Thermodynamics. The gas laws

What is thermodynamics?

• Thermodynamics is the study on the heat, work and energy on a system. It focuses on the stability of systems. It is able to answer the question “what will happen with systems?”.

• Question:
  • Is water stable at 120 °C and 1 atmospheric pressure?
Why gas?

Gas properties:
• Much lower density than that of liquid and solid;
• It can be easily filled into any containers with different shapes;
• It is the most compressible state of matter. Hence, gas system can be easily utilized to do work.

\[ W = P \cdot \Delta V \]

• Elements that exist as gases at \(25^0C\) and 1 atmosphere

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2015.08.31.
Pressure and Temperature

• Pressure

\[ P = \frac{\text{Force}}{\text{Area}} \]

• Manometers used to measure gas pressures

Temperature

• A relative measure or indication of hotness or coldness. It is a reflection of the role of molecular motions in systems.

• Temperature Scale
Absolute Zero Temperature

• the lowest temperature in our universe.
• $T=0 \text{ K} = -273.15 \text{ °C}$

$$T_{\text{Kelvin}} = T_{\text{Celsius}} + 273.15$$

William Thomson, 1st Baron Kelvin (1824-1907)

Phase diagram

• $P$-$T$ (pressure-temperature diagram for water)
Gas laws

• **Boyle’s law** states that the pressure of a fixed amount of gas at a constant temperature is inversely proportional to the volume of the gas.

\[ V \propto \frac{1}{P} \]
\[ P_1 \cdot V_1 = P_2 \cdot V_2 \]

• Question:
At a constant temperature, a gas sample occupies 2.5 L at 3 atm, if the pressure is increased to 6 atm, please calculate its volume.

Gas laws

• **Charles’s & Gay-Lussac’s Law** states that the volume of a gas maintained at constant pressure is directly proportional to the absolute temperature (in Kelvin) of the gas.

\[ V \propto T \]
\[ \frac{V_1}{T_1} = \frac{V_2}{T_2} \]

• Question:
At -10 °C, the volume of one balloon is 5 L. What will be volume of this balloon if I take it into a room at 35 °C?
Gas laws

- **Avogadro’s law** states that the volume of a sample of gas is directly proportional to the number of moles in the sample at constant temperature and pressure.

\[ V \propto n \]

\[ \frac{V_1}{n_1} = \frac{V_2}{n_2} \]

- **Question:**

5.0 L of a gas is known to contain 0.9 mol. If the amount of gas is increased to 1.8 mol, what new volume will result (at an unchanged temperature and pressure)?

The Ideal Gas Law

\[ V \propto \frac{1}{P} \quad V \propto T \quad V \propto n \]

- **Boyle’s law**

- **Charles’s law**

- **Avogadro’s law**

\[ V \propto \frac{nT}{P} \]

\[ V = R \cdot \frac{n \cdot T}{P}, \quad R = 8.314 \text{ J/mol/K} \]

\[ P \cdot V = n \cdot R \cdot T \]

- Please calculate the volume 1 mole gas at 25 °C and 1 atmospheric pressure.
Question

• Sodium peroxide (Na₂O₂) is used to remove carbon dioxide from (and add oxygen to) the air supply in spacecrafts. It works by reacting with CO₂ in the air to produce sodium carbonate (Na₂CO₃) and O₂.

• 2Na₂O₂(s) + 2CO₂(g) → 2Na₂CO₃(s) + O₂(g)

• What volume (in liters) of CO₂ (at STP) will react with a kilogram of Na₂O₂?

The Ideal Gas Law

• What kind of requirements does ideal gas meet?
  • The volume of the gas molecule itself is negligible.
  • No attractive or repulsive force among gas molecules
  • Intermolecular collision or the collision between gas molecules and inner walls of container are completely elastic. No energy lost during collisions.

• Difference between ideal gas and real gas

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<th>Ideal Gas</th>
<th>Real Gas</th>
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<tr>
<td>Obey PV=nRT</td>
<td>Always</td>
<td>Only at very low P and high T</td>
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<tr>
<td>Molecular volume</td>
<td>Zero</td>
<td>Small but nonzero</td>
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<td>Molecular attractions</td>
<td>Zero</td>
<td>Small</td>
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<tr>
<td>Molecular repulsions</td>
<td>Zero</td>
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**Gas mixture**

- **Dalton’s law of partial pressure** states that the total pressure exerted by a gas mixture is the sum of the partial pressures exerted by each component of the mixture:

\[ P_{\text{Total}} = \sum P_{\text{component}} \]

\[ P_{\text{Total}} = \frac{n_{\text{Total}} \cdot R \cdot T}{V} = \frac{\sum n_{\text{component}} \cdot R \cdot T}{V} \]

\[ = \sum \frac{n_{\text{component}} \cdot R \cdot T}{V} = \sum P_{\text{component}} \]

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**Dalton’s law of partial pressure**

\[ P_A = \frac{n_A}{n_A + n_B} \cdot P_{\text{Total}}, \quad P_B = \frac{n_B}{n_A + n_B} \cdot P_{\text{Total}} \]

- **Question:**

A 1.00-L vessel contains 0.215 mole of N\(_2\) gas and 0.0118 mole of H\(_2\) gas at 25.5 °C. Determine the partial pressure of each component and the total pressure in the vessel.
Classical vs statistical thermodynamics

- Classical thermodynamics (1824)
  - analyses what can be deduced solely from the macroscopic properties of the system and the laws of thermodynamics, regardless of microscopic interpretation.

- Statistical thermodynamics (1880)
  - analyses thermodynamic properties by relating them to molecular-level models of microscopic behavior in the thermodynamic system.