# Gaseous State for JEE Main Preparation

A Comprehensive Synopsis for Classes X-XII

Detailed Theory, Examples, Exercises, and More

Prepared for JEE Main Aspirants

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# Contents

# Chapter Synopsis

This booklet provides an in-depth study guide for the "Gaseous State" chapter, a critical topic for JEE Main. Designed for Classes X-XII students, it includes:

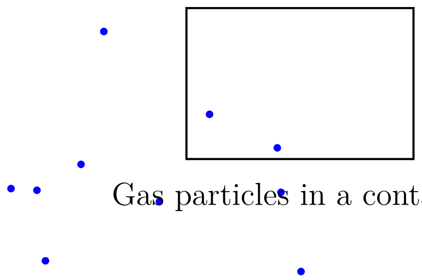
- **Theory with Illustrations**: Detailed explanations with diagrams.
- **JEE-Level Concepts**: Emphasis on high-weightage topics.
- **Solved Examples**: Step-by-step solutions.
- **Practice Exercises**: Extensive problems with solutions.
- **Question Types**: MCQs, Assertion-Reason, Integer-Type.
- **Summary and Formula Sheet**: Quick revision aid.

This 30+ page booklet ensures thorough preparation with detailed descriptions of gas laws, kinetic theory, and real gas behavior.

# 1 Theory with Illustrations

## 1.1 Introduction to Gaseous State

Gases are characterized by their ability to fill containers, high compressibility, and low density compared to liquids and solids. Key properties include pressure ($P$), volume ($V$), temperature ($T$), and number of moles ($n$). These properties are interrelated through gas laws.



Gas particles in a container

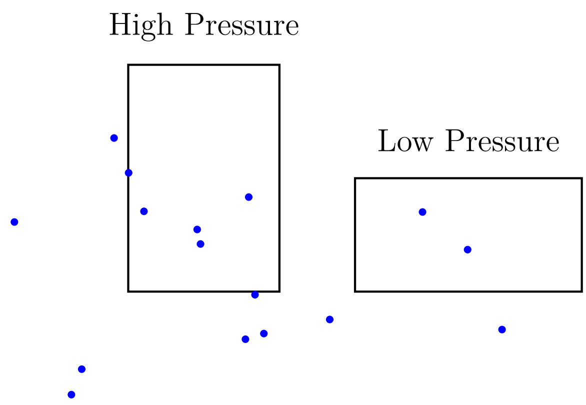
## 1.2 Gas Laws

### 1.2.1 Boyle's Law

At constant temperature, the volume of a gas is inversely proportional to its pressure:

$$PV = \text{constant} \quad \text{or} \quad P_1V_1 = P_2V_2$$

**Derivation**: Consider a gas in a piston. As pressure increases, the gas compresses, reducing volume proportionally.




### 1.2.2 Charles's Law

At constant pressure, the volume of a gas is directly proportional to its absolute temperature:

$$\frac{V}{T} = \text{constant} \quad \text{or} \quad \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

**Derivation**: Heating a gas increases molecular kinetic energy, causing expansion to maintain constant pressure.

### 1.2.3 Gay-Lussac's Law

At constant volume, the pressure of a gas is directly proportional to its absolute temperature:

$$\frac{P}{T} = \text{constant} \quad \text{or} \quad \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

### 1.2.4 Avogadro's Law

At constant temperature and pressure, the volume of a gas is directly proportional to the number of moles:

$$V \propto n \quad \text{or} \quad \frac{V}{n} = \text{constant}$$

## 1.3 Ideal Gas Equation

Combining the gas laws gives the ideal gas equation:

$$PV = nRT$$

where $R = 8.314\,\mathrm{J/(mol \cdot K)}$ or $0.0821\,\mathrm{L \cdot atm/(mol \cdot K)}$. This equation assumes ideal gas behavior: negligible molecular volume and no intermolecular forces.

## 1.4 Kinetic Theory of Gases

The kinetic molecular theory explains gas behavior through:

- Gas molecules are in constant random motion.
- Molecular volume is negligible compared to container volume.
- No intermolecular forces except during collisions.

- Collisions are elastic.
- Average kinetic energy is proportional to absolute temperature.

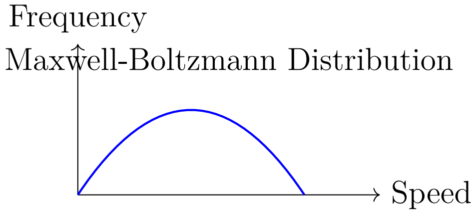
The average kinetic energy per molecule:

$$KE = \frac{3}{2}kT, \quad k = \frac{R}{N_A}$$

Root mean square speed:

$$v_{\text{rms}} = \sqrt{\frac{3RT}{M}}$$

where $M$ is the molar mass.




## 1.5 Real Gases and Deviations

Real gases deviate from ideal behavior at high pressures and low temperatures due to:

- Non-negligible molecular volume.
- Intermolecular forces.

The van der Waals equation corrects for these:

$$\left(P + \frac{an^2}{V^2}\right)(V - nb) = nRT$$

where $a$ accounts for intermolecular attractions, and $b$ is the excluded volume.

The compressibility factor $Z$:

$$Z = \frac{PV}{nRT}$$

For ideal gases, $Z = 1$. For real gases, $Z \neq 1$.

## 1.6 Dalton's Law of Partial Pressures

The total pressure of a gas mixture is the sum of partial pressures:

$$P_{\text{total}} = P_1 + P_2 + \cdots$$

Partial pressure:

$$P_i = x_i P_{\text{total}}, \quad x_i = \frac{n_i}{n_{\text{total}}}$$

## 1.7 Graham's Law of Diffusion

The rate of diffusion is inversely proportional to the square root of molar mass:

$$\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}$$

# 2 Important JEE-Level Concepts

- **Gas Law Calculations**: Combining Boyle's, Charles's, and ideal gas equations.
- **Kinetic Energy and Speeds**: $v_{\text{rms}}$, average speed, most probable speed.
- **Real Gas Behavior**: van der Waals equation, compressibility factor.
- **Mixture Problems**: Dalton's law, mole fraction.
- **Diffusion and Effusion**: Graham's law applications.
- **Critical Phenomena**: Critical temperature, pressure, and volume.

# 3 Solved Examples

## 3.1 Example 1: Ideal Gas Equation

**Problem**: Calculate the volume of 2 moles of an ideal gas at 300 K and 2 atm ($R = 0.0821\,\text{L}\cdot\text{atm}/(\text{mol}\cdot\text{K})$).

**Solution**:

$$PV = nRT$$

$$V = \frac{nRT}{P} = \frac{2 \cdot 0.0821 \cdot 300}{2} = 24.63\,\text{L}$$

**Answer**: $24.63\,\text{L}$.

## 3.2 Example 2: Dalton's Law

**Problem**: A mixture contains 1 mole of $O2$ and 2 moles of $N2$ at a total pressure of 3 atm. Find the partial pressure of $O2$.

**Solution**: Mole fraction of $O2$:

$$x_{O2} = \frac{1}{1+2} = \frac{1}{3}$$

$$P_{O2} = x_{O2} \cdot P_{\text{total}} = \frac{1}{3} \cdot 3 = 1\,\text{atm}$$

**Answer**: $1\,\text{atm}$.

## 3.3 Example 3: Graham's Law

**Problem**: Compare the diffusion rates of $H2$ ($M = 2\,\text{g/mol}$) and $O2$ ($M = 32\,\text{g/mol}$).

**Solution**:

$$\frac{r_{H2}}{r_{O2}} = \sqrt{\frac{M_{O2}}{M_{H2}}} = \sqrt{\frac{32}{2}} = \sqrt{16} = 4$$

**Answer**: $H2$ diffuses 4 times faster.

### 3.4 Example 4: Kinetic Energy

**Problem**: Calculate the total kinetic energy of 1 mole of an ideal gas at 273 K ($R = 8.314\,\mathrm{J/(mol \cdot K)}$).

**Solution**:

$$KE = \frac{3}{2}RT = \frac{3}{2} \cdot 8.314 \cdot 273 \approx 3403.5\,\mathrm{J}$$

**Answer**: $3403.5\,\mathrm{J}$.

# 4 Practice Exercises

### 4.1 Exercise 1

Calculate the pressure of 0.5 moles of an ideal gas in a 10 L container at 400 K ($R = 8.314\,\mathrm{J/(mol \cdot K)}$).

### 4.2 Exercise 2

A gas mixture has 2 moles of $CO2$ and 3 moles of $He$ at 5 atm. Find the partial pressure of $He$.

### 4.3 Exercise 3

Find the $v_{\mathrm{rms}}$ of $N2$ ($M = 28\,\mathrm{g/mol}$) at 300 K ($R = 8.314\,\mathrm{J/(mol \cdot K)}$).

### 4.4 Exercise 4

Calculate the ratio of diffusion rates of $NH3$ ($M = 17\,\mathrm{g/mol}$) to $Cl2$ ($M = 71\,\mathrm{g/mol}$).

# 5 Solutions to Practice Exercises

### 5.1 Solution to Exercise 1

$$PV = nRT$$

$$P = \frac{nRT}{V} = \frac{0.5 \cdot 8.314 \cdot 400}{10} = 166.28\,\mathrm{Pa}$$

**Answer**: $166.28\,\mathrm{Pa}$.

### 5.2 Solution to Exercise 2

Mole fraction of $He$:

$$x_{He} = \frac{3}{2+3} = \frac{3}{5}$$

$$P_{He} = \frac{3}{5} \cdot 5 = 3\,\mathrm{atm}$$

**Answer**: $3\,\mathrm{atm}$.

### 5.3 Solution to Exercise 3

$$v_{\text{rms}} = \sqrt{\frac{3RT}{M}}$$

$$M = 28 \times 10^{-3}\,\text{kg/mol}, \quad v_{\text{rms}} = \sqrt{\frac{3 \cdot 8.314 \cdot 300}{28 \times 10^{-3}}} \approx 515.1\,\text{m/s}$$

**Answer**: 515.1 m/s.

### 5.4 Solution to Exercise 4

$$\frac{r_{NH3}}{r_{Cl2}} = \sqrt{\frac{M_{Cl2}}{M_{NH3}}} = \sqrt{\frac{71}{17}} \approx 2.04$$

**Answer**: 2.04.

## 6 Multiple Choice Questions

1. The pressure of an ideal gas is doubled while volume is halved at constant temperature. The new pressure is:
   (a) Same
   (b) Doubled
   (c) Quadrupled
   (d) Halved

   **Answer**: (c) Quadrupled

2. The average kinetic energy of a gas depends on:
   (a) Pressure
   (b) Volume
   (c) Temperature
   (d) Molar mass

   **Answer**: (c) Temperature

3. For a real gas, $Z < 1$ indicates:
   (a) Ideal behavior
   (b) Attractive forces dominate
   (c) Repulsive forces dominate
   (d) High temperature

   **Answer**: (b) Attractive forces dominate

# 7 Assertion-Reason Questions

1. **Assertion**: At constant temperature, doubling the pressure halves the volume.
   **Reason**: Boyle's law states $PV = \text{constant}$.
   **Answer**: Both true, Reason explains Assertion.
2. **Assertion**: Real gases behave ideally at high pressure.
   **Reason**: Intermolecular forces are negligible at high pressure.
   **Answer**: Assertion false, Reason false.

# 8 Integer-Type Questions

1. The total kinetic energy of 1 mole of an ideal gas at 200 K is approximately (in kJ, $R = 8.314\,\mathrm{J/(mol \cdot K)}$): **Answer**: 2
2. The ratio of $v_{\mathrm{rms}}$ of $He$ ($M = 4$) to $N2$ ($M = 28$) at the same temperature (rounded to nearest integer): **Answer**: 3

# 9 Advanced Concepts for JEE Main

## 9.1 Critical Phenomena

The critical temperature ($T_c$) is the temperature above which a gas cannot be liquefied:

$$T_c = \frac{8a}{27Rb}$$

Critical pressure and volume are similarly defined.

## 9.2 Liquefaction of Gases

Gases liquefy when cooled below their critical temperature and compressed. This is key for JEE questions on real gas behavior.

## 9.3 Maxwell-Boltzmann Distribution

The distribution of molecular speeds varies with temperature and molar mass, affecting $v_{\mathrm{rms}}$, average speed, and most probable speed.

# 10 Additional Solved Examples

## 10.1 Example 5: van der Waals Equation

**Problem**: Calculate the pressure of 1 mole of a gas in a 1 L container at 300 K using the van der Waals equation ($a = 1.39\,\mathrm{L^2 \cdot atm/mol^2}$, $b = 0.039\,\mathrm{L/mol}$, $R = 0.0821\,\mathrm{L \cdot atm/(mol \cdot K)}$).

**Solution**:

$$\left(P + \frac{a}{V^2}\right)(V - b) = RT$$

$$P = \frac{RT}{V - b} - \frac{a}{V^2}$$

$$P = \frac{0.0821 \cdot 300}{1 - 0.039} - \frac{1.39}{1^2} \approx 25.64 - 1.39 = 24.25\,\text{atm}$$

**Answer**: 24.25 atm.

### 10.2 Example 6: Compressibility Factor

**Problem**: Find $Z$ for 1 mole of an ideal gas at 2 atm and 10 L ($R = 0.0821\,\text{L} \cdot \text{atm}/(\text{mol} \cdot \text{K})$).

**Solution**:

$$Z = \frac{PV}{nRT}$$

For ideal gas, $Z = 1$. Verify:

$$PV = nRT \implies Z = 1$$

**Answer**: 1.

## 11 More Practice Exercises

### 11.1 Exercise 5

Calculate the volume of 3 moles of an ideal gas at 500 K and 1.5 atm.

### 11.2 Exercise 6

Find the $v_{\text{rms}}$ of $O2$ ($M = 32\,\text{g/mol}$) at 400 K.

### 11.3 Exercise 7

A mixture of 1 mole $CH4$ and 1 mole $CO2$ has a total pressure of 2 atm. Find the partial pressure of $CH4$.

### 11.4 Exercise 8

Calculate the temperature at which $v_{\text{rms}}$ of $He$ equals that of $N2$ at 300 K.

## 12 Solutions to More Practice Exercises

### 12.1 Solution to Exercise 5

$$V = \frac{nRT}{P} = \frac{3 \cdot 0.0821 \cdot 500}{1.5} \approx 82.1\,\text{L}$$

**Answer**: 82.1 L.

### 12.2 Solution to Exercise 6

$$v_{\text{rms}} = \sqrt{\frac{3 \cdot 8.314 \cdot 400}{32 \times 10^{-3}}} \approx 557.7\,\text{m/s}$$

**Answer**: 557.7 m/s.

### 12.3 Solution to Exercise 7

$$x_{CH4} = \frac{1}{1+1} = 0.5$$

$$P_{CH4} = 0.5 \cdot 2 = 1\,\text{atm}$$

**Answer**: 1 atm.

### 12.4 Solution to Exercise 8

$$v_{\text{rms}} = \sqrt{\frac{3RT}{M}}$$

$$\sqrt{\frac{T_{He}}{4 \times 10^{-3}}} = \sqrt{\frac{300}{28 \times 10^{-3}}}$$

$$T_{He} = 300 \cdot \frac{4}{28} \approx 42.86\,\text{K}$$

**Answer**: 42.86 K.

## 13 Additional MCQs

1. The gas law relating pressure and temperature at constant volume is:
   (a) Boyle's
   (b) Charles's
   (c) Gay-Lussac's
   (d) Avogadro's

   **Answer**: (c) Gay-Lussac's

2. The compressibility factor for an ideal gas is:
   (a) 0
   (b) 1
   (c) $< 1$
   (d) $> 1$

   **Answer**: (b) 1

# 14 Additional Assertion-Reason

1. **Assertion**: $v_{\text{rms}}$ increases with temperature.
   **Reason**: $v_{\text{rms}} \propto \sqrt{T}$.
   **Answer**: Both true, Reason explains Assertion.

# 15 Additional Integer-Type

1. The number of moles of an ideal gas in a 22.4 L container at 1 atm and 273 K is:
   **Answer**: 1

# 16 Summary and Formula Sheet

## 16.1 Summary

The gaseous state is fundamental to understanding physical chemistry. Key points:

- Gas laws describe relationships between $P$, $V$, $T$, and $n$.
- Kinetic theory explains macroscopic properties via molecular motion.
- Real gases deviate from ideal behavior, corrected by the van der Waals equation.
- Dalton's and Graham's laws apply to mixtures and diffusion.

## 16.2 Formula Sheet

- Ideal Gas: $PV = nRT$
- Boyle's: $P_1V_1 = P_2V_2$
- Charles's: $\frac{V_1}{T_1} = \frac{V_2}{T_2}$
- Gay-Lussac's: $\frac{P_1}{T_1} = \frac{P_2}{T_2}$
- Avogadro's: $\frac{V}{n} = \text{constant}$
- Kinetic Energy: $KE = \frac{3}{2}RT$
- $v_{\text{rms}}$: $\sqrt{\frac{3RT}{M}}$
- van der Waals: $\left(P + \frac{an^2}{V^2}\right)(V - nb) = nRT$
- Dalton's: $P_{\text{total}} = P_1 + P_2 + \cdots$
- Graham's: $\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}$

# 17 Conceptual Questions for Revision

1. Derive the ideal gas equation from Boyle's, Charles's, and Avogadro's laws.
2. Explain why real gases deviate from ideal behavior.

3. Discuss the significance of the Maxwell-Boltzmann distribution.

# 18 Final Practice Set

1. Calculate the pressure of 2 moles of a gas in a 5 L container at 350 K using the van der Waals equation ($a = 2.5\,\text{L}^2 \cdot \text{atm/mol}^2$, $b = 0.042\,\text{L/mol}$).
2. Find the partial pressure of $N2$ in a mixture of 1 mole $N2$ and 2 moles $O2$ at 4 atm.
3. Determine the temperature at which the $v_{\text{rms}}$ of $CO2$ equals that of $He$ at 400 K.

# 19 Solutions to Final Practice Set

- **Answer to Q1**: $\approx 37.8\,\text{atm}$
- **Answer to Q2**: $\frac{4}{3}\,\text{atm}$
- **Answer to Q3**: $4400\,\text{K}$