**Chapter 2**

## **THE BEHAVIOUR OF GASES**

This chapter begins by describing molecular motion as a basis for developing the ideal gas equation and the properties of pressure. The text shows how variations in gas properties follow from the ideal gas equation. After showing how to treat gaseous mixtures, gas stoichiometry is addressed. The chapter ends by describing some of the chemistry of the Earth's atmosphere.

**Section 2.1**

**Pressure**

## **Learning Objective:** understand gas pressure and be able to express pressure in various units

We begin by showing that the collective result of countless collisions among gas molecules is pressure. Devices for measuring pressure, manometers and barometers, are described. Units of pressure and their conversion factors are presented. The influence of pressure on properties of substances and the need for tabulating properties at 1 bar are discussed in more detail in Chapters 3 and 12.

**Section 2.2**

**Describing Gases**

## **Learning Objective:** relate pressure, volume, temperature and amount of gas

This section begins by describing the gas relationships observed by Boyle, Charles, and other early scientists. The proportionalities between volume, pressure, temperature, and amount of gas are combined into the ideal gas equation, using the Kelvin scale for temperature. Variations on the ideal gas equation provide an approach to solving a number of quantitative gas problems.

**Section 2.3**

**Gas Mixtures**

## **Learning Objective:** use the concept of partial pressures in gas mixtures

Dalton’s law of partial pressures is introduced. Chemical compositions of gas mixtures are described in terms of mole fraction, parts per million, and parts per billion.

**Section 2.4**

**Gas Stoichiometry**

## **Learning Objective:** use stoichiometry to solve problems involving gas-phase chemical reactions

This section opens by pointing out that the ideal gas equation can be rearranged to give an equation for number of moles. Several sample problems are used to illustrate that calculations involving gas stoichiometry are no different conceptually than stoichiometric calculations presented in Chapter 1. This section concludes by reiterating the equations for determining moles of pure liquids or solids, liquid solutions, and gases, and then shows how to solve a stoichiometry problem in which all these equations must be employed.

**Section 2.5**

**Molecular View of Gases**

## **Learning Objective:** explain the basic concepts of kinetic molecular theory: molecular speed, energy, and the effects of temperature and volume on gas pressure

Here we describe molecular beam experiments that quantitatively characterize the distribution of molecular velocities and its relationship to energy and temperature. Kinetic energy distributions and average kinetic energy are discussed. Characteristics and the behaviour of ideal gases are presented.

**Section 2.6**

**Additional Gas Properties**

## **Learning Objective:** calculate gas densities and molar masses from pressure–volume–temperature data

This section shows how the ideal gas equation can be manipulated to determine the molar mass or the density of a gas under specific conditions. Focus 2-1, “Tools for Discovery: High Vacuum” emphasizes that many scientific experiments require gas densities low enough to provide collision-free environments and highlights mass spectrometry. Rates of gas movement, effusion, and diffusion, are discussed.

**Section 2.7**

**Real Gases**

## **Learning Objective:** calculate gas densities and molar masses from pressure–volume–temperature data calculate the pressure of a gas under nonideal conditions, and explain the deviations from ideality

This section discusses how gases at high pressure and/or low temperature deviate from the ideal gas equation. Corrections for both the molecular volume and the intermolecular forces lead to the van der Waals equation. Several gases are compared by plotting pV/nRT versus pressure. Reasons for non-ideal behaviour are discussed.

**Section 2.8**

**Chemistry of The Earth's Atmosphere**

## **Learning Objectives:** do calculations involving water vapour pressure and relative humidity and describe some of the basic chemistry of the troposphere

This final section describes the composition and chemistry of the Earth's atmosphere with emphasis on the troposphere. How the composition of the atmosphere changes with altitude is explored in Chapter 4. Vapour pressure is introduced in this section using water in the atmosphere as an example. Intermolecular forces and vapour pressure are discussed in more detail in Chapter 8. Formation and reactions of oxides of nitrogen and sulphur, major contributors to atmospheric pollution, are addressed. Focus 2-2, “Chemistry and the Environment: Does Human Activity Change the Weather?” discusses current trends in global climate.

**LECTURE OUTLINE - Chapter 2**

**THE BEHAVIOUR OF GASES**

I. Pressure

A. Measuring devices

1. Barometers are used to measure the pressure of the atmosphere

2. Manometers are used to measure the pressure of confined gases

B. Units of pressure

1. Standard atmosphere (atm)

2. Torr

a. One Torr is the pressure exerted by a 1 mm column of Hg

b. 760 Torr = 760 mm Hg = 1 atm

3. Pascal (Pa)

a. 1 Pa = 1 N/m2

b. 1 atm = 1.01325 x 105 Pa

4. Bar

a. 1 bar = 105 Pa

b. 1 atm = 1.01325 bar

II. Describing gases

A. Variations in gas properties

1. The volume (*V*) of a gas is inversely proportional to its pressure (*p*) when the amount of gas (*n*) and temperature (*T*) remain constant

2. The volume of a gas is directly proportional to its absolute temperature when the amount and pressure of the gas remain constant

3. The volume of a gas is directly proportional to the amount of gas when the pressure and temperature remain constant

B. Ideal gas equation

1. Ideal gas constant (*R*) = 0.08314 L bar mol-1 K-1 = 8.314 m3 Pa mol-1 K-1

2. *pV* = *nRT*

3. Any of the variables in the ideal gas equation can change or stay constant

A. Properties of ideal gas molecules

1. Volume

2. Intermolecular forces

3. Pressure

a. Effect of molecular mass

b. Effect of molecular velocity

B. Relationship between temperature and pressure

C. Molecular density

1. Effect of volume

2. Effect of number of molecules

D. Relationship between molecular density and pressure

III. Gas mixtures

A. Dalton's law of partial pressures

B. Expressing the composition of a gaseous mixture

1. Partial pressure

2. Mole fraction

3. Parts per million

4. Parts per billion

IV. Gas stoichiometry

A. Moles of gas are related to physical properties by the ideal gas equation

B. Moles ratios are given by coefficients in balanced equations

*Table 2-1* “Summary of Mole Relationships”

V. Molecular view of gases

A. Molecular density

B. Molecular speeds

1. Distribution of molecular speeds at a specified temperature

2. Effect of molecular mass

C. Kinetic energy

1. Temperature dependence

2. Relationship to molecular mass

*Table 2-2* “Some Gaseous Substances”

3. At a given temperature, all gases have the same molecular kinetic energy distribution

4. Average kinetic energy

a. Average kinetic energy differs from most probable kinetic energy

b. One mole of any gas has an average kinetic energy of 3/2 *RT*

D. Ideal gases

1. The volume occupied by the molecules of an idea gas is negligible compared with the volume of its container

2. The energies generated by forces among ideal gas molecules are negligible compared with molecular kinetic energies

3. Pressure

a. The total pressure exerted by a gas is the sum of the pressures of the individual molecules

b. The pressure of a gas is directly proportional to the amount of gas when temperature and volume remain constant

c. The pressure of a gas is directly proportional to the temperature when the amount of gas and volume remain constant

d. The pressure of a gas is inversely proportional to the volume when the amount of gas and temperature remain constant

VI. Additional gas properties

A. Molar mass can be determined from the temperature, volume, and pressure of a gas

B. Density

1. The density of a gas increases linearly with pressure at a given temperature

2. The density of a gas decreases linearly with temperature at a given pressure

3. Densities of different gases at the same temperature and pressure increase linearly with molar mass

C. Rates of gas movement

1. The average speed of a gas molecule depends on its temperature

2. Effusion

3. Diffusion

VII. Non-ideal (Real) Gases

1. Gas molecules have non-zero volumes and experience attractive forces
2. The van der Waals equation
3. The ‘a’ term
4. The ‘b’ term

*Table 2-3* “van der Waals Equation Constants”

VIII. The troposphere

A. Composition of dry air

*Table 2-4* “Composition of Dry Air at Sea Level”

B. Water vapour

1. Vapour pressure

*Table 2-5* “Vapour Pressures (*pvap*) of Water at Various Temperatures (*T*)”

2. Relative humidity

C. Chemical reactions in the troposphere

1. Oxides of nitrogen

2. Oxides of sulphur

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**Suggestions for relating “The Behaviour of Gases” to real-life experiences**

Pressure units, barometers, and monometers can be introduced by discussing weather reports and the atmospheric pressure expressed in units of mm Hg, and by describing what is meant by “the barometer is rising, or falling.”

Relationships among the pressure, volume, temperature, and amount of gas can be related to the necessity of checking the pressure and adding air to automobile tires in the winter and removing air in the summer. A small balloon can be blown up and placed in a sink of hot water, and then cold water, to show the effect of temperature on the volume of a gas.

The dependency of gas density on temperature can be introduced by discussing hot air balloons.

Vapour pressure and relative humidity can be presented in the context of climate and/or changes in the weather.

Oxides of nitrogen and sulphur can be discussed in the context of air pollution.

CHAPTER 2 CONCEPT MAP

Gases

manometers

exert

exhibit properties as stated by the

applies to

gases collected over water

are related by

coefficients in balanced equations

can be used to calculate

compositions of gaseous mixtures

can be expressed as

gas density

can be calculated using

Dalton’s law

total pressure of a gaseous mixture

of individual gases sum to give the

parts per billion

parts per million

mole fractions

partial pressures

affects

molecular speed

kinetic

energy

molar mass

moles of gas

relates

volume

temperature

pressure

ideal gas equation

can be expressed in units of

can be measured with

barometers

bar

Torr

pascal

standard

atmosphere

the van der Waals equation

differ from

real gases

can be treated quantitatively using

ideal gases