GAS LAWS

PROPERTIES OF GASES

- Gases are highly compressible
- Gas particles are further apart relative to liquids or solids
- The volume occupied by gases is mostly empty space
- Gases expand to fill every available space
- Gases are in rapid random motion
- All gases diffuse in one another
- The attraction between gas particles is weaker relative to liquids or solids
- If a fixed sample of gas is left undisturbed at constant V & T, the P of the gas remains constant.

FACTORS IMPORTANT TO GASES

1) PRESSURE **P**

- Units & conversion

2) TEMPERATURE **T**

- Equations & conversions

3) STP **S**

- conditions

4) AVOGADRO'S HYPOTHESIS **A**

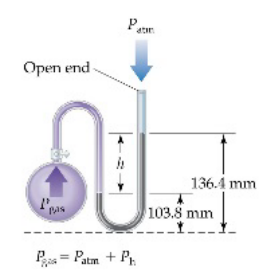
PRESSURE

A physical property of matter that describes the force particles have on a surface. Pressure is the force per unit area, P = F/A

- Pressure can be measured in:
  - atmosphere (atm)
  - millimeters of mercury (mmHg)
  - (torr) after Torricelli, the inventor of the mercury barometer (1643)
  - pounds per square inch (psi)

1 atm = 760 mmHg = 760 torr

760 torr = 14.69 psi = 101.3 kPa



Example 1

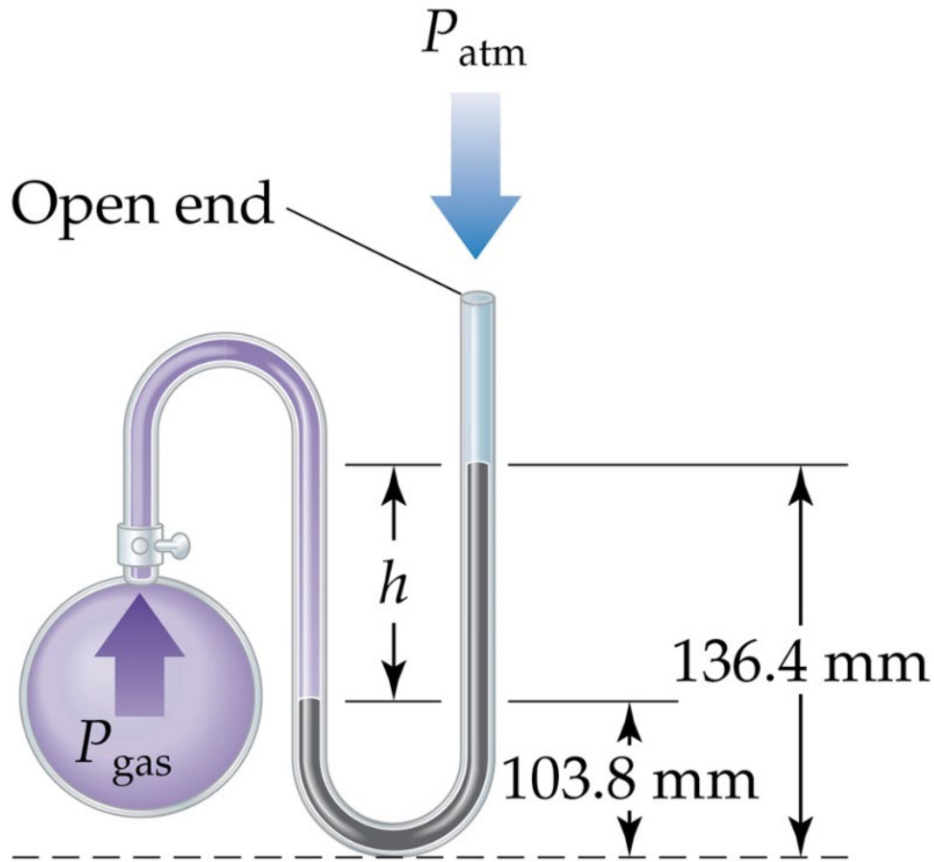
barometer

Example 2

Manometer

Example 2

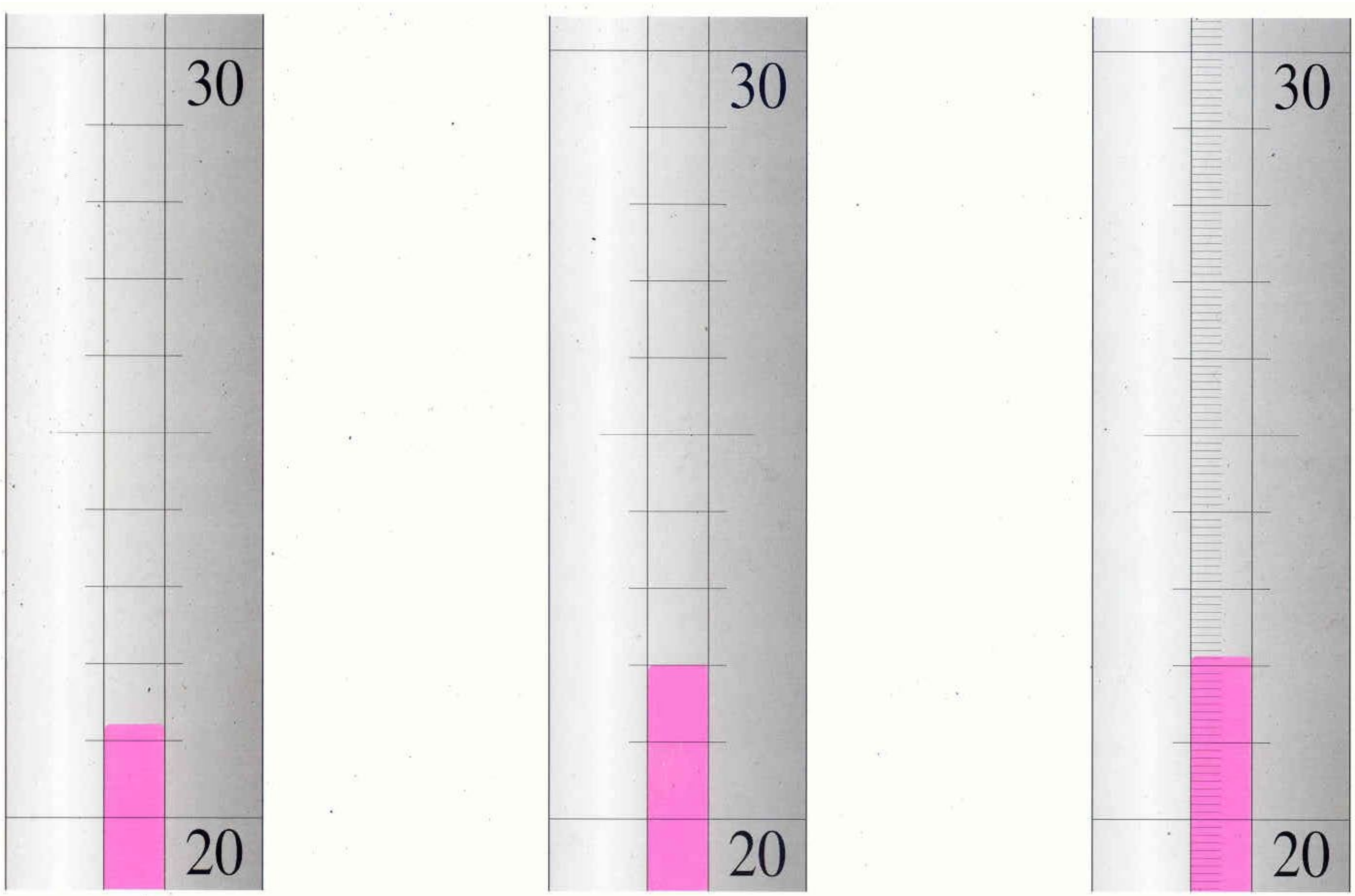
- The **manometer** is used to measure the difference in pressure between atmospheric pressure and that of a gas in a vessel.



$$P_{gas} = P_{atm} + P_h$$

The sum of the heights in both arms must remain constant regardless of the change in pressure.)

TEMPERATURE



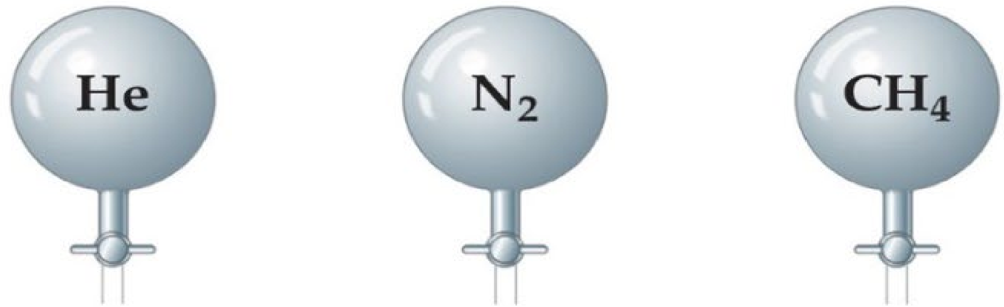
$^oF = (1.8\ ^oC) + 32$ $^oC = (^oF - 32)/1.8$ $K = {^oC} + 273.15$

At STP, gas molecules are so far apart that for 1 mole of gas, the overall volume does not change.

STP : P = 1 atm & T = 273 K

GAS	WEIGHT	MOLAR VOLUME
H_2	2.0 g/mol	22.4 L/mol
N_2	28.0 g/mol	22.4 L/mol
Xe	131.3 g/mol	22.4 L/mol

Avogadro's Law



Volume	22.4 L	22.4 L	22.4 L
Pressure	1 atm	1 atm	1 atm
Temperature	0 °C	0 °C	0 °C
Mass of gas	4.00 g	28.0 g	16.0 g
Number of gas molecules	6.02×10^{23}	6.02×10^{23}	6.02×10^{23}

- The volume of a gas at constant temperature and pressure is directly proportional to the number of moles of the gas.
- So, at STP, one mole of ANY gas occupies 22.4 L.
- Mathematically:

$$V = \text{constant} \times n, \text{ or } \frac{V_1}{n_1} = \frac{V_2}{n_2}.$$

Calculating Pressure

What is the pressure, in kilopascals, on the body of a diver if she is 31.0 m below the surface of the water when the atmospheric pressure on the surface is 98 kPa? Assume that the density of the water is 1.00 g/cm^3 = 1.00 × 10^3 kg/m^3. The gravitational constant is 9.81 m/s^2, and 1 Pa = 1 kg/m-s^2.

Plan: The total pressure on the diver equals that of the atmosphere plus … . The pressure of the water can be cal… with Equation $P = F/A$. The force, F, due to the water above the diver is given by its mass times the acceleration due to gravity, $F = mg$, where $g = 9.81$ m/s^2.

Solve The pressure caused by the water is

$$P = \frac{F}{A} = \frac{mg}{A}$$

The mass of the water is related to its density ($d = m/V$, so $m = d \times V$). We can treat the water as a column whose volume equals its cross-sectional area times its height: $V = A \times h$. When we make these substitutions for mass ($m = d \times V$) and volume ($V = A \times h$), we have

$$P = \frac{mg}{A} = \frac{dVg}{A} = \frac{d(\cancel{A}h)g}{\cancel{A}} = dhg$$

Calculating Pressure

What is the pressure, in kilopascals, on the body of a diver if she is 31.0 m below the surface of the water when the atmospheric pressure on the surface is 98 kPa? Assume that the density of the water is 1.00 g/cm^3 = 1.00 × 10^3 kg/m^3. The gravitational constant is 9.81 m/s^2, and 1 Pa = 1 kg/m-s^2.

Inserting SI quantities, we have

$$P = dhg = (1.00 \times 10^3\,\mathrm{kg/m^{\cancel{3}}})(31.0\,\cancel{\mathrm{m}})(9.81\,\cancel{\mathrm{m}}/\mathrm{s^2})$$

$$= 3.00 \times 10^5 \frac{\mathrm{kg}}{\mathrm{m\text{-}s^2}} = 3.00 \times 10^5\,\mathrm{Pa}$$

Thus, the total pressure on the diver is

$$P_{total} = 98\,\mathrm{kPa} + 300\,\mathrm{kPa} = 398\,\mathrm{kPa}$$

$$398\,\mathrm{kPa}\,(\,{}^{1\,\mathrm{atm}}/{}_{101.3\,\mathrm{kPa}}) =$$

This corresponds to a pressure of 3.94 atm.

Practice Exercise 1

What would be the height of the column in a barometer if the external pressure was 101 kPa and water (d = 1.00 g/cm^3) was used in place of mercury?

(a) 0.0558 m
(b) 0.760 m
(c) 1.03×10^4 m
(d) 10.3 m
(e) 0.103 m

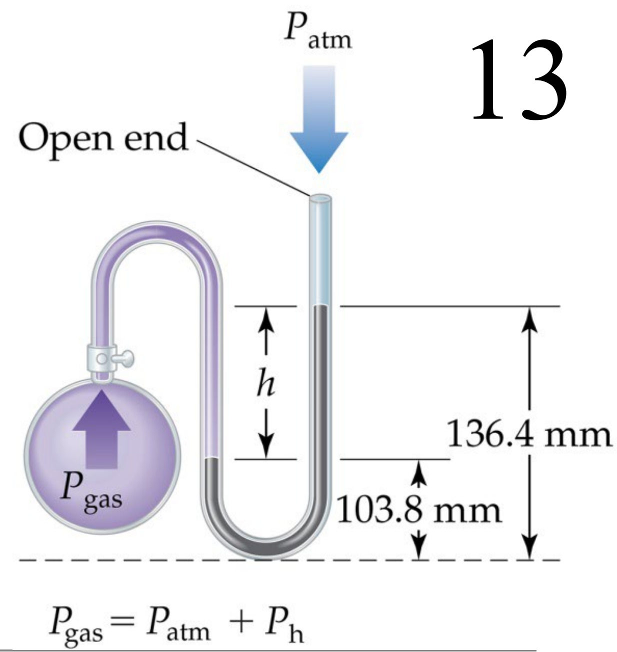
$$P_{ext} = dhg$$

$$\mathbf{101x10^3\ kg/m\text{-}s^2 = (1x10^3\ kg/m^3)\ (h)\ (9.81\ m/s^2)}$$

h= 10.3 m or (d)

Sample Exercise 10.2 Using a Manometer to Measure Gas Pressure

On a certain day, a laboratory barometer indicates that the atmospheric pressure is 764.7 torr. A sample of gas is placed in a flask attached to an open-end mercury manometer and a meter stick is used to measure the height of the mercury in the two arms of the U tube. The height of the mercury in the open-ended arm is 136.4 mm, and the height in the arm in contact with the gas in the flask is 103.8 mm. What is the pressure of the gas in the flask **(a)** in atmospheres?



Solution

Plan We will use the difference in height between the two arms (h in Figure 10.3) to obtain the amount by which the pressure of the gas exceeds atmospheric pressure. Because an open-end mercury manometer is used, the height difference directly measures the pressure difference in mm Hg or torr between the gas and the atmosphere.

Analyze We are given the atmospheric pressure (764.7 torr) and the mercury heights in the two arms of the manometer and asked to determine the gas pressure in the flask. *We know that the gas pressure from the flask must be greater than atmospheric pressure because the mercury level in the arm on the flask side (103.8 mm) is lower than the level in the arm open to the atmosphere (136.4 mm).* Therefore, the gas from the flask is pushing mercury from the arm in contact with the flask into the arm open to the atmosphere.

Sample Exercise 10.2 Using a Manometer to Measure Gas Pressure

Solve

The pressure of the gas equals the atmospheric pressure plus *h*:

$$\begin{aligned} P_{\text{gas}} &= P_{\text{atm}} + h \\ &= 764.7\ \text{torr} + (136.4\ \text{torr} - 103.8\ \text{torr}) \\ &= 797.3\ \text{torr} \end{aligned}$$

We convert the pressure of the gas to atmospheres:

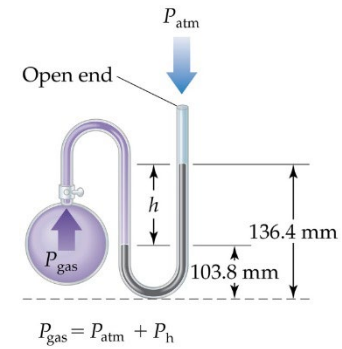
$$P_{\text{gas}} = (797.3\ \cancel{\text{torr}})\left(\frac{1\ \text{atm}}{760\ \cancel{\text{torr}}}\right) = 1.049\ \text{atm}$$

Check The calculated pressure is a bit more than 1 atm, which is about 101 kPa. This makes sense because we anticipated that the pressure in the flask would be greater than the atmospheric pressure (764.7 torr = 1.01 atm) acting on the manometer.

Practice Exercise 2

If the pressure of the gas inside the flask were increased and the height of the column in the open-ended arm went up by 5.0 mm, what would be the new pressure of the gas in the flask, in torr?(*Hint*: The sum of the heights in both arms must remain constant regardless of the change in pressure.)

Sum of the heights = 136.4mm + 103.8mm = 240.2mm
If the open-end height increased by 5 mm
therefore 136.4 + 5 = 141.4mm
So 240.2mm – 141.4mm = 98.8 mm for the closed end.



So now $P_{gas} = P_{atm} + P_h$

P_{gas} = 764.7 torr + (141.5 – 98.8)

P_{gas} = 807.4 torr or mmHg

Return to P

Avogadro's Law

Equal volumes of gas at the same temperature and pressure contain equal numbers of molecules.

$V \propto n$

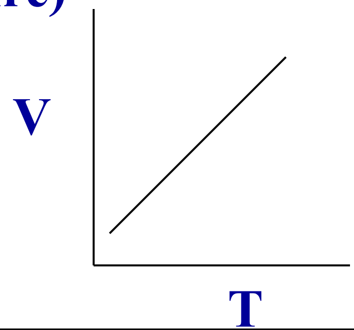
$V/n = k$

Charles' Law

The volume of a fixed amount of gas at constant pressure is proportional to the absolute temperature of the gas (absolute – Kelvin temperature)

$V \propto T\ (K)$

$V/T = k$

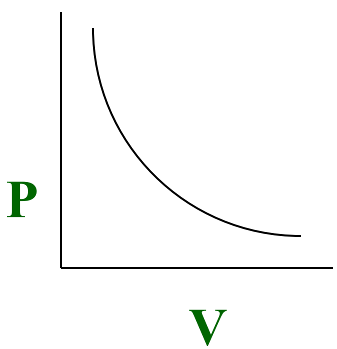


Boyle's Law

The volume of a fixed amount of gas at constant temperature is inversely proportional to the gas pressure.

$P \propto 1/V$

$PV = k$

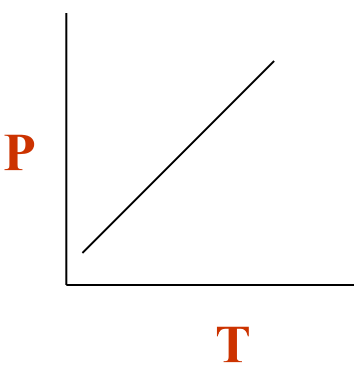


Gay-Lussac's Law

The pressure of a fixed amount of gas at constant volume is proportional to the absolute temperature of the gas.

$P \propto T\ (K)$

$P/T = k$



EMPIRICAL GAS LAWS

Boyle's Law	$P_1V_1 = P_2V_2$
Charles' Law	$V_1 / T_1 = V_2 / T_2$
Guy-Lussac's Law	$P_1 / T_1 = P_2 / T_2$
Avogadro's Law	$V_1 / n_1 = V_2 / n_2$

Combined Gas Law:

$$P_1V_1 / T_1 = P_2 V_2 / T_2$$

Empirical Gas Laws [2]

1. At 25°C, a sample of N_2 gas under a pressure of 689 mmHg occupies 124 mL in a piston-cylinder arrangement before compression. If the gas is compressed to 75% of its original volume, what must be the new pressure (in atm) at 25°C?

   First make a list of the measurements made:

P_1=689 mmHg	V_1 = 124 mL
P_2 = ?	V_2 = 75% V_1

From the variables, choose the appropriate equation, in this case Boyle's Law: $P_1V_1=P_2V_2$

$$(689\text{ mmHg})\ (124\text{ mL}) = P_2\ (0.75 \times 124\text{ mL})$$

Solve for P_2:

$$P_2 = (689\text{mmHg})\ (124\text{ mL}) / (93\text{ mL}) = 919\text{ mmHg}$$

Now convert to atm:

$$919\text{ mmHg}\ (1\text{ atm} / 760\text{ mmHg}) = \mathbf{1.21\text{ atm}}$$

Empirical Gas Laws - lecture

1. At 35^{o}C, a sample of N_2 gas under a pressure of 578 mmHg occupies 290.0 mL in a piston-cylinder arrangement before compression. If the gas is compressed to 90.0% of its original volume, what must be the new pressure (in atm) at 35^{o}C?

Empirical Gas Laws [3]

2. The gas in a Helium filled ball at 25^{o}C exerts a volume of 4.2 L. If the ball is placed in a freezer and the volume decreases to 1/8 of its original value, what is the temperature inside the ball?

First make a list of the measurements made:

V_1=4.2 atm　　　　T_1 = 25 ^{o}C + 273.15 = 298.15K

V_2 = 1/8 V_1　　　　T_2 = ?

From the variables, choose the appropriate equation, in this case Charles' Law: $V_1/T_1=V_2/T_2$

$$(V_1) / (298\ K) = (1/8\ V_1) / T_2$$

Solve for T_2:

$$T_2 = [(298\ K)\ (1/8\ V_1)] / (V_1) = 298 / 8$$

T_2 = 37.3 K or -235 ^{o}C

Empirical Gas Laws – lecture 2

2. The pressure gauge reads 225.0 psi on a 0.140-m^3 compressed air tank when the gas is at 45.0 ^oC. To what pressure (IN ATM) will the contents of the tank experience if the temperature is lowered to 13.5^oC?

GROUP QUIZ #18B Empirical Gas Laws

1) An oxygen cylinder contains 35.4 L of oxygen gas at a pressure of 149.6 atm. How much volume would the oxygen occupy if it were transferred to a container that maintained a pressure of 1.00 atm if the temperature remains constant?

2) A balloon containing 6.50 grams of NH_3 has a volume of 10.30 L at a temperature of 20.0^oC and a pressure of 689.2 torr. What would be the pressure of NH_3 if the volume decreased to 2.50 L without a change in temperature?

COMBINED GAS LAW

- A sample of carbon dioxide occupies 0.300 L at 10.0 °C and 750 torr. What volume will the gas have at 30.0 °C and 850 torr?

$$P_1 V_1 / T_1 = P_2 V_2 / T_2$$

$$\frac{P_o V_o}{T_o} = \frac{P_f V_f}{T_f}$$

rearranged to solve for V_2 is:

$$V_2 = P_1 V_1 T_2 / P_2 T_1$$

$$V_2 = \frac{(750\ \text{mmHg})(0.300\text{L})(273+30\ \text{K})}{(850\ \text{mmHg})\ (273+10\ \text{K})}$$

$$V_2 = 283\ \text{mL}$$

LECTURE QUIZ - COMBINED GAS LAW

- **A gas occupies a volume of 720 mL at 37°C and 640 mmHg pressure.**
  - **Calculate the pressure if the temperature is increased to 1000°C & the volume expands to 900 mL.**
  - **Calculate the temperature if the pressure is decreased to 10 torr & the volume is reduced to 500 mL.**

PRACTICE PROBLEMS – PUT IT ALL TOGETHER

1. You prepared carbon dioxide by adding aqueous HCl to marble chips, calcium carbonate. According to your calculations, you should obtain 79.4 mL of carbon dioxide at 0 ^{o}C and 760 mmHg. How many milliliters of gas would you obtain at 27^{o}C at the same pressure?

87.3 mL

2. Divers working from a North Sea drilling platform experiences pressures of 50 atm at a depth of 5.0×10^2 m. If a balloon is inflated to a volume of 5.0 L (the volume of a lung) at that depth at a water temperature of 4.0^{o}C, what would the volume of the balloon be on the surface (1.0 atm) at a temperature of 11 ^{o}C?

256 L

3. The pressure gauge reads 125 psi on a 0.140-m^3 compressed air tank when the gas is at 33.0 ^{o}C. To what volume will the contents of the tank expand if they are released to an atmospheric pressure of 751 torr and a temperature of 13^{o}C?

1.126 m^3

4. A gas has a volume of 397.0 mL at 14.70 atm. What will be its pressure (in torr) if the volume is changed to 4.100 L?

1082 torr

EMPIRICAL GAS LAWS

Boyle's Law	$P_1V_1 = P_2V_2$
Charles' Law	$V_1 / T_1 = V_2 / T_2$
Guy-Lussac's Law	$P_1 / T_1 = P_2 / T_2$
Avogadro's Law	$V_1 / n_1 = V_2 / n_2$
Combined Gas Law	$P_1V_1 / T_1 = P_2 V_2 / T_2$

Ideal Gas Law $PV = nRT$

P = pressure (atm) V = volume (L)

n = chemical amount (mol) T = Temperature (K)

R = ideal gas constant = 0.08206 L-atm / mol-K

R

- The ideal gas constant makes the equation and equality, not only a proportion.
- $PV = nRT$

Table 10.2 Numerical Values of the Gas Constant R in Various Units

Unit	Numerical Value
L - atm/mol - K	0.08206
J/mol - K*	8.314
cal/mol - K	1.987
m^3 - Pa/mol - K*	8.314
L - torr/mol - k	62.36

*SI unit

IDEAL GAS LAW [2]

Q. **What is the pressure inside a gas balloon if it filled with 852 g of Xe gas at 25.0°C and occupies a volume of 7.00 L?**

P = ?   852 g Xe (1 mol / 131 g) = 6.50 mol

V = 7.00 L   T = 25°C + 273 = 298 K

$$\mathbf{P = \frac{nRT}{V}}$$

$$P = \frac{(6.50\ \text{mol})\ (0.082\ \text{L-atm / mol-K})\ (298\ \text{K})}{7.00\ \text{L}}$$

P = 22.7 atm

IDEAL GAS LAW

2) How much would a balloon weigh if it contained 40.0 L of O_2 gas at 987 mmHg and 45.3 ^{o}C?

IDEAL GAS LAW examples

1) The Goodyear blimp contains 5.74×10^6 L of helium at 25.0 °C and 1.00 atm. What is the mass in grams of the helium inside the blimp?

$$n = \frac{PV}{RT}$$

(a) 2.30×10^7 g
(b) 2.80×10^6 g
(c) 1.12×10^7 g
(d) 2.34×10^5 g
(e) 9.39×10^5 g

$$n = \frac{(1.00 \text{ atm}) \quad (5.74\text{x}10^6 \text{ L})}{(0.082 \ ^{\text{L-atm}} / _{\text{mol-K}})\ (298\text{K})}$$

n = 234899 mol (4g/mol) = $9.40\text{x}10^5$ g (E)

2) Tennis balls are usually filled with either air or N_2 gas to a pressure above atmospheric pressure to increase their bounce. If a tennis ball has a volume of 144 cm^3 and contains 0.330 g of N_2 gas, what is the pressure inside the ball at 24.0 °C?

$$\mathbf{P = \frac{nRT}{V}} \qquad P = \frac{(0.33\text{g }(1\text{mol}/28\text{g}))\ (0.082 \ ^{\text{L-atm}} /_{\text{mol-K}})\ (24+273 \text{ K})}{144 \text{ mL}(1\text{L}/1000\text{mL})}$$

P = 1.99 atm

IDEAL GAS LAW Practice Problems

1) What would be the temperature, in °C, of 100.0 g of Ar gas contained in a 500.0 L sealed container at 0.8976 atm.

$T = 1914\ ^{o}C$

2) How much would a balloon weigh if it contained 40.0 L of O_2 gas at 987 mmHg and 45.3 ^{o}C?

mass $O_2 = 63.7$ g

STOICHIOMETRY & THE GAS LAWS

1. **Write a balanced chemical equation**

2. **Convert to moles (if gas, use PV=nRT or Molar Volume)**

3. **Use the mole ratio to convert from moles of "A" to moles of "B".**

4. **Convert moles of "B" to desired measurement, if a gas use PV=nRT.**

STOICHIOMETRY & THE GAS LAWS

1. What volume of O_2 is needed to combust 348.0 L of C_3H_8 at STP?

$$C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$$

Due to Avogadro's Hypothesis, the moles of a gas are directly related to the volume of a gas therefore it is possible to use the mole ratio on volumes of gas.

$$348.0\ L\ C_3H_8\ (^{5\ mol\ O_2}/_{1\ mol\ C_3H_8}) = 1740\ L\ O_2$$

STOICHIOMETRY & THE GAS LAWS

2. How many grams of CO_2 is produced from 348.0 L of C_3H_8 if the temperature is 40.0°C and the pressure is 654 torr?

$$C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$$

P = 654 torr (1 atm / 760 torr) = 0.861 atm

T = 40°C + 273 = 313 K

$$PV / RT = n$$

$$n = (0.861\ \text{atm})\ (348.0\ \text{L})\ /(0.082\ ^{\text{L-atm}}/_{\text{mol-K}})\ (313\ \text{K})$$

$$n = 11.67\ \text{mol of}\ C_3H_8$$

Now convert moles of propane to moles of CO_2:

11.67 mol C_3H_8 (3mol CO_2 / 1mol C_3H_8) = 35.02 mol CO_2

Convert mole to gram:

35.02 mol CO_2 (44 g / 1 mol) = **1541 g of CO_2**

STOICHIOMETRY & THE GAS LAWS 2

1. What volume of CO_2 is produced in the combustion of 50.0L of C_4H_{10} at STP?

NOTE: Due to Avogadro's Hypothesis, the moles of a gas are directly related to the volume of a gas therefore it is possible to use the mole ratio on volumes of gas.

STOICHIOMETRY & THE GAS LAWS

2. How many grams of O_2 is needed if 50.0 L of C_4H_{10} is combusted and the temperature is 40.0°C and the pressure is 654 torr?

STOICHIOMETRY & THE GAS LAWS

3. In lab a student decomposed potassium chlorate into oxygen and potassium chloride. What volume of O_2 at STP can be formed from 3.00 g of potassium chlorate?

$$2\ KClO_3 \rightarrow 3\ O_2 + 2\ KCl$$

$$3.00\ g\ KClO_3\ (^{1\ mol}/_{122.6g}) = 0.02447\ mol\ KClO_3$$

$$0.02447\ mol\ KClO_3\ (^{3\ mol\ O_2}/_{2\ mol\ KClO_3}) = 0.03670\ mol\ O_2$$

$$0.03670\ mol\ O_2\ (\ 22.4\ L\ /\ 1\ mol) = 0.822\ L\ or\ 822\ mL$$

STOICHIOMETRY & THE GAS LAWS 6

3. Carbon monoxide is produced by the reaction of coke with oxygen from preheated air. How many liters of atmospheric oxygen at an effective pressure of 182 torr and a temperature of 29.0^{o}C are required to react 10.00 g of coke.

Combined Gas law vs Stoichiometry

We burn methane as a source of energy to heat and cook. What volume of oxygen, measured at 25 °C and 730 torr, is required to react with 1.0 L of methane measured at 45 °C and 625 mmHg?

$$\frac{P_o V_o}{T_o} = \frac{P_f V_f}{T_f}$$

This is not physical but chemical so step 1 is to make a balanced chemical reaction; the mole ratio is needed

$$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$$

V	1.0 L	V=?
T	45°C	25°C
P	625 mmHg	730 torr

n = PV/RT = (625/760) atm (1.0L) /R (45+273) = 0.002586 mol/R

0.002586 mol/R (2 mol O_2 / 1 mol CH_4) = 0.005172 mol/R

V = nRT/P = (0.005172 mol/R) R (298K) / (730/760)atm

V = 1.6 L

You try it

1) A sample of gas has a volume of 2.40 mL at a pressure of 0.993 atm. Determine the volume of the gas at a pressure of 0.500 atm.

2) A sample of ammonia occupies 2.670 L at 70 °C and 650 torr. What volume will the gas have at 20 °C and 790 torr?

3) We burn methane as a source of energy to heat and cook. What volume of oxygen, measured at 35 °C and 770 torr, is required to react with 5.0 L of methane measured under the same conditions of temperature and pressure?

4) An acetylene tank for an oxyacetylene welding torch provides 9340 L of acetylene gas, C_2H_2, at STP. How many tanks of oxygen, each providing 7.00×10^3 L of oxygen at STP, will be required to burn the acetylene?

PRACTICE PROBLEM mixed

1. At STP, 560 mL of a gas has a mass of 1.08 g. What is the molecular weight of the gas?

43.2 g/mol

2. Determine the volume of 655 g methane at 25 °C and 745 torr. 1.0×10^3 L

3. What volume would 5.30 L of H_2 gas at STP occupy if the temperature was increased to 70°F and the pressure to 830 torr? 5.23 L

4. How many moles of hydrogen gas are required to fill a 16.80 L balloon with a pressure of 1.050 atm and a temperature of 38 °C? **0.69 mol**

5. A sample of ammonia is found to occupy 0.250 L under laboratory conditions at 27.0 °C and 0.850 atm. Find the volume under STP conditions. **0.193 L**

6. When a 2.0 L bottle of concentrated HCl was spilled, 3.0 kg of $CaCO_3$ was required to neutralize the spill. $CaCO_3\ (s) + 2HCl\ (aq) \rightarrow CaCl_2\ (aq) + H_2O\ (l) + CO_2\ (g)$ What volume of CO_2 gas was released by the neutralization at 735 mmHg and 20 °C?

745 L

7 Carbon monoxide is produced by the reaction of coke with oxygen from preheated air. $2\ C + O_2 \rightarrow 2\ CO$. How many liters of atmospheric oxygen at an effective pressure of 182 torr and a temperature of 29.0°C are required to produce 895 L of carbon monoxide at 846 torr and 1700°C? 12.9 L