CHEMISTRY 135
THE GAS LAWS AND RELATED MATTERS

Attempt all of the following questions if possible. You will probably not be asked to submit them for marking. However, you should submit at least some answers to your lecturer for feedback. Remember that setting out, logical argument, and the inclusion of correct units are all extremely important. Answers are given at the end of the document.

1) Account for the following observations in terms of the kinetic theory of gases.
   a) The volume of a gas is easily decreased by increasing the applied pressure.
   b) Gases are generally miscible in all proportions.
   c) The pressure exerted by a gas increases as its temperature increases.
   d) 6 grams of nitrogen in a vessel of volume $3dm^3$, at a certain temperature and pressure, exert twice the pressure of 3 grams of nitrogen under the same conditions.
   e) The rates of diffusion and effusion of gases increase as the temperature increases.

2) What is meant by the term ***ideal gas***? What laws do ideal gases obey? What does the temperature of an ideal gas measure according to the kinetic theory of matter?

3) The volume of a sample of gas at a temperature of 300K and a pressure of 100 000 Pa is 6•00 dm^3. What is its volume at 250 K and 80 000 Pa?

4) a) The pressure on a sample of gas is doubled. What happens to the volume provided the temperature remains constant?
   b) i) The kelvin temperature of a gas is halved. What happens to the volume of the gas provided the pressure remains constant?
      ii) If the Celsius temperature of a gas is halved can you say anything about what happens to the volume?
   c) The pressure of a sample of gas is tripled and the kelvin temperature is reduced to one third of its previous value. What happens to the volume?

5) A sample of gas occupies a volume of 250 cm^3 at a pressure of 1.2atm and a temperature of 27°C. The volume is reduced to $200cm^3$ and the temperature increased to 77°C. What is the new pressure?

6) A sample of oxygen gas occupies a volume of 30 cm^3 when kept in a fridge. Its temperature is 2°C and its pressure is 760 mmHg. Later the oxygen is transferred to a larger container and allowed to come up to room temperature. Its volume is now 35 cm^3 and the pressure of the gas is measured as 805 mmHg. What is room temperature in this case?

7) 25 cm^3 of hydrogen gas were collected at a pressure of 740 mmHg and a temperature of 22°C. What would its volume be at S.T.P.?

8) The volume of gas in a syringe is found to be 90 cm^3 when immersed in a freezing mixture. The syringe had originally been filled to 100 cm^3 at 25°C. What must have been the temperature of the freezing

mixture in °C if the pressure remained constant throughout?

9) 100 feet beneath the surface of the sea the pressure is 4 atmospheres. A diver with a lung capacity of 2 dm^3 takes a breath of air at this depth from a tank on his back and then quickly rises to the surface. Assuming that the temperature remains constant, calculate the volume that the air in the diver's lungs should occupy at the surface and use your result to explain why the diver must blow bubbles as he rises.

10) 0•500mol of an ideal gas exert a pressure of 100 Pa at a temperature of 35°C. Calculate the volume of the container. (R = 8•31 $Jmol^{-1}K^{-1}$)

11) 2520 dm^3 of helium is pumped into a meteorological balloon at sea level where the temperature is 27°C and the pressure is 1.00 atm. It rises to a height where the pressure is only 0.500 atm and the temperature -60°C.
   a) Calculate the volume of the balloon assuming the external pressure is equal to the internal pressure.
   b) How many moles of gas does the balloon contain?
   c) Calculate the mass of helium and the mass of air it displaces and hence the lift of the balloon. (RAM of He = 4.00, Air = 28.8)

12) Calculate the pressure inside a television picture tube given that its volume is 5•00 dm^3, its temperature is 23°C, and it contains 0•010mg of nitrogen. (RAM of nitrogen = 14•0, R = 8•31 $Jmol^{-1}K^{-1}$)

13) a) Starting with the ideal gas law, derive an expression relating the density of a gas (in g m^{-3}) to its relative molecular mass, pressure, and temperature. Adapt your expression to show the density in g dm^{-3}.

   b) The average relative molecular mass of air is 28•96. Calculate the density of air at 101•3kPa and 25°C. The density of water is 1000gdm^{-3}. How can you explain this great discrepancy (especially in view of the fact that a water molecule is only about half as heavy as an air molecule)?

   c) The compound geraniol is a sweet smelling oil which can be extracted from roses. At 260°C and 0•136atm it is found that the density of geraniol vapour is 0•480 g dm^{-3}. Calculate its relative molecular mass.

14) Calculate the density of $CCl_4(g)$ in g m^{-3} at 50°C and 744 mmHg pressure.

15) Calculate the molar mass of a gas if 10.0 L weighs 9.25 g at 0.986 atm pressure and 65°C.
If the empirical formula of the gas is CH, what is its molecular formula?

16) A gas had a density of 1.96 g dm^{-3} at 100°C and 0.770 atm pressure. If it is 7.7% hydrogen and 92.3% carbon by mass, what is its molecular formula?

17) What is meant by the term "real gas"? Name two real gases. Can you name an ideal gas? Why do you think that you spend so much time studying ideal gases when they don't exist? Under what conditions does a real gas behave least like an ideal gas? What factors are principally responsible for this non-ideal behaviour?

18) Define the term "partial pressure". In a mixture of three gases, the partial pressure of nitrogen is 0•55 atm, that of argon is 0•25 atm, and that of oxygen is 0•30 atm. What is the pressure of the mixture?

19) What are the partial pressures of each of the gases in air at 1•00 atm given that its composition is 78•09% nitrogen, 20•95% oxygen, 0•93% argon, and 0•03% carbon dioxide, all percentages by volume.

20) a) Two glass bulbs have the same volume. One is filled with oxygen, and the other is filled with sulphur dioxide gas, both being at the same temperature and pressure.
   i) Compare the number of moles of the gases.
   ii) Compare the number of molecules of the gases.
   iii) Compare the number of grams of the gases.
   iv) Compare the rates of effusion of the gases.
b) The kelvin temperature of the oxygen gas is now doubled, the volume remaining constant.
   i) How does the pressure of the two gases now compare?
   ii) Compare the number of moles of the two gases.
c) The contents of the bulbs are now restored to the same temperature and pressure and the two bulbs connected via a porous plug through which slow diffusion can take place. How does the pressure vary on the oxygen side of the plug as compared with the pressure on the sulphur dioxide side of the plug?

21) a) Calculate the final volume if the pressure of 1 dm^3 of hydrogen is increased from 1•00 atm to 2•00 atm at constant pressure.
b) Calculate the final volume if the pressure of 500 cm^3 is decreased from 753 mmHg to 693 mmHg at constant temperature.
c) Calculate the final pressure when 1 dm^3 of air at 1•00 atm expands to 2•00 dm^3 at constant temperature.
d) Calculate the final pressure if a sample of air at 760•0 mmHg is heated from 0°C to 25°C in a sealed container.
e) Calculate the volume at s.t.p. of a sample of gas whose volume is measured as 450 cm^3 at 35°C and 770 mmHg.

22) a) Calculate the volume occupied by sample of gas after drying if the volume is measured over water as 98 cm^3 at a pressure of 760 mmHg. The vapour pressure of water at this temperature is 30 mmHg.
b) 3 mol of argon is mixed with 2 mol of xenon gas and the total pressure is found to be 10 000 Pa. What is the partial pressure of each gas?
c) A flask contains 2 dm^3 of hydrogen at 3×10^5 Pa. A second flask contains 6 dm^3 of argon at 1×10^5 Pa pressure. If the flasks are connected what will be the final pressure if the temperature remains constant throughout?
d) 1•6 g of oxygen and 0•08 mol of nitrogen are placed in a vessel of volume 150 cm^3 at 10°C. What is the pressure of the mixture?

23) Calculate the number of moles of hydrogen sulphide (H_2S) in :
a) 12 g of this gas.
b) 6.00 dm^3 of the gas at s.t.p.

c) $6 \bullet 0$ dm^3 of the gas at 100°C and 737 mmHg.

24) It is possible under special conditions to obtain pressures as low as 10^{-10} mmHg. calculate the number of molecules in $22 \bullet 4$ dm^3 of hydrogen at this pressure and 10°C.

25) Find the density in g dm^{-3} of chlorine trifluoride gas (ClF_3) at:
   a) s.t.p.
   b) 20°C and 764 mmHg.

26) a) A certain volume of an unknown gas weighs $1 \bullet 945$ g under certain conditions of temperature and pressure. The same volume of nitrogen under the same conditions weighs $1 \bullet 000$ g. If the relative atomic mass of nitrogen is known to be 14, calculate the relative molecular mass of the unknown gas.
   b) If the gas in part (a) is found on analysis to consist of $34 \bullet 9\%$ fluorine and $65 \bullet 1\%$ chlorine find its molecular formula.

27) A gas has a density of $1 \bullet 27$ g dm^{-3} at 30°C and 747 mmHg pressure. Find the molar mass of the gas.

28) $0 \bullet 612$ g of a gas occupy a volume of 419 cm^3 at 70°C and 742 mmHg. Calculate the relative molecular mass of the gas.

29) 1 dm^3 of argon takes 15 minutes to effuse through a small orifice. The same volume of a second gas takes 30 minutes to escape through the same hole. What is the relative molecular mass of the second gas?

30) It takes 1 hour for 1 dm^3 of methane to escape through a tiny hole in a gas cylinder. How long would it take the same volume of helium to escape under the same conditions?

31) $0 \bullet 001$ mol each of oxygen and nitrogen are placed in a gas syringe. The syringe is connected through a tap to a very narrow jet. The syringe is mounted vertically and a weight placed on top of the syringe plunger. The tap is opened and the gases allowed to escape. Calculate the composition (in terms of the relative numbers of moles of oxygen and nitrogen) of the gas first escaping from the syringe.

32) A container filled with a sample of gas is connected to a mercury manometer. The level of mercury in the limb connected to the container is 15mm higher than in the limb open to the atmosphere. The pressure of the atmosphere was separately recorded as 740mmHg. Sketch the set up of the apparatus. Is the pressure in the container lower or higher than atmospheric? Calculate it's value in (i) mmHg, (ii) atmospheres, and (iii) Pascals.

33) How tall would a barometer have to be to measure an atmospheric pressure of 1 standard atmosphere if it contained water rather than mercury? (Neglect the vapour pressure of water for this first calculation.) The vapour pressure of water is about 32mmHg at 30°C. What would be the height of the water column at this temperature taking this vapour pressure of water into account? (The densities of water and mercury are $1 \bullet 00$ and $13 \bullet 5$ g cm^{-3} respectively.)

34) Small pressure differences are often measured using a manometer filled with water rather than mercury. Give three

advantages to using water rather than mercury under these conditions.

Answers

1) a) The molecules of a gas are far apart and therefore easily pushed closer together.
   b) For the same reason as in (a). The molecules of a gas can easily pass between the molecules of another gas. In addition, forces between molecules of a gas are very weak.
   c) The molecules move more rapidly as temperature increases. They therefore hit the walls more frequently and more violently. This amounts to a higher pressure.
   d) 6g of nitrogen contain twice as many molecules as 3g of nitrogen under the same conditions of T & P. Therefore the collisions of molecules with the walls of the container are twice as frequent, giving double the pressure.
   e) As the temperature increases the average speed of the molecules increases. If the molecules are moving faster they can diffuse and effuse more quickly.

2) Ideal gas: one in which the molecules take up no volume and in which forces between molecules are zero. They obey Boyle's and Charles's laws, as well as Gay-Lussac's, Graham's and Dalton's laws. Temperature measures the average kinetic energy of the molecules (not average speed).

3) 6•25 dm^3

4) a) The volume is halved.
   b) i) The volume is halved
      ii) No.
   c) The volume is reduced to one ninth of its previous value.

5) 1•75atm

6) "Room temperature" turns out to be 67°C. This seems to be a little excessive.

7) 22•5cm^3

8) -5°C

9) 8dm^3

10) 12•8m^3

11) a) 3580 dm^3
    b) 102 mol
    c) 409 g, 2950 g, lift = 2540 g

12) 0•176 Pa

13) a) PV = nRT and n = m/M, where m is the mass in grams and M is the molar mass.
    ∴ Substituting for n we have
    PV = (m/M)RT
    ∴ PM = (m/V)RT
    But m/V is the density of the gas (D) in g m^{-3}
    ∴ PM = DRT
    or D = PM/(RT) Q.E.D.
    b) 1•18 kg m^{-3}. This is roughly 1000 times less than the density of water under the same conditions. This discrepancy arises because the molecules of air are separated by relatively large distances, whereas those of water, though lighter, are packed together much more tightly.
    c) 155 (Published value: 154•25)

14) 5670 g m^3

15) 26.0 g mol^{-1}, C_2H_2

16) C_6H_6

17) A real gas is any gas which actually exists, such as nitrogen or oxygen. Real gases do not obey the gas laws exactly since there are forces acting between the molecules and the molecules have a finite volume. These are the principal differences between real gases and ideal gases, in which there are no intermolecular forces and in which the molecules have no volume. An ideal gas cannot be named since no real gas is ideal. Ideal gases are important because they obey simple laws, and under most conditions real gases behave approximately like ideal gases.

18) The partial pressure of a gas is the pressure it would have if it alone filled the container at the same temperature.

19) 1•1atm

20) 0•781atm, 0•210atm, 0•0093atm, and 0•0003atm (nitrogen, oxygen, argon, and carbon dioxide respectively)

21) a) 0•5dm^3
    b) 543cm^3
    c) 0•5atm
    d) 830mmHg
    e) 404cm^3

22) a) 94cm^3
    b) Partial pressure of argon = 6000Pa
    Partial pressure of xenon = 4000Pa
    c) 1•5x10^5Pa
    d) 2•0x10^6Pa

23) a) 0•35mol
    b) 0•27mol
    c) 0•19mol

24) 8x10^{10}

25) a) 4•12kgm^{-3}
    b) 3•86kgm^{-3}

26) a) 54•5
    b) ClF

27) 32•2$gmol^{-1}$

28) 42•2

29) 160

30) 0•5hr

31) 48% O_2, 52% N_2

32) LOWER, 725 mmHg, 0•954 atm, 96 300 Pa

33) 10•3 m, 9•83 m

34) a) H_2O gives a larger change in height than Hg for a smaller pressure difference.
    b) H_2O is more readily available than Hg.
    c) H_2O is non-toxic whilst Hg is not.
    d) H_2O is much cheaper than Hg.