Thermal Physics

Exercise A

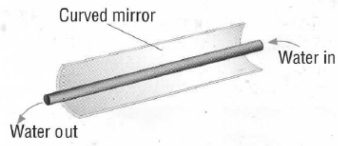

Figure 3

1 One method of heating water using the Sun's rays is to place a tube carrying the water at the focus of a curved mirror (see Figure 3).
For a particular arrangement on a particular day, 820 J of solar energy are absorbed each second by the water, which is flowing at 0.015 kg s^{-1} through the tube. Calculate the maximum possible increase in temperature of the water.

2 A polystyrene cup of soup of mass 400 g is placed in a microwave oven rated at 650 W.

(a) Calculate the maximum possible increase in temperature of the soup after being heated for two minutes. Assume that the soup has the same thermal properties as water.

(b) The person heating the soup uses a tight-fitting lid on top of the cup rather than one with a hole in it. Two changes will occur in the vapour above the soup, increasing the pressure there. Name these changes and explain why each causes the pressure to increase.

3 The air in a living room of dimensions 5.5 m × 4.5 m × 2.1 m is heated by a convector heater of power 1.5 kW. Estimate the minimum time required to raise the temperature of the air in the room from 10°C to 18°C. The density of air is 1.2 kg m^{-3}. Comment on your answer.

Exercise B

1 A 3.0 kW electric kettle contains boiling water. It is boiled for 2.00 minutes sitting on a top pan balance. The initial reading is 1.487 kg and the final reading 1.343 kg.

(a) Use these results to calculate the energy required to vaporise **(i)** 1.00 kg of water and **(ii)** 1.00 mole of water. The molar mass of water is 0.018 kg mol^{-1}.

(b) Suggest why the answer to **(a)(i)** differs from the value given in the main text above.

2 One way to reduce the cooking time of food is to use a pressure cooker in which water boils at a temperature above 100°C. The variation of boiling temperature T with pressure p measured in Pa is shown in the graph of Figure 3.

(a) Verify that the value of p at 373 K is 1.0×10^5 Pa.

(b) Use the graph to find the increase in boiling temperature that occurs when the pressure in the pressure cooker is doubled.

3 In some hot countries, tea is served in a pot with a glass 2/3 full of ice. The boiling tea is poured into the glass to fill it. Estimate the temperature of the resulting drink. (Use data given in this and the last spread to solve this problem.)

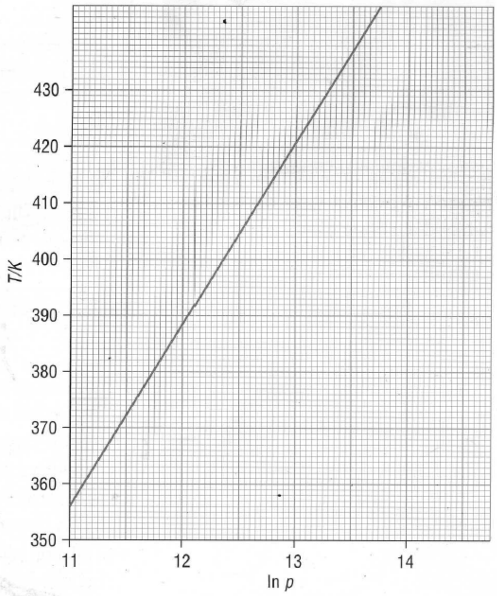

Figure 3

Exercise C

1 A bubble of diameter 1.5 mm escapes from a diver's helmet at a depth of 40 m where the pressure is 5.0 atmospheres.
(a) Calculate the minimum diameter at the surface.
(b) Why is the diameter likely to be greater than your calculated answer?

2 A cylinder of volume 0.020 m^3 contains nitrogen gas at a pressure of 80 atmospheres. The valve is opened and gas is collected at atmospheric pressure until the pressure in the cylinder has fallen to 60 atmospheres. What is the volume of the released nitrogen gas?

3 A simple mercury barometer consists of a vertical glass tube sealed at its upper end containing a column of mercury. The space between the top of the mercury column and the upper end of the tube is a vacuum. A mercury column height of 760 mm is equivalent to atmospheric pressure 1.0×10^5 Pa.
A school experiment to find atmospheric pressure before the days of modern health legislation was as follows. A length of air was trapped in a capillary tube sealed at one end by a thread of mercury. When the tube was held horizontally, the length of the trapped air column was 82 mm and the length of the thread of mercury was 39 mm. When the tube was held vertically with the open end upwards, the air column was squashed to 78 mm.

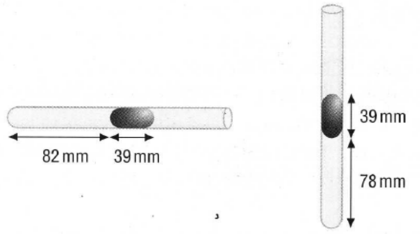

Figure 3

Find the value of atmospheric pressure in mm of mercury (mmHg).

Exercise D

1 A meteorological balloon has a volume of 6.0 m^3 when at ground level where the temperature is 293 K. The gas in it is at atmospheric pressure 1.0×10^5 Pa. The balloon rises to a height where the pressure has fallen to 4.4×10^4 Pa and the temperature to 257 K. Calculate the volume of the balloon at this height.

2 The inner tube of a bicycle tyre contains a volume of 8.0×10^{-4} m^3 of air. The pressure of the gas in the tyre is 4.0×10^5 Pa, and the temperature is 20°C. Towards the end of a race the outer tyre splits and the inner tube expands to 8.3×10^{-4} m^3. The pressure in the tube is 4.1×10^5 Pa. Estimate the temperature in °C of the gas in the tube when the accident occurred.

3 A cylinder in a diesel engine contains a mixture of fuel and air at a temperature of 330 K and a pressure of 1.0×10^5 Pa. The volume of the mixture is reduced by a factor of 18, and the temperature rises to 1100 K. Calculate the resulting pressure in the cylinder.

4 Two containers of volume V and $4V$ are connected by a capillary tube of negligible volume. Both are initially at room temperature, 293 K, and contain air at atmospheric pressure 1.0×10^5 Pa. The larger container is placed in boiling water and is heated to 373 K. Calculate the final pressure of the gas in the two containers. Hint: the total mass of gas in the two containers must remain constant.

Exercise E

$R = 8.31$ J mol^{-1} K^{-1}, molar volume = 22.43×10^{-3} m^3 and $N_A = 6.02 \times 10^{23}$ mol^{-1}.

1 The density of air is 1.29 kg m^{-3}. Calculate:
 (a) the molar mass of air
 (b) the number of molecules in 1.0 kg of air.

2 A cylinder of volume of 0.020 m^3 at room temperature (290 K) contains nitrogen gas of molar mass 0.028 kg mol^{-1} at 70 atmospheres (atm) pressure (70×10^5 Pa).
 (a) How many moles of gas does the cylinder contain?
 (b) What mass of gas does the cylinder contain?
 (c) When the gas is released into the atmosphere, what volume does it fill?
 (d) An identical cylinder contains hydrogen gas of molar mass 0.02 kg mol^{-1} at the same temperature (290 K) and pressure (70 atm). How many moles of hydrogen does it contain?

3 A spherical flask of volume 2.0×10^{-3} m^3 contains air at 300 K. Air, molar mass 0.029 kg mol^{-1}, behaves as an ideal gas at room temperature. The air is removed from the flask using a vacuum pump until the pressure is reduced to 150 Pa.
Calculate **(a)** the number of air molecules remaining in the flask and **(b)** the density of the air.

4 The flask in Question 3 is returned to atmospheric pressure 1.0×10^5 Pa and sealed with a rubber stopper.
 (a) Calculate the number of gas molecules in the flask.
 (b) The flask is heated until at 400 K the rubber stopper pops out of the flask. Calculate the pressure in the flask.
 (c) Suppose the rubber stopper did not seal the flask because it had a hole in it. How many gas molecules would remain in the flask at 400 K?

Exercise F

1 A 1.0 mole sample of gas is contained in a cylinder of volume V at a temperature of 300 K. The mean pressure exerted by each molecule of the sample is 5.0×10^{-19} Pa.
 (a) What is the volume V of the cylinder?
 (b) What is the pressure in the cylinder?
 (c) Would either or both of the answers to **(a)** and **(b)** have been different if the cylinder had contained 2.0 moles of gas?

2 **(a)** The r.m.s. speed of nitrogen molecules at 273 K is 490 m s^{-1}. Calculate:
  (i) the mean translational kinetic energy of a molecule **(ii)** its mass.
 (b) The mass of a helium atom is 1/7 that of a nitrogen molecule. Calculate:
  (i) the mean translational kinetic energy at 273 K and at 820 K
  (ii) the speed of a helium atom at 273 K and at 820 K.

3 The escape velocity from the Earth is 11 km s^{-1}. This means that a gas molecule at the top of the atmosphere travelling upwards at 11 km s^{-1} will escape into space.
 (a) The upper atmosphere is at about 1000 K. Calculate the mean kinetic energy of a molecule at this temperature.
 (b) Calculate the r.m.s. speeds of **(i)** hydrogen, with molar mass 0.002 kg mol^{-1}, and **(ii)** helium, with molar mass 0.004 kg mol^{-1}, at this temperature.
 (c) If the r.m.s. speed of the molecules of a gas is greater than 0.2 of the escape velocity, then over the period of the Earth's existence all of the gas will have escaped. Use this fact to explain whether we expect to find any hydrogen or helium in the atmosphere.

4 Estimate the melting point of a solid if the energy required to separate its molecules is 1.1×10^{-20} J.
