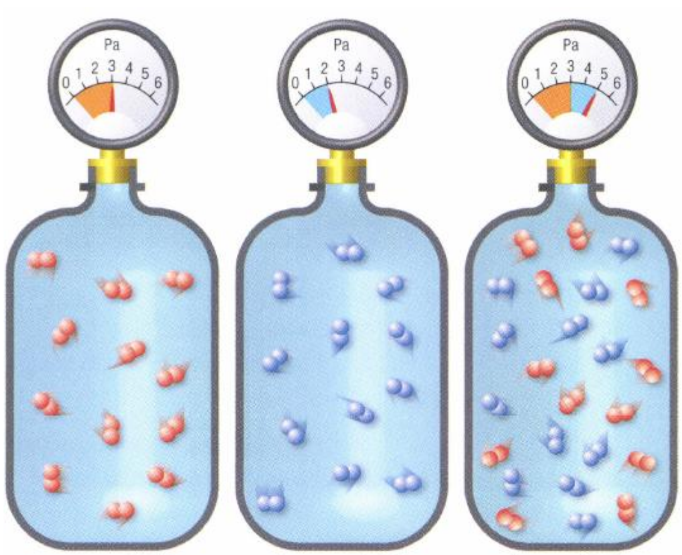
5.2 Partial and Vapour Pressures of Gases

Partial Pressure

When Dalton was conducting his studies, which led him to the atomic-molecular theory of matter, he also included studies of the behaviour of gases. These led him to propose, in 1803, what is now called ______________________________:

For a mixture of gases in a container, the total pressure exerted is the sum of the pressures that each gas would exert if it were alone.

This law can be expressed in equation form as:



oxygen at 3 Pa

nitrogen at 2 Pa

a mixture of nitrogen gas and oxygen gas at 5 Pa

where p is the total or measured pressure and p1, p2, ... are the partial pressures of the individual gases. For air, an appropriate form of Dalton's law would be:

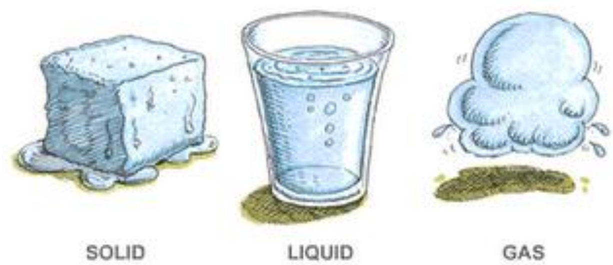
At temperatures near ordinary room temperature, the __________________________ of each of the components of air is directly proportional to the number of ________ of that component in any volume of air.

When the total pressure of air is 100 kPa or one bar, the partial pressures of each of its components (in kPa) are numerically equal to the mole per cent of that component (Table).

Thus the partial pressures of the major components of dry air at ____ kPa are nitrogen, ___ kPa; oxygen, ___ kPa; argon, ___ kPa; and carbon dioxide, ___ kPa.

The same substance may be found in different physical states under different conditions.

Water, for example, can exist as a solid phase (ice), a liquid phase (water), and a gas phase (steam or water vapour) at different temperatures.



The processes by which a substance is converted from one phase to another are called by specific names.

- The conversion from solid to liquid is ____________ and the reverse conversion from liquid to solid is ________________.
- The conversion from liquid to gas is called boiling or ________________ and the reverse conversion from gas to liquid is called _______________.
- The conversion from solid to gas, when it occurs directly without going through a liquid state as in the case of iodine and carbon dioxide, is called ___________________; the reverse conversion from gas to solid shares the name of _________________________.

Sample: In a compressed air tank for scuba diving to a depth of 30 m, a mixture with an oxygen partial pressure of 28 atm and a nitrogen partial pressure of 110 atm is used. What is the total pressure in the tank?

Table: Composition of Dry Air at Sea Level

Component	Mole Percent	Molar Mass
N_2	78.08	28.013
O_2	20.948	31.998
Ar	0.934	29.948
CO_2	0.0314	44.010
Ne	0.001818	20.183
He	0.000524	4.003
CH_4	0.002	16.043
Kr	0.000114	83.80
H_2	0.00005	2.016
N_2O	0.00005	44.013
Xe	0.0000087	131.30

Table Footnotes: The amounts of water vapour and of trace gases such as ozone, carbon monoxide, sulfur dioxide, nitrogen dioxide, and ammonia in air are variable under natural conditions.

Unusually high concentrations of these gases are often found in urban air as a result of human activities.

The values given as ______________________ in this table are numerically equal to the partial pressures of the gases, in kPa, when the total atmospheric pressure is 100 kPa or one bar.

Sample 2: Beyond 60 m, compressed air is not used for underwater diving because of the toxicity of oxygen at high partial pressures. Suppose a commercial diver needs to work at a pressure of 14.0 atm using a helium–oxygen breathing mixture (known as heliox) containing 1.1 atm of oxygen. What is the partial pressure of helium in this mixture?

Vapour Pressures

All solids and liquids, that is, all substances in condensed phases, exhibit a vapour pressure. This is a pressure of the substance in the gas phase which is established at a particular temperature. The vapour pressure of a substance depends upon the temperature. A table of vapour pressures at 25°C for a few selected substances is given below.

Table: Vapor Pressures and Densities of Pure Substances at 25°C

Substance	**Vapour Pressure (kPa)**	**Density (kg/m^3)**
$H_2O(l)$	3.1691	0.99702
$CH_3OH(l)$	16.8511	0.791
$C_2H_5OH(l)$	7.8279	0.785
$C_6H_6(l)$	12.6893	0.899
Hg(l)	0.2460	13.5340
$I_2(s)$	0.1889	4.93

If a dish of water is placed in a chamber which is evacuated by means of a vacuum pump, the pressure will drop only until the vapour pressure of water at that temperature is reached. The liquid water will then boil, replacing the water vapour as the pump removes it, until either the liquid water has all boiled away or the pump is shut off. The pressure in the chamber while this is going on will remain constant at the vapour pressure of water.

The vapour pressure of any pure substance is characteristic of that substance and of the temperature. At room temperature the vapour pressure of ethanol is much higher, and the vapour pressure of mercury or potassium chloride is much lower, than is the vapour pressure of water. Since water is the most important as well as one of the most common substances on earth, its vapour pressure at different temperatures is given in the Table below.

Table: Vapour Pressure and Density of Water at Different Temperatures

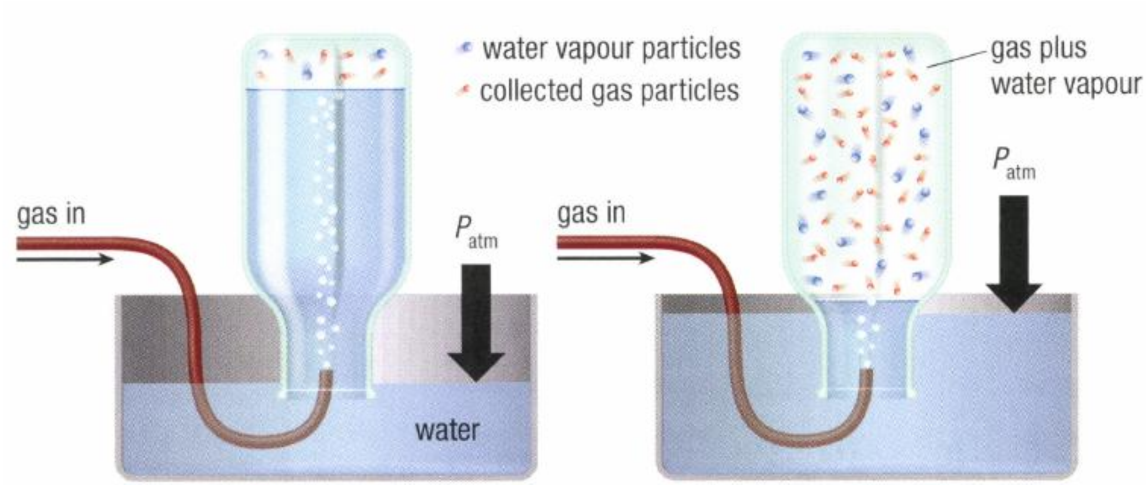
Temperature (^oC)	**Vapor Pressure (kPa)**	**Density (kg/m^3)**
0.01	0.61173	0.99978
1	0.65716	0.99985
4	0.81359	0.99995
5	0.87260	0.99994
10	1.2281	0.99969
15	1.7056	0.99909
20	2.3388	0.99819
25	3.1691	0.99702
30	4.2455	0.99561
35	5.6267	0.99399
40	7.3814	0.99217
45	9.5898	0.99017
50	12.344	0.98799
55	15.752	0.98565
60	19.932	0.98316
65	25.022	0.98053
70	31.176	0.97775
75	38.563	0.97484
80	47.373	0.97179
85	57.815	0.96991
90	70.117	0.96533
95	84.529	0.96192
100	101.325	101.32
105	120.79	0.95475

The __________________________ of all substances __________________,

and in many cases increases very significantly, with ______________________. The bond structure of solids is in general stronger than that in liquids, and as a general rule the vapour pressures of solids are much lower than those of similar liquids at the same temperature.

Vapour Pressure As a Partial Pressure

Collection of gases over any liquid which has a vapour pressure, such as water, is carried out as shown in the Figure below.



The total pressure measured, p, is the sum of the partial pressure of the collected gas and the partial pressure of the liquid, which is its vapour pressure. If the liquid is water, as is most often the case, the pressure of the gas collected must be:

The measured or total pressure is obtained using a barometer and manometer. The vapour pressure of water at the appropriate temperature is obtained from a table such as that given above.

Example: A volume of 546.3 mL of hydrogen is collected over water at 30°C when the atmospheric pressure is 100.45 kPa. The actual pressure of the hydrogen and the amount of hydrogen present are calculated as follows.

Sample: In a laboratory, oxygen gas was collected by water displacement at an atmospheric pressure of 96.8 kPa and a temperature of 22°C. Using the previous table, calculate the partial pressure of dry oxygen.

Worksheet 5.2: Partial and Vapour Pressure

1. A gas mixture consists of 60.0% Ar, 30.0% Ne, and 10.0% Kr by volume. If the pressure of this gas mixture is 80.0 kPa, what is the partial pressure of each of the gases?

2. The total pressure of a mixture of H_2, He, and Ar is 99.3 kPa. The partial pressure of the He is 42.7 kPa, and the partial pressure of Ar is 54.7 kPa. What is the partial pressure of hydrogen?

3. A cylinder contains 40 g of He, 56 g of N_2, and 40 g of Ar.
a. How many moles of each gas are in the mixture?
b. If the total pressure of the mixture is 10 atm, what is the partial pressure of He?

4. What is the partial pressure of each gas in a mixture which contains 40 g of He, 56 g of N_2, and 16 g of O2, if the total pressure of the mixture is 505 kPa?

5. The composition of dry air by volume is 78.1% N_2, 20.9% O_2, and 1% other gases. Calculate the partial pressures, in atmospheres and kPa, in a tank of dry air compressed to 10.0 atmospheres.

6. When nitrogen is prepared and collected over water at 30°C and a total pressure of 98.4 kPa, what is its partial pressure in atm?

7. If you were to prepare oxygen and collect it over water at 10°C and a total pressure of 100.1 kPa, what is its partial pressure in atm, kPa and torr?

8. A sample of carbon monoxide was prepared and collected over water at a temperature of 20°C and a total pressure of 99.8 kPa. It occupied a volume of 275 mL. Calculate the partial pressure of this gas in the sample in kPa and its dry volume in mL under a pressure of 101.3 kPa.

9. A sample of hydrogen was prepared and collected over water at a temperature of 25°C and a total pressure of 98.1 kPa. It occupied a volume of 295 mL. Calculate its partial pressure, in atm, and what its dry volume would be in mL under a pressure of 101.3 kPa.

10. What volume of "wet" methane would you have to collect at 20°C and 98.6 kPa to be sure the sample contained 240 mL of dry methane at the same pressure?

11. What volume of "wet" oxygen would you have to collect if you needed the equivalent of 260 mL of dry oxygen at 101.3 kPa and the atmospheric pressure in the lab that day was 99.4 kPa? The oxygen is to be collected over water at a temperature of 15.0°C.

12. Exactly 100 mL of oxygen are collected over water at 25°C and 106.66 kPa. What is the pressure being exerted by the pure oxygen at 25°C.

13. In an experiment, a student collects 107 mL of hydrogen over water at a pressure of 104.8 kPa and a temperature of 31°C. What volume would this hydrogen occupy at SATP?

14. If 80.0 mL of oxygen are collected over water at 20°C and 95.0 kPa. What volume would the dry oxygen occupy at STP?

15. If 450 mL of hydrogen at STP occupy 511 mL when collected over water at 18°C, what is the atmospheric pressure?

16. In an experiment a student collects 58 mL of oxygen gas by the downward displacement of water at 18°C and 105 kPa pressure. What would the mass of the dry oxygen be?