JAZAN UNIVERSITY

COLLEGE OF ENGINEERING
CHEMICAL ENGINEERING DEPARTMENT

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CHE 111
Physical Chemistry

Semester 2020 2

Dr. Isam Yassin Qudsieh
isamyq@yahoo.com

19/1/2020

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Course Title: Physical Chemistry
Course Code: CHE 111 **Credit Hours**: 3 ch
Pre-Requisite:
Contact Hours: 3 Lectures
Lecturer: DR. Isam Yassin Qudsieh
Time: based on the time table for 14 weeks Semester
Required Reading:
Textbook, Mortimer R.G. ،"Physical Chemistry", Elsevier ،3rd Ed. (2008)
Reference, By Tinoco, I, Sauer, K, Wang, J. C. & Puglisi, J.D. Physical Chemistry: Principles and Applications in Biological Sciences, Prentice Hall, Inc. Copyright © 2002.
No make up exams will be given. Special circumstances may be required in the event of an excusable exam absence.
A compulsory, Final Exam will cover all topics.
The student can review his mid-term exams within two weeks of the announcement grades.

Evaluation Method:

1st Exam-	--/--/2020	15%
2nd Exam-	--/--/ 2020	15%
Qz1		10%
Qz2 (HW, Assignment)		10%
Final Exam		50%
TOTAL		100%

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- ✓ **Time to learn is the key. The accepted wisdom is that you need six or more hours a week (including weekends), not counting laboratory preparation and completion.**
- ✓ **Lecture attendance helps the huge majority of students and is highly recommended.**

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UNIT 1

BEHAVIOR OF GASES (IDEAL AND REAL GAS)

Physical Chemistry

Physical chemistry: is the study of macroscopic, atomic, subatomic, and particulate phenomena in chemical systems in terms of laws and concepts of physics. It applies the principles, practices and concepts of physics such as motion, energy, force, time, thermodynamics, quantum chemistry, statistical mechanics, dynamics and equilibrium.

Thermodynamics and Thermochemistry

- Thermodynamics – the study of energy and its transformations
- Thermochemical changes – energy changes associated with chemical reactions

Studying Systems

- Systems can be either
  - macroscopic
  - microscopic

What chemical symbols mean

H_2O

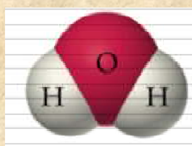
big, thick wall

microscopic

Bond angles

Bond lengths

Dipole moments



macroscopic

phase

temperature

density

Specific heat

pressure

Glucose

Chemical Equations: Symbols

$$C_6H_{12}O_6(s)+6\,O_2(g)\rightarrow 6\,CO_2(g)+6\,H_2O(g)$$

- **Microscopic** viewpoint: 1 molecule of glucose reacts with 6 molecules of oxygen to form 6 molecules of carbon dioxide and six molecules of water.
- **Macroscopic** viewpoint: Solid glucose reacts with gaseous oxygen to form gaseous carbon dioxide and gaseous water. The mass of all the glucose and oxygen is the same as the mass of all the carbon dioxide and water

Clearly, a chemical reaction has microscopic scale information (molecule names and ratios), and macroscopic scale information (phases), but the majority of the important information (for us) is on the microscopic scale.

Chemical Equations: Conservation of mass

Recall ,the law of mass conservation is closely related to chemical equations.
Since chemical equations contain information both macroscopic and microscopic, let's see how the law of mass conservation plays on both levels.

Macroscopic

The total mass of the reactants must be exactly the same as the total mass of the products. Mass cannot be created or destroyed.

Microscopic

Every atom of every element in the reactants must appear in the products. Atoms cannot be created or destroyed.

↑

This is the origin of balancing reactions!

State of a System

- Described by variables such as
  - Temperature (T)
  - Pressure (P)
  - Volume (V)
  - Energy (U)
  - Enthalpy (H)
  - Gibbs energy (G)
  - Entropy (S)

State and Path Functions

- State Function
  - a system property whose values depends only on the initial and final states of the system.
- Path Functions
  - system quantity whose value is dependent on the manner in which the transformation is carried out.

State and Path Functions (Continued)

- Examples of state functions
  - Δ H
  - Δ G
  - Δ V
  - Δ T
- Examples of path functions
  - work (w)
  - heat (q)

The Definition of a Gas

- Gas - a substance that is characterised by widely separated molecules in rapid motion
- Mixtures of gases are uniform. Gases will expand to fill containers.

Examples of Gaseous Substances

- Common gases include - O_2 and N_2, the major components of "air"
- Other common gases - F_2, Cl_2, H_2, He, and N_2O (laughing gas)

The Definition of Pressure

- The pressure of a gas is best defined as the forces applied by gas on the walls of the container
- Define P = force/area
- The SI unit of pressure is the Pascal
- 1 Pa = $N/m^2 = (kg\ m/s^2)/m^2$

The Measurement of Pressure

- How do we measure gas pressure?
- We use an instrument called the barometer - invented by *Torricelli*
- Gas pressure conversion factors
  - 1 atm = 760 mm Hg = 760 torr
  - 1 atm = 101.325 kPa = 1.01325 bar
  - 1 bar = 1×10^5 Pa (exactly)

The Gas Laws

- Experiments with a wide variety of gases shown that four variables were sufficient to fully describe the state of a gas
  - Pressure (P)
  - Volume (V)
  - Temperature (T)
  - The amount of the gas in moles (n)

Boyle's Law

Pressure and volume are inversely related at **constant temperature**.

$PV = K$

As one goes up, the other goes down.

$P_1V_1 = P_2V_2$

"Father of Modern Chemistry"

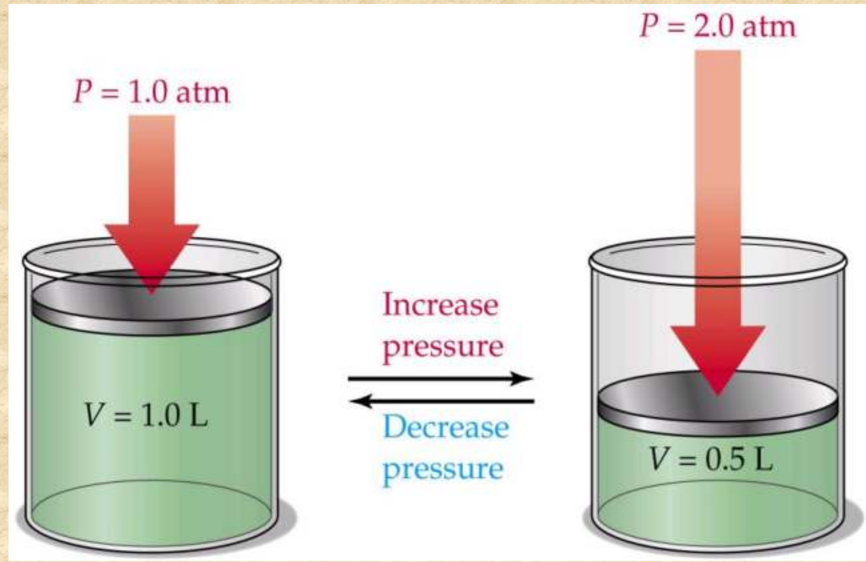
Robert Boyle

Chemist & Natural Philosopher

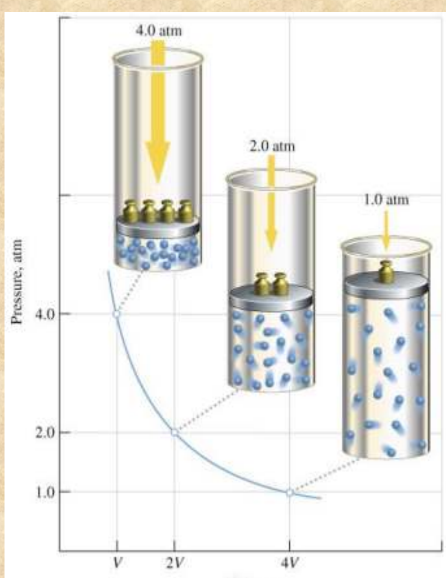
Listmore, Ireland

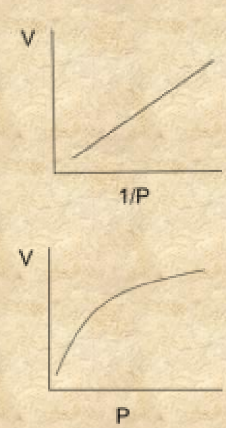
January 25, 1627 – December 30, 1690

Boyle's Law: $P_1V_1 = P_2V_2$



Boyle's Law: $P_1V_1 = P_2V_2$





Example #1:

2.00 L of a gas is at 740.0 mmHg pressure.
What is its volume at standard pressure?

Solution:

Example #2:

5.00 L of a gas is at 1.08 atm.
What pressure is obtained when the volume is 10.0 L?

Example #3:
9.48 L of a gas was at an unknown pressure.
However, at standard pressure, its volume was measured to be 8.00 L.
What was the unknown pressure?
Solution:

Charles' Law

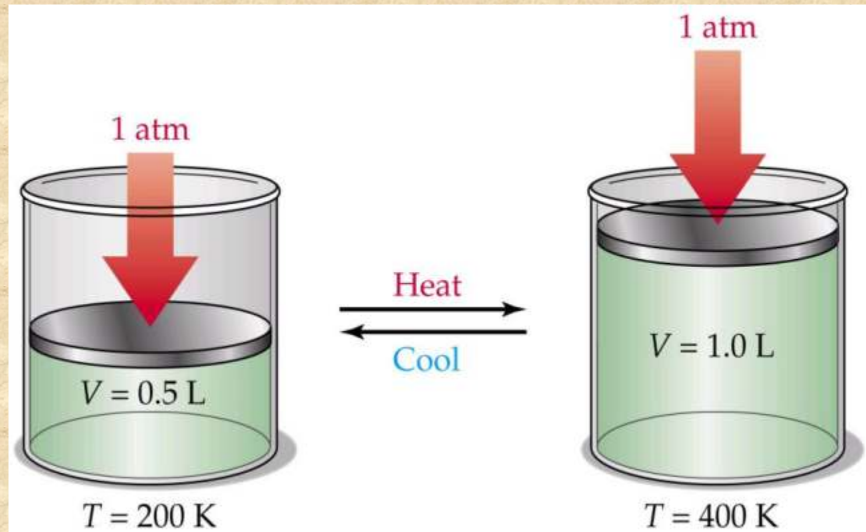
Volume of a gas **varies directly with** the absolute **temperature** at **constant pressure.**

V = KT

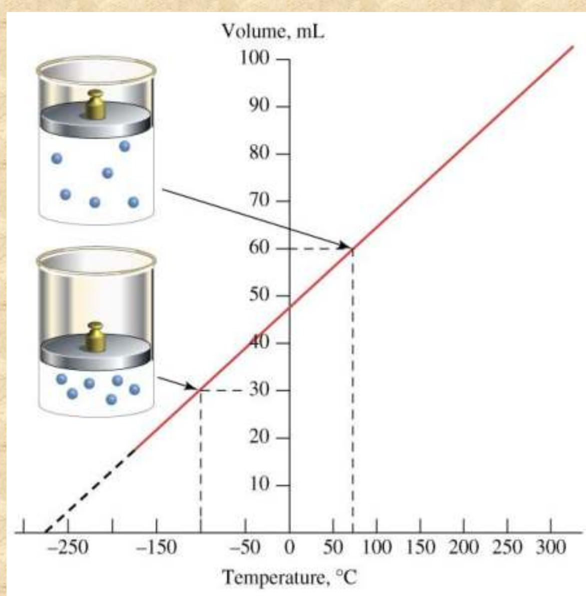
$V_1 / T_1 = V_2 / T_2$

Jacques-Alexandre Charles
Mathematician, Physicist, Inventor
Beaugency, France
November 12, 1746 – April 7, 1823

Charles' Law: $V_1/T_1 = V_2/T_2$



Charles' Law: $V_1/T_1 = V_2/T_2$



Example #4:
A gas is collected and found to fill 2.85 L at 25.0 °C.
What will be its volume at standard temperature?
Solution:
1) Convert 25.0 °C to Kelvin and you get 298 K. Standard temperature is 273 K
2) We plug into our equation like this:

$$\frac{2.85\ \text{L}}{298\ \text{K}} = \frac{x}{273\ \text{K}}$$

Remember that you have to plug into the equation in a very specific way. Temperatures and volumes come in connected pairs and you must put them in the proper place.
2) Cross-multiply and divide:
$x = V_2 = 2.61$ L

Example #5:
4.40 L of a gas is collected at 50.0 °C.
What will be its volume upon cooling to 25.0 °C?
Comment: 2.20 L is the wrong answer.
Sometimes a student will look at the temperature being cut in half and reason that the volume must also be cut in half.
That would be true if the temperature was in Kelvin.
However, in this problem the Celsius is cut in half, not the Kelvin.
Solution:
1) Convert 50.0 °C to 323 K and 25.0 °C to 298 K.
2) Then plug into the equation and solve for x, like this:

$$\frac{4.40\ \text{L}}{323\ \text{K}} = \frac{x}{298\ \text{K}}$$

2) Cross-multiply and divide:
$x = V_2 = 4.06$ L

Amedeo Avogadro
Physicist
Turin, Italy
August 9, 1776 – July 9, 1856

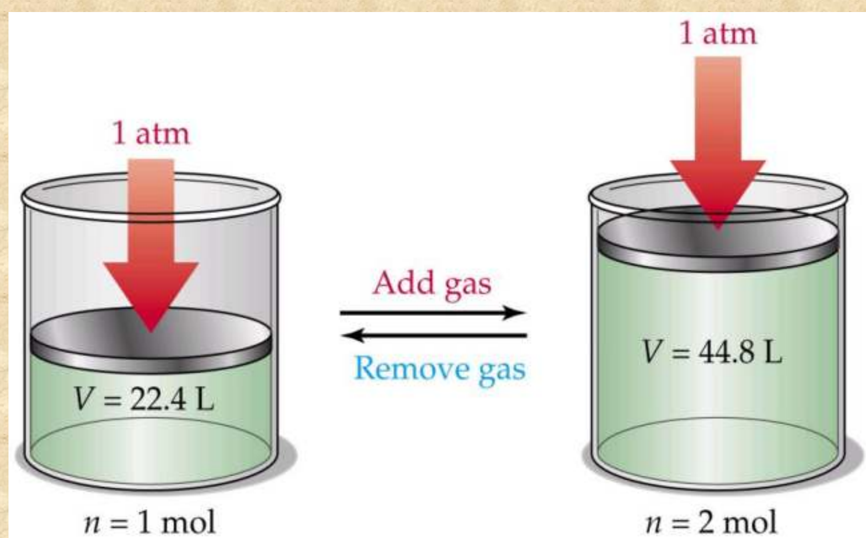
Avogadro's Law

At **constant temperature and pressure**, the **volume** of a gas is **directly related to the number of moles**.

$V = K\,n$

$V_1 / n_1 = V_2 / n_2$

Avogadro's Law: $V_1/n_1=V_2/n_2$



Example #6:

5.00 L of a gas is known to contain 0.965 mol.
If the amount of gas is increased to 1.80 mol, what new volume will result (at an unchanged temperature and pressure)?

Solution:

Example #7:

A cylinder with a movable piston contains 2.00 g of helium, He, at room temperature. More helium was added to the cylinder and the volume was adjusted so that the gas pressure remained the same.
How many grams of Helium were added to the cylinder if the volume was changed from 2.00 L to 2.70 L at constant temperature?

Solution:

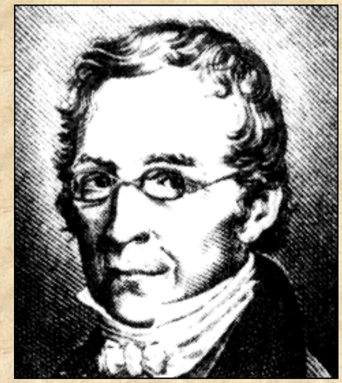
1) Convert grams of He to moles:
2.00 g / 4.00 g/mol = 0.500 mol
2) Use Avogadro's Law:
$V_1/n_1 = V_2/n_2$
$2.00\ \text{L} / 0.500\ \text{mol} = 2.70\ \text{L} / n_2$
$n_2 = 0.675$ mol
3) Compute grams of He added:
0.675 mol - 0.500 mol = 0.175 mol
0.175 mol x 4.00 g/mol = 0.7 grams of He added

Gay-Lussac Law

At **constant volume**, **pressure** and **absolute temperature** are **directly related**.

$P = k\,T$

$P_1 / T_1 = P_2 / T_2$



Joseph-Louis Gay-Lussac
Experimentalist
Limoges, France
December 6, 1778 – May 9, 1850

Example #8:

10.0 L of a gas is found to exert 97.0 kPa at 25.0°C. What would be the required temperature (in Celsius) to change the pressure to standard pressure?

Solution:

Example #9:

5.00 L of a gas is collected at 22.0°C and 745.0 mmHg.
When the temperature is changed to standard, what is the new pressure?

Solution:

Dalton's Law

The **total pressure** in a container is the **sum of the pressure of each gas** would apply if it was alone in the container.

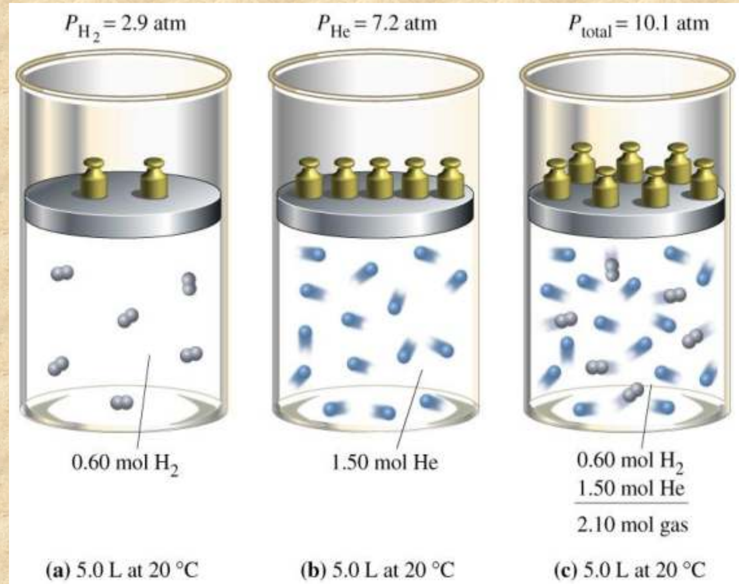
The total pressure is the sum of the partial pressures.

$P_{Total} = P_1 + P_2 + P_3 + P_4 + P_5 \ldots$

(For each gas $P = nRT/V$)

John Dalton
Chemist & Physicist
Eaglesfield, Cumberland, England
September 6, 1766 – July 27, 1844

Dalton's Law



Example #10

The pressure of a mixture of nitrogen, carbon dioxide, and oxygen is 150 kPa. What is the partial pressure of oxygen if the partial pressures of the nitrogen and carbon dioxide are 100 kPa and 24 kPa, respectively?

Solution:

The Kelvin temperature scale

- Lord Kelvin – all temperature/volume plots intercepted the t_c axis at -273.15°C).
- Kelvin termed this absolute 0 – the temperature - where the volume of an ideal gas is 0 and all thermal motion stops!

The Temperatures Scales

- T (K) = [t_c (°C) + 273.15°C] K/°C
  - Freezing point of water: t_c = 0 °C; T = 273.15 K
  - Boiling point of water: t_c = 100 °C; T = 373.15 K
  - Room temperature: t_c = 25 °C; T = 298 K

Amonton's Law

- The pressure/temperature relationship
- For a given quantity of gas at a fixed volume, $P \propto T$, i.e., if we heat a gas cylinder, P increases!

The Ideal Gas Equation of State

- We have four relationships
  - $V \propto 1/P$; Boyle's law
  - $V \propto T$; Charles' law
  - $V \propto n$; Avogadro's law
  - $P \propto T$; Amonton's law and Gay-Lussac's law

The Ideal Gas Law

- Combine these relationships into a single fundamental equation of state - the ideal gas equation of state

$$PV = nRT$$

$$R = 8.314\,\frac{J}{K\ mole} = 0.08206\,\frac{L\ \text{atm}}{\text{K mole}}$$

The Definition of an Ideal Gas

- An ideal gas is a gas that obeys totally the ideal gas law over its entire P-V-T range
- Ideal gases – molecules have negligible intermolecular attractive forces and they occupy a negligible volume compared with the container volume.

Standard Temperature and Pressure

- Define: STP (Standard Temperature and Pressure)
  - Temperature - 0.00 °C = 273.15 K
  - Pressure - 1.000 atm
  - The volume occupied by 1.000 mole of an ideal gas at STP is 22.41 L!

Standard Ambient Temperature and Pressure

- Define: SATP (Standard Ambient Temperature and Pressure)
  - Temperature : 25.00 °C = 298.15 K
  - Pressure : 1.000 bar (10^5 Pa)
  - The volume occupied by 1.000 mole of an ideal gas at SATP is 24.78 L!

Partial Pressures

- The pressure applied by gas #1
  - $P_1 = n_1\ RT / V$
- The pressure applied by gas #2
  - $P_2 = n_2\ RT / V$
- The total pressure of the gases
  - $p_T = n_T\ RT / V$
- n_T represents the total number of moles of gas present in the mixture

Partial Pressures (continued)

- P_1 and P_2 are the partial pressures of gas 1 and gas 2, respectively.
  - $P_T = P_1 + P_2 = n_T\ (RT/V)$
  - $P_T = P_1 + P_2 + P_3 = \Sigma_j\ P_J$
  - note P_j is known as the partial pressure of gas j

Example #11:
The volume of hydrogen collected over water is 453 mL at 18° C and 780. mm Hg.
What is its volume dry at STP? vapor pressure of water at 18° C is 15.5. mmHg

Solution:

Example #12:
A 423 mL sample of dry oxygen at STP is transferred to a container over water at 22° C and 738 mm Hg.
What is the new volume of the oxygen?
Hint: P of H2O is 19.8mmHg
Solution: