The Kinetic Theory of Gases Supplementary Questions

Study Guide 24

Part 1 - The Gas Laws

Standard temperature 273 K and standard pressure/one atmosphere is 1.01 x 10^5 Pa

1. A sample of gas, originally at standard temperature and pressure, has volume 3.0 x 10^{-5} m^3 under such conditions. When the pressure is increased to 4.0 x 10^5 Pa, the temperature rises to 40 °C. What is the new volume of the sample?

2. A party balloon has a volume of 1.50 litres (1 litres = 0.001 m^3) and the pressure of the air in it is 128 kPa. The balloon is squashed so that its volume becomes 1.30 litres, but its temperature remains unchanged. What is the new pressure of the balloon?

3. A gas chamber of volume 4.5 x 10^{-3} m^3 contains oxygen at a temperature of 14 °C and a pressure of 3.0 MPa. Compute:
   i) the equivalent volume of oxygen at standard temperature and pressure;
   ii) the mass of oxygen in the cylinder if the density of oxygen is 1.4 kg/m^3 at standard temperature and pressure.

4. A fixed mass of gas is held at 30 °C. To what temperature must it be heated if its volume doubles whilst its pressure remains constant?

5. A sealed chamber contains a fixed mass of gas at a pressure of 1.75 x 10^5 Pa when the temperature is 19 °C. At what temperature will the pressure inside the chamber be 2.75 x 10^5 Pa.

6. A fixed mass of gas has a volume 250 cm^3 at a temperature of 67 °C and a pressure of 1.04 x 10^5 Pa. Find the volume of the gas at standard temperature and pressure.

7. A helium-filled balloon is released at ground level, where the temperature is 17 °C and the pressure is 1.0 atmosphere. The balloon rises to a height of 2.5 km, where the pressure is 0.75 atmospheres and the temperature is 5 °C. Calculate the ratio of the volume of the balloon at 2.5 km to that at ground level.

8. A gas cylinder has a volume of $0.050\ m^3$ and contains air at a pressure of 2.5 MPa. Assuming all changes are isothermal, determine:

   i) the equivalent volume of air at atmospheric pressure;

   ii) the volume of air, at atmospheric pressure, which escapes from the cylinder when it is opened to the atmosphere.

9. A gas cylinder has a volume of $2.5 \times 10^{-2}\ m^3$. It contains a gas at a temperature of 23 °C and an excess pressure of 4.2×10^5 Pa above atmospheric pressure. Calculate the mass of gas in the cylinder, given that the density of the gas at standard temperature and pressure is $1.34\ kg/m^3$

10*. A flask containing air is corked when the atmospheric pressure is 1.01×10^5 Pa and the temperature is 18 °C. The temperature of the flask is now raised slowly. The cork, which has a mass of 25 g and a cross-sectional area of $3.14 \times 10^{-4}\ m^2$, shoots out vertically upwards when the pressure in the flask exceeds atmospheric pressure by 2.00×10^4 Pa. Determine:

   i) the temperature of the flask when this occurs;

   ii) the resultant force acting on the cork;

   iii) the initial acceleration of the cork.

11*. On a day when the atmospheric pressure is 102 kPa and the temperature is 8 °C, the pressure in a car tyre is 190 kPa above atmosphere pressure. After a long journey the temperature of the air in the tyre rises to 29 °C. Calculate the pressure above atmospheric of the air in the tyre at 29 °C. [Assume the volume of the tyre remains constant].

12*. A metal box in the form of a cube of side 30 cm is filled with air at a pressure of 1.01×10^5 Pa at 15 °C. The box is sealed and heated in an oven to 200 °C, then brought out into normal atmospheric conditions. Calculate the net force on each side of the box.

13*. A fixed mass of an ideal gas has a pressure p. If its thermodynamic temperature is trebled and its volume doubled, what does its pressure become (in terms of p)?

14**. Two containers, each of equal and constant volume, are connected by a tube of negligible volume. When the temperature of both containers is 27 °C, the pressure of the gas in the containers is 2.1×10^5 Pa. One container is heated to a temperature of 127 °C, whilst the other is maintained at 27 °C. Calculate the final pressure in the containers.

Part 2 - Ideal Gases

1. A cylinder of volume 0.20 m^3 contains gas at a pressure of 200 kPa and a temperature of 290 K. Calculate:
   i) how many moles of gas are present in the cylinder;
   ii) how many molecules of gas are present in the cylinder.

2. A balloon is filled with air until its volume is 0.002 m^3 and the pressure is 105 kPa. The temperature of the air is 290 K. Determine:
   i) how many molecules are present in the balloon;
   ii) how many more molecules must be blown into the balloon to increase its pressure to 120 kPa. Assume that the volume and temperature remain constant throughout the inflation.

3. The volume of a sample of gas is 3.2×10^{-2} m^3 when the pressure is 8.6×10^4 Pa and the temperature is 27 °C. Determine:
   i) how many moles of gas there are in the sample;
   ii) how many molecules of gas there are in the sample;
   iii) the number of molecules per cubic metre.

4. A volume of 1.50×10^3 m^3 of hydrogen, at a pressure of 2.00×10^5 Pa and a temperature of 30 °C, is heated until both volume and pressure are doubled. Determine:
   i) the final temperature;
   ii) the mass of hydrogen gas (molar mass of H_2 is 2 g/mol).

5. Determine the number of molecules per cubic metre of air at standard temperature and pressure.

6. One mole of an ideal gas at a pressure of 1×10^6 Pa and temperature 300 K occupies a volume of 25 dm^3. At 600 K and 5×10^5 Pa, determine the volume occupied in m^3.

7. A particular balloon has the capacity to hold 100 litres of air. If a person blows up this balloon to maximum capacity with 3 moles of oxygen gas at a pressure of 1 atmosphere, what will the temperature of the air inside the balloon be?

8. The mean mass of one mole of air is 0.029 kg. What is the density of air at standard temperature and pressure?

9. The molar mass of chlorine is 3.55×10^{-2} kg. A sample of Cl_2 gas contains 6.02×10^{22} molecules. Determine:

i) the number of moles of the gas;

ii) the mass of the gas;

iii) the volume occupied by the gas at a pressure of 1.15×10^5 Pa and a temperature of 290 K.

10*. Consider one mole of gas at standard temperature and pressure. Calculate:

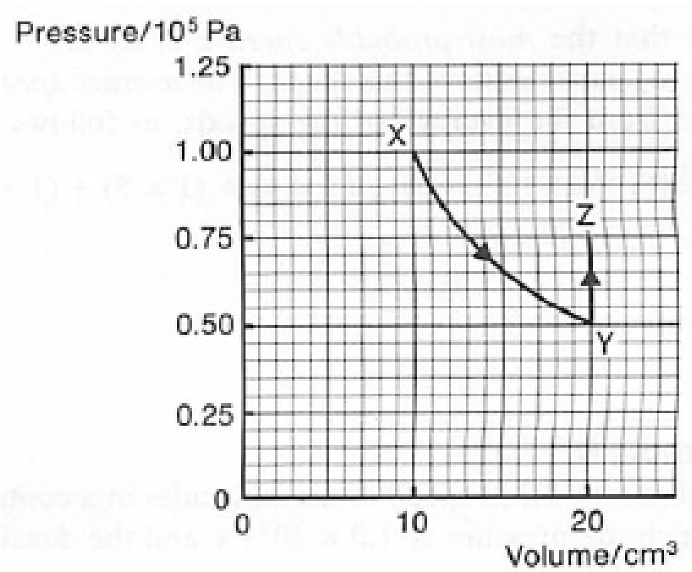
i) the Loschmidt number N_L, i.e. the number of molecules there are per cubic metre of this gas;

ii) the average distance between the molecules.

If the diameter of a molecule of this gas is about 2.5×10^{-10} m, estimate:

iii) the fraction of each cubic metre that is occupied by matter.

11*. A fixed mass of an ideal gas, temperature 300 K, has the pressure and volume indicated by the point X on the graph below. The graph is taken through the changes represented by the path XYZ.



Determine the temperature of the gas at the point Z.

12*. A vessel of volume $0.20\ m^3$ contains a mixture of 2.0 g of hydrogen molecules and 4.0 g of helium atoms. The temperature is 320 K. Determine:

i) the number of moles of each gas;

ii) the total number of moles of gas present;

iii) the pressure in the vessel.

13**. Two vessels, one having three times the volume of the other, are connected by a narrow tube of negligible volume. Initially the whole system is filled with gas at a pressure of 1.05×10^5 Pa and a temperature of 290 K. The smaller vessel is then cooled to 250 K and the larger vessel heated to 400 K. Determine the final pressure in the system.

Part 3 - Energy and Temperature

1. Find the average kinetic energy of a molecule in an ideal gas at a temperature of 10 K.

2. What is the temperature of a gas if its molecules have an average kinetic energy of 6.21×10^{-21} J?

3. What is the average kinetic energy at 288 K of the atoms/molecules of the following gases: hydrogen; chlorine; radon.

4. Some helium, which has a molar mass of 4.0×10^{-3} kg, is contained within a chamber of volume 8.0×10^{-4} m^3 at a temperature of 300 K. The pressure of the gas is 200 kPa. Determine:
   i) the mass of helium present;
   ii) the internal energy of a single helium atom;
   iii) the total internal energy of the gas.

5. Find the total kinetic energy of the molecules in one mole of an ideal gas at standard temperature.

6. If the mean speed of the molecules in an ideal gas is doubled, by what factor does the thermodynamic temperature of the gas increase?

7. Find the root-mean-square speed (r.m.s. speed) of the molecules in oxygen gas at -12 °C. The mass of an oxygen molecule is 5.3×10^{-26} kg.

8. Estimate the r.m.s. speed of helium atoms near the surface of the Sun, where the temperature is 6000 K. The mass of a helium atom is 6.6×10^{-27} kg.

9*. A mixture of two gases X and Y is contained within a constant temperature enclosure. The molecular mass of X is four times the molecular mass of Y. Determine the ratio of the r.m.s. speed of the molecules of X to the r.m.s. speed of the molecules of Y.

10*. A fixed mass of an ideal gas at pressure P is heated at constant volume until the pressure becomes 2P. What will the r.m.s. speed of the molecules be if their initial r.m.s. speed was v?

11*. A cylinder is fitted with a frictionless piston and contains one mole of gas at a constant pressure of 500 kPa. The area of the piston is 1.0×10^{-2} m^2. Initially, the volume in the cylinder is 5.0×10^{-3} m^3. Determine:
   i) the force the gas initially exerts on the piston;
   ii) the initial temperature of the gas.

   The gas forces the piston to move 5 mm. This causes the pressure to drop to 200 kPa. Determine:
   iii) the final temperature of the gas.

Answers - The Kinetic Theory of Gases Supplementary Questions

Part 1

1. 8.68×10^{-6} m^3
2. 1.48×10^5 Pa
3. i) 1.27×10^{-1} m^3 ii) 0.178 kg
4. 333 °C
5. 186 °C
6. 207 cm^3
7. 1.28
8. i) 1.24 m^3 ii) 1.19 m^3
9. 0.159 kg

10*. i) 349 K ii) 6.03 N
iii) 241 m/s^2

11*. 212 kPa

12*. 5840 N

13*. 3p/2

14**. 2.4×10^5 Pa

Part 2

1. i) 16.6 mol ii) 1.00×10^{25}
2. i) 5.25×10^{22} ii) 7.47×10^{21}
3. i) 1.10 mol ii) 6.65×10^{23}
iii) 2.08×10^{25} molecules/m^3
4. i) 939 °C ii) 2.38×10^2 kg
5. 2.68×10^{25} molecules/m^3
6. 0.1 m^3
7. 132 °C
8. 1.29 kg/m^3
9. i) 0.1 mol ii) 3.55×10^{-3} kg
iii) 2.10×10^{-3} m^3

10*. i) 2.68×10^{25} molecules/m^3
ii) 3.34×10^{-9} m iii) 2.19×10^{-4}

11*. 450 K

12*. i) H_2: 1 mole; He: 1 mole
ii) 2 moles iii) 2.66×10^4 Pa

13**. 1.26×10^5 Pa

Part 3

1. 2.07×10^{-22} J
2. 300 K
3. 5.96×10^{-21} J (for each gas)
4. i) 2.57×10^{-4} kg ii) 6.21×10^{-21} J
iii) 240 J
5. 3400 J
6. Factor of 4
7. 452 m/s
8. 6130 m/s

9*. 0.5

10*. $\sqrt{2}\, v$

11*. i) 5000 ii) 301 K
iii) 122 K