Precise

PHYSICS

Vol. I

BASED ON NEW PAPER PATTERN

Std. XII Science

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Precise
PHYSICS (Vol. I)
Std. XII Sci.

Salient Features

- Written as per Latest Board Paper Pattern
- Subtopic-wise segregation for powerful concept building
- Complete coverage of Textual Exercise Questions, Intext Questions and Numericals
- Includes selective Board questions from March 2013 to July 2022
- Includes selective questions from NCERT textbook for practice
- Marks provided to the Questions as per relevant weightage as deemed necessary
- ‘Solved Examples’ provided to cover numerical aspect of the topic in detail.
- ‘Quick Review’ at the end of every chapter facilitates quick revision
- ‘Important Formulae’ offers compilation of formulae covered in a chapter
- ‘Reading Between the Lines’ to elucidate concept
- Video/pdf links provided via QR codes for boosting conceptual retention
- Includes Board Question Paper of February 2023 (Solution in pdf format through QR code)

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PREFACE

Precise Physics Vol. I, Std. XII Sci. is intended for every Maharashtra State Board aspirant of Std. XII, Science. The scope, sequence, and level of the book are designed to match the new textbook of Maharashtra State board.

We believe that the study of Physics needs driving desire to learn and willingness to work hard. The earnestness to dive into the subject eventuates naturally when students are presented with meaningful content that is easy to read and understand rather than being mired down with facts and information. Students do much better when they grasp the nub of the subject.

While beginning with a chapter in Physics, students should study to understand the content and not merely read point blankly. They can go slowly, knowing Physics can't be read like a novel, choosing their own pace. But it is essential for students to comprehend the concepts involved, ruminate and reproduce their own versions of the same.

To quote Albert Einstein, **"If you can't explain it simply, you don't understand it yourself."**

Students should then attempt theoretical questions based on these concepts to gauge the level of understanding achieved.

Next advance after gaining command over theory would be numericals. Though Physics is communicated in English, it is expressed in Mathematics. Hence, it is essential to befriend formulae and derivations. These should be learnt and memorized. Once physical mathematics of concept is ingrained, solved numericals should be studied, starting from simple problems to difficult by escalating level of complexity gradually. Students are required to practise numericals and ascertain their command on problem solving. Calculations at this stage must be done using log table keeping in mind that calculators are not allowed in Board Exams. **When it comes to problems in Physics nothing makes students perfect like practice!**

Amongst building concepts, advancing into numbers and equations, it is essential to ponder underlying implications of subject. Students should read from references, visit authentic websites and watch relevant fascinating links.

Such a holistic preparation of subject is the key to succeed in the board examination.

After all, **"Success is no accident. It is hard work, perseverance, learning, studying, sacrifice and most of all, love of what you are doing or learning to do,"** as said by legendary football player Pele and students should bear it in mind!

Our **Precise Physics Vol. I, Std. XII Sci.** adheres to our vision and achieves several goals: **building concepts**, **developing competence to solve numericals, recapitulation and self-study** —all while encouraging students toward cognitive thinking.

Features of the book presented below will explicate more about the same!

We hope the book benefits the learner as we have envisioned.

Publisher
Edition: Fifth

The journey to create a complete book is strewn with triumphs, failures and near misses. If you think we've nearly missed something or want to applaud us for our triumphs, we'd love to hear from you.
Please write to us on: mail@targetpublications.org

KEY FEATURES

Reading between the lines

Reading between the lines provides elaboration or missing fragments of concept essential for complete understanding of the concept.

QR Codes

QR code provides:
i. Access to a video/PDF in order to boost understanding of a concept or activity
ii. Solutions to Board Question Paper February 2023

Solved Examples

Solved Examples offer complete solution to numerical including log (as seemed required).

Important Formulae

Important Formulae includes all of the key formulae in the chapter.

Quick Review

Quick review includes tables/ flow chart to summarize the key points in chapter.

Exercise

Exercise includes subtopic-wise additional questions and problems.

Multiple Choice Questions

Multiple Choice Question includes textual as well as additional MCQs.

Board Questions

Includes selective and relevant Board questions from March 2013 to July 2022

PAPER PATTERN

- There will be single question paper of 70 Marks and practical examination of 30 Marks in Physics.
- Duration of the paper will be 3 hours.

Section A: **(18 Marks)**

This section will contain Multiple Choice Questions and Very Short Answer (VSA) type of questions.
There will be 10 MCQs and 8 VSA type of questions, each carrying one mark.
Students will have to attempt all these questions.

Section B: **(16 Marks)**

This section will contain 12 Short Answer (SA-I) type of questions, each carrying 2 marks.
Students will have to attempt any 8 questions.

Section C: **(24 Marks)**

This section will contain 12 Short Answer (SA-II) type of questions, each carrying 3 marks.
Students will have to attempt any 8 questions.

Section D: **(12 Marks)**

This section will contain 5 Long Answer (LA) type of questions, each carrying 4 marks.
Students will have to attempt any 3 questions.

Distribution of Marks According to the Type of Questions

Type of Questions		
MCQ	1 Mark each	10 Marks
VSA	1 Mark each	8 Marks
SA - I	2 Marks each	16 Marks
SA - II	3 Marks each	24 Marks
LA	4 Marks each	12 Marks

Percentage wise distribution of marks	
Theory	63%
Numerical	37%

Disclaimer

This reference book is transformative work based on textbook Physics; Reprint: 2022 published by the Maharashtra State Bureau of Textbook Production and Curriculum Research, Pune. We the publishers are making this reference book which constitutes as fair use of textual contents which are transformed by adding and elaborating, with a view to simplify the same to enable the students to understand, memorize and reproduce the same in examinations.

This work is purely inspired upon the course work as prescribed by the Maharashtra State Bureau of Textbook Production and Curriculum Research, Pune. Every care has been taken in the publication of this reference book by the Authors while creating the contents. The Authors and the Publishers shall not be responsible for any loss or damages caused to any person on account of errors or omissions which might have crept in or disagreement of any third party on the point of view expressed in the reference book.

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[Reference: Maharashtra State Board of Secondary and Higher Secondary Education, Pune - 04**]**

Note:
1. * mark represents Textual question.
2. # mark represents Intext question.
3. + mark represents Textual examples.
4. 🔔 symbol represents textual questions that need external reference for an answer.
5. Chapters 8 to 16 are a part of Std. XII: Precise Physics (Vol. II).

3 Kinetic Theory of Gases and Radiation

Contents and Concepts

3.1 Introduction

Q.1. Using the gas laws, prove that PV = Nk_BT. Also state the significance of terms involved.

OR

Can you recall? *(Textbook page no. 56)*

How do you get ideal gas equation from the gas laws? **[3 Marks]**

Ans:

i. The three gas laws applied to a fixed mass m of an enclosed gas are,

a. Boyle's law: $V \propto \frac{1}{P}$ at constant T.

b. Charles' law: $V \propto T$ at constant P.

c. Gay-Lussac's law: $P \propto T$ at constant V.

ii. Combining the three laws,

$PV \propto T$ i.e., $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

iii. In terms of number of moles (n) of the gas,

$PV \propto nT$

$\therefore$ $PV = nRT$ ….(1)

Where, R = proportionality constant = Universal gas constant.

iv. But, number of moles (n)

$= \frac{\text{mass of the gas}(m)}{\text{molar mass}(M_0)} = \frac{N}{N_A}$ ….(2)

Where, N = number of molecules,
M_0 = mass of 1 mole of gas
N_A = Avogadro's number

v. The universal gas constant can also be expressed in terms of Boltzmann constant (k_B) as,

$R = N_Ak_B$ ….(3)

Substituting equations (2) and (3) in equation (1), we get,

$\therefore$ $PV = \frac{N}{N_A} \times N_Ak_BT = Nk_BT$

Q.2. Why is an ideal gas equation known as equation of state? [1 Mark]

Ans: For a gas, its state is specified by a number of physical quantities such as pressure P, temperature T, volume V, internal energy E, etc. Hence, the equation relating these quantities i.e., ideal gas equation is known as the equation of state.

***Q.3. Write ideal gas equation for a mass of 7 g of nitrogen gas. [1 Mark]**

Ans: Ideal gas equation for 7 g of nitrogen gas is,

$PV = \frac{RT}{4}$.

Reading between the lines

Ideal gas equation, PV = nRT

Here, $n = \frac{m}{M_0}$

$m = 7\,g$, $(M_0)_{N_2} = 28$ g/mol

$\therefore$ $n = \frac{7}{28} = \frac{1}{4}$

$\therefore$ $PV = \frac{1}{4} \times RT = \frac{RT}{4}$

Solved Examples

Q.4. Using the ideal gas equation, determine the value of R. Given that one gram molecule of a gas at S.T.P. occupies 22.4 litre. [2 Marks]

Solution:

Given: At S.T.P., $P = 1 \times 10^5$ N/m^2,
$V = 22.4$ litre
$= 22.4 \times 10^{-3}$ m^3,
$T = 273$ K

To find: Universal gas constant (R)

Formula: $PV = RT$

Calculation: From formula,

$$R = \frac{PV}{T}$$

$$\therefore \quad R = \frac{1 \times 10^5 \times 22.4 \times 10^{-3}}{273}$$

$$\therefore \quad R = \frac{320}{39}$$

$$\therefore \quad R = \mathbf{8.205\ J\ mol^{-1}\ K^{-1}}$$

Ans: The value of universal gas constant R is **8.205 J mol^{-1} K^{-1}**.

Reading between the lines

There is difference between values of pressure and temperature at S.T.P. (standard temperature pressure) and N.T.P. (normal temperature pressure) conditions.

At S.T.P., *$P = 10^5$ Pa = 1 bar = 1 atm and $T = 0$ °C = 273 K*

At N.T.P., *$P = 101.32$ k Pa = 1.013×10^5 Pa and $T = 20$ °C = 293 K (Room temperature)*

Q.5. 16 g of oxygen occupy 0.025 m^3 at 27 °C. If the universal gas constant is 8.4 J/mol K. Find the pressure exerted by it. [Molecular weight of oxygen = 32] [2 Marks]

Solution:

Given: $m = 16$ g, $V = 0.025$ m^3,
$T = 27$ °C $= 273 + 27 = 300$ K,
$R = 8.4$ J/ mol K, $M = 32$ g/mol

To find: Pressure (P)

Formula: $PV = nRT$

Calculation: Since, $n = \frac{m}{M} = \frac{16}{32} = \frac{1}{2} = 0.5$

From formula,

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

$$= \frac{0.5 \times 8.4 \times 300}{0.025}$$

$$\therefore \quad P = \mathbf{50.4 \times 10^3\ N/m^2}$$

Ans: The pressure exerted by 16 g of oxygen is **50.4 × 10^3 N/m^2**.

***Q.6. Two vessels A and B are filled with same gas where volume, temperature and pressure in vessel A is twice the volume, temperature and pressure in vessel B. Calculate the ratio of number of molecules of gas in vessel A to that in vessel B. [2 Marks]**

Solution:

Given: $P_A = 2P_B$, $T_A = 2T_B$, $V_A = 2V_B$

To find: Ratio of number of molecules ($N_1 : N_2$)

Formulae: i. $n = \frac{PV}{RT}$ ii. $n = \frac{N}{N_A}$

Calculation:

From formula (i)

$$n_A = \frac{P_A V_A}{R\,T_A} \quad \text{....(1)}$$

$$n_B = \frac{P_B V_B}{R\,T_B} \quad \text{....(2)}$$

Dividing equation (1) by equation (2),

$$\therefore \quad \frac{n_A}{n_B} = \frac{2P_B \times 2V_B \times T_B}{2T_B \times P_B \times V_B}$$

$$\therefore \quad \frac{n_A}{n_B} = \frac{2}{1}$$

From formula (ii),

$$\frac{(N_1 / N_A)}{(N_2 / N_A)} = \frac{2}{1}$$

$$\therefore \quad \frac{N_1}{N_2} = \mathbf{\frac{2}{1}}$$

Ans: The ratio of number of molecules is **2 : 1.**

3.2 Behaviour of a Gas

Q.7. Why is it necessary to make assumptions while studying behaviour of a gas? [2 Marks]

Ans:

i. For any solid object, its motion can be described well with the help of Newton's laws of motion.

ii. Similarly, a gas enclosed in a container can be characterised by macroscopic state variables like pressure, volume and temperature.

iii. However, as gas molecules are always in random motion, it is difficult to understand behaviour of a gas in terms of motion of a single molecule.

iv. The number of molecules in the gas is so large ($\approx 10^{23}$ per m^3) that motion of individual molecule cannot be related with macroscopic parameters P, V, T and energy E.

Hence, it is necessary to make certain assumptions while studying behaviour of a gas.

3.3 Ideal Gas and Real Gas

***Q.8. What is an ideal gas? Does an ideal gas exist in practice? [2 Marks]**

Ans: A gas which obeys ideal gas equation at all pressures and temperatures is an ideal gas. No, such gas does not exist in reality.

***Q.9. Mention the conditions under which a real gas obeys ideal gas equation. [1 Mark]**

Ans: Conditions under which a real gas obeys ideal gas equation are:

Low density, low pressure or high temperature. In other words, at condition where gas molecules are far apart so that molecular interactions are negligible.

Reading between the lines

i. *In an ideal gas, there are no intermolecular interactions whereas, real gases are composed of atoms or molecules which do interact with each other.*

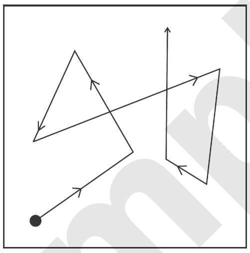
ii. *When the atoms or molecules of a real gas are so far apart that there are no interatomic or intermolecular interactions possible, the real gas is said to be in ideal state.*

3.4 Mean Free Path

Q.10. Explain the concept of mean free path of a gas molecule. [3 Marks]

Ans:

i. The molecules of a gas are uniformly dispersed throughout the volume of the gas, but are executing random motion. The typical path followed by a particle during Brownian motion is shown in figure.



A typical molecule in a gas executing random motion

ii. When a molecule approaches another molecule, there is a repulsive force between them, due to which the molecules behave as small hard spherical particles. This leads to elastic collisions between the molecules.

iii. Therefore, both the speed and the direction of motion of the molecules change abruptly. The molecules also collide with the walls of the container.

iv. Molecules exert force on each other only during collisions. Thus, in between two successive collisions the molecules move along straight paths with constant velocity.

v. *The average distance traversed by a molecule with constant velocity between two successive collisions is called mean free path.*

vi. The mean free path (λ) varies

a. inversely with density $\rho = \frac{N}{V}$ of the gas.
Where, N = number of molecules,
V = volume of the gas

b. inversely with square of the diameter of molecule d^2 (because it depends on the cross-section of a molecule).

vii. Thus, from above proportionalities, it can be shown that,

$$\lambda = \frac{1}{\sqrt{2}\,\pi d^2 (N/V)}$$

Q.11. How does mean free path varies when pressure is reduced? [1 Mark]

Ans: If the pressure of a gas in an enclosure is reduced by evacuating it, the density of the gas decreases and the mean free path increases.

Solved Examples

+Q.12. Obtain the mean free path of nitrogen molecule at 0 °C and 1.0 atm pressure. The molecular diameter of nitrogen is 324 pm (assume that the gas is ideal).

(Example 3.1 of Textbook page no. 58)

[3 Marks]

Solution:

Given: $T = 0^\circ C = 273\ K$,
$P = 1.0\ atm = 1.01 \times 10^5\ Pa$,
$d = 324\ pm = 324 \times 10^{-12}\ m$,
$k_B = 1.38 \times 10^{-23} J/K$

To find: Mean free path of N_2 (λ)

Formulae: i. $PV = Nk_BT$

ii. $\lambda = \frac{1}{\sqrt{2}\,\pi d^2 \left(\frac{N}{V}\right)}$

Calculation:

From formula (i),

$$\frac{N}{V} = \frac{P}{k_B T}$$

Using this in formula (ii),

$$\lambda = \frac{k_B T}{\sqrt{2}\pi d^2 P}$$

$$= \frac{1.38 \times 10^{-23} \times 273}{\sqrt{2}\,\pi \left(324 \times 10^{-12}\right)^2 \times 1.01 \times 10^5}$$

$= \text{antilog}\ \{\log (1.38) + \log (273) - \log (1.414) - \log (3.142) - 2 \log (324) - \log (1.01)\} \times 10^{-4}$

....(using $\sqrt{2} = 1.414$)

$= \text{antilog}\ \{0.1399 + 2.4362 - 0.1504 - 0.4972 - 5.0210 - 0.0043\} \times 10^{-4}$

$= \text{antilog}\ \{\bar{4}.9032\} \times 10^{-4}$

$= 8.002 \times 10^{-4} \times 10^{-4} \approx 8 \times 10^{-8}$

$\mathbf{= 0.8 \times 10^{-7}\ m}$

Ans: Mean free path of N_2 molecule is $\mathbf{0.8 \times 10^{-7}\ m}$.

Q.13. Mean free path of oxygen molecule is 70 nm at S.T.P. Find the molecular diameter of the oxygen (in pm) assuming it to be an ideal gas. (Take value of Boltzmann constant as 1.38×10^{-23} J/K.) [2 Marks]

Solution:

Given: At S.T.P., $T = 0\ °C = 273$ K,
$P = 1 \times 10^5$ Pa,
$\lambda = 70\ \text{nm} = 7 \times 10^{-8}$ m,
$k_B = 1.38 \times 10^{-23}$ J/K

To find: Molecular diameter of oxygen (d)

Formula: $\lambda = \dfrac{k_B T}{\sqrt{2}\,\pi d^2 P}$

Calculation: From formula,

$$d^2 = \frac{k_B T}{\sqrt{2}\,\pi \lambda P}$$
$$= \frac{1.38 \times 10^{-23} \times 273}{\sqrt{2} \times 3.142 \times 7 \times 10^{-8} \times 10^5}$$
$$= \frac{1.38 \times 273}{1.414 \times 3.142 \times 7} \times 10^{-20}$$
$$= \frac{1.38 \times 39}{1.414 \times 3.142} \times 10^{-20}$$
$$= \text{antilog}\,\{\log(1.38) + \log(39) - \log(1.414) - \log(3.142)\} \times 10^{-20}$$
$$= \text{antilog}\,\{0.1399 + 1.5911 - 0.1504 - 0.4972\} \times 10^{-20}$$
$$= \text{antilog}\,\{1.0834\} \times 10^{-20}$$
$$d^2 = 1.212 \times 10^{-20} \times 10$$
$$d = 3.481 \times 10^{-10}\ \text{m}$$
$$= \mathbf{348.1\ pm}$$

Ans: Molecular diameter of oxygen is **348.1 pm.**

3.5 Pressure of Ideal Gas

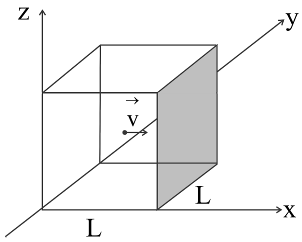
Q.14. Derive an expression for a pressure exerted by a gas on the basis of kinetic theory of gases. [4 Marks] [Mar 22]

Ans:

i. Let there be n moles of an ideal gas enclosed in a cubical box of volume V (= L^3) with sides of the box parallel to the coordinate axes, as shown in figure. The walls of the box are kept at a constant temperature T.

ii. The gas molecules are in continuous random motion, colliding with each other and hitting the walls of the box and bouncing back.

iii. As per one of the assumptions, we neglect intermolecular collisions and consider only elastic collisions with the walls.



iv. A typical molecule moving with the velocity $\vec{v}$, about to collide elastically with the shaded wall of the cube parallel to yz-plane.

v. During elastic collision, the component v_x of the velocity will get reversed, keeping v_y and v_z components unaltered.

vi. Hence the change in momentum of the particle is only in the x component of the momentum, Δp_x is given by,

Δp_x = final momentum – initial momentum

$= (-mv_x) - (mv_x) = -2\,mv_x$ ....(1)

vii. Thus, the momentum transferred to the wall during collision is + $2mv_x$. The re-bounced molecule then goes to the opposite wall and collides with it.

viii. After colliding with the shaded wall, the molecule travels to the opposite wall and travels back towards the shaded wall again.

ix. This means that the molecule travels a distance of 2L in between two collisions.

x. As L is the length of the cubical box, the time for the molecule to travel back and forth to the shaded wall is $\Delta t = \dfrac{2L}{v_x}$.

xi. Average force exerted on the shaded wall by molecule 1 is given as,

Average force = Average rate of change of momentum

$\therefore$ $F_{avg} = \dfrac{2mv_{x_1}}{2L/v_{x_1}} = \dfrac{mv_{x_1}^2}{L}$ ....(2)

where v_{x_1} is the x component of the velocity of molecule 1.

xii. Considering other molecules 2, 3, 4 ... with the respective x components of velocities $v_{x_2}, v_{x_3}, v_{x_4}$ ...., the total average force on the wall is,

$F_{avg} = \dfrac{m}{L}\left(v_{x_1}^2 + v_{x_2}^2 + v_{x_3}^2 + ...\right)$ ....[From (2)]

$\therefore$ The average pressure

$$P = \frac{\text{Average force}}{\text{Area of shaded wall}}$$
$$= \frac{m\left(v_{x_1}^2 + v_{x_2}^2 + ...\right)}{L \times L^2}$$

xiii. The average of the square of the x component of the velocities is given by,

$$\overline{v_x^2} = \frac{v_{x_1}^2 + v_{x_2}^2 + v_{x_3}^2 + ... + v_N^2}{N}$$

$\therefore$ $P = \dfrac{mN\overline{v_x^2}}{V}$

where $\overline{v_x^2}$ is the average over all possible values of v_x.

Quick Review

Ideal Gas

Equation of state

- $PV = nRT$
- $PV = Nk_BT$

where,
$k_B = 1.38 \times 10^{-23}$ J/K

Mean free path

- The average distance traversed by a molecule between two succesive collisions
- $\lambda = \dfrac{1}{\sqrt{2}\pi d^2\left(\dfrac{N}{V}\right)}$

Kinetic energy

- Average K.E:

  $\text{K.E.} = \frac{1}{2}m\overline{v^2}$

  $\text{K.E.} = \frac{3}{2}PV$

  $\frac{\text{K.E.}}{\text{molecule}} = \frac{3}{2}k_BT$

  $\frac{\text{K.E.}}{\text{mol}} = \frac{3}{2}RT$

RMS speed

- Average speed at given temperature
- $v_{rms} = \sqrt{\dfrac{3RT}{M_0}}$

  $= \sqrt{\dfrac{3}{2}k_BT}$

Pressure of gas

- Pressure exerted by gas is,

  $P = \frac{1}{3}\frac{MN}{V}\overline{v^2}$

Law of equipartition of energy

- For a gas in thermal equilibrium at temperature T, the average energy for molecule associated with each quadratic term is $\frac{1}{2}k_BT$.
- **Translational K.E.:**

  $\frac{1}{2}mv_x^2 + \frac{1}{2}mv_y^2 + \frac{1}{2}mv_z^2$
- **Rotational K.E.:**

  $\frac{1}{2}I\omega_x^2 + \frac{1}{2}I\omega_y^2 + \frac{1}{2}I\omega_z^2$
- **Vibrational K.E.:** $\frac{1}{2}mu^2 + \frac{1}{2}kr^2$

Degrees of Freedom

- The total number of coordinates or independent quantities required to describe the position and configuration of the system completely
- **Monatomic Gas:**

  Translation dof : 3
- **Diatomic Gas:**

  Translation dof : 3

  Rotational dof : 2 or 3

  Vibrational dof : 0 or 2

Specific heat capacity

Mayer's Relation	Monatomic Gas	Diatomic Gas (Rigid)	Diatomic Gas (non-rigid)	Polyatomic Gas
• $C_P - C_V = R$ • $S_p - S_V = \frac{R}{M_0J}$ • $\frac{C_P}{C_V} = \gamma$	• $C_P = \frac{5}{2}R$ • $C_V = \frac{3}{2}R$ • $\gamma = \frac{5}{3}$	• $C_P = \frac{7}{2}R$ • $C_V = \frac{5}{2}R$ • $\gamma = \frac{7}{5}$	• $C_P = \frac{9}{2}R$ • $C_V = \frac{7}{2}R$ • $\gamma = \frac{9}{7}$	• $C_P = (4 + f)R$ • $C_V = (3 + f)R$ • $\gamma = \frac{(4+f)}{(3+f)}$

Radiation

Absorption

- Coefficient of Absorption (a) $a = \frac{Q_a}{Q}$

Reflection

- Coefficient of reflection (r) $r = \frac{Q_r}{Q}$

Transmission

- Coefficient of transmission (t_r) $t_r = \frac{Q_t}{Q}$

$a + r + t_r = 1$

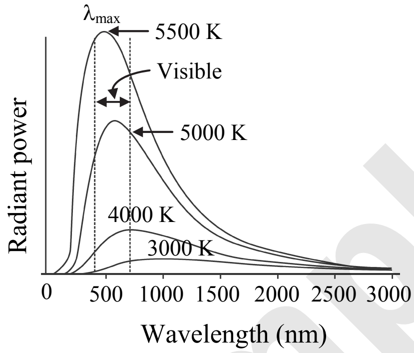
Emission

- Coefficient of emission or emissivity (e) $e = \frac{R}{R_B}$
- **Emissive power** $R = \frac{Q}{At}$

Perfect blackbody

- A body which absorbs the entire radiant energy incident on it.
- For perfect blackbody, a = 1
- In practice, Ferry's body is considered perfect blackbody as lampblack used in it absorbs 97% of incident energy.
- It appears black in light and glows in dark because good absorber is always a good emitter.

Spectrum of blackbody



- **Wien's displacement law:** $\lambda_{max} = \frac{b}{T}$

Prevost's theory of heat exchange

- All bodies at all temperatures above 0 K radiate thermal energy and at the same time, they absorb radiation received from surroundings.

Stefan-Boltzmann law

- Radiating power per unit time is directly proportional to fourth power of the temperature.
  $Q = \sigma At T^4$ (for perfect blackbody)
  $Q = e\sigma At T^4$ (for ordinary body)
- σ = Stefan's Constant $= 5.67 \times 10^{-8}$ J/s m^2 K^4

Kirchhoff's Law of radiation

- At a given temperature, the ratio of emissive power to coefficient of absorption of a body is equal to the emissive power of a perfect blackbody at the same temperature for all wavelengths
  $a = e = \frac{R}{R_B}$

Impotant formulae

1. **Ideal gas equation:**

i. $PV = nRT$

ii. $PV = Nk_BT$

2. **Mean free path:**

i. $\lambda = \frac{1}{\sqrt{2}\pi d^2\left(\frac{N}{V}\right)}$

ii. $\lambda = \frac{k_BT}{\sqrt{2}\pi d^2 P}$

3. **Pressure exerted by gas:**

$P = \frac{1}{3}\frac{N}{V} m\overline{v^2}$

4. **Root mean square speed:**

i. $v_{rms} = \sqrt{\frac{3RT}{M_0}}$

ii. $v_{rms} = \sqrt{\frac{3P}{\rho}}$

iii. $v_{rms} = \sqrt{\frac{3}{2}k_BT}$

5. **Kinetic energy of gas molecule:**

i. K.E of gas molecules = $\frac{3}{2}$ PV

ii. K.E per unit mole = $\frac{3}{2}$ RT

iii. K.E per unit mass = $\frac{3}{2}\frac{RT}{M_0}$

iv. K.E per molecule = $\frac{3}{2}k_BT$

6. Relation between C_p and C_v:

i. $C_P - C_V = R$

….(When all quantities are expressed in same unit.)

$C_P - C_V = \frac{R}{J}$

….(When C_P, C_V are in heat units and R is in work unit.)

ii. $\frac{C_P}{C_V} = \gamma$ iii. $S_p - S_v = \frac{R}{M_0 J}$

7. Radiant energy incident on a surface:

$Q = Q_a + Q_r + Q_t$

8. Coefficient of radiation:

i. **Coefficient of absorption,** $a = \frac{Q_a}{Q}$

ii. **Coefficient of reflection,** $r = \frac{Q_r}{Q}$

iii. **Coefficient of transmission,** $t_r = \frac{Q_t}{Q}$

9. Relation between a, r, and t: $a + r + t_r = 1$

10. Coefficient of emission (Emissivity): $e = \frac{R}{R_b} = a$

11. Emissive power: $R = \frac{Q}{At}$

12. Quantity of radiant heat emitted by a blackbody:

i. $Q = \sigma AT^4t$

(When temperature of surrounding is not given)

ii. $Q = \sigma A(T^4 - T_0^4)t$

(When temperature of the surrounding is given)

13. Radiant energy emitted by ordinary body:

i. $Q = eA\sigma T^4 t$ ii. $Q = eA\sigma (T^4 - T_0^4)\, t$

14. Wien's law: $\lambda_{max} = \frac{b}{T}$

15. Rate of heat radiation: $\frac{dQ}{dt} = eA\sigma(T^4 - T_0^4)$

16. Total radiant energy emitted from a body:

$Q = eAt\sigma(T^4 - T_0^4)$

Exercise

3.1 Introduction

1. Prove the relation, $PV = Nk_BT$. **[3 Marks]**

Ans: *Refer Q.1*

2. 14 g of nitrogen occupy 0.028 m^3 at 27 °C. If the universal gas constant is 8.4 J/mol K. Find the pressure exerted by it. [Molecular weight of nitrogen = 28] **[2 Marks]**

Ans: 45×10^3 N/m^2

3.2 Behaviour of a Gas

3. Why cannot the behaviour of a gas molecule be studied using Newtonian mechanics? **[2 Marks]**

Ans: *Refer Q.7*

3.3 Ideal Gas and Real Gas

4. Define ideal gas. **[1 Mark]**

Ans: *Refer Q.8*

5. When can a real gas be treated as ideal gas? **[1 Mark]**

Ans: *Refer Q.9*

3.4 Mean Free Path

6. What is a mean free path? **[1 Mark]**

Ans: *Refer Q.10 (v)*

7. How does a mean free path of a gas molecule vary with number density and size of the molecule? **[1 Mark]**

Ans: *Refer Q.10 (vi)*

8. Obtain the mean free path of nitrogen molecule at 0 °C and 1.0 atm pressure. The molecular diameter of oxygen is 335 pm (assume that the gas is ideal). (Take $k_B = 1.38 \times 10^{-23}$ J/K) **[3 Marks]**

Ans: 74.65 nm

3.5 Pressure of Ideal Gas

9. Prove the relation between pressure of the gas and speed of its molecules. **[4 Marks]**

Ans: *Refer Q.14*

10. A gas in a cylinder is at pressure 500 N/m^2. If the masses of all the molecules are made one fifth of their original value and their speeds are doubled, then find the resultant pressure. **[2 Marks]**

Ans: 400 N/m^2

3.6 Root Mean Square (rms) Speed

11. Show that r.m.s. velocity of a gas molecule is directly proportional to the square root of the absolute temperature of the gas. **[2 Marks] [Mar 14]**

Ans: *Refer Q.17*

12. State the relation between mean square velocity of a gas molecule and its absolute temperature. **[1 Marks]**

Ans: *Refer Q.18*

13. Compare the speed of sound in a gas and r.m.s. speed of that gas molecule. **[2 Marks]**

Ans: *Refer Q.20*

14. Calculate the temperature (in °C) at which the r.m.s velocity of O_2 gas molecule will be 0.5 km s^{-1}. [Given R = 8.311 J mol^{-1} K^{-1}] **[2 Marks]**

Ans: 47.86 °C

15. Determine the pressure of oxygen at 0 °C, if the density of oxygen at N.T.P is 1.44 kg/m^3 and r.m.s. speed of the molecules at N.T.P is 456.4 m/s. **[2 Marks]**

Ans: 10^5 N/m^2

16. Calculate the ratio of mean square speeds of molecules of a gas at 30 K and 150 K. **[1 Mark]**

Ans: 1 : 5

17. The r.m.s speed of oxygen molecules at N.T.P is 461.2 m/s. Find the temperature at which the r.m.s speed becomes 90% of the speed at N.T.P. **[2 Marks]**

Ans: 221.13 K

3.7 Interpretation of Temperature in Kinetic Theory

18. Explain how kinetic energy of gas molecules varies with the temperature using kinetic theory of gases. **[3 Marks]**

Ans: *Refer Q.29*

19. Deduce Boyle's law using the expression for pressure exerted by the gas. **[2 Marks][Feb 20]**

Ans: *Refer Q.30*

20. Find kinetic energy of 2.5 litre of a gas at S.T.P. Given standard pressure is 1× 10^5 N/m^2. **[2 Marks]**

Ans: 375 J

21. The kinetic energy of 1 kg of oxygen at 300 K is 1.356 × 10^6 J. Find the kinetic energy of 4 kg of oxygen at 400 K. **[2 Marks]**

Ans: 7.232 × 10^6 J

22. Find the average kinetic energy of a molecule of nitrogen at 27 °C. [Boltzmann constant, k_B = 1.381 × 10^{-23} J/molecule K] **[2 Marks]**

Ans: 6.215 × 10^{-21} J

23. Calculate the molecular K.E per k mol and per kg of hydrogen at 127 °C. [R = 8310 J/k mol K, molecular weight of hydrogen = 2] **[3 Marks]**

Ans: 4.986 × 10^6 J, 2.493 × 10^6 J

3.8 Law of Equipartition of Energy

24. What is the law of equipartition of energy? **[3 Marks]**

Ans: *Refer Q.36*

25. What are degrees of freedom of a system? How many degrees of freedom a body moving in a plane has? **[2 Marks]**

Ans: *Refer Q.37 and Q.38*

26. How many degrees of freedom a monatomic gas has? **[1 Mark]**

Ans: *Refer Q.40*

27. Describe the energy associated with each degree of freedom for a diatomic gas. **[3 Marks]**

Ans: *Refer Q.41*

3.9 Specific Heat Capacity

28. Calculate molar specific heat at constant volume and constant pressure of a diatomic gas. **[2 Marks]**

Ans: *Refer Q.44 (ii)*

29. Deduce the molar specific heat at constant volume and constant pressure of a monatomic gas. **[2 Marks]**

Ans: *Refer Q.44 (i)*

30. The difference between the two molar specific heats of a gas is 9000 J/kg K. If the ratio of the two specific heats is 1.5, calculate the two molar specific heats. **[2 Marks] [Mar 22]**

Ans: C_V = 1.8 × 10^4 J/ kg K, C_P = 2.7 × 10^4 J/ kg K.

31. The ratio of specific heats of a gas is 1.4. Its specific heat at constant volume is 4.96 k cal/k mol K. Calculate the universal gas constant. [J = 4200J/ k cal] **[2 Marks]**

Ans: 8332.8 J/k mol K

32. Specific heat of nitrogen at constant pressure and at constant volume is 0.24 kcal/kg-K and 0.17 kcal/kg-K respectively. Calculate the mechanical equivalent of heat. [Molecular weight of nitrogen = 28, R = 8.31 × 10^3 J/k mol k cal] **[2 Marks]**

Ans: 4.24 × 10^3 J /K

3.10 Absorption, Reflection and Transmission of Heat Radiation

33. Derive the relation between a, r and t_r. **[2 Marks]**

Ans: *Refer Q.48*

34. Define:

i. Coefficient of absorption
ii. Coefficient of transmission **[2 Marks]**

Ans: *Refer Q.49 (i) and (iii)*

35. What are athermanous and diathermanous substances? **[2 Marks]**

Ans: *Refer Q.50*

36. What is coefficient of reflection? When can a body be said to be a perfect reflector? **[2 Marks]**

Ans: *Refer Q.49 (ii) and Q. 51 (ii)*

3.11 Perfect Blackbody

37. What is perfectly blackbody? **[1 Mark] [Mar 19, July 22]**

Ans: *Refer Q.52*

38. Describe Ferry's blackbody with the help of a neat labelled diagram. **[3 Marks]**

Ans: *Refer Q.53*

39. Draw a neat labelled diagram for Ferry's perfectly blackbody. **[2 Marks] [Mar 13; July 18]**

Ans: *Refer Q.53 (Diagram only)*

40. Explain what is cavity radiator. **[2 Marks]**

Ans: *Refer Q.54*

3.12 Emission of Heat Radiation

41. How does heat exchange takes place according to Prevost's theory? **[3 Marks]**

Ans: *Refer Q.57*

42. On which factors does amount of heat radiated by a body depend? **[2 Marks]**

Ans: *Refer Q. 58*

43. What is emissive power? **[1 Mark]**

Ans: *Refer Q.59*

44. Define coefficient of emission. **[1 Mark] [July 22]**

Ans: *Refer Q.60*

45. The energy of 3000 J is radiated in 2 minutes by a body of surface area 100 cm^2. Find emissive power of the body. **[2 Marks]**

Ans: 2500 J/m^{2}s

3.13 Kirchhoff's Law of Heat Radiation and its Theoretical Proof

46. State Kirchhoff's law of heat radiations. **[1 Mark]**

Ans: *Refer Q.64(Statement only)*

47. Prove Kirchhoff's law of radiation theoretically. **[2 Marks] [July 17]**

Ans: *Refer Q.64 (Theoretical proof only)*

3.14 Spectral Distribution of Blackbody Radiation

48. Explain energy distribution spectrum of a black body radiation in terms of wavelength. **[3 Marks] [Feb 20]**

Ans: *Refer Q.65*

49. For a perfectly blackbody at temperature of 4000 K, find the value of λ_{max}.
(Take b = 2.897×10^{-3} m K) **[2 Marks]**

Ans: 7242.5 Å

50. Calculate the value of λ_{max} for radiations coming from a star with surface temperature of 6500 K.
(b = 2.897×10^{-3} m K) **[2 Marks]**

Ans: 4457 Å

51. Find the temperature of a blackbody if its spectrum has a peak at λ_{max} = 500 nm (visible) **[2 Marks]**

Ans: 5794 K

3.15 Stefan-Boltzmann Law of Radiation

52. What does Stefan-Boltzmann law state? **[1 Mark]**

Ans: *Refer Q.71*

53. Obtain the expression for the rate of loss of heat by a blackbody in cooler surroundings. **[2 Marks]**

Ans: *Refer Q.73*

54. Calculate the energy radiated in half a minute by a black body of surface area 200 cm^2 at 127 °C. **[3 Marks] [July 22]**

Ans: 875.5 J

55. A body of surface area 20 cm^2 and temperature 527 °C emits 400 J of energy per minute. Find its emissivity.
[Given: $\sigma = 5.67 \times 10^{-8}$ watt/m^{2}K^4] **[2 Marks]**

Ans: 0.1435

56. Compare the rates of emission of heat by a blackbody maintained at 327 °C and at 127 °C, if the blackbodies are surrounded by an enclosure (black) at 27 °C. What would be the ratio of their rates of loss of heat? **[3 Marks]**

Ans: 243 : 35 or 6.94 : 1

Multiple Choice Questions

[1 Mark Each]

*1. In an ideal gas, the molecules possess
(A) only kinetic energy
(B) both kinetic energy and potential energy
(C) only potential energy
(D) neither kinetic energy nor potential energy

2. In the case of ideal gases,
(A) the molar specific heat at constant pressure is the same for all gases.
(B) the molar specific heat at constant volume is the same for all gases.
(C) the ratio of the molar specific heats at constant volume and at constant pressure is the same for all gases.
(D) the difference between the molar specific heats at constant pressure and at constant volume is the same for all gases.

*3. The mean free path λ of molecules is given by
(A) $\sqrt{\frac{2}{\pi nd^2}}$ (B) $\frac{1}{\pi nd^2}$
(C) $\frac{1}{\sqrt{2}\pi nd^2}$ (D) $\frac{1}{\sqrt{2\pi nd}}$
where n is the number of molecules per unit volume and d is the diameter of the molecules.

*4. If pressure of an ideal gas is decreased by 10% isothermally, then its volume will
(A) decrease by 9%
(B) increase by 9%
(C) decrease by 10%
(D) increase by 11.11%

5. The average distance covered by a molecule between two successive collision is _______.
(A) free path
(B) constant path
(C) mean free path
(D) free path per unit time.

6. 'P' is the pressure and 'd' is the density of gas at constant temperature, then
(A) $P \propto d$
(B) $P \propto 1/d$
(C) $P \propto \sqrt{d}$
(D) $P \propto 1/\sqrt{d}$

7. The expression for pressure of gas and the gas equation shows that the absolute temperature of a gas is proportional to the average
(A) sum of vibrational, translational and rotational kinetic energies of molecules.
(B) translational kinetic energy of molecules.
(C) rotational kinetic energy of molecules.
(D) vibrational kinetic energy of molecules.

8. The root mean square speed of the molecules of a gas is proportional to _______. **[Mar 22]**
(T = Absolute temperature of gas)
(A) $\sqrt{T}$
(B) $\frac{1}{\sqrt{T}}$
(C) T
(D) $\frac{1}{T}$

9. The absolute temperature of a gas increased three times. The root mean square velocity of the gas will be _______.
(A) 3 times
(B) 9 times
(C) $\frac{1}{3}$ times
(D) $\sqrt{3}$ times

10. The kinetic energy per molecule of a gas at temperature T is _______. **[Mar 18]**
(A) $\left(\frac{3}{2}\right)RT$
(B) $\left(\frac{3}{2}\right)k_BT$
(C) $\left(\frac{2}{3}\right)RT$
(D) $\left(\frac{3}{2}\right)\left(\frac{RT}{M}\right)$

11. The average K.E. of a gas is _______. **[July 22]**
(A) directly proportional to absolute temperature of gas
(B) directly proportional to square of absolute temperature of gas
(C) directly proportional to square root of absolute temperature of gas
(D) inversely proportional to absolute temperature of gas

12. If the total kinetic energy per unit volume of gas enclosed in a container is E, the pressure exerted by the gas is _______. **[July 17]**
(A) E
(B) $\frac{3}{2}E$
(C) $\sqrt{3}E$
(D) $\frac{2}{3}E$

13. The root mean square velocity of gas molecules is 10 km s^{-1}. The gas is heated till its pressure becomes 4 times. The velocity of the gas molecules will now be
(A) 10 km s^{-1}
(B) 20 km s^{-1}
(C) 40 km s^{-1}
(D) 80 km s^{-1}

14. The law of equipartition of energy is valid for
(A) high temperatures
(B) extremely low temperatures
(C) only absolute zero temperature
(D) temperatures within the range −273 K to −100 K.

15. For hydrogen gas C_P = 4000 cal/kg K and C_V = 3000 cal/kg K and R = 8300 J/k mol K. The value of J will be [mol. wt. of H_2 = 2]
(A) 4.18
(B) 4.17
(C) 4.16
(D) 4.15

16. According to the law of equipartition of energy, the average kinetic energy of one molecule of diatomic gas will be
(A) $3k_BT/2$
(B) $5k_BT/2$
(C) 3RT/2
(D) 5RT/2

17. If the degrees of freedom for polyatomic gas are f, then the average kinetic energy per molecule of the gas will be [N_A: Avogadro's number]
(A) fk_BT/N
(B) $fk_BT/2N$
(C) $fk_BT/2$
(D) fk_BT

18. For polyatomic molecules having 'f' vibrational modes, the ratio of two specific heats, $\frac{C_P}{C_V}$ is _______. **[Mar 16]**
(A) $\frac{1+f}{2+f}$
(B) $\frac{2+f}{3+f}$
(C) $\frac{4+f}{3+f}$
(D) $\frac{5+f}{4+f}$

19. Coefficient of emission or emissivity (e) is defined as
(A) ratio of emissive power of a surface to that of a perfectly black surface at the same temperature.
(B) product of the emissive powers of the surface and perfectly blackbody at the same temperature.
(C) ratio of emissive power of the surface to that of perfectly blackbody.
(D) product of emissive powers of the surface and perfectly blackbody.

20. If the incident energy is 200 cal, absorptive power is 0.31 and reflection coefficient is 0.41, then the amount of energy transmitted will be
(A) 48 cal
(B) 56 cal
(C) 58 cal
(D) 54 cal

21. A body which absorbs all the radiations incident over it is called a
(A) blackbody.
(B) perfectly blackbody.
(C) good absorber.
(D) good emitter.

22. The best ideal blackbody is
(A) lamp of charcoal heated to a high temperature.
(B) metal coated with a black dye.
(C) glass surface coated with coal tar.
(D) hollow enclosure blackened inside and having a small hole.

*23. If a = 0.72 and r = 0.24, then the value of t_r is
(A) 0.02 (B) 0.04 (C) 0.4 (D) 0.2

24. The amount of thermal radiation emitted per unit time depends on
(A) nature of emitting surface
(B) temperature of emitting surface
(C) area of emitting surface
(D) all of these

25. Find the wavelength at which a blackbody radiates maximum energy, if its temperature is 427 °C. [Wien's constant b = 2.898×10^{-3} mK] **[Mar 17]**
(A) 0.0414×10^{-6} m (B) 4.14×10^{-6} m
(C) 41.4×10^{-6} m (D) 414×10^{-6} m

26. "Good absorbers are good emitters" This statement is of
(A) Newton's law (B) Kirchhoff's law
(C) Stefan's law (D) Wien's law

27. Two stars emit maximum radiation at wavelength 3600 Å and 4800 Å respectively. The ratio of their temperature is
(A) 1 : 2 (B) 3 : 4
(C) 4 : 3 (D) 2 : 1

28. The mathematical relation of Stefan's law is
(A) $Q = \sigma T^2$ (B) $Q = \sigma T^3$
(C) $Q = \sigma T^4$ (D) $Q = \sigma T^5$

*29. The ratio of emissive power of perfectly blackbody at 1327 °C and 527 °C is
(A) 4 : 1 (B) 16 : 1
(C) 2 : 1 (D) 8 : 1

30. If wavelengths of maximum intensity of radiations emitted by the Sun and the moon are 0.5×10^{-6} m and 10^{-4} m respectively, the ratio of their temperature is
(A) 1/100 (B) 1/200
(C) 100 (D) 200

31. The temperature of a blackbody is increased by 50%. The amount of radiations emitted by the body increases by
(A) 50% (B) 100%
(C) 225% (D) 500%

32. The surface area of a blackbody maintained at 127°C radiating energy at the rate of 1459.2 J/s is ________. [$\sigma = 5.7 \times 10^{-8}$ S.I. unit]
(A) 4 m^2 (B) 3 m^2
(C) 2 m^2 (D) 1 m^2

33. The SI unit of Stefan's constant is
(A) N m/s K^4 (B) W/m K^4
(C) J/s m^2 K^4 (D) erg/s m^3 K^4

Answers to Multiple Choice Questions

1.	(A)	2.	(D)	3.	(C)	4.	(D)
5.	(C)	6.	(A)	7.	(B)	8.	(A)
9.	(D)	10.	(B)	11.	(A)	12.	(D)
13.	(B)	14.	(A)	15.	(D)	16.	(B)
17.	(C)	18.	(C)	19.	(A)	20.	(B)
21.	(B)	22.	(D)	23.	(B)	24.	(D)
25.	(B)	26.	(B)	27.	(C)	28.	(C)
29.	(B)	30.	(D)	31.	(D)	32.	(D)
33.	(C)						

Hints to Multiple Choice Questions

4. From ideal gas equation,
PV = nRT
For isothermal process, T = constant
∴ PV = constant …(i)
∴ When pressure is decreased by 10%,
$$P' = P - \frac{10}{100}P$$
∴ $P' = 0.9P$ …(ii)
Now, $P'V' = PV$ …[from (i)]
∴ $\frac{V'}{V} = \frac{P}{P'} = \frac{1}{0.9}$ …[from (ii)]
∴ $\frac{V' - V}{V} = \frac{0.1}{0.9}$.
∴ $\frac{V' - V}{V} \times 100 = 0.1111 \times 100 = 11.11\%$
As, in isothermal process
$P \propto \frac{1}{V}$
V will increase by 11.11%

14. Law of equilibrium of energy cannot be applied where quantum effects become important.

23. $a + r + t_r = 1$
∴ $0.72 + 0.24 + t_r = 1$
∴ $t_r = 1 - 0.96 = 0.04$

25. According to Wien's displacement law,
$$\lambda_m = \frac{b}{T} = \frac{2.898 \times 10^{-3}}{700} = 4.14 \times 10^{-6} \text{ m}$$

29. Power (P) ∝ T^4
∴ $$\frac{P_1}{P_2} = \left(\frac{T_1}{T_2}\right)^4 = \frac{(1327 + 273)^4}{(527 + 273)^4} = \left(\frac{1600}{800}\right)^4 = 16 : 1$$

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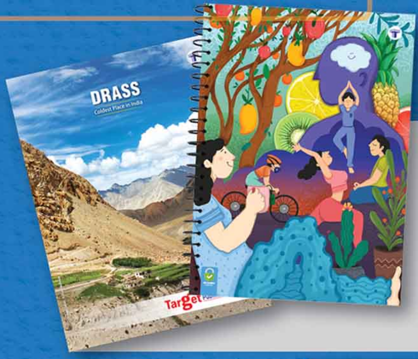

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