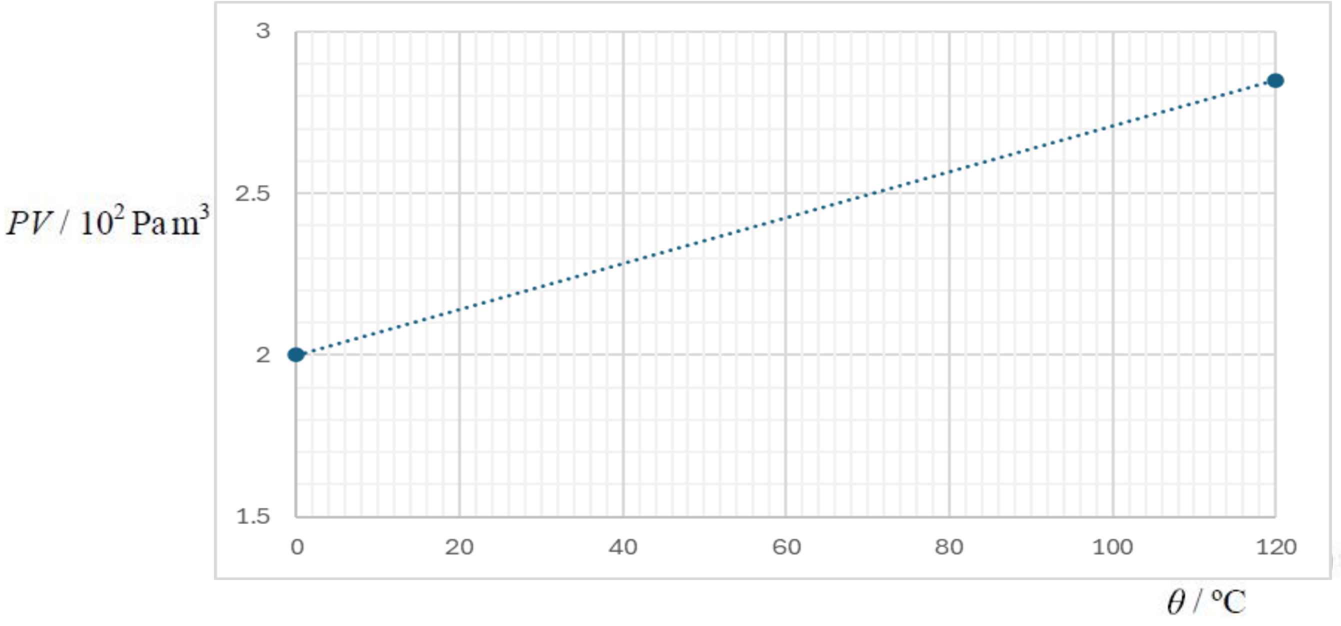
The energy of a particle at a given temperature can be said to be:

$$E = \frac{3kT}{2}$$

This tells us larger temperatures have higher energy.

This equation is true for only single particles and needs to be adapted for multiple particles in a gas!

Calculate the energy of a single particle at $0^{o}C$



Calculate the gradient of the graph and state what the gradient tells you.

Calculate the number of moles in the gas above and therefore calculate the number of particles present.

Calculate the mass of gas in the above experiment and the internal energy of the gas at 40°C.
The mass of each gas particle is 4×10^{-26} kg

A gas is at a temperature of 20°C. The mass of each molecule is 4.7×10^{-26} kg.

i. Show that the root mean square (r.m.s.) speed the gas molecules is about 500 m s^{-1}.

[3]

ii. A gas molecule makes a head-on collision with a **stationary** smoke particle. Fig. 20 shows the gas molecule and the smoke particle before and after the collision. The final speed of the smoke particle is 23 m s^{-1}.

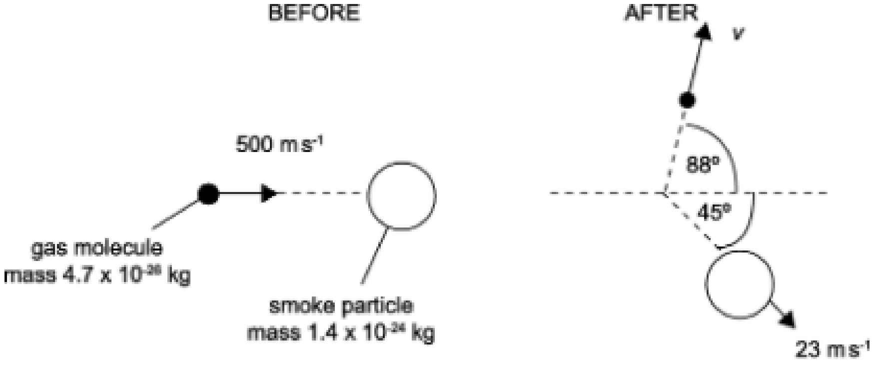


Fig. 20

1. State and explain the **total** momentum of the molecule and smoke particle after the collision in a direction perpendicular to initial velocity of the gas molecule.

-- **[2]**

2. Calculate the speed v of the gas molecule after the collision.

v = ______________________ m s^{-1} **[2]**

A mass of gas is enclosed in a tank. The gas is cooled until it becomes a liquid. During this process its internal energy changes.

i. State what is meant by the *internal energy* of the gas.

--- **[1]**

ii. Explain why the internal energy of the gas differs from that of its liquid phase.

--- **[2]**

The ideal gas equation is $pV = nRT$.
Show that the pressure p exerted by a fixed mass of gas is given by the equation

$$p = \frac{\rho RT}{M}$$

where ρ is the density of the gas and M is the mass of one mole of gas.

[3]

A scuba diver uses air in which the percentage of nitrogen is reduced by adding helium to form a substance known as Trimix. A 1.2×10^{-2} m^3 rigid steel scuba diving tank contains 45 mol of air at a temperature of 20 °C.

i. Calculate the pressure in the tank.

pressure = ________________________ Pa **[2]**

ii. The tank is then connected to a cylinder of volume 2.0×10^{-3} m^3 containing helium at a pressure of 5.0×10^7 Pa and a temperature of 20 °C as shown in Fig. 6.2.

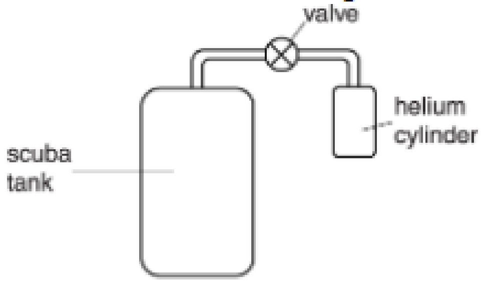


Fig. 6.2

The valve is opened allowing the gases to mix. When mixed the final temperature is 20 °C. Calculate the final pressure of the resulting Trimix in the scuba tank helium cylinder system.

pressure = ________________________ Pa **[3]**

iii. Explain why you would expect this pressure to decrease when the tank is used by a diver in water where the temperature is 4 °C.

-- **[1]**

A gas syringe contains 2.0 moles of an ideal gas of volume of 0.040 m^3.
An additional amount of 0.5 moles of the same gas is added to the syringe. The temperature and pressure of the gas remain the same.

What is the final volume of gas in the syringe?

A 0.010 m^3
B 0.032 m^3
C 0.050 m^3
D 0.090 m^3

Your answer

[1]

The latent heat of vaporisation of a liquid is 2300 kJ kg^{-1} and it has a molar mass of 0.018 kg mol^{-1}.

What is the energy required to change 30 moles of the liquid to gas?

A 4.1×10^4 J
B 1.2×10^6 J
C 6.9×10^7 J
D 3.8×10^9 J

Your answer **[1]**

The volume of one mole of an ideal gas is V. The gas exerts pressure p and has thermodynamic temperature T.

Which of the following has the units J mol^{-1} K^{-1}?

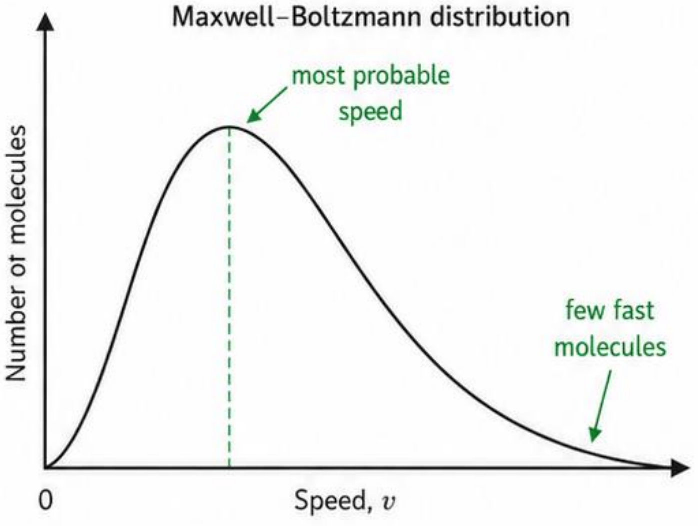
A pV
B $\frac{p}{T}$
C $\frac{V}{T}$
D $\frac{pV}{T}$

Your answer **[1]**

Maxwell–Boltzmann distributions

Key idea

Molecules in a gas do not all move at the same speed.
There is a range of speeds (and kinetic energies).
A Maxwell–Boltzmann distribution shows how many molecules have each speed.



Read the graph

1. What does the x-axis represent?

   ____

2. What does the y-axis represent?

   ____

3. What does the peak of the curve tell us?

   ____

4. Why does the curve have a long tail?

   ____

Write your answers to the questions above.

____

____

____

____

____

____

Explain in your own words

Explain why molecules in a gas do not all have the same speed.

____

____

____

____

____

____

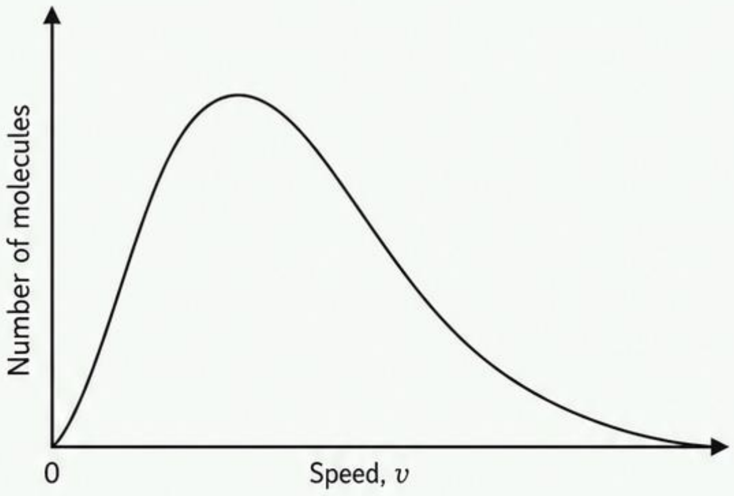
____

Checklist

- ✓ I can label the axes
- ✓ I can describe the shape of the curve
- ✓ I can explain what the peak means

Compare distributions

On the graph, draw a distribution for a hotter gas and a cooler gas.



1. Which curve should have the higher peak?

   ____

2. Which curve should be further to the right?

   ____

3. What happens to the most probable speed as temperature increases?

   ____

4. Why is the area under each curve the same?

   ____

Explain the pattern

Describe how increasing temperature changes the shape of a Maxwell–Boltzmann distribution.

____

____

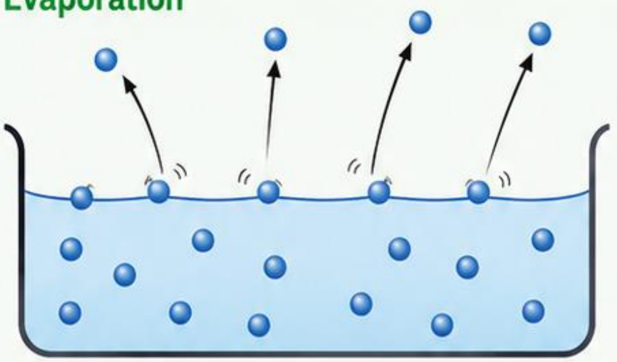
____

____

____

____

Evaporation



Use this idea to explain why a pool of water slowly evaporates in the Sun.

____

____

____

____

____

____

Stretch

Why does evaporation cause cooling? ______________________

____

____

Here are some data about a volume of an ideal gas:

volume = 0.30×10^{-3} m^3

pressure = 0.30 MPa

temperature = 30° C

What is the number of particles in the volume of gas?

A 3.0×10^{19}

B 2.2×10^{22}

C 3.0×10^{23}

D 2.2×10^{25}

The temperature of a fixed volume of an ideal gas is raised from 300 K to 330 K.

Which of the following statements about the gas is/are true?

1 The mean energy of the particles of the gas increases by 10%.

2 The mean square velocity of the particles of the gas increases by 10%.

3 The number of collisions per second with the walls of the container increases by 10%

A 1, 2, 3 are correct

B Only 1 and 2 are correct

C Only 2 and 3 are correct

D Only 1 is correct

Five molecules are moving with the speeds and directions shown.

300 m s^{-1} 100 m s^{-1} 100 m s^{-1} 300 m s^{-1} 500 m s^{-1}

What is the root mean square (r.m.s,) speed of these molecules?

A 100 m s^{-1}

B 224 m s^{-1}

C 300 m s^{-1}

D 500 m s^{-1}

The pressure p of a gas occupying a volume V and containing N molecules of gas of mass m and mean square speed $\bar{c^2}$ is given by

$$p = \frac{1}{3}\frac{Nm}{V}\bar{c^2}.$$

The density of argon at a pressure of 1.00 x 10^5 Pa and at a temperature of 300 K is 1.6 kg m^{-3}.
What is the root mean square (r.m.s.) speed of argon molecules at this temperature?

A 216 m s^{-1}

B 250 m s^{-1}

C 306 m s^{-1}

D 433 m s^{-1}

Additional notes

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Thermal Physics

Worked solutions — A-level Physics

Quick answers

1	E — $m^2\ s^{-2}\ K^{-1}$
2	42 °C
3	A — 1.50×10^3 J kg^{-1} K^{-1}
4	(a) definition; (b) kettle also heats; $P \approx 1.6$ kW
5	C — 0.90 kW
6	D — $\sqrt{(2c\Delta\theta)}$
7	C — 1.0 K
8	B — 20 °C
9	B — 2.50 h
10	A — J kg^{-1}
11	$E = 9.98$ kJ; $L = 9.6 \times 10^4$ J kg^{-1}
12	B — about 8 K

Q1 Unit of specific heat capacity

[O&C 90]

Specific heat capacity has unit J kg⁻¹ K⁻¹.
Substitute the SI base unit for the joule:

$$1\,\mathrm{J} = 1\,\mathrm{kg\,m^2\,s^{-2}}$$
$$\mathrm{J\,kg^{-1}\,K^{-1}} = (\mathrm{kg\,m^2\,s^{-2}})\,\mathrm{kg^{-1}\,K^{-1}}$$
$$\mathrm{J\,kg^{-1}\,K^{-1}} = \mathrm{m^2\,s^{-2}\,K^{-1}}$$

A-level point: For unit conversions, expand the derived unit first, then cancel.

Answer: E — $\mathrm{m^2\,s^{-2}\,K^{-1}}$

Q2 Hot aluminium placed in water

The calorimeter has water equivalent 0.02 kg, so:

$$m_{\text{eff}} = 0.22 + 0.02 = 0.24\,\mathrm{kg}$$

Water and calorimeter warm from 16 °C to 21 °C, so ΔT = 5 K.

$$E_{\text{gained}} = mc\Delta T = 0.24 \times 4.2 \times 5 = 5.04\,\mathrm{kJ}$$

Assuming negligible heat loss: energy lost by aluminium = energy gained by water.

$$0.20 \times 1.2 \times (t - 21) = 5.04$$
$$0.24(t - 21) = 5.04$$
$$t - 21 = 21 \quad \Rightarrow \quad t = 42^\circ\mathrm{C}$$

A-level point: The hot metal cools to 21 °C; the water warms to 21 °C.

Answer: 42 °C

Q3 Specific heat capacity from cooling rate

[AEB 95]

At steady temperature, heater power = rate of heat loss = 15 W.
Immediately after switch-off, the initial cooling rate gives the same heat-loss rate.

$$1.2\,\mathrm{K\,min^{-1}} = \frac{1.2}{60} = 0.020\,\mathrm{K\,s^{-1}}$$
$$P = mc\frac{dT}{dt}$$
$$15 = 0.50 \times c \times 0.020$$
$$c = 1.50 \times 10^3\,\mathrm{J\,kg^{-1}\,K^{-1}}$$

A-level point: Use seconds, not minutes, when power is in watts.

Answer: **A — 1500 J kg^{-1} K^{-1}**

Q4 Specific heat capacity and kettle heating

[C 95]

(a) Specific heat capacity is the energy needed to raise the temperature of 1 kg of a substance by 1 K, with no change of state.

(b)(i) The time does not double because some energy heats the kettle itself in both experiments.

(b)(ii) Let C be the heat capacity of the kettle. Temperature rise = 80 K.

$$150P = (0.50 \times 4200 + C) \times 80$$
$$258P = (1.00 \times 4200 + C) \times 80$$

Subtract the first equation from the second, so the unknown kettle term cancels:

$$(258 - 150)P = (4200 - 2100) \times 80$$
$$108P = 168000$$
$$P = 1.56 \times 10^3\,\mathrm{W} = 1.56\,\mathrm{kW}$$

A-level point: Two equations and subtraction is the clean way to remove C.

Answer: **1.56 kW, so about 1.6 kW**

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Q5 Mean rate of energy loss from a kettle *[AEB 94]*

Electrical input energy:

$$E_{\text{in}} = Pt = 2500 \times 200 = 5.00 \times 10^5 \text{ J}$$

Useful energy gained by the water:

$$E_{\text{water}} = mc\Delta T = 1.0 \times 4000 \times 80 = 3.20 \times 10^5 \text{ J}$$

Energy transferred to surroundings:

$$E_{\text{lost}} = 5.00 \times 10^5 - 3.20 \times 10^5 = 1.80 \times 10^5 \text{ J}$$

$$P_{\text{lost}} = \frac{1.80 \times 10^5}{200} = 900\,\text{W} = 0.90\,\text{kW}$$

A-level point: Input energy minus useful thermal gain gives the loss.

Answer: C — 0.90 kW

Q6 Kinetic energy converted to thermal energy *[C 95]*

All kinetic energy becomes internal energy of the ball-bearing:

$$\frac{1}{2}mv^2 = mc\Delta\theta$$

Cancel the mass m:

$$\frac{1}{2}v^2 = c\Delta\theta$$

$$v^2 = 2c\Delta\theta$$

$$v = \sqrt{2c\Delta\theta}$$

A-level point: Mass appears in both energy expressions, so it cancels.

Answer: D — v = √(2cΔθ)

Q7 Cooling an X-ray tube with flowing water

[NEAB 92]

A heat-transfer rate of 1 kW means 1000 J is removed each second.
In each second, 0.24 kg of water flows through.

$$P = \dot{m}c\Delta T$$
$$1000 = 0.24 \times 4200 \times \Delta T$$
$$\Delta T = \frac{1000}{1008} = 0.992\,\mathrm{K} \approx 1.0\,\mathrm{K}$$

A-level point: Use mass flow rate in kg s⁻¹ for continuous-flow problems.

Answer: C — 1.0 K

Q8 Newton's law of cooling

[AEB 92]

Cooling rate is proportional to temperature difference from surroundings.
Let surrounding temperature be T_s.

$$12 = k(100 - T_s)$$
$$6 = k(60 - T_s)$$
$$\frac{12}{6} = \frac{100 - T_s}{60 - T_s}$$
$$2(60 - T_s) = 100 - T_s$$
$$T_s = 20^\circ\mathrm{C}$$

A-level point: The proportional quantity is excess temperature above surroundings.

Answer: B — 20 °C

Q9 Melting ice at constant power

[O&C 94]

The ice starts at 0 °C, so the supplied energy is used for melting.

$$E = mL = 1.5 \times 3.0 \times 10^5 = 4.5 \times 10^5 \text{ J}$$

$$t = \frac{E}{P} = \frac{4.5 \times 10^5}{50} = 9.0 \times 10^3 \text{ s}$$

$$t = \frac{9000}{3600} = 2.50 \text{ h}$$

A-level point: During melting, temperature stays constant while state changes.

Answer: B — 2.50 h

Q10 Unit of specific latent heat

[AEB 94]

Specific latent heat is energy transferred per unit mass during a change of state.

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

$$\text{unit of } L = \frac{\text{J}}{\text{kg}} = \text{J kg}^{-1}$$

There is no K^{-1} term because latent heat does not involve a temperature change.

A-level point: Specific latent heat is per kilogram, not per kelvin.

Answer: A — J kg^{-1}

Q11 Latent heat of vaporisation using an electric heater

[L 95, p]

Electrical power supplied:

$$P = IV = 2.6 \times 8.0 = 20.8\,\mathrm{W}$$

Heating time: 8 min = 480 s

$$E = Pt = 20.8 \times 480 = 9984\,\mathrm{J} \approx 9.98\,\mathrm{kJ}$$

Mass vaporised = 104 g = 0.104 kg

$$L = \frac{E}{m} = \frac{9984}{0.104} = 9.60 \times 10^4\,\mathrm{J\,kg^{-1}}$$

A-level point: Convert grams to kilograms and minutes to seconds first.

Answer: Energy = 9.98 kJ; L = 9.6 × 10^4 J $\mathrm{kg^{-1}}$

Q12 Ice cube added to warmer water

[NEAB 94]

The intended MCQ estimate is the temperature fall needed to supply the latent heat for melting the ice.

$$E = mL = 0.010 \times 3.4 \times 10^5 = 3.4 \times 10^3\,\mathrm{J}$$

$$\Delta T = \frac{E}{mc} = \frac{3400}{0.10 \times 4200} = 8.10\,\mathrm{K}$$

A full equilibrium calculation gives about 8.7 K, but the nearest MCQ option is still 8 K.

A-level point: The answer is a temperature fall, so the unit is K.

Answer: B — about 8 K

Consolidation 1: Thermal foundations

Use this page to connect the particle model, temperature, internal energy and changes of state.

Specification confidence check

Point	RAG	Next step
Describe solids, liquids and gases in terms of spacing, arrangement and motion.	R A G	
Explain Brownian motion using collisions with unseen particles.	R A G	
Define internal energy as random kinetic + potential energy of particles.	R A G	
Define absolute zero and convert between °C and K.	R A G	
Explain thermal equilibrium and direction of thermal energy transfer.	R A G	
Explain internal-energy changes during melting, boiling and cooling.	R A G	

Core questions

1. A metal block at 80 °C is placed in water at 20 °C. Describe the energy transfer until thermal equilibrium is reached.
2. Explain why temperature remains constant while a pure substance melts, even though energy is still being transferred.
3. Sketch a heating curve for ice starting below 0 °C and ending as steam. Label the regions where kinetic energy changes and where potential energy changes.
4. Explain Brownian motion in smoke particles. Your answer must refer to random motion and collisions.

Command words

- [ ] Define: precise meaning only.
- [ ] Explain: include cause and effect.
- [ ] Describe: say what happens, not why.
- [ ] Sketch: label axes and key regions.

Show-that style check

A gas thermometer shows that pressure is directly proportional to absolute temperature. A sample has pressure 100 kPa at 27 °C. Show that its pressure at 87 °C is about 120 kPa, assuming volume is constant.

Then explain why the same calculation would be invalid if the gas could expand freely.

Confidence reflection

One idea I can explain clearly:

One idea I need to revisit:

Consolidation 2: Thermal properties of materials

Practise specific heat capacity, latent heat, practical methods and energy conservation.

Specification confidence check

Point	RAG	Next step
Use $E = mc\Delta\theta$ for specific heat capacity calculations.	R A G	
Describe an electrical method to determine SHC of a metal or liquid.	R A G	
Explain techniques that reduce uncertainty and heat loss in SHC experiments.	R A G	
Use $E = mL$ for specific latent heat calculations.	R A G	
Describe electrical methods for SLH of fusion and vaporisation.	R A G	
Explain why temperature is constant during a change of state.	R A G	

$E = mc\Delta\theta$

$E = Pt = IVt$

$E = mL$

energy lost = energy gained

Practical detail to include

- ☐ Measure mass, voltage, current and time.
- ☐ Use insulation and a lid where appropriate.
- ☐ Record initial and final temperature.
- ☐ Repeat and average readings.
- ☐ Use a graph when power/time data are collected.

Mixed questions

1. A 0.80 kg metal block absorbs 14.4 kJ and its temperature rises by 6.0 K. Calculate its specific heat capacity.
2. A heater supplies 48 W for 6.0 minutes to a liquid. 7.5 g evaporates. Calculate the specific latent heat of vaporisation, assuming negligible heat loss.
3. A hot 0.25 kg metal object at 90 °C is placed in 0.40 kg of water at 20 °C. Write the energy-conservation equation needed to find the final temperature.
4. Explain why the measured SHC is often larger than the accepted value when heat loss to the surroundings is ignored.

Examiner trap

Do not put a kelvin term in the unit for specific latent heat. Latent heat is energy per kilogram during a change of state, so the unit is J kg^{-1}, not J kg^{-1} K^{-1}.

Consolidation 3: Ideal gases and kinetic theory

Link moles, particles, pressure, molecular motion and internal energy.

Specification confidence check

Point	RAG	Next step
Use $N = nN_A$ to convert between particles and moles.	○ R ○ A ○ G	
Use $pV = nRT$ and $pV = NkT$ for ideal-gas calculations.	○ R ○ A ○ G	
Apply Boyle's law, Charles's law and Gay-Lussac's law with correct conditions.	○ R ○ A ○ G	
Explain pressure using molecular collisions with container walls.	○ R ○ A ○ G	
Use $pV = \frac{1}{3}Nm\langle c^2\rangle$ and identify mean square speed.	○ R ○ A ○ G	
Use $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$ and internal energy of a monatomic ideal gas.	○ R ○ A ○ G	

$N = nN_A$

$pV = nRT$

$pV = NkT$

$pV = \frac{1}{3}Nm\langle c^2\rangle$

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

Before calculating

- [ ] Convert °C to K.
- [ ] Convert cm^3, mm^3 and litres to m^3.
- [ ] Convert kPa/MPa to Pa.
- [ ] Check whether mass, volume or temperature is constant.
- [ ] Use atoms for helium and molecules for molecular gases.

Mixed questions

1. A sealed rigid container holds 2.0×10^{22} gas molecules at 300 K in a volume of 0.080 m^3. Calculate the pressure.

2. A fixed mass of gas has volume 0.50 m^3 at 290 K. At constant pressure it is heated to 360 K. Calculate the new volume.

3. Explain why increasing the temperature of a fixed volume of gas increases the pressure.

4. A helium atom has mass 6.6×10^{-27} kg. Calculate the rms speed of helium atoms at 300 K.

Precision note

Use "mean square speed", not "mean square velocity". Direction changes, but speed is the scalar used in the kinetic-theory equations.

Final consolidation: Mixed thermal physics check

Complete these without notes first, then mark RAG and choose the next topic to revisit.

Final confidence snapshot

Particle model	R A G	Thermal equilibrium	R A G
SHC	R A G	SLH	R A G
Gas laws	R A G	Kinetic theory	R A G

Final mixed questions

1. A 60 W heater warms 0.50 kg of water from 21 °C to 25 °C in 2.5 minutes. Calculate the specific heat capacity of water and comment on the result.

2. A fixed volume of gas is heated from 20 °C to 80 °C. Its initial pressure is 110 kPa. Calculate the final pressure.

3. A liquid of mass 0.018 kg completely vaporises at constant temperature. Its specific latent heat of vaporisation is 2.3×10^{6} J kg^{-1}. Calculate the energy transferred.

4. Explain, using kinetic theory, why a gas exerts pressure on the walls of a container.

5. A graph of temperature against time has two flat sections. Explain what is happening to the internal energy during each flat section.

Targeted revision plan

My weakest specification point is: ____________________

The exact skill I need to practise is: ____________________

My next 20-minute revision task: ____________________

Aim for evidence: every calculation should show equation, substitution, answer and unit.

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