CHAPTER 5: Gases

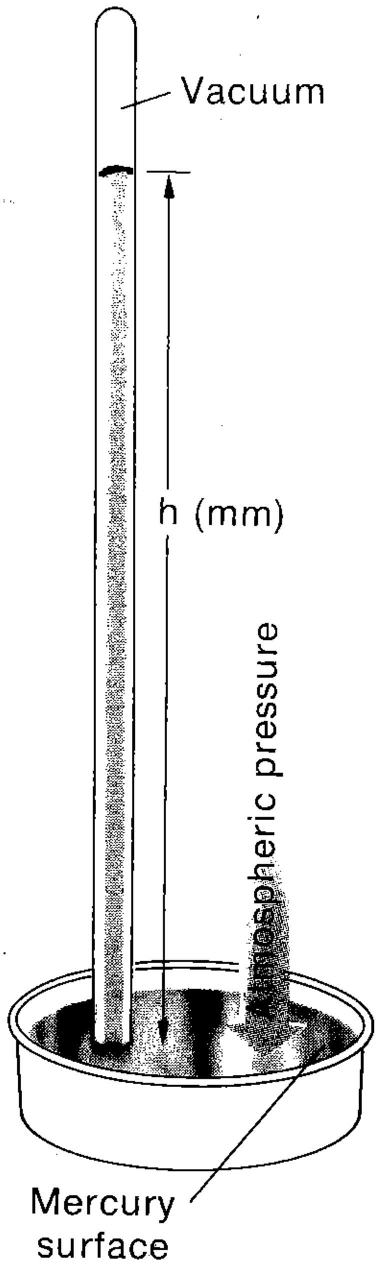
Section 5.1: Measurement on Gases Pressure, Volume and Temperature

Relationship Among Pressure Units

1 atm = 760 mm Hg = 14.70 lb/in^2 = 1033 g/cm^2 = 101.3 kPa

1 torr = 1 mm Hg

D_{Hg} = 13.59 g/cm^3



$P = \frac{Force}{Area} = \frac{mass \times acceleration}{Area} = \frac{mass}{area}$ (leaving acc out of equation)

$Density = \frac{Mass}{Volume} \rightarrow Mass = Density \times Volume$

$P = \frac{mass}{area} = \frac{Density \times Volume}{Area} = \frac{Density \times (Area \times height)}{Area}$

$P = Density \times height$

$height = \frac{Pressure}{Density}$ (height of a barometer)

Mercury

$height = \frac{P}{D} = \frac{1033\ g/cm^2}{13.59\ g/cm^3}$

height = 76.0 cm Hg
= 760 mm Hg

Water

$height = \frac{P}{D} = \frac{1033\ g/cm^2}{1.00\ g/cm^3}$

height = 1033 cm H_2O
= 10.33 m H_2O

A barometer made with water would be 10.33 m tall.

Relations Between Length, Volume, and Mass Units

METRIC		ENGLISH		METRIC-ENGLISH	
Length					
1 km	$= 10^3$ m	1 ft	= 12 in	1 in	= 2.54 cm*
1 cm	$= 10^{-2}$ m	1 yd	= 3 ft	1 m	= 39.37 in
1 mm	$= 10^{-3}$ m	1 mile	= 5280 ft	1 mile	= 1.609 km
1 nm	$= 10^{-9}$ m = 10Å				
Volume					
1 m^3	$= 10^6$ cm^3 $= 10^3$ L	1 gallon	= 4 qt = 8 pt	1 ft^3	= 28.32 L
1 cm^3	= 1 mL $= 10^{-3}$ L	1 qt (Can.)	= 69.35 in^3	1 L	= 0.8799 qt (Can.)
		1 qt (U.S. liq.)	= 57.75 in^3	1 L	= 1.057 qt (U.S. liq.)
Mass					
1 kg	$= 10^3$ g	1 lb	= 16 oz	1 lb	= 453.6 g
1 mg	$= 10^{-3}$ g	1 short ton	= 2000 lb	1 g	= 0.03527 oz
1 metric ton	$= 10^3$ kg			1 metric ton	= 1.102 short ton

*This conversion factor is exact; the inch is defined to be exactly 2.54 cm. The other factors listed in this column are approximate, quoted to four significant figures. Additional digits are available if needed for very accurate calculations. For example, the pound is defined to be 453.59237 g.

1. A five-gallon propane tank contains 0.784 mol of propane (C_3H_8) at 68°F. Express the volume of the tank in liters, the amount of propane in the tank in grams, and the temperature of the tank in Kelvin.

$5 \text{ gallons}\left(\frac{4 \text{ qts}}{1 \text{ gal}}\right)\left(\frac{1 \text{ L}}{1.057 \text{ qt}}\right) = 18.92 \text{ L}$

$.784 \text{ mol } C_3H_8\left(\frac{44 \text{ g}}{1 \text{ mol}}\right) = 34.5 \text{ g}$

68°F

$°C = \frac{°F-32}{1.8} = \frac{68-32}{1.8} = 20.0°C$

$K = °C + 273 = 293 \text{ K}$

3. Complete the following table of pressure conversions.

mm Hg	Atmospheres	Kilopascals
913	1.20	122
633	0.833	84.4
915	1.20	122

$913 \text{ mmHg}\left(\frac{1 \text{ atm}}{760 \text{ mmHg}}\right) = 1.20 \text{ atm}\left(\frac{101.3 \text{ kPa}}{1 \text{ atm}}\right) = 121.7 \text{ kPa} = 122 \text{ kPa}$

$.833 \text{ atm}\left(\frac{760 \text{ mmHg}}{1 \text{ atm}}\right) = 633 \text{ mmHg}\left(\frac{101.3 \text{ kPa}}{760 \text{ mmHg}}\right) = 84.4 \text{ kPa}$

$122 \text{ kPa}\left(\frac{1 \text{ atm}}{101.3 \text{ kPa}}\right) = 1.20 \text{ atm}\left(\frac{760 \text{ mmHg}}{1 \text{ atm}}\right) = 915.3 \text{ mmHg} = 915 \text{ mmHg}$

CHAPTER 5: GASES

Section 5.2: The Gas Laws of Boyle, Charles, Gay-Lussac & Avogadro

Name the formulas of each gas law:

BOYLE: $P_1V_1 = P_2V_2$ (const T, n)

CHARLES': $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ (const P, n)

GAY-LUSSAC: $\frac{P_1}{T_1} = \frac{P_2}{T_2}$ (const V, n)

AVOGADRO'S: $\frac{V_1}{n_1} = \frac{V_2}{n_2}$ (const P, T)

1. A diver at a depth of 100 ft (pressure approximately 3 atm) exhales a small bubble of air with a volume equal to 100 mL. What will be the volume of the bubble (assume the same amount of air) at the surface?

$P_1 = 3\text{ atm}$ $P_2 = 1\text{ atm}$
$V_1 = 100\text{ mL}$ $V_2 = ?$

$P_1V_1 = P_2V_2$
$(3\text{ atm})(100\text{ mL}) = (1\text{ atm})(V_2)$

$V_2 = 300\text{ mL}$

2. What would be the volume of gas contained in an expandable 1.0 L cylinder at 15 Mpa (1 Mpa = 10^6 Pa) be at 1 atm (assuming constant temperature)?

$P_1 = 1.5\times10^7\text{ Pa} = 1.5\times10^4\text{ kPa}$ $P_2 = 1\text{ atm} = 101.3\text{ kPa}$
$V_1 = 1.0\text{ L}$ $V_2 = ?$

$P_1V_1 = P_2V_2$
$(1.5\times10^4\text{ kPa})(1\text{ L}) = (101.3\text{ kPa})V_2$

$V_2 = 148.0\text{ L}$

3. A sample tube containing 103.6 mL of CO gas at 20.6 torr is connected to an evacuated 1.13-liter flask. (The new volume is the sum of those of the tube and the flask.) What will the pressure be when the CO is allowed into the flask?

$P_1 = 20.6\text{ torr}$ $P_2 = ?$
$V_1 = .1036\text{ L}$ $V_2 = .1036\text{ L} + 1.13 = 1.2336\text{ L}$

$P_1V_1 = P_2V_2$
$(20.6\text{ torr})(.1036\text{ L}) = P_2(1.2336\text{ L})$

$P_2 = 1.73\text{ torr}$

4. A gas has a pressure of 3.2 atm and occupies a volume of 45 L. What will the pressure be if the volume is compressed to 27 L at a constant temperature?

$P_1 = 3.2\text{ atm}$ $P_2 = ?$
$V_1 = 45\text{ L}$ $V_2 = 27\text{ L}$

$P_1V_1 = P_2V_2$
$(3.2\text{ atm})(45\text{ L}) = P_2(27\text{ L})$

$P_2 = 5.33\text{ atm}$

5. The volume of a gas (held at constant pressure) is to be used "as a thermometer." If the volume at 0.0 °C is 75.0 cm^3 what is the temperature when the measured volume is 56.7 cm^3?

$V_1 = 75.0\ cm^3$ $V_2 = 56.7\ cm^3$

$T_1 = 0°C = 273\ K$ $T_2 = ?$

$\frac{V_1}{T_1} = \frac{V_2}{T_2}$ $\frac{75.0\ cm^3}{273K} = \frac{56.7\ cm^3}{T_2}$

$T_2 = 206.388K = -66.6°C$

6. The gas in a closed container has a pressure of 3.00 x 10^2 Pa at 30 °C. What will the pressure be if the temperature is lowered to –172 °C?

$P_1 = 3.00\times10^2\ Pa$ $P_2 = ?$

$T_1 = 30°C = 303K$ $T_2 = -172°C = 101K$

$\frac{P_1}{T_1} = \frac{P_2}{T_2}$ $\frac{3\times10^2 Pa}{303K} = \frac{P_2}{101K}$

$P_2 = 100\ Pa = 1.00\times10^2\ Pa$

7. The gas in a closed balloon has a pressure of 795 torr at 25 °C. What will the pressure be if the temperature is doubled? Is halved?

$P_1 = 795\ torr$

$T_1 = 25°C = 298K$

a) $P_2 = ?$

$T_2 = 298\times2 = 596K$

$\frac{795\ torr}{298K} = \frac{P_2}{596K}$ $P_2 = 1590\ torr$

b) $P_2 = ?$

$T_2 = 298\times\frac{1}{2} = 149K$

$\frac{795\ torr}{298K} = \frac{P_2}{149K}$ $P_2 = 397.5\ torr$

8. If a 16.6 L sample of a gas contains 9.2 moles of F_2, how many moles of gas would there be in a 750 mL sample at the same temperature and pressure?

$V_1 = 16.6\ L$

$n_1 = 9.2\ moles$

$V_2 = 750\ mL = .750\ L$

$n_2 = ?$

$\frac{V_1}{n_1} = \frac{V_2}{n_2}$ $\frac{16.6\ L}{9.2\ moles} = \frac{.750\ L}{n_2}$

$n_2 = .416\ moles$

9. An 11.2 L sample of gas is determined to contain 0.50 moles of N_2. At the same temperature and pressure how many moles of gas would there be in a 20. L sample?

$V_1 = 11.2\ L$

$n_1 = .50\ moles$

$V_2 = 20.0\ L$

$n_2 = ?$

$\frac{V_1}{n_1} = \frac{V_2}{n_2}$ $\frac{11.2L}{.50\ moles} = \frac{20.0\ L}{n_2}$

$n_2 = .893\ moles$

10. Consider a 3.57 L sample of an unknown gas at a pressure of 4.3 x 10^3 Pa. If the pressure is changed to 2.1 x 10^4 Pa at a constant temperature, what will the new volume of the gas be?

$V_1 = 3.57\ L$

$P_1 = 4.3\times10^3\ Pa$

$V_2 = ?$

$P_2 = 2.1\times10^4\ Pa$

$P_1V_1 = P_2V_2$

$(4.3\times10^3\ Pa)(3.57L) = (2.1\times10^4\ Pa)(V_2)$

$V_2 = .731\ L$

Section 5.2/5.3: The Ideal Gas Law

Initial and Final States

12. A basketball is inflated in a garage at 25°C to a gauge pressure of 8.0 psi. Gauge pressure is the pressure above atmospheric pressure, which is 14.7 psi. The ball is used on the driveway at a temperature of −7°C and feels "flat." What is the actual pressure of the air in the ball? What is the gauge pressure?

$T_1 = 25°C = 298K$

$P_1 = 8 psi + 14.7 psi = 22.7 psi$

$T_2 = -7°C = 266K$

$P_2 = ?$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\frac{22.7 psi}{298K} = \frac{P_2}{266K}$$

$P_2 = 20.2 psi$ - Actual P

5.56 psi - Gauge P

14. A 3.50-cm³ air bubble forms in a deep lake at a depth where the temperature is 6°C at a total pressure of 2.50 atm. The bubble rises to a depth where the temperature and pressure are 13°C and 1.75 atm, respectively. Assuming that the amount of air in the bubble has not changed, calculate its new volume.

$V_1 = 3.50 cm^3 = 3.50 mL$

$T_1 = 6°C = 279K$

$P_1 = 2.50 atm$

$V_2 = ?$

$T_2 = 13°C = 286K$

$P_2 = 1.75 atm$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{(2.50 atm)(3.50 mL)}{279K} = \frac{(1.75 atm)(V_2)}{286K}$$

$V_2 = 5.13 mL$

Ideal Gas Law; Calculation of One Variable

$PV = nRT$

20. Compressed-air tanks used by scuba divers have a volume of 8.0 L and are filled with air to a pressure of 135 atm at 20°C. How many grams of helium are required to fill a tank under the above conditions?

$$n = \frac{PV}{RT} = \frac{(135\,atm)(8.0\,L)}{(.0821\,\frac{L\cdot atm}{mol\,K})(293\,K)} = 44.9\,mol\,He\left(\frac{4.0\,g}{1\,mole}\right) = \underline{179.6\,g\,He}$$

22. Complete the following table for carbon monoxide gas. CO

	Pressure	Volume	Temperature	Moles	Grams
a)	493 mm Hg	3.75 L	36°C	____	____
b)	1.28 atm	6.39 L	____	0.500	____
c)	125 kPa	____	99°C	____	43.2
d)	____	2.98 L	125°C	____	0.827

a) $$n = \frac{PV}{RT} = \frac{(\frac{493}{760})(3.75\,L)}{(.0821)(36+273)} = .0959\,mol\,CO\left(\frac{28\,g}{1\,mol\,CO}\right) = ~~3.64~~\ 2.69\,g\,CO$$

b) $$T = \frac{PV}{nR} = \frac{(1.28\,atm)(6.39\,L)}{(.500\,mol)(.0821\,\frac{L\cdot atm}{mol\,K})} = 199.2\,K$$

$$.500\,mol\,CO\left(\frac{28\,g}{1\,mol}\right) = 14.0\,g\,CO$$

c) $$43.2\,g\,CO\left(\frac{1\,mole}{28\,g}\right) = 1.54\,mol\,CO$$

$$V = \frac{nRT}{P} = \frac{(1.54\,mol)(.0821\,\frac{L\cdot atm}{mol\,K})(372\,K)}{(\frac{125\,kPa}{101.3\,kPa})}$$

$\boxed{V = 38.2\,L}$

d) $$.827\,g\,CO\left(\frac{1\,mol}{28\,g}\right) = .0295\,mol\,CO$$

$$P = \frac{nRT}{V} = \frac{(.0295\,mol)(.0821\,\frac{L\cdot atm}{mol\,K})(398\,K)}{2.98\,L}$$

$\boxed{P = .324\,atm}$

$PV = nRT$

$PV = \frac{mass}{MM} RT$

$MM = \frac{mass \cdot R \cdot T}{V \cdot P} = \frac{D \cdot R \cdot T}{P}$

$D = \frac{P \cdot MM}{R \cdot T}$

Ideal Gas Law; Density and Molar Mass

25. Calculate the densities (in g/L) of the following gases at 97°C and 755 mm Hg.

(a) hydrogen chloride HCl $MM = 36.5\ g/mol$

(b) sulfur dioxide SO_2 $MM = 64\ g/mol$

25a) $D = \frac{P \cdot MM}{R \cdot T} = \frac{\left(\frac{755\ mmHg}{760\ mmHg}\right)(36.5\ g/mol)}{\left(.0821\ \frac{L \cdot atm}{mol \cdot K}\right)(370K)} = \boxed{1.19\ g/L}$

b) $D = \frac{P \cdot MM}{R \cdot T} = \frac{\left(\frac{755\ mmHg}{760\ mmHg}\right)(64\ g/mol)}{\left(.0821\ \frac{L \cdot atm}{mol \cdot K}\right)(370K)} = \boxed{2.13\ g/L}$

29. Freon is a gas made up of carbon, fluorine, and chlorine atoms. It was used as a refrigerant in car air conditioners. It is also one of the culprits in the depletion of the ozone layer. It has a density of 4.65 g/L at 735 mm Hg and 33°C.

(a) What is the molar mass of Freon?

(b) Freon is made up of 9.92% C, 58.6% Cl, and 31.4% F. What is its molecular formula?

a) $MM = \frac{D \cdot R \cdot T}{P} = \frac{(4.65\ g/L)\left(.0821\ \frac{L \cdot atm}{mol \cdot K}\right)(306K)}{\left(\frac{735\ mmHg}{760\ mmHg/atm}\right)} = \boxed{120.8\ g/mol}$

b)

	C	Cl	F
%	9.92	58.6	31.4
MM	12	35.5	19
moles	.827	1.65	1.65

÷ .827

C : Cl : F

1 : 2 : 2

Emp Form = CCl_2F_2

Mass of EF = $12 + (2 \times 35.5) + (2 \times 19)$

Mass of EF = 121

$\frac{\text{Molar Mass}}{\text{Emp Mass}} = \frac{120.8}{121} = 1$

Mol. Form: CCl_2F_2

30. Phosgene is a highly toxic gas made up of carbon, oxygen, and chlorine atoms. Its density at 1.05 atm and 25°C is 4.24 g/L.

(a) What is the molar mass of phosgene?

(b) Phosgene is made up of 12.1% C, 16.2% O, and

a) $MM = \frac{DRT}{P} = \frac{(4.24\,g/L)(.0821\,\frac{L\cdot atm}{mol\,K})(298\,K)}{1.05\,atm} = 98.8\,g/mole$

b)

	C	O	Cl
%	12.1	16.2	71.7
MM	12	16	35.5
moles	1.01	1.01	2.02

1.01

C:O:Cl
1:1:2

EF = $COCl_2$

Mass of EF = 12 + 16 + (2·35.5) = 99

$\frac{MM}{Emp\,Mass} = \frac{98.8}{99} = 1$

Mole. Form: $COCl_2$

33. A 1.58-g sample of $C_2H_3X_3(g)$ has a volume of 297 mL at 769 mm Hg and 35°C. Identify the element X.

$MM = \frac{D\cdot R\cdot T}{P} = \frac{mass\cdot R\cdot T}{V\cdot P} = \frac{(1.58\,g)(.0821\,\frac{L\cdot atm}{mol\,K})(308\,K)}{(.297\,L)(\frac{769\,mmHg}{760\,mmHg/atm})} = 132.9\,g/mol$

$C_2H_3X_3$

$2(12) + 3(1) + 3(MM_x) = 132.9$

$MM_x = 35.3$

Element X = Chlorine