Practice questions

1 Thermal energy is supplied at the rate of 2.5 kW for 140 s to 0.8 kg of sunflower oil inside a saucepan with negligible heat capacity. This produces a temperature change of 219 K. The specific heat capacity of sunflower oil, in $J\,kg^{-1}\,K^{-1}$, is

A 1500 **C** 2000

B 1800 **D** 2200

2 An ice sculpture of mass 25 kg at 0 °C absorbs thermal energy from its surroundings at an average rate of 45 W. The specific latent heat of fusion of ice is 334 $kJ\,kg^{-1}$. The time, in days, for the sculpture to melt is

A 1.8 **C** 3.3

B 2.1 **D** 4.9

3 A 0.010 kg ice cube at 0°C is dropped into a glass containing 0.10 kg of lemonade at 15°C. The ice cube melts, cooling the lemonade. What is the new temperature of the drink in °C? The specific latent heat of fusion of ice is 334 $kJ\,kg^{-1}$, and the specific heat capacity of water (lemonade) is 4200 $J\,kg^{-1}\,K^{-1}$.

A 6 **C** 10

B 8 **D** 12

4 A deep-sea diver is working at a depth where the pressure is 3.2 atm. She is breathing out air bubbles. The volume of each bubble is 1.9 cm^3. She decompresses at a depth of 10 m where the pressure is 2.1 atm. What is the volume of each bubble at this depth in cm^3?

A 0.6 **C** 1.9

B 3.6 **D** 2.9

5 The helium in a sealed weather balloon at a temperature of 283 K has a volume of 1.4 m^3 and a pressure of 1.01×10^5 Pa. The balloon rises to a height of 300 m, where the temperature is 274 K and the pressure is 0.98×10^5 Pa. The volume of the air in the balloon at 300 m, in m^3, is

A 1.1 **C** 1.9

B 1.5 **D** 2.4

6 A mixture of helium and argon is used in a fire extinguisher system. The molar masses are 4.0 $g\,mol^{-1}$ and 40 $g\,mol^{-1}$, respectively, and the extinguisher contains one mole of each gas. The ratio of the pressure exerted by the helium and the argon, respectively, on the inside of the extinguisher is

A 1 : 1 **C** 1 : 10

B 100 : 1 **D** 10 : 1

7 A deodorant can with a volume of 330 cm^3 at 18°C contains deodorant particles that exert a pressure of 3.2×10^5 Pa on the inside of the can. The number of moles of deodorant particles in the can is

A 0.04 **C** 400

B 4 **D** 40 000

8 The density of air at 15°C and 1.01×10^5 Pa is 1.225 $kg\,m^{-3}$. The r.m.s. velocity of air particles, in $m\,s^{-1}$, is

A 604 **C** 498

B 603 **D** 497

9 Five nitrogen gas molecules have the following velocities, in $m\,s^{-1}$: 300, 450, 675, 700, 800. The root mean square velocity of the particles, in $m\,s^{-1}$, is

A 413 **C** 613

B 513 **D** 713

10 Carbon particles of mass 2.0×10^{-26} kg in the hottest part of a Bunsen burner flame have a temperature of 1200°C. The r.m.s. velocity of these particles, in $m\,s^{-1}$, is

A 823 **C** 1746

B 1235 **D** 2143

11 A jewellery maker is making a gold pendant. She prepares a 3.0 kg iron mould and then pours in 25.0 g of molten gold at a temperature of 1064°C. The mould's temperature rises from 31°C up to 35°C when it is then in thermal equilibrium with the solid gold.

Here is the thermal data about the gold and the iron:

- mass of iron mould = 3.0 kg
- specific heat capacity of iron = 440 $J\,kg^{-1}\,K^{-1}$
- specific latent heat of fusion of gold = 63×10^3 $J\,kg^{-1}$

a) Calculate the thermal energy absorbed by the iron mould. *(2)*

b) Calculate the thermal energy given out by the gold as it changes state from a liquid to a solid. *(1)*

c) Use the data to determine the specific heat capacity (c) of gold. *(3)*

d) State one assumption that you have made for your calculation of c. *(1)*

12 A student is making iced tea lollies using her family's freezer. She initially pours 0.050 kg of lukewarm tea at a temperature of 40.0°C into a 0.12 kg aluminium mould at a temperature of 5.0°C. The specific heat capacity of tea is 4250 $J\,kg^{-1}\,K^{-1}$ and the specific heat capacity of aluminium is 900 $J\,kg^{-1}\,K^{-1}$.

a) Calculate the equilibrium temperature of the tea and the mould. *(3)*

b) The tea and the mould are then put into the freezer, which removes thermal heat from the tea and the mould at a rate of 32 W.

Calculate how long it takes for the tea to freeze, if the specific latent heat of fusion of tea is 3.38×10^5 $J\,kg^{-1}$, stating any assumptions that you make. *(4)*

13 A gas combi-boiler can heat water with a power of 15 kW. Cold water with a temperature of 5°C flows into the heater at a rate of 0.24 $kg\,s^{-1}$. The specific heat capacity of water is 4200 $J\,kg^{-1}\,K^{-1}$.

a) Combi-boilers are highly efficient and you can assume that all the thermal energy from the heater is transferred to the water. Calculate the output temperature of the water. *(2)*

b) The water supply to the heater fails and 0.24 kg of water is trapped inside the heating compartment of the heater. The water inside the compartment has an average temperature of 35°C and the heater continues to heat the water. How long will it take before the water reaches 80°C, when the emergency cut-out valve turns off the gas supply? *(2)*

14 Formula 1 tyres have a volume of 0.09 m^3 and are filled with nitrogen to a pressure of 1.4×10^5 Pa at 285 K.

a) Calculate the number of moles of nitrogen in the tyre. *(1)*

b) F1 tyres are designed to work at an optimum racing temperature of 363 K. Calculate the racing pressure in the tyre. You can assume that the tyre does not expand when heated. *(2)*

c) Calculate the root mean square (r.m.s.) velocity of the nitrogen molecules in the tyre when it is at racing pressure. The molar mass of nitrogen is 0.028 $kg\,mol^{-1}$. *(3)*

d) Describe one similarity and one difference in the way that the nitrogen molecules behave in the tyre at the different pressures. *(2)*

15 A fixed mass of helium gas is enclosed in a container with a volume of 0.055 m^3. The gas is cooled and a student measures and records the pressure of the gas, in atm, for different temperatures. The table shows the results:

Temperature, *T*/K	320	300	280	260	240
Pressure, *p*/atm	1.30	1.22	1.17	1.08	0.95

a) Use the data to plot a graph of the results, with temperature on the *x*-axis and pressure on the *y*-axis. Start both axes at zero. *(3)*

b) Use your graph to calculate the number of moles of helium gas present in the container. *(3)*

c) The pressure inside the container is reduced to 0.50 atm by cooling the container. Use your graph to determine the temperature of the gas at this pressure. *(1)*

d) Use your answer to (c) to calculate the average kinetic energy of a helium atom at a pressure of 0.5 atm. *(2)*

e) Hence calculate the total internal energy, *U*, of the helium. *(2)*

16 This question is about ideal gases.

a) State what is meant by an 'ideal gas'. *(2)*

b) An ideal gas at 300 K is enclosed inside a gas canister of volume $3.3 \times 10^{-4}\,m^3$ at a pressure of 2.02×10^5 Pa. Calculate the number of moles of gas enclosed inside the canister. *(2)*

c) The molar mass of the gas is 0.084 $kg\,mol^{-1}$. Calculate the density of the gas inside the canister. *(3)*

d) The canister is taken to the top of Mount Kilimanjaro, where it is used to inflate an air-mat. If the temperature at the top of the mountain is 266 K and the air pressure is 0.50×10^{-5} Pa, what is the combined volume of the canister and air-mat that could be inflated by the gas in the canister at this pressure. *(1)*

Stretch and challenge

The questions that follow here are British Physics Olympiad questions.

17 a) State Boyle's law.

Figure 4.23(a) shows a length of capillary tubing in which a column of air is trapped by a mercury column of length 100 mm. The length of the air column is 400 mm. The bottom of the tubing is sealed and the top is open to the atmosphere.

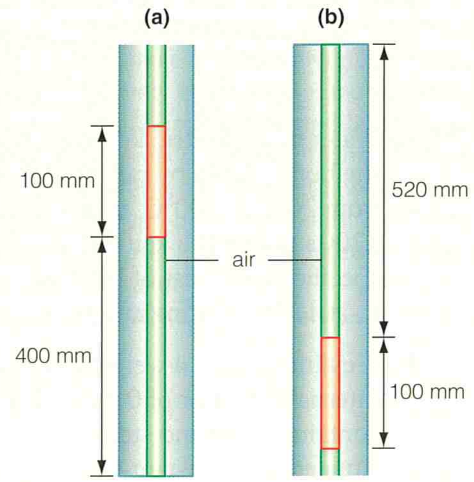


Figure 4.22

b) The tubing is now inverted, as shown in Figure 4.23(b), and the air column is seen to increase in length to 520 mm. Use this observation to calculate a value for atmospheric pressure, expressed in mm of mercury.

c) A typical value for atmospheric pressure, expressed in SI units, is 101 kPa. The surface area, *A*, of the Earth is related to its mean radius by the expression, $A = 4\pi R^2$, where *R* has the value 6400 km. Calculate:

i) the sum of the magnitudes of the forces exerted by the atmosphere on the surface of the Earth

ii) the mass of the Earth's atmosphere, assuming that g does not vary with height above the Earth's surface

iii) the number of molecules in the atmosphere, assuming that the molar mass of air is 30 $g\,mol^{-1}$

iv) the height of the atmosphere if the density $\rho = 1.2\,kg\,m^{-3}$.

d) The height of the atmosphere calculated in c) iv) is less than the height at which many aircraft fly. Explain why our calculation gives a low result for the height.

e) The height of the atmosphere is typically given as 200 km. Does this mean that our calculation of the mass is completely wrong (by a significant factor)?

(BPhO A2-2005 Q2; and A2-2011 Q4)

18 An accurate thermometer, of heat capacity 20.0 $J\,K^{-1}$, reads 18.0°C. It is then placed in 0.250 kg of water and both reach the same final temperature of 50°C. Calculate the temperature of the water before the thermometer was placed in it. The specific heat capacity of water is 4200 $J\,kg^{-1}\,K^{-1}$.

(BPhO R1-2005 Q1(a))

19 Wet clothing at 0°C is hung out to dry. The air temperature is 0°C and there is a dry wind blowing. After some time it is found that some of the water has evaporated and the water remaining on the clothes has frozen. The specific heat of fusion of ice is 333 $kJ\,kg^{-1}$ and the specific latent heat of evaporation of water is 2500 $kJ\,kg^{-1}$.

a) What is the source of energy required to evaporate the water? Explain the mechanism of evaporation.

b) Estimate the fraction, by mass, of water originally in the clothes that freezes.

(BPhO R1-2005 Q1(e))

20 A lead bullet at 320 K is stopped by a sheet of steel so that it reaches its melting point of 600 K and completely melts. If 80% of the kinetic energy of the bullet is converted into internal energy, calculate the speed with which the bullet hit the steel sheet. The specific heat capacity of lead is 0.12 kJ kg^{-1} K^{-1} and its specific latent heat of fusion is 21 kJ kg^{-1}.

(BPhO R1-2007 Q1(f))

21 a) Water in an electric kettle is brought to the boil in 180 s by raising its temperature from 20°C to 100°C. It then takes a further 1200 s to boil the kettle dry. Calculate the specific latent heat of vaporisation of water, l_v, at 100°C, stating any assumptions made.

b) A cylinder, with a weightless piston, has an internal diameter of 0.24 m. The cylinder contains water and steam at 100°C. It is situated in a constant-temperature water bath at 100°C, as shown in Figure 4.24. Atmospheric pressure is 1.01×10^5 Pa. The steam in the cylinder occupies a length of 0.20 m and has a mass of 0.37 g.

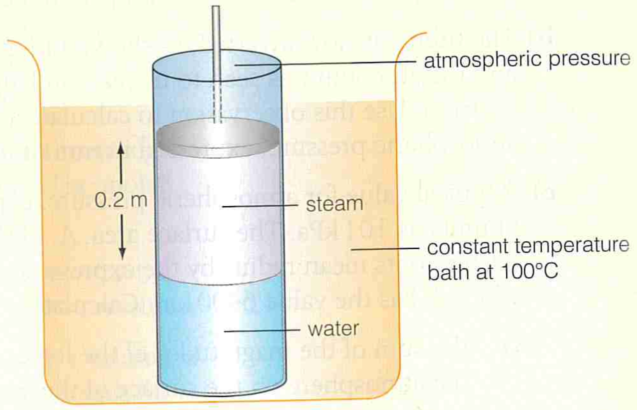


Figure 4.23

i) What is the pressure p of the steam in the cylinder?

ii) If the piston moves very slowly down a distance 0.10 m, how much work, W, will be done in reducing the volume of the steam?

iii) What is the final temperature, T_f, in the cylinder?

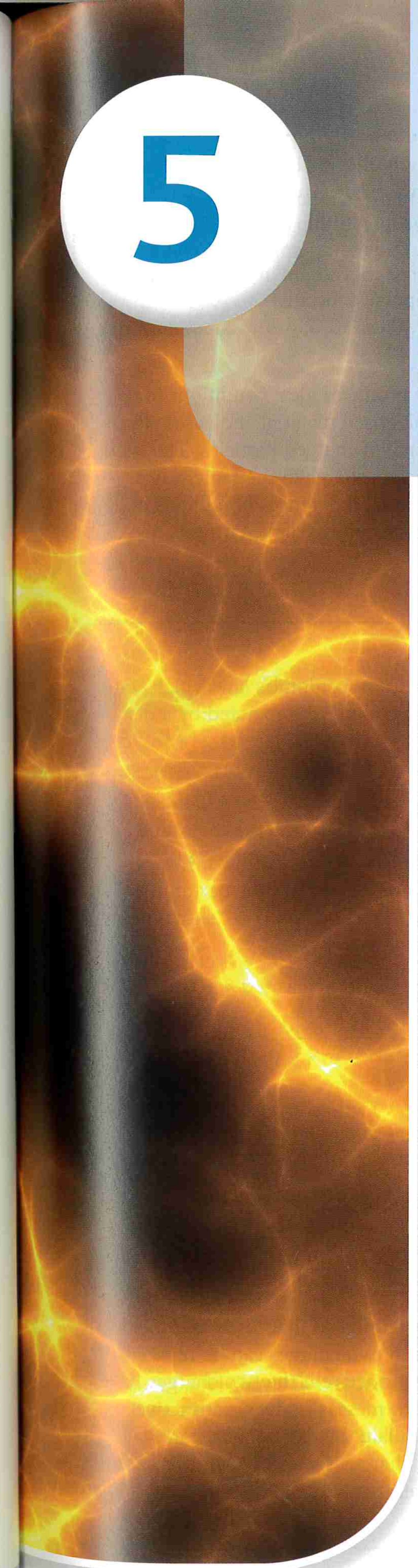
iv) Determine the heat, Q_c, produced in the cylinder.

c) A molecule of oxygen near the surface of the Earth has a velocity vertically upwards equal in magnitude to the root mean square (r.m.s.) value. If it does not encounter another molecule, calculate:

i) the height H reached if the surface temperature is 283 K

ii) the surface temperature, T_s, required for the molecule to escape from the Earth's gravitational field if the potential energy per unit mass at the Earth's surface is $\left(-G\frac{M_E}{R_E}\right)$. The oxygen molecule has a molar mass of 0.032 kg mol^{-1}.

(BPhO R1-2002 Q2)



5 Electric fields

PRIOR KNOWLEDGE

Before you start, make sure that you are confident in your knowledge and understanding of the following points:

- Atoms and molecules contain protons and electrons, which carry positive and negative charges, respectively. These charges are equal in size. An atom is neutral because there are as many positively charged protons as there are negatively charged electrons.
- Some materials, such as plastic, can become charged by rubbing with a cloth. If the plastic is charged positively, then electrons have been removed from the plastic and transferred to the cloth, which now carries a negative charge. Another type of plastic might be charged negatively when rubbed by a cloth – electrons have been transferred to the plastic and the cloth will be charged positive.
- Like charges repel each other, and unlike charges attract each other (Figure 5.1).

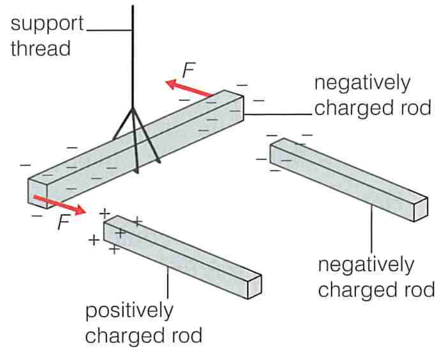


Figure 5.1

- Electric charges exert a force on each other over a distance. For example, a charged comb can pick up pieces of paper (Figure 5.2).

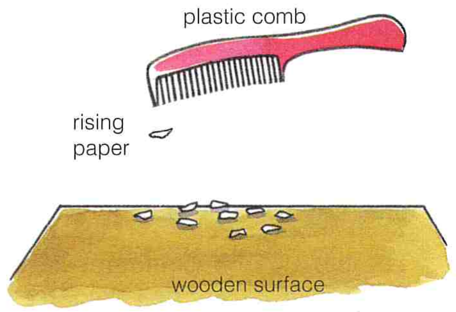


Figure 5.2

- Charges produce an electric field.
- An electric field is a region in space where a charged object experiences a force.
- Forces between charges are stronger when they are closer together. The forces are weaker when the charges are further apart.