? Test yourself

1 A hot body is brought into contact with a colder body until their temperatures are the same. Assume that no other bodies are nearby.

a Discuss whether the energy lost by one body is equal to the energy gained by the other.

b Discuss whether the temperature drop of one body is equal to the temperature rise of the other.

2 a A body of mass 0.150 kg has its temperature increased by 5.00 °C when 385 J of energy is provided to it. Calculate the body's specific heat capacity.

b Another body of mass 0.150 kg has its temperature increased by 5.00 K when 385 J of energy is provided to it. Calculate this body's specific heat capacity.

3 A calorimeter of mass 90 g and specific heat capacity 420 J kg^{-1} K^{-1} contains 310 g of a liquid at 15.0 °C. An electric heater rated at 20.0 W warms the liquid to 19.0 °C in 3.0 min. Assuming there are no energy losses to the surroundings, estimate the specific heat capacity of the liquid.

4 A calorimeter for which $mc = 25\,\mathrm{J\,K^{-1}}$ contains 140 g of a liquid. An immersion heater is used to provide energy at a rate of 40 W for a total time of 4.0 min. The temperature of the liquid increases by 15.8 °C. Calculate the specific heat capacity of the liquid. State an assumption made in reaching this result.

5 A car of mass 1360 kg descends from a hill of height 86 m at a constant speed. Assuming that all of the gravitational potential energy lost by the car goes into heating the brakes, estimate the rise in the temperature of the brakes. (It takes 16 kJ of energy to increase the temperature of the brake drums by 1 K; ignore any energy losses to the surroundings.)

6 A radiator made out of iron of specific heat capacity 450 J kg^{-1} K^{-1} has a mass of 45.0 kg and is filled with 23.0 kg of water of specific heat capacity 4200 J kg^{-1} K^{-1}.

a Determine the energy required to raise the temperature of the radiator–water system by 1 K.

b If energy is provided to the radiator at the rate of 450 W, calculate how long it will take for the temperature to increase by 20.0 °C.

7 How much ice at −10 °C must be dropped into a cup containing 300 g of water at 20 °C in order for the temperature of the water to be reduced to 10 °C? The cup itself has a mass of 150 g and is made out of aluminium. Assume that no energy is lost to the surroundings.

8 The surface of a pond of area 20 m^2 is covered by ice of uniform thickness 6 cm. The temperature of the ice is −5 °C. Calculate how much energy is required to melt this amount of ice into water at 0 °C. (Take the density of ice to be 900 kg m^{-3}.)

9 Radiation from the Sun falls on the frozen surface of a pond at a rate of 600 W m^{-2}. The ice temperature is 0 °C.

a Calculate how long it will take to melt a 1.0 cm thick layer of ice. (Take the density of ice to be 900 kg m^{-3}.)

b Suggest why the actual mass of ices that melts is less than your answer to **a**.

10 a Calculate how much energy is required to warm 1.0 kg ice initially at −10 °C to ice at 0 °C.

b Calculate how much energy is required to melt the ice at 0 °C.

c Calculate how much energy is required to further increase the temperature of the water from 0 °C to 10 °C.

d State in which stage (warming the ice, melting the ice, warming the water) the energy requirement is largest.

11 Ice at 0 °C is added to 1.0 kg of water at 20 °C, cooling it down to 10 °C. Determine how much ice was added.

12 A quantity of 100 g of ice at 0 °C and 50 g steam at 100 °C are added to a container that has 150 g water at 30 °C. Determine the final temperature in the container. Ignore the container itself in your calculations.

Nature of science

Models must be correct but also simple

Boyle thought that a gas consists of particles joined by springs. Newton thought that a gas consists of particles that exert repulsive forces on each other. Bernoulli thought that a gas is a collection of a very large number of particles that exert forces on each other only when they collide. All three could explain why a gas exerts a pressure on its container but it is Bernoulli's picture that is the simplest. We assume that the ordinary laws of mechanics apply to the individual particles making up the gas. Even though the laws apply to each individual particle we cannot observe or analyse each particle individually since there are so many of them. By concentrating on average behaviours of the whole gas and using probability and statistics, physicists developed a new field of physics known as statistical mechanics. This has had enormous success in advancing our understanding of gases and other systems, including where the approximation to an ideal gas breaks down.

Test yourself

13 Calculate the number of molecules in 28 g of hydrogen gas (molar mass $2\,\mathrm{g\,mol^{-1}}$).

14 Calculate the number of moles in 6.0 g of helium gas (molar mass $4\,\mathrm{g\,mol^{-1}}$).

15 Determine the number of moles in a sample of a gas that contains 2.0×10^{24} molecules.

16 Determine the mass in grams of carbon (molar mass $12\,\mathrm{g\,mol^{-1}}$) that contains as many molecules as 21 g of krypton (molar mass $84\,\mathrm{g\,mol^{-1}}$).

17 A sealed bottle contains air at 22.0 °C and a pressure of 12.0×10^5 Pa. The temperature is raised to 120.0 °C. Calculate the new pressure.

18 A gas has pressure 8.2×10^6 Pa and volume $2.3 \times 10^{-3}\,\mathrm{m^3}$. The pressure is reduced to 4.5×10^6 Pa at constant temperature. Calculate the new volume of the gas.

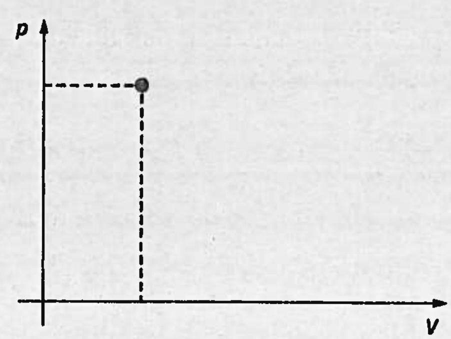
19 A mass of 12.0 kg of helium is required to fill a bottle of volume $5.00 \times 10^{-3}\,\mathrm{m^3}$ at a temperature of 20.0 °C. Determine the pressure in helium.

20 Determine the mass of carbon dioxide required to fill a tank of volume $12.0 \times 10^{-3}\,\mathrm{m^3}$ at a temperature of 20.0 °C and a pressure of 4.00 atm.

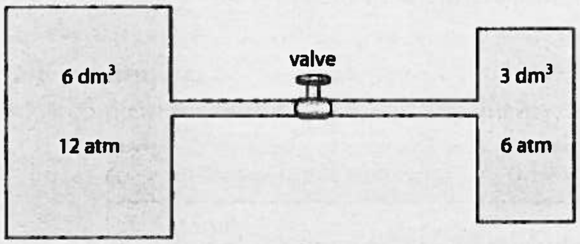
21 A flask of volume $300.0 \times 10^{-6}\,\mathrm{m^3}$ contains air at a pressure of 5.00×10^5 Pa and a temperature of 27.0 °C. The flask loses molecules at a rate of 3.00×10^{19} per second. Estimate how long it takes for the pressure in the flask to fall to half its original value. (Assume that the temperature of the air remains constant during this time.)

22 The point marked in the diagram represents the state of a fixed quantity of ideal gas in a container with a movable piston. The temperature of the gas in the state shown is 600 K. Copy the diagram. Indicate on the diagram the point representing the new state of the gas after the following separate changes.

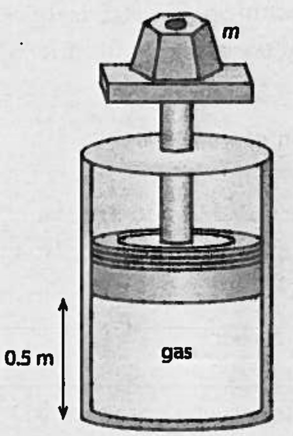
a The volume doubles at constant temperature.
b The volume doubles at constant pressure.
c The pressure halves at constant volume.



23 Two ideal gases are kept at the same temperature in two containers separated by a valve, as shown in the diagram. Estimate the pressure when the valve is opened. (The temperature stays the same.)



24 The diagram shows a cylinder in a vacuum, which has a movable, frictionless piston at the top. An ideal gas is kept in the cylinder. The piston is at a distance of 0.500 m from the bottom of the cylinder and the volume of the cylinder is $0.050\,m^3$. The weight on top of the cylinder has a mass of 10.0 kg. The temperature of the gas is 19.0 °C.



a Calculate the pressure of the gas.

b Determine how many molecules there are in the gas.

c The temperature is increased to 152 °C. Calculate the new volume of the gas.

25 The molar mass of a gas is $28\,g\,mol^{-1}$. A container holds 2.00 mol of this gas at 0.00 °C and a pressure of 1.00×10^5 Pa. Determine the mass and volume of the gas.

26 A balloon has a volume of $404\,m^3$ and is filled with helium of mass 70.0 kg. The temperature inside the balloon is 17.0 °C. Determine the pressure inside the balloon.

27 A flask has a volume of $5.0 \times 10^{-4}\,m^3$ and contains air at a temperature of 300 K and a pressure of 150 kPa.

a Calculate the number of moles of air in the flask.

b Determine the number of molecules in the flask.

c Estimate the mass of air in the flask. You may take the molar mass of air to be $29\,g\,mol^{-1}$.

28 The molar mass of helium is $4.00\,g\,mol^{-1}$.

a Calculate the volume of 1.0 mol of helium at standard temperature and pressure (stp) i.e. at $T = 273\,K$, $p = 1.0 \times 10^5\,Pa$.

b Determine the density of helium at stp.

c Estimate the density of oxygen gas at stp (the molar mass of, oxygen gas is $32\,g\,mol^{-1}$).

29 The density of an ideal gas is $1.35\,kg\,m^{-3}$. The temperature in kelvin and the pressure are both doubled. Calculate the new density of the gas.

30 Calculate the average speed (r.m.s.) of helium atoms at a temperature of 850 K. The molar mass of helium is $4.0\,g\,mol^{-1}$.

31 Show that the average (r.m.s.) speed of molecules of a gas of molar mass M (in $kg\,mol^{-1}$) kept at a temperature T is given by $c = \sqrt{\frac{3RT}{M}}$.

32 a Calculate the average random kinetic energy of a gas kept at a temperature of 300 K.

b Determine the ratio of the average speeds (r.m.s. speeds) of two ideal gases of molar mass $4.0\,g\,mol^{-1}$ and $32\,g\,mol^{-1}$, which are kept at the same temperature.

Exam-style questions

1 Body X whose temperature is 0 °C is brought into thermal contact with body Y of equal mass and temperature 100 C. The only exchanges of heat that take place are between X and Y. The specific heat capacity of X is greater than that of Y. Which statement about the final equilibrium temperature T of the two bodies is correct?

A $T = 50\,°C$
B $0 < T < 50\,°C$
C $100\,°C > T > 50\,°C$
D Answer depends on value of mass

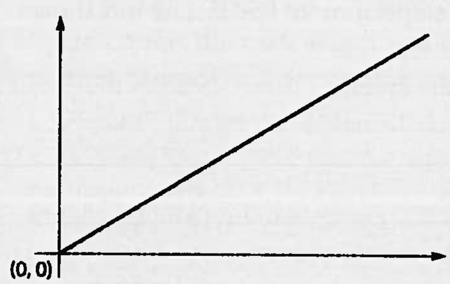
2 Energy is provided to a liquid at its boiling point at a rate of P joules per second. The rate at which mass is boiling away is μ kg per second. The specific latent heat of vaporisation of the liquid is

A μP **B** $\frac{P}{\mu}$ **C** $\frac{\mu}{P}$ **D** $\frac{1}{\mu P}$

3 The following are all assumptions of the kinetic theory of gases, except which one?

A The duration of a collision is very small compared to the time in between collisions.
B The collisions are elastic.
C The average kinetic energy of molecules is proportional to temperature.
D The volume of molecules is negligible compared to the volume of the gas.

4 In the context of a fixed mass of an ideal gas, the graph could represent the variation of:



A pressure with volume at constant temperature
B volume with Celsius temperature at constant pressure
C pressure with Celsius temperature at constant volume
D pressure with inverse volume at constant temperature

5 The temperature of an ideal gas of pressure 200 kPa is increased from 27 °C to 54 °C at constant volume. Which is the best estimate for the new pressure of the gas?

A 400 kPa **B** 220 kPa **C** 180 kPa **D** 100 kPa

6 A container of an ideal gas that is isolated from its surroundings is divided into two parts. One part has double the volume of the other. The pressure in each part is p and the temperature is the same. The partition is removed. What is the pressure in the container now?

A p **B** $2p$ **C** $\frac{3p}{2}$ **D** $4p$

7 Different quantities of two ideal gases X and Y are kept at the same temperature. Which of the following is a correct comparison of the average kinetic energy and internal energy of the two gases?

	Average kinetic energy	Internal energy
A	same	same
B	same	different
C	different	same
D	different	different

8 The temperature of an ideal gas is doubled. The average speed of the molecules increases by a factor of

A $\sqrt{2}$ **B** 2 **C** $2\sqrt{2}$ **D** 4

9 Two ideal gases X and Y are kept at the same temperature. Gas X has molar mass m_X and gas Y has molar mass μ_Y. The ratio of average speeds of the molecules of gas X to that of gas Y is

A $\frac{\mu_X}{\mu_Y}$ **B** $\frac{\mu_Y}{\mu_X}$ **C** $\sqrt{\frac{\mu_X}{\mu_Y}}$ **D** $\sqrt{\frac{\mu_Y}{\mu_X}}$

10 The pressure of a fixed quantity of ideal gas is doubled. The average speed of the molecules is also doubled. The original density of the gas is ρ. Which is the new density of the gas?

A $\frac{\rho}{2}$ **B** ρ **C** 2ρ **D** 4ρ

11 **a** Calculate the volume of 1 mol of helium gas (molar mass 4 g mol−1) at temperature 273 K and pressure 1.0 × 105 Pa. [2]

b **i** Find out how much volume corresponds to each molecule of helium. [2]

ii The diameter of an atom of helium is about 31 pm. Discuss whether or not the ideal gas is a good approximation to the helium gas in **a**. [2]

c Consider now 1 mol of lead (molar mass 207 $\mathrm{g\,mol^{-1}}$, density $11.3 \times 10^3\,\mathrm{kg\,m^{-3}}$). How much volume corresponds to each atom of lead? [3]

d Find the ratio of these volumes (helium to lead) and hence determine the order of magnitude of the ratio: separation of helium atoms to separation of lead atoms. [2]

12 a Define what is meant by **specific heat capacity** of a substance. **[1]**

b Consider two metals that have different specific heat capacities. The energies required to increase the temperature of 1 mol of aluminium and 1 mol of copper by the same amount are about the same. Yet the specific heat capacities of the two metals are very different. Suggest a reason for this. **[2]**

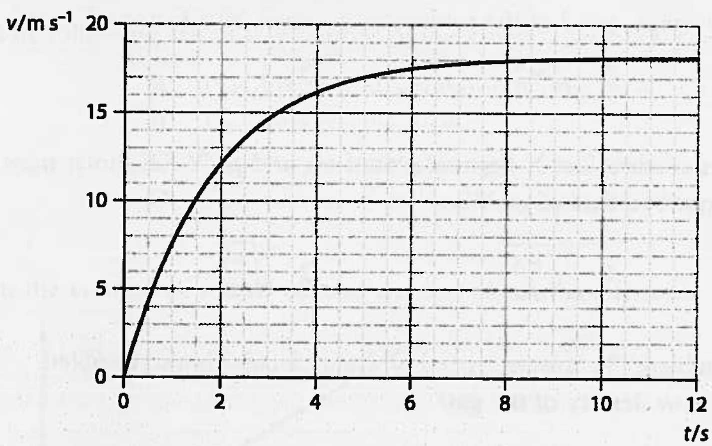
A hair dryer consists of a coil that warms air and a fan that blows the warm air out. The coil generates thermal energy at a rate of 600 W. Take the density of air to be $1.25\,\text{kg}\,\text{m}^{-3}$ and its specific heat capacity to be $990\,\text{J}\,\text{kg}^{-1}\,\text{K}^{-1}$. The dryer takes air from a room at 20 °C and delivers it at a temperature of 40 °C.

c What mass of air flows through the dryer per second? **[2]**

d What volume of air flows per second? **[1]**

e The warm air makes water in the hair evaporate. If the mass of water in the air is 180 g, calculate how long it will take to dry the hair. (The heat required to evaporate 1 g of water at 40 °C is 2200 J.) **[2]**

13 The graph shows the variation with time of the speed of an object of mass 8.0 kg that has been dropped (from rest) from a certain height.



The body hits the ground 12 seconds later. The specific heat capacity of the object is $320\,\text{J}\,\text{kg}^{-1}\,\text{K}^{-1}$.

a **i** Explain how we may deduce that there must be air resistance forces acting on the object. **[2]**

ii Estimate the height from which the object was dropped. **[2]**

iii Calculate the speed the object would have had if there were no air resistance forces. **[2]**

b Estimate the change in temperature of the body from the instant it was dropped to just before impact. List any assumptions you make. **[4]**

14 A piece of tungsten of mass 50 g is placed over a flame for some time. The metal is then quickly transferred to a well-insulated aluminium calorimeter of mass 120 g containing 300 g of water at 22 °C. After some time the temperature of the water reaches a maximum value of 31 °C.

a State what is meant by the internal energy of a piece of tungsten. **[1]**

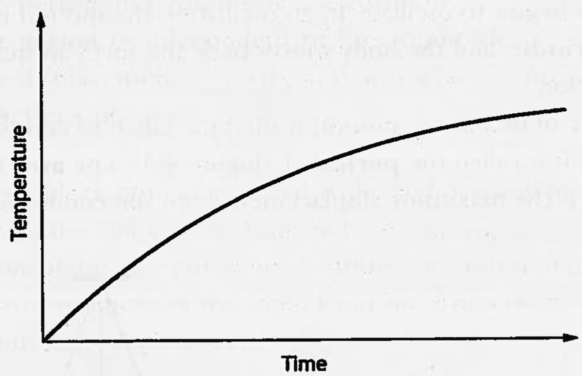
b Calculate the temperature of the flame. You may use these specific heat capacities: water $4.2 \times 10^3\,\mathrm{J\,kg^{-1}\,K^{-1}}$, tungsten $1.3 \times 10^2\,\mathrm{J\,kg^{-1}\,K^{-1}}$ and aluminum $9.0 \times 10^2\,\mathrm{J\,kg^{-1}\,K^{-1}}$. **[3]**

c State and explain whether the actual flame temperature is higher or lower than your answer to **b**. **[2]**

15 a Describe what is meant by the internal energy of a substance. **[1]**

b A student claims that the kelvin temperature of a body is a measure of its internal energy. Explain why this statement is not correct by reference to a solid melting. **[2]**

c In an experiment, a heater of power 35 W is used to warm 0.240 kg of a liquid in an uninsulated container. The graph shows the variation with time of the temperature of the liquid.



The liquid never reaches its boiling point.

Suggest why the temperature of the liquid approaches a constant value. **[2]**

d After the liquid reaches a constant temperature the heater is switched off. The temperature of the liquid decreases at a rate of $3.1\,\mathrm{K\,min^{-1}}$.

Use this information to estimate the specific heat capacity of the liquid. **[3]**

16 The volume of air in a car tyre is about $1.50 \times 10^{-2}\,\mathrm{m^3}$ at a temperature of 0.0 °C and pressure 250 kPa.

a Calculate the number of molecules in the tyre. **[2]**

b Explain why, after the car is driven for a while, the pressure of the air in the tyre will increase. **[3]**

c Calculate the new pressure of the tyre when the temperature increases to 35 °C and the volume expands to $1.60 \times 10^{-2}\,\mathrm{m^3}$.

d The car is parked for the night and the volume, pressure and temperature of the air in the tyre return to their initial values. A small leak in the tyre reduces the pressure from 250 kPa to 230 kPa in the course of 8 h. Estimate (stating any assumptions you make):

i the average rate of loss of molecules (in molecules per second) **[2]**

ii the total mass of air lost (take the molar mass of air to be $29\,\mathrm{g\,mol^{-1}}$). **[3]**