4 • The Gas Laws

P R E S S U R E   U N I T S

1 atm = 760 mmHg = 760 torr = 101.3 kPa = 14.7 psi

Background:
Pressure is defined as Force / Area such as pounds per square inch (psi).
The weight of air pushing down per square inch is 14.7 pounds per square inch or **14.7 psi.**

A barometer can be used to measure pressure. A column of mercury (Hg) that is 0.760 meter (760 mm) tall has the same weight as a column of air from sea level to the edge of the stratosphere. The height of this column is a good measure of air pressure… **760 mmHg.**

Evangelista Torricelli did a lot of experiments with pressure and so 1 mmHg is also called 1 torr. So, air pressure has a value of **760 torr.** This amount of pressure is also called **1 atm** (one atmosphere) because it IS the atmosphere.

In metric units, pressure if Newtons (force) per square meter (area). One Newton is not very much pressure… about the weight of a small apple (get it… apple… Newton)… and if that force is exerted over a square meter, the amount of pressure is very small and called a pascal (Pa). It is more useful to talk of kilopascals (kPa) which would be the weight of 1000 small apples exerted over a square meter. Air pressure is equal to **101.3 kPa.**

Since each of these values (see the top of the page) represent the same amount of pressure, any two of them can be used as a conversion factor. You can convert one pressure unit into another.

Example:

What is 515 mmHg in kPa? $515 \text{ mmHg} \times \frac{101.3kPa}{760mmHg} = 68.6440789 \text{ kPa} = 68.4 \text{ kPa}$

Problems:

1. 745 mmHg into psi
2. 727 mmHg into kPa
3. 52.5 kPa into atm
4. 0.729 atm into mmHg
5. 522 torr into kPa
6. 1.10 atm into psi
7. 800. mmHg into atm
8. 125 kPa into torr

4 • The Gas Laws

BOYLE'S LAW

Boyle's Law states that the volume of a gas varies inversely with its pressure if temperature is held constant. (If one goes up, the other goes down.) We use the formula:

$$P_1 \times V_1 = P_2 \times V_2$$

Solve the following problems (assuming constant temperature). Assume all number are 3 significant figures.

1. A sample of oxygen gas occupies a volume of 250 mL at 740 torr pressure. What volume will it occupy at 800 torr pressure?

2. A sample of carbon dioxide occupies a volume of 3.50 Liters at 125 kPa pressure. What pressure would the gas exert if the volume was decreased to 2.00 liters?

3. A 2.00-Liter container of nitrogen had a pressure of 3.20 atm. What volume would be necessary to decrease the pressure to 1.00 atm?

4. Ammonia gas occupies a volume of 450 mL as a pressure of 720 mmHg. What volume will it occupy at standard pressure (760 mmHg)?

5. A 175 mL sample of neon had its pressure changed from 75.0 kPa to 150 kPa. What is its new volume?

6. A sample of hydrogen at 1.50 atm had its pressure decreased to 0.50 atm producing a new volume of 750 mL. What was the sample's original volume?

7. Chlorine gas occupies a volume of 1.20 liters at 720 torr pressure. What volume will it occupy at 1 atm pressure?

8. Fluorine gas exerts a pressure of 900 torr. When the pressure is changed to 1.50 atm, its volume is 250 mL. What was the original volume?

4• The Gas Laws

CHARLES'S LAW

Charles' Law states the volume of a gas varies directly with the Kelvin temperature, assuming the pressure is constant. We use the following formulas:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad \text{or} \quad V_1 \times T_2 = V_2 \times T_1$$

$$K = {}^\circ C + 273$$

Solve the following problems assuming a constant pressure. Assume all numbers are 3 significant figures.

1. A sample of nitrogen occupies a volume of 250 mL at 25 °C. What volume will it occupy at 95 °C?

2. Oxygen gas is at a temperature of 40 °C when it occupies a volume of 2.30 Liters. To what temperature should it be raised to occupy a volume of 6.50 Liters?

3. Hydrogen gas was cooled from 150 °C to 50 °C. Its new volume is 75.0 mL. What was its original volume?

4. Chlorine gas occupies a volume of 25.0 mL at 300 K. What volume will it occupy at 600 K?

5. A sample of neon gas at 50 °C and a volume of 2.50 Liters is cooled to 25 °C. What is the new volume?

6. Fluorine gas at 300 K occupies a volume of 500 mL. To what temperature should it be lowered to bring the volume to 300 mL?

7. Helium occupies a volume of 3.80 Liters at –45 °C. What volume will it occupy at 45 °C?

8. A sample of argon gas is cooled and its volume went from 380 mL to 250 mL. If its final temperature was –55 °C, what was its original temperature?

4 • The Gas Laws

THE COMBINED GAS LAW

In practical terms, it is often difficult to hold any of the variables constant. When there is a change in pressure, volume and temperature, the combined gas law is used.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \quad \text{or} \quad P_1 \times V_1 \times T_2 = P_2 \times V_2 \times T_1$$

$$K = °C + 273$$

Complete the following chart.

	P_1	V_1	T_1	P_2	V_2	T_2
1	1.50 atm	3.00 L	20.0 °C	2.50 atm		30.0 °C
2	720. torr	256. mL	25.0 °C		250. mL	50.0 °C
3	600. mmHg	2.50 L	22.0 °C	760. mmHg	1.80 L	
4		750. mL	0.00 °C	2.00 atm	500. mL	25.0 °C
5	95.0 kPa	4.00 L		101. kPa	6.00 L	471. K or 198. °C
6	650. torr		100. °C	900. torr	225. mL	150. °C
7	850. mmHg	1.50 L	15.0 °C		2.50 L	30.0 °C
8	125. kPa	125. mL		100. kPa	100 mL	75.0 °C

THE IDEAL GAS LAW

$PV = nRT$ where
P = pressure in atmosphere
V = volume in liters
n = number of moles of gas
R = Universal Gas Constant = 0.0821 L·atm/mol·K
T = Kelvin temperature

1. What is the pressure of 1.20 moles of SO_2 gas in a 4.00 L container at 30°C?

2. How many moles of oxygen will occupy a volume of 2.50 liters at 1.20 atm and 25 °C?

3. What is the volume of 0.60 moles of helium gas at 50°C if the pressure is 600 torr?

4. At what temperature will 1.80 moles of gas occupy 4.00 L if the pressure is 350 mmHg?

5. A balloon filled with helium has a volume of 1.30 L at 15°C when the atmospheric pressure is 700 torr. How many molecules of helium is in the balloon?

6. What is the mass of a 300 mL sample of gaseous hydrogen chloride at 2.0 atm and 30°C?

What is the density of this sample?

7. A 30.0 g sample of CH_4 occupies 150 mL at 0°C. What is the pressure of this sample of gas?

8. What volume (in liters) does a 85.0-g sample of CO_2 gas occupy at 1.40 atm and 80°C?

What is the density of this gas?

9. How many moles of an unknown diatomic gas are contained in a 500 mL container at 1.20 atm and 25°C?

If this unknown diatomic gas has a mass of 0.93 g, what is the molar mass of the gas? What is the gas?

4• Gases and Their Properties

STUDY QUESTIONS

1. Convert the following pressures to atm.
   a. 726 torr
   b. 2.31 bar
   c. 98 kPa
   d. 16.33 psi

2. Consider the following changes imposed upon a sample of gas, assuming the variables not mentioned remain constant:
   a. What happens to the pressure if the temperature in K is doubled?
   b. What happens to the volume if the pressure is tripled?
   c. What happens to the volume if the temperature decreases from 300K to 200K?
   d. What happens to the temperature if one-half of the gas is removed?
   e. What happens to the pressure if volume decreases from 4 Liters to 2 Liters and the temperature increases from 25°C to 323°C? (Note: in the answers to 2.e., there is a wrong word (doubled should be "halved" for the volume.)

3. Methane burns in air to produce carbon dioxide and water:

   $$CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(l)$$

   What volume of carbon dioxide, at 1 atm pressure and 112°C, will be produced when 80.0 grams of methane is burned?

4. What is the volume of 6 moles of helium gas at 0.34 atm pressure and 33°C? What is the density of the helium gas under these conditions?

5. Jacques Charles used the reaction of hydrochloric acid on iron to produce the hydrogen for one of his balloons. For one flight in 1783 he used 1000 lbs of iron and excess acid. What volume of hydrogen gas (in cubic meters) did he produce for this flight? Assume the pressure is 1 atm and the temperature is 22°C. $Fe(s) + 2\ HCl(aq) \rightarrow FeCl_2(aq) + H_2(g)$

6. If 1.0 Liter of oxygen at 2.0 atm pressure, 2.00 Liters of nitrogen at 1.0 atm pressure, and 2.0 Liters of helium at 2.0 atm pressure, are all mixed in a 3.0 Liter vessel with no change in temperature, what is the final pressure of the mixture in the 3.0 Liter vessel?

7. What is the partial pressure of oxygen in the atmosphere at the top of Mt. Everest? Atmospheric pressure at the summit of Mt. Everest is 253 torr. The partial pressure of oxygen in air at 1 atm pressure is 0.20946 atm.

8. An ideal gas occupies a volume of 10 Liters at 27°C. If the pressure on the gas is tripled at this temperature, the volume changes. To what value must the temperature change to restore the volume to the initial 10 Liters at the new pressure?

9. Using the Maxwell equation, calculate the root mean square speed of nitrogen gas at 25°C. What happens to the rms speed if the temperature is doubled to 50°C?

10. Imagine three automobiles traveling down the road at 20 mph, 34 mph, and 68 mph. Calculate the average speed and the rms speed. What is the significance of the rms speed?

11. A gas diffuses $^5/_3$ times faster than carbon dioxide. Which gas might it be?
a. O_2 b. N_2 c. CO d. He e. CH_4

12. For nitrogen, the van der Waals constants a and b have values of 1.39 and 0.0391 respectively. Calculate the pressure of 5 moles of nitrogen gas confined to a 1.0 Liter vessel at a temperature of 300K using the ideal gas equation and the van der Waals equation of state. Comment on the difference.

4• Gases and Their Properties

PRACTICE TEST

1. Which of the following represents the largest gas pressure?
   a) 5.0 torr
   b) 5.0 mmHg
   c) 5.0 atm
   d) 5.0 kPa
   e) 5.0 psi

2. A mixture of the gases neon and krypton is in a 2.00 Liter container. The partial pressure of the neon is 0.40 atm and the partial pressure of the krypton is 1.20 atm. What is the mole fraction of neon?
   a) 0.20
   b) 0.25
   c) 0.33
   d) 0.60
   e) 0.80

3. If the volume of a confined gas is doubled while the temperature remains constant, what change (if any) would be observed in the pressure?
   a) It would be half as large.
   b) It would double.
   c) It would be four times as large.
   d) It would be ¼ as large.
   e) It would remain the same.

4. A given mass of a gas in a rigid container is heated from 100°C to 500°C. Which of the following responses best describes what will happen to the pressure of the gas? The pressure will
   a) decrease by a factor of five.
   b) increase by a factor of five.
   c) increase by a factor of about two.
   d) increase by a factor of about eight.
   e) increase by a factor of about twenty-five.

5. A gas occupies a volume of 1.50 L at 400 mmHg and 100 °C. Which mathematical expression gives the correct volume at 700 mmHg and 200°C?
   a) $1.50 \text{ x } \frac{400}{700} \text{ x } \frac{373}{473}$
   b) $1.50 \text{ x } \frac{400}{700} \text{ x } \frac{473}{373}$
   c) $1.50 \text{ x } \frac{700}{400} \text{ x } \frac{373}{473}$
   d) $1.50 \text{ x } \frac{700}{400} \text{ x } \frac{473}{373}$
   e) $1.50 \text{ x } \frac{400}{700} \text{ x } \frac{200}{100}$

6. A 4.50 L flask of Ar at 23°C and 734 torr is heated to 55°C. What is the new pressure?
   a) 366 torr
   b) 935 torr
   c) 1.25 torr
   d) 1.07 atm
   e) 2.58 atm

7. At what temperature will 41.6 grams N_2 exert a pressure of 815 torr in a 20.0 L cylinder?
   a) 134 K
   b) 176 K
   c) 238 K
   d) 337 K
   e) 400 K

8. When 0.34 moles of He are mixed with 0.51 moles of Ar in a flask, the total pressure in the flask is found to be 5.0 atm. What is the partial pressure of Ar in this flask?
   a) 0.85 atm
   b) 1.5 atm
   c) 2.0 atm
   d) 3.0 atm
   e) 5.0 atm

9. Which of the following gases has the greatest density at 0°C and 1 atm?
   a) N_2
   b) O_2
   c) F_2
   d) Ne
   e) CO

10. What is the density of CH_4 at 200°C and 0.115 atm?
   a) 0.0475 g/L
   b) 0.0716 g/L
   c) 0.542 g/L
   d) 0.870 g/L
   e) 2.09 g/L

11. What is the molar mass of a gas which has a density of 1.30 g/L measured at 27°C and 0.400 atm?
   a) 38.0 g/mol
   b) 48.0 g/mol
   c) 61.5 g/mol
   d) 80.0 g/mol
   e) 97.5 g/mol

12. Non-ideal behavior for a gas is most likely to be observed under conditions of
   a) standard temperature and pressure.
   b) low temperature and high pressure.
   c) low temperature and low pressure.
   d) high temperature and high pressure.
   e) high temperature and low pressure.

13. Which of the following gases effuses at the highest rate?
   a) N_2
   b) O_2
   c) F_2
   d) Ne
   e) CO

14. The empirical formula of a certain hydrocarbon is CH_2. When 0.125 moles of this hydrocarbon is completely burned with excess oxygen, it is observed that 8.40 Liters of CO_2 gas are produced at STP. What is the molecular formula of the unknown hydrocarbon?
   a) CH_2
   b) C_2H_4
   c) C_2H_3
   d) C_3H_6
   e) C_4H_8

15. Carbon dioxide gas diffuses through a porous barrier at a rate of 0.20 mL/minute. If an unknown gas diffuses through the same barrier at a rate of 0.25 mL/minute, what is the molar mass of the unknown gas?
   a) 28 g/mol
   b) 35 g/mol
   c) 39 g/mol
   d) 68 g/mol
   e) 84 g/mol

16. Which of the following statements is true?
   a) All particles moving with the same velocity have the same kinetic energy.
   b) All particles at the same temperature have the same kinetic energy.
   c) All particles having the same kinetic energy have the same mass.
   d) As the kinetic energy of a particle is halved, the velocity is also halved.
   e) As the velocity of a particle is doubled, the kinetic energy decreases by a factor of four.

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Name ____________________________________
Period ___ Date ___/___/___

12 • Gases and Their Properties

TEST ANSWERS

Please use **CAPITAL** letters:

1. _____
2. _____
3. _____
4. _____
5. _____

6. _____
7. _____
8. _____
9. _____
10. _____

11. _____
12. _____
13. _____
14. _____
15. _____

16. _____

Useful Information

STP = 0°C = 273 K and
1 atm = 760 torr = 760 mmHg
= 101.3 kPa = 14.7 psi
= 14.7 **Fehler!**

Ideal Gas Constant, R
= 62.4 **Fehler!**
= 0.0821 **Fehler!**
= 8.31 **Fehler!**

Boyle's Law
PV = constant

Charles' Law
Fehler!= constant

Gay-Lussac's Law
Fehler!= constant

Combined Gas Law
Fehler!= constant

Ideal Gas Law
PV = nRT

$$\frac{P_A}{P_{TOTAL}} = \frac{moles_A}{moles_{TOTAL}}$$

KE = $^1/_2$ m·v^2

Fehler!= **Fehler!**

1.C 2.B 3.A 4.C 5.B 6.D 7.B 8.D 9.C
10.A 11.D 12.B 13.D 14.D 15.A 16.B