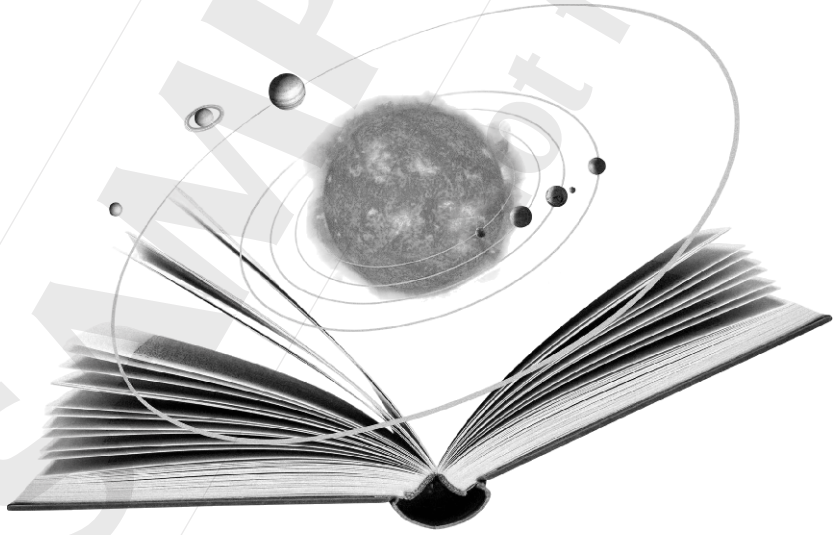
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Class 12th

Unique Notes

PHYSICS

Prepared for the Session 2026-27
According to the New Curriculum of PECTAA 2025-26



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UNIQUE NOTES, PHYSICS 12th

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Chapter 13

THERMAL PHYSICS

1. Brownian Motion
2. Kinetic Theory of Gases
3. Pressure in a Gas and Derivation of $PV = \frac{1}{3}Nm < v^2 >$
4. Average Translational Kinetic Energy of Gas
5. Kinetic Theory and Statistical Physics
6. Stellar Evolution

DESCRIPTIVE QUESTIONS

INTRODUCTION TO THERMAL PHYSICS

Q1. Define thermal physics. Differentiate between macroscopic and microscopic systems, and explain the scope and applications of thermal physics in daily life.

12113001

Ans. **Key points:**

Definition and Scope of Thermal Physics | Macroscopic and Microscopic Systems | Applications of Thermal Physics

Definition and Scope of Thermal Physics

Thermal physics is an important area of study which deals with the relationship between heat, work, temperature, and other forms of energy. The laws of thermodynamics describe the mechanism of the change of energy in a system and the system can perform useful work on its surroundings.

Macroscopic and Microscopic Systems

A large system containing many atoms or molecules is called a macroscopic system, and a system consisting of a single atom or molecule is called a microscopic system. Macroscopic systems have properties such as temperature and pressure, these are thermal properties of the whole system. They can be observed and studied without reference to the molecular nature of matter. Microscopic systems have properties such as kinetic energy and momentum. In thermal physics, we deal with large number of particles of the order of Avogadro's number. These particles may be atoms or molecules in gases, liquids and solids. We can extend it to the electron motion in metals and neutrons in neutron stars.

Applications of Thermal Physics

- There are number of applications of the kinetic theory of gases in daily life such as in automobile engines, turbines, pumps, air conditioners, production of food, and environment etc. These diverse applications make thermal physics an important area.
- Thermal physics is an area which includes the knowledge of statistical mechanics, and kinetic theory of gases. In order to study thermal physics, the knowledge of statistical mechanics, and kinetic theory of gases is needed.

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BROWNIAN MOTION

Q2. Define Brownian motion. Explain its cause on the basis of molecular collisions and describe the factors that affect the speed of Brownian motion. 12113002

Ans. **Key points:**

Definition and Discovery of Brownian Motion | Cause of Brownian Motion (Molecular Collisions) | Factors Affecting Brownian Motion

Definition and Discovery of Brownian Motion

Brownian motion is the random and irregular motion of molecules in a gas. In 1827, Robert Brown, a botanist observed under microscope that tiny particles of pollens plant were moving around in the liquid randomly. These particles were identified as dust particles. Later, it was proved to be one of the effects of molecular motion.

Cause of Brownian Motion (Molecular Collisions)

A molecule in a gas changes its path after collision with another molecule. When it keeps on colliding with other molecule, the colliding molecule follows a random or zig-zag motion. In fact, collision transfers or exchanges the momentum and energy between the molecules (Fig13.1). Brownian motion describes randomness and chaos, therefore, it represents one of the simple models of randomness.

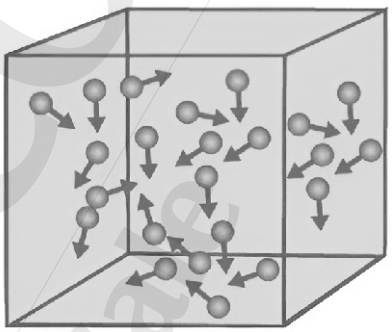


Fig. 13.1: Particles are in random motion

Factors Affecting Brownian Motion

There are various reasons and causes of this motion which are given as under:

1. The size of the molecules is inversely proportional to the speed of the motion. We know that the transfer of momentum is inversely proportional to the mass of the particles. Lighter particles obtain greater speeds from collisions.
2. The speed of the particles is inversely proportional to the viscosity of the fluid. Low viscosity of the fluid results in the faster Brownian movement.
3. Viscosity describes the magnitude of the internal friction in a fluid. It represents the resistance to flow of the fluid.
4. Brownian movement causes the molecules/particles in a fluid to be in constant motion.

For your information

Albert Einstein explained the pollen movement in a liquid assisted by the molecules in 1905. In 1908, a French physicist J Perrin experimentally verified Einstein's explanation which earned him the 1926 Nobel Prize in physics.

KINETIC THEORY OF GASES – BASIC POSTULATES

Q3. What is the kinetic theory of gases? State and explain the basic assumptions (postulates) of the kinetic theory of gases. 12113003

Ans. **Key points:**

Meaning and Scope of Kinetic Theory | Assumptions (Postulates) of Kinetic Theory of Gases

Meaning and Scope of Kinetic Theory

The kinetic theory of gases describes the molecular composition of the gas and their motion. In this theory, the gas pressure arises due to particles colliding with each other and the walls

of the container. It also defines properties such as temperature, volume and pressure, as well as transport properties such as viscosity and thermal conductivity and diffusivity.

Assumptions (Postulates) of Kinetic Theory of Gases

The kinetic molecular theory applies to the ideal gases. However, the basic assumptions are:

1. Gases consist of very large number of tiny spherical particles that are far apart from one another compared to their sizes.
2. Gas particles are in constant rapid motion in random directions.
3. Collisions between gas particles and the container walls are perfectly elastic collisions.
4. There are no forces of attraction or repulsion between gas particles until the particles perform collisions with each other.
5. The average kinetic energy of gas particles is dependent upon the temperature of the gas.

Do you know?

A small 'cube' of air can have as many as 10^{20} molecules. Volume of the gas particles is negligible compared to the volume of the empty spaces.

For your information

The mean free path is average distance a moving particle covered before it undergoes a collision that significantly alters its direction or energy.

DERIVATION OF PRESSURE OF AN IDEAL GAS, PV = 1/3 Nm<V²>

Q4. Derive the expression for the pressure exerted by an ideal gas on the walls of its container, PV = 1/3 Nm<v²>, starting from the motion of a single molecule in a cubical box and hence show that $P = \frac{2}{3} N_\circ < K \cdot E >_T$. **12113004**

Ans. **Key points:**

Ideal Gas Equation (PV = nRT and PV = NK_BT) | Momentum Change and Force on the Wall (One Molecule) | Total Pressure of All Molecules and the RMS Velocity Concept | Final Pressure Formula: PV = 1/3 Nm<v²>

Ideal Gas Equation (PV = nRT and PV = NK_BT)

- We can use the kinetic theory of the gas to derive an equation which relates the macroscopic properties of a gas (pressure and volume) to the microscopic properties of its molecules (mass and speed). It is assumed that a single molecule is moving in a cube-like box of each side L (Fig. 13.2). This molecule has mass m, and is moving with speed "v". It moves back and forth, colliding at regular intervals with the walls and therefore, it contributes to the pressure of the gas. We are going to work out the pressure exerted by this one molecule on the wall of the box and then deduce the total pressure produced by all the molecules.
- According to the kinetic theory of gases, a gas consists of a large number of tiny particles (atoms or molecules) that are in

Brain teaser

What is the difference between mole (gram-molecule) and Avogadro's number? Does Avogadro's number depend on state of the substance?

Ans: The atomic mass of an element or molecular mass of a compound expressed in grams is called one mole.

The number of atoms, molecules or ions present in one mole of a substances is called Avogadro's number. It has same value $N_A = 6.02 \times 10^{23}$ particles / mole.

It is same for solid, liquids and gases.

constant random motion. These particles move freely in all directions and frequently collide with one another and with the walls of the container. When gas molecules strike the walls, they exert a force on them due to the change in momentum during each collision. The pressure of a gas is defined as the force exerted per unit area of the container walls as a result of these collisions. Since the collisions are elastic, no energy is lost, and the average kinetic energy of the molecules is directly proportional to the absolute temperature of the gas i.e., $<\text{K.E.}> \propto T$. Thus, an increase in temperature increases the speed of the molecules, leading to more collisions, and consequently, a higher pressure.

The ideal gas obeys the gas law which would relate the gas temperature with other parameters and the gas law is:

$$PV = nRT \ \ldots\ldots\ldots (13.1)$$

where P is the pressure, n is number of moles, R is general gas constant equals to $N_A k_B$, $k_B = 1.38\times10^{-23}\ \text{JK}^{-1}$ is the Boltzmann constant, ($N_A = 6.02\times10^{23}$ molecules) is the Avogadro number and T is the temperature of the gas. Therefore,

$$PV = nN_A k_B T$$

The number of moles in terms of number of particle N is defined as; $n = \frac{N}{N_A}$, then

$$PV = NK_B T \ \ldots\ldots\ldots (13.2)$$

As pressure is force per unit area, exerted on walls of the container, therefore, each time a gas particle (molecule or atom) collides with walls of the container, and exerts a force on the walls of the container. This force spreads over whole wall area of the container.

Momentum Change and Force on the Wall (One Molecule)

Consider a collision in which the molecule with velocity v strikes one face of the cube along x-axis. It rebounds elastically in the opposite direction having velocity-v, its momentum changes from (mv) to (–mv). Change in momentum along x-axis;

$$\Delta\vec{p} = -mv_x - (mv_x) = -mv_x - mv_x = -2mv_x$$

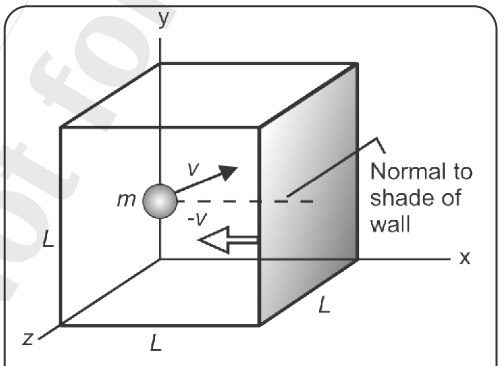


Fig. 13.2: Molecule moving with velocity v

The molecule travels a distance $2L$ between the consecutive collisions with the same wall of the cube. Hence, time between two consecutive collisions with one side of the cube is:

$$\Delta t = \frac{2L}{v_x} \ \ldots\ldots\ldots (13.3) \quad \left(\text{using } t = \frac{s}{v}\right)$$

The force on molecule due to wall is : $F = \frac{\Delta\vec{p}}{\Delta t} = \frac{-2mv_x}{\frac{2L}{v_x}} = \frac{-mv_x^2}{L}$

The average force exerted by the wall of cube on the molecule can be found using Newton's second law of motion. We know that force is equal to the rate of change of momentum. The area of the wall is L^2 Thus,

$$F = \frac{\text{Change in momentum}}{\text{Time}} = -\left(\frac{-mv_x^2}{L}\right) = \frac{mv_x^2}{L} \ \ldots\ldots\ldots (13.4)$$

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This expression represents the force exerted on the container wall by one molecule in the x-direction. The positive sign in the change of momentum is due to the force of the molecule by the wall which is in opposite direction to the change in momentum as a result of the Newton's third law of motion.

Pressure $= \frac{Force}{Area} = \frac{F}{L^2}$

Using equation, $P = \frac{\frac{mv_x^2}{L}}{L^2}$

$$P = \frac{mv_x^2}{L^3} = \frac{mv_x^2}{V} \ldots\ldots\ldots(13.5)$$

This is the pressure exerted on container wall by one molecule.

Brain teaser

How does the Kinetic theory of gases relate to the Boyle's law and Charles' law?

Ans. According to kinetic theory, gas pressure is produced by the continuous collisions of rapidly moving gas molecules with the walls of the container. In Boyl's law decreasing the volume causes more frequent collisions, so the pressure increases. In Charle's law, increasing the temperature increases kinetic energy of molecules, making them move faster and causing the gas to expand at constant pressure. Thus, the kinetic theory provides molecular explanation of both Boyl's law and Charle's law.

Total Pressure of All Molecules and the RMS Velocity Concept

The total force, we must add up the contributions of all the molecules that strike the wall, allowing for the possibility that they all have different speeds. Dividing the magnitude of the total force F_x along x-axis by the area of the wall (L^2), then gives the pressure *P* on that wall:

$$P = \frac{m}{V}\left(v_{1x}^2 + v_{2x}^2 + v_{3x}^2 + \cdots\right) \ldots\ldots\ldots(13.6)$$

where v_{1x}^2 is the velocity of particle 1 in the x-direction, and v_{2x}^2 the velocity of particle 2 in the x-direction and so on. If there are *N* number of particles in the container, then total mass is the number of particles times mass of the particle (i.e. $M = mN$).

As we know that velocity striking the wall is v_x and after striking the wall it is $-v_x$ which would result in average velocity zero. This means simple average does not suit here. In order to avoid this zero, we need to do the square of the velocities before averaging.

$$< v_x^2 >= \frac{v_{1x}^2 + v_{2x}^2 + v_{3x}^2 + \cdots + v_{Nx}^2}{N} = \frac{\sum_{i=1}^{N} v_{ix}^2}{N}$$

(OR)

$$v_{1x}^2 + v_{2x}^2 + \cdots\cdots + v_{Nx}^2 = N < v_x^2 >$$

Put in Eq. (13.6)

$$P = \frac{mN}{v} < v_x^2 > \ldots\ldots\ldots(13.7)$$

Root mean square velocity: If we take the square root of the average square of the velocities, it is known as the root mean square (rms) velocity and is written as:

$$\left(v_{rms}\right)_x = < \sqrt{v_x^2} > \ldots\ldots\ldots(13.8)$$

Since the molecules are moving randomly in all directions, only one-third of their total velocity will be directed along any one Cartesian axis. So,

$$< v^2 >=< v_x^2 > + < v_y^2 > + < v_z^2 > \ldots\ldots\ldots(13.9)$$

Since gas molecules are moving randomly and have the same average speed in all three directions. i.e;

$$< v_x^2 >=< v_y^2 >=< v_z^2 >$$

Put in Eq. (13.9)

$$< v^2 >=< v_x^2 > + < v_x^2 > + < v_x^2 >= 3 < v_x^2 > \ldots\ldots\ldots(13.10)$$

Total average velocity is:

$$< v_x^2 >= \frac{< v^2 >}{3} \ldots\ldots\ldots(13.11)$$

Put in Eq. (13.7)

$$P = \frac{N}{3V} m < v^2 > \ldots\ldots\ldots(13.2)$$

Then $$PV = \frac{1}{3} Nm < v^2 > \ldots\ldots\ldots(13.13)$$

This is the pressure of the gas molecules on the wall. The pressure in terms of density can be written as:

$$\rho = \frac{\text{Total mass}}{\text{Volume}} = \frac{M}{V} = \frac{Nm}{V}$$

Rearranging the pressure, Eq. (13.13) for P, and substituting the density

$$P = \frac{1}{3} \rho < v^2 > \ldots\ldots\ldots(13.14)$$

This is the pressure of the gas which depends on the density and root mean square of velocity. From equation 13.13

$$P = \frac{mN}{3V} < v^2 >$$

$$P = \frac{2}{3} \frac{N}{V} < \frac{1}{2} mv^2 >$$

$$P = \frac{2}{3} N_\circ < \frac{1}{2} mv^2 > \left(\text{Here} \frac{N}{V} = N_\circ \right)$$

$$P = \frac{2}{3} N_\circ < K.E._T >$$

The pressure exerted by gas molecules on the walls of container is directly proportional to the average translational kinetic energy of the gas molecules.

AVERAGE TRANSLATIONAL KINETIC ENERGY OF A GAS

Q5. Derive an expression for the average translational kinetic energy of a gas molecule and show that the temperature of a gas is a direct measure of the average kinetic energy of its molecules. **12113005**

Ans. **Key points:**

Derivation of the Average K.E Formula | Temperature as a Direct Measure of Average K.E| Kinetic Energy in Electron Volt (eV) Units

Derivation of the Average K.E Formula

We have calculated the pressure of the gas molecule with $n = N/V$ molecules by using the gas law $PV = nRT$ and kinetic theory.

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$$PV = \frac{N}{3} m < v^2 >$$

The gas constant R is related with Boltzmann constant and Avogadro number. $k_B = R / N_A$

Equating these equations, we have

$$nRT = \frac{N}{3} m < v^2 >= \frac{N}{3} m v_{rms}^2 \ldots\ldots\ldots (13.15)$$

$$m v_{rms}^2 = \frac{3nRT}{N}$$

Where $\frac{N}{n} = N_A$ is the number of molecules in one mole and it is Avogadro number.

Boltzmann factor $m v_{rms}^2 = \frac{3RT}{N_A}$

or $\frac{1}{2} m v_{rms}^2 = \frac{3RT}{2N_A}$

or $v_{rms}^2 = \frac{3RT}{mN_A}$

$$v_{rms} = \sqrt{\frac{3RT}{mN_A}} \quad \ldots\ldots\ldots (13.16) \therefore \frac{R}{N_A} = K_B \text{ (Boltzmann constant)}$$

We rewrite the equation as

$$\frac{1}{2} m < v^2 >= \frac{3}{2} k_B T \ldots\ldots\ldots (13.17)$$

In this equation, $\frac{1}{2} m v_{mrs}^2$ is the average translational kinetic energy and it is denoted by <K.E.$_T$>. Therefore, the above equation is written as:

$$< K.E._T >= \frac{3}{2} k_B T \ldots\ldots\ldots (13.18)$$

For your information

Kinetic theory helps to understand the interaction between pollutants and the atmosphere. This knowledge is used to develop the systems to monitor the quality of air.

Temperature as a Direct Measure of Average K.E.

The average translational kinetic energy of the molecules in a gas is given by a simple constant times the temperature. So, if this model is accurate, the temperature of a gas is a direct measure of the average translational kinetic energy of its molecules.

Kinetic Energy in Electron Volt (eV) Units

For an air molecule at room temperature (300 K), the quantity $k_B T$ is $(1.38 \times 10^{-23} JK^{-1} \times 300K)$ $= 4.14 \times 10^{-21} J$. For such a small quantity, we use electron volt instead of joule (J). The electron volt is the kinetic energy of an electron that has been accelerated through a voltage difference of one volt: $1eV = 1.6 \times 10^{-19} J$.

Boltzmann constant is $8.62 \times 10^{-5} eVK^{-1}$, so at room temperature, value of $k_B T = (8.62 \times 10^{-5}$ $eVK^{-1})(300K) = 0.026eV$.

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DAILY-LIFE EXAMPLES AND THE BOLTZMANN DISTRIBUTION LAW

Q6. Explain the kinetic theory of gases with the help of daily-life examples (popcorn and car tyres). Also explain the Boltzmann distribution law and its significance in statistical physics. **12113006**

Ans. **Key points:**

Daily-Life Examples (Popcorn and Car Tyres) | Statistical Physics and Molecular Energy States | Boltzmann Distribution Law

Daily-Life Examples (Popcorn and Car Tyres)

Examples from daily life are the popcorn and pressure in tyre of a car. When popcorn kernel is heated, the moisture trapped in popcorn kernel becomes steam. The pressure in the kernel is increased and it ruptures the corn cover releasing the gelatinous starch. It becomes solid after cooling. When air is pumped into the tyres of a car, the number of air molecules increases which raises the air pressure inside the tyres. We know that more molecules result in frequent molecular collisions with tyre's walls due to limited volume. The pressure gives the tyre its hardness and bears the car's weight without deflating.



Fig. 13.3

Statistical Physics and Molecular Energy States

So far we know that kinetic theory of gases is used to determine the pressure of the ideal gas using the gas laws assuming the thermal or random motion of molecules. For large number of molecule, we use statistical physics. It is the branch of physics that uses probability theory. Accordingly, atoms and molecules of a system may exist in different energy states (levels) E_1, E_2, E_3, ..., etc due to different speeds.

For your information

In 1860 James Clark Maxwel (1831-1879) derived an expression that describes the distribution of molecular speeds within the system at thermal equilibrium. About 60 years later, experiments were performed to confirm Maxwell's predictions.

Boltzmann derived the Boltzmann kinetic equation. This equation describes the dynamic processes in gases having large number of molecules. Boltzmann constant is also related to the population of atoms in two levels.

$$\frac{N_2}{N_1} = e^{\frac{-\Delta E}{k_B T}} \quad \ldots\ldots\ldots (13.19)$$

where ($e^{\frac{-\Delta E}{k_B T}}$ = Boltzmann factor) N_1 and N_2 are the population of lower and higher energy states, $\Delta E = (E_2 - E_1)$ is the energy difference between these states. The number density is directly proportional to the pressure.

Boltzmann Distribution Law

This equation is known as the Boltzmann distribution law and is important in describing the statistical mechanics of a large number of molecules. It states that the probability of finding

the molecules in a particular energy state varies exponentially as the negative of the energy divided by k_BT ; therefore, more particles reside in lower energy states than in higher ones.

In a gas container, a molecule undergoes billions of collisions every second. Each collision changes the speed of molecule thereby changing the kinetic energy, but kinetic theory concludes that average kinetic energy at temperature T is:

$$E_{av} = \frac{3}{2}k_BT \text{ .....(13.20)}$$

Where k_B is effectively the gas constant per molecule.

STELLAR EVOLUTION – HYDROSTATIC EQUILIBRIUM OF A STAR

Q7. Explain how a star is formed from a cloud of gas and dust. Describe the hydrostatic equilibrium condition that balances gravitational force and internal pressure inside a star. **12113007**

Ans. **Key points:**

Formation of Stars (Proto-star Stage) | Balance Between Gravity and Pressure | Hydrostatic Equilibrium Equation

Formation of Stars (Proto-star Stage)

The kinetic theory of gases, when extended to astrophysical systems like stars and galaxies, helps us understand the evolution of stars in a galaxy or gas atoms in a stellar atmosphere. Stellar evolution deals with the star changes over the time. Star can have range of lifetime from a few million years to trillions of years. The life of a star depends on the mass of the star. The most massive have longer life which is even longer than the current age of the universe. All stars are formed from the clouds of gas and dust which are often called nebulae or molecular clouds. This is also called a proto-star. As the cloud contracts, its density and temperature increase due to the rise in K.E. of particles ($K \propto T$). After a millions of years, these proto-stars can become a star having achieved a state of equilibrium. The rms velocity of gases in the star increases with rise of density. This in turn increases the average kinetic energy and finally temperature increases with time.

Balance Between Gravity and Pressure

Figure 13.4 represents the competition between gravity and pressure.

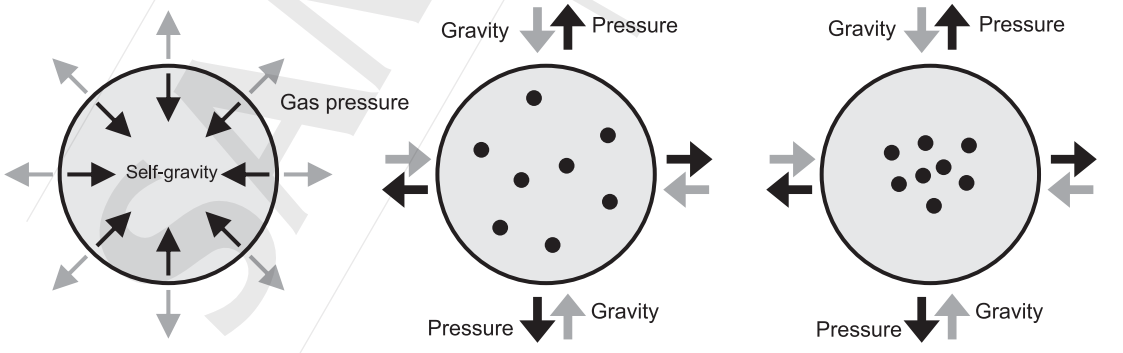


Fig 13.4: Gravity compression is balanced by pressure outward. Greater gravity compresses the gas, making it denser and hotter.

As the temperature increases, the internal pressure also rises. A stable star is formed when the inward gravitational force is exactly balanced by the outward pressure.

Hydrostatic Equilibrium Equation

This condition is described by the hydrostatic equation; $\frac{\Delta P}{\Delta r} = -\frac{GM_r \rho_r}{r^2}$.

This equation ensures that the star neither collapses under gravity nor expands indefinitely. P is the pressure inside the star (force per unit area), $\Delta P / \Delta r$ is the rate of change of pressure with radius (how pressure changes from the centre outward), r is distance from the centre of the star, G is gravitational constant $\left(6.67 \times 10^{-11} Nm^2 kg^{-2}\right)$, M_r is mass enclosed within radius r, ρ_r is density at radius r, and negative sign indicates that pressure decreases outward, while gravity pulls inward. There are two possibilities if the balance between pressure force and gravitational force is not maintained.

(i) Gravitational force > Internal pressure (ii) Gravitational force < Internal pressure

LIFE CYCLE OF STARS, NEUTRON STARS AND THE SUN

Q8. Describe the life cycle of a star from nuclear fusion to its final stage (white dwarf, neutron star or black hole) depending on its mass. Also explain neutron stars, pulsars and the life cycle of our Sun. **12113008**

Ans. **Key points:**

Nuclear Fusion and Expansion of a Star | Red Giant Stage and the Final Fates of Stars | Red Dwarf Stars | Neutron Stars and Pulsars | Life Cycle of the Sun

Nuclear Fusion and Expansion of a Star

As the temperature within a star's core rises, nuclear fusion is initiated, allowing hydrogen nuclei to combine and form helium. This process releases an immense amount of energy, which sustains the star and powers it for the majority of its lifetime. The continuous energy production not only maintains equilibrium against gravitational collapse but also leads to a gradual increase in internal temperature. As a consequence, the star begins to expand.

Do you know?

A parsec is a unit of distance that is used by astronomers as an alternative to the light-year, just as kilometres are being used as an alternative to miles. In fact, one parsec is approximately 3.26 light years, or almost 19 trillion miles (31 trillion km)

Red Giant Stage and the Final Fates of Stars

With further increases in temperature and changes in core composition, the star may expand significantly to become a red giant. At this stage, stars possessing at least about half the mass of the Sun are capable of initiating helium fusion in their cores, producing heavier elements such as carbon and oxygen. In more massive stars, the process continues with the fusion of even heavier elements in successive stages, forming increasingly complex nuclei up to iron.

The final fate of a star depends primarily on its mass. Once a star exhausts its nuclear fuel, it can no longer support itself against gravitational collapse. In low and intermediate mass stars, the core contracts into a dense white dwarf, while the outer layers are expelled into space, forming a planetary nebula. In contrast, stars with masses roughly ten times greater than that of

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the Sun undergo a dramatic supernova explosion. During this event, the inert iron core collapses under gravity, leading to the formation of dense remnants such as neutron stars or black holes.

Red Dwarf Stars

Red dwarf stars, due to their low mass and highly efficient fuel consumption, follow a much slower evolutionary path. The universe is not yet old enough for any red dwarf to have completed its life cycle. However, theoretical models indicate that these stars will gradually become hotter and more luminous over time before eventually exhausting their hydrogen fuel and evolving into low mass white dwarfs.

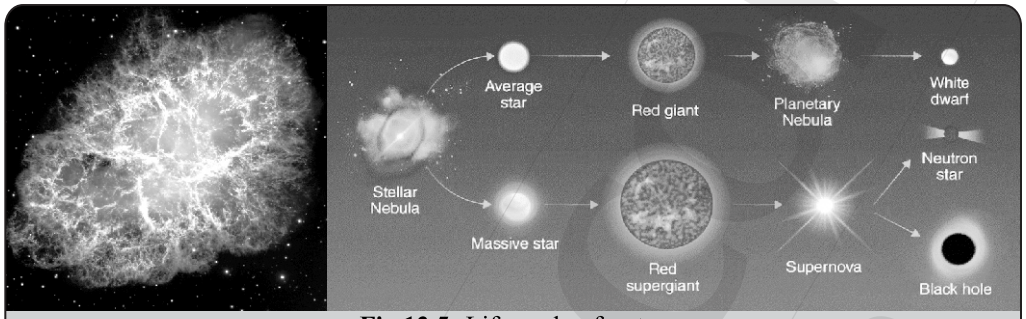


Fig 13.5: Life cycle of a star

Neutron Stars and Pulsars

Neutron stars are among the densest known objects in the universe, second only to black holes. The nearest are many parsecs away, making direct study difficult. Due to their extremely high density, matter inside neutron stars behaves like a degenerate gas and their strong gravitational fields make them challenging to model. According to estimates by NASA, there may be up to a billion neutron stars in the Milky Way galaxy. Many of the neutron stars observed so far are relatively young and rotate rapidly, emitting beams of radiation. These are known as pulsars.

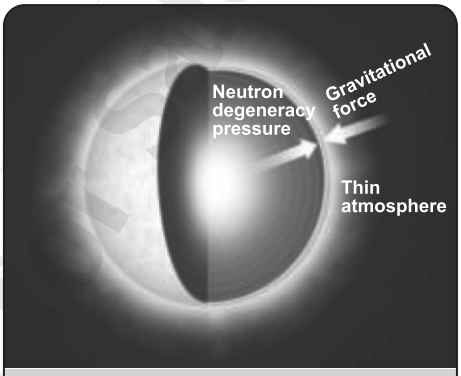


Fig. 13.6: Section of neutron star

Scientists believe that pulsar radiation is produced when strong magnetic fields channel matter toward the magnetic poles of neutron stars. When a star collapses to form a neutron star, not only is its mass compressed, but its magnetic field is also greatly intensified. Magnetic fields represented by field lines become stronger as these lines are squeezed closer together during the collapse of the stellar core.

Life Cycle of the Sun

The Sun is the nearest star to Earth and the main source of heat and light for our planet. It was formed about 4.6 billion years ago from a huge cloud of gas and dust called a solar nebula. Due to gravitational contraction, the temperature at the centre increased and a protostar was formed. When the core became extremely hot, nuclear fusion started in which hydrogen changed into helium and released a large amount of energy. The life stages of the Sun are: nebula, protostar, main sequence, red giant, planetary nebula, and white dwarf. At present, the

Sun is in the main sequence stage, where it is producing heat and light by converting hydrogen into helium. In thermal physics, the Sun is important because it is a natural source of enormous heat energy and transfers this energy mainly by radiation.

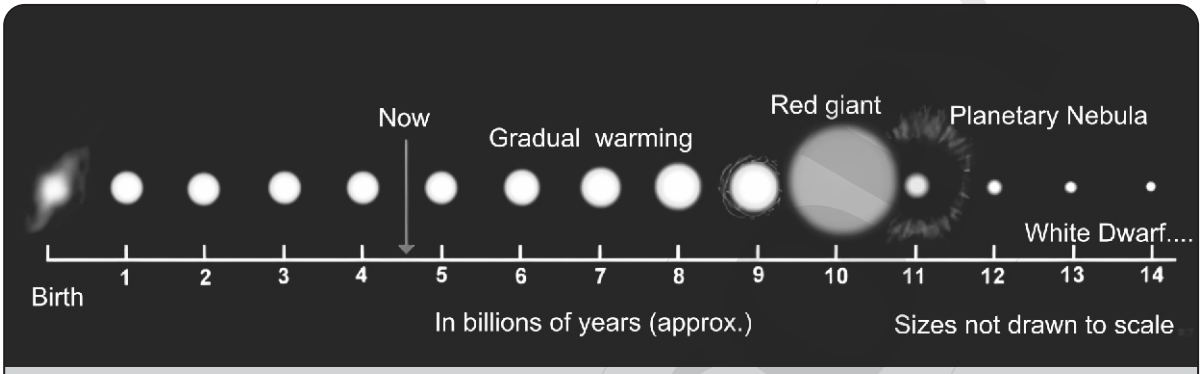


Fig 13.5: Life cycle of the Sun

APPLIED EQUATIONS (FORMULA SHEET) OF UNIT

Sr. No.	Formula	Description
1	$P = \frac{2}{3} N_{\circ} \left(K \cdot E \right)$	Pressure of a gas
2	$P = \frac{1}{3} \rho < v^2 >$	Pressure of a gas
3	$K \cdot E = \frac{3}{2} K_B T$	Kinetic energy of gas molecule
4	$V_{rms} = \sqrt{\frac{3RT}{mN_A}}$	Root mean square velocity
5	$V_{rms} = \sqrt{\frac{3P}{\rho}}$	Root mean square velocity
6	$V_{rms} = \sqrt{\frac{3k_B T}{m}}$	Root mean square velocity
7	$\frac{V_{rms2}}{V_{rms1}} = \sqrt{\frac{T_2}{T_1}}$	Root mean square velocity in terms of temperatures.
8	$P_g \approx \frac{GM^2}{R^4}$	Simplified version of gravitational pressure of a star
9	$PV = nRT$	Gas equation
10	$P = \rho gh$	Pressure of a fluid

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SOLVED EXAMPLES

Example 13.1 **An ideal gas has a density of 4.5 kg m^{-3} at a pressure of 9.3×10^5 Pa and a temperature of 504 K. Determine the root-mean-square speed of the gas atoms.** 12113009

Solution: $\rho = 4.5 kg\,m^{-3}$, $P = 9.3\times10^5$ Pa , $V_{rms} = ?$

Pressure is defined as; $P = \frac{1}{3}\rho < v^2 >$

or $< v^2 >= \frac{3P}{\rho}$

$$< v^2 >= \frac{3\times(9.3\times10^5 Pa)}{4.5 kg\,m^{-3}} = 6.2\times10^5 m^2 s^{-2}$$

To find the rms value, take the square root of the mean-square-speed, thus

$$v_{rms} = \sqrt{< v^2 >} = \sqrt{6.2\times10^5 m^2 s^{-2}} = 787 ms^{-1} \approx 7.9\times10^2 m\,s^{-1}$$

Example 13.2 **What is the rms speed of air molecules (O_2 and N_2) at room temperature e.g. 25°C?** 12113010

Solution: Mass of oxygen O_2 = 32 u and Mass of nitrogen N_2 = 28 u

$1u = 1.66\times10^{-27} kg$; $k_B = 1.38\times10^{-23}\,J\,K^{-1}; T = 25°\,C = 298K$

Mass of oxygen O_2 $= 32\times1.66\times10^{-27} kg = 5.3\times10^{-26} kg$

Mass of nitrogen N_2 $= 28\times1.66\times10^{-27} kg = 4.6\times10^{-26} kg$

The rms speed of oxygen is:

$$v_{rms} = \sqrt{\frac{3k_B T}{m}} = \sqrt{\frac{3\times(1.38\times10^{-23}\,JK^{-1})\times298K}{5.3\times10^{-26} kg}} = 481 ms^{-1} \approx 4.81\times10^2 m\,s^{-1}$$

Similarly, the rms speed of nitrogen is $v_{rms} = 515 m\,s^{-1} \approx 5.15\times10^2 m\,s^{-1}$

The speed of air molecules is much greater than the speed of sound which is about 340 m s^{-1}.

Example 13.3 **A star mass 2×10^{30} kg and radius 7×10^8 m. Calculate gravitational pressure and compare it with internal pressure 1.0×10^{14} Pa.** 12113011

Solution: As $P_g \approx \frac{GM^2}{R^4}$, therefore,

$$P_g = \frac{(6.67\times10^{-11} Nm^2 kg^{-2})(2\times10^{30} kg)^2}{(7\times10^8 m)^4}$$

$$= \frac{6.67\times4\times10^{49}}{2.410\times10^{35}} \approx 1.3\times10^{14} Pa$$

i.e., $P_g = P_{internal}$

As both pressures are nearly equal, therefore, the star is in stable equilibrium.

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Example 13.4 **A massive star has mass 4×10^{30} kg , radius 5×10^{8} m and internal pressure 1×10^{14} Pa. Check whether the star is stable.** 12113012

Solution: As $P_g \approx \frac{GM^2}{R^4}$, therefore,

$$P_g = \frac{\left(6.67\times10^{-11}Nm^2kg^{-2}\right)\left(4\times10^{30}kg\right)^2}{\left(5\times10^{8}m\right)^4}$$

$$= \frac{6.67\times16\times10^{49}}{6.25\times10^{34}} \approx 1.7\times10^{15}Pa$$

Gravity is stronger, therefore, the star will contract and may eventually collapse (possible neutron star or black hole formation).

Example 13.5 **A star has mass 1×10^{30} kg , radius 1×10^{9} m and internal pressure 5×10^{14} Pa. Determine the state of the star.** 12113013

Solution: As $P_g \approx \frac{GM^2}{R^4}$, therefore,

$$P_g = \frac{\left(6.67\times10^{-11}Nm^2kg^{-2}\right)\left(1\times10^{30}kg\right)^2}{\left(1\times10^{9}m\right)^4}$$

$$= \frac{6.67\times10^{49}}{10^{36}} \approx 6.67\times10^{13}Pa$$

Internal pressure dominates, therefore, the star will expand and may evolve into a red giant.

MULTIPLE CHOICE QUESTIONS (EXERCISE)

1. Which condition is necessary for most gases to behave nearly ideally? 12113014
(a) Low temperature and low pressure
(b) High temperature and low pressure
(c) Constant temperature and low pressure
(d) High temperature and constant pressure

2. v_{rms} of the gas molecule is 300 ms^{-1}. If its absolute temperature is reduced to half and molecular weight is doubled, then v_{rms} will become: 12113015
(a) 75 m s^{-1} (b) 150 m s^{-1}
(c) 300 m s^{-1} (d) 600 m s^{-1}

3. The rms speed of the gas at 27 °C is v. If temperature of the gas is raised to 327 °C, the rms speed of the gas is: 12113016
(a) v (b) $v/\sqrt{2}$
(c) $\sqrt{2}v$ (d) $3v$

4. Ratio of the rms velocities of O_2 and H_2 at equal temperature will be: 12113017
(a) 1:1 (b) 1:4
(c) 2:1 (d) 4:1

5. In a closed room, there is a gas with pressure of $3.2\times10^{5}Nm^{-2}$. If the gas density is 6 kgm^{-3}, what is the effective speed of each gas particle? 12113018
(a) 400 m s^{-1} (b) 300 m s^{-1}
(c) 250 m s^{-1} (d) 330 m s^{-1}

6. Which statement is not the statement of kinetic theory of gases? 12113019
(a) Molecules interact during collisions
(b) Molecules are in continuous random motion
(c) Collisions are of short duration
(d) Molecules are tiny hard sphere undergoing inelastic collisions

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7. **Which equation ensures that a star remains stable against gravitational collapse?** 12113020
   (a) Mass continuity equation
   (b) Energy gravitational equation
   (c) Hydrostatic equilibrium equation
   (d) Energy transport equation

8. **What happens to a star when its gravitational force becomes greater than its internal pressure?** 12113021
   (a) The star expands and becomes a red giant
   (b) The star contracts and its core temperature increases
   (c) The star remains stable with no changes
   (d) Nuclear fusion stops immediately

SLO BASED MULTIPLE CHOICE QUESTIONS

Brownian Motion

9. **Brownian motion is the:** 12113022
   (a) Ordered motion of particles
   (b) Random motion of particles
   (c) Circular motion of particles
   (d) Stationary motion

10. **Who explained the motion of pollen particles in liquid in 1905?** 12113023
    (a) Newton (b) Einstein
    (c) Maxwell (d) Bohr

11. **Brownian motion becomes faster when the fluid viscosity is:** 12113024
    (a) High (b) Infinite
    (c) Low (d) Constant

12. **Collision between molecules causes transfer of:** 12113025
    (a) Only mass
    (b) Only heat
    (c) Momentum and energy
    (d) Density only

Kinetic Theory of Gases

13. **Gas pressure is produced due to:** 12113026
    (a) Weight of gas
    (b) Molecular collisions
    (c) Volume of gas only
    (d) Volume of gas only

14. **According to kinetic theory, gas molecules are in:** 12113027
    (a) Circular motion
    (b) Periodic motion
    (c) Random motion
    (d) Rest

15. **Collisions between gas molecules are assumed to be:** 12113028
    (a) Inelastic (b) Perfectly elastic
    (c) Partially elastic (d) Impossible

16. **The average kinetic energy of gas molecules depends upon:** 12113029
    (a) Pressure (b) Mass
    (c) Temperature (d) Volume

17. **The volume of gas particles is considered:** 12113030
    (a) Very large
    (b) Equal to container volume
    (c) Negligible
    (d) Infinite

Pressure and RMS Speed

18. **The rms speed of gas molecules is obtained from:** 12113031
    (a) Average velocity
    (b) Square root of mean square speed
    (c) Pressure equation
    (d) Density equation

19. **The pressure of a gas is directly proportional to:** 12113032
    (a) Density and mean square speed
    (b) Only volume
    (c) Only mass
    (d) Only temperature

20. **The SI unit of pressure is:** 12113033
    (a) Joule (b) Pascal
    (c) Newton (d) Watt

21. **If the temperature of a gas increases, the rms speed will:** 12113034
    (a) Decrease (b) Become zero
    (c) Increase (d) Remain unchanged

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Average Kinetic Energy

22. The average translational kinetic energy of a gas molecule is: 12113035
(a) $(1/2)K_BT$ (b) $(3/2)K_BT$
(c) $2K_BT$ (d) $3K_BT$

23. Boltzmann constant is represented by: 12113036
(a) R (b) NA
(c) k_B (d) T

24. Temperature is a direct measure of: 12113037
(a) Mass
(b) Density
(c) Average kinetic energy
(d) Volume

Statistical Physics and Stellar Evolution

25. Statistical physics mainly uses: 12113038
(a) Geometry (b) Probability theory
(c) Optics (d) Magnetism

26. The probability of finding molecules in higher energy states is: 12113039
(a) Greater (b) Equal
(c) Lower (d) Infinite

27. A stable star exists when: 12113040
(a) Pressure is zero
(b) Gravity balances pressure
(c) Gravity disappears
(d) Fusion stops

28. When gravitational force becomes greater than internal pressure, the star: 12113041
(a) Expands
(b) Contracts
(c) Remains unchanged
(d) Disappears

29. The Sun is currently in which stage? 12113042
(a) Red giant
(b) White dwarf
(c) Main sequence
(d) Planetary nebula

30. Rapidly rotating neutron stars emitting radiation are called: 12113043
(a) Galaxies (b) Nebulae
(c) Pulsars (d) Asteroids

ANSWER KEY

1.	b	2.	b	3.	c	4.	b	5.	a	6.	d	7.	c	8.	b	9.	b	10.	b
11.	c	12.	c	13.	b	14.	c	15.	b	16.	c	17.	c	18.	b	19.	a	20.	b
21.	c	22.	b	23.	c	24.	c	25.	b	26.	c	27.	b	28.	b	29.	c	30.	c

SHORT QUESTION ANSWERS (EXERCISE)

1. Do all gases have the same kinetic energy at the same temperature? If yes, give example. 12113044

Ans. Yes, all gases have the same average translational kinetic energy at the same temperature. According to the kinetic theory of gases is given by:

$$<K.E.> = (3/2)\, K_BT$$

This expression depends only on the Boltzmann constant K_B and temperature T and is independent of the type of gas or mass of the molecules.

Example both oxygen (O_2) and nitrogen (N_2) molecules at room temperature (300 K) have the same average kinetic energy $\approx 6.21\times10^{-21}$ J, even though they have different molecular masses.

2. A vessel is fitted with a mixture of two different gases. Will the mean kinetic energy per molecule of gases be equal? Explain briefly. 12113045

Ans. Yes, the mean kinetic energy per molecule of both gases in the mixture will be equal. The average translational kinetic energy of a gas molecule is given by:

$$<K.E.> = (3/2)\, k_BT$$

Since both gases are present in the same vessel, they are at the same temperature T.

The formula shows that kinetic energy depends only on temperature and not on the mass or type of molecule. Therefore, regardless of their different molecular masses, both gases will have equal mean kinetic energy per molecule as long as they remain at the same temperature.

3. If density of a gas is doubled, keeping all other factors unchanged, what will be the effect on the pressure of the gas? 12113046

Ans. The pressure of the gas will be doubled.

Explanation:

The pressure of a gas is related to its density by:

$$P = (1/3)\,\rho\,\langle v^2\rangle$$

If density ρ is doubled to 2ρ, while the mean-square speed $\langle v^2\rangle$ remains unchanged (since temperature is constant), then:

$$P' = (1/3)(2\rho)\langle v^2\rangle = 2P$$

Therefore, doubling the density doubles the pressure of the gas.

4. A gas enclosed in a container is heated up. What is the effect of pressure on gas molecules? 12113047

Ans. The pressure increases.

Explanation: When a gas enclosed in a container is heated up, the temperature of the gas increases. According to kinetic theory,

$$\langle K.E.\rangle = (3/2)k_BT.$$

When the gas is heated, the molecules gain kinetic energy and move faster. They strike the walls more often and with greater force. As

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

So the pressure on the container increases.

5. The number of molecules of a gas in a container is doubled. What will be the effect on the rms speed? 12113048

Ans. There will be no effect on the rms speed.

Explanation:

The rms speed is given by:

$$v_{rms} = \sqrt{(3K_BT/m)}$$

This expression depends only on temperature T and the mass m of each molecule. It does not depend on the number of molecules N. Therefore, if the number of molecules of a gas in a container is doubled there will be no effect on the rms speed.

6. Explain briefly, why it is not possible to increase the temperature of the gas while keeping its volume and pressure constant. 12113049

Ans. It is not possible to increase the temperature of a gas while keeping both volume and pressure constant simultaneously. From the ideal gas law:

$$PV = NRT$$

If P and V are both kept constant, then the right-hand side (NRT) must also remain constant. Since N and R are constant, T cannot change. Therefore, it is physically impossible to raise the temperature while holding both P and V constant.

7. On reducing the volume of a gas at constant temperature, the pressure of the gas increases. Explain briefly on the basis of kinetic theory of gases. 12113050

Ans. When the volume of a gas is reduced at constant temperature, the rms speed of the molecules stays the same because the temperature has not changed. When the volume decreases, the same number of molecules occupies a smaller space. As a result, they collide with the walls more frequently. The total force on the walls increases. Since

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

The wall area also decreases with reduced volume, the net result is a significant increase in pressure. This is consistent with Boyle's Law as explained by kinetic theory.

8. How does the balance between gravitational force and internal pressure determine whether a star expands or contracts during its evolution? 12113051

Ans. The state of a star depends entirely on the balance between its inward gravitational force and outward internal pressure. This balance is governed by the hydrostatic equilibrium equation:

$$\Delta P/\Delta r = -GM_r\rho_r/r^2$$

Equilibrium (Gravity = Pressure): The star is stable neither expanding nor contracting.
Gravity > Pressure: The star contracts inward, its core density and temperature rise. Depending on the mass, it may eventually collapse into a neutron star or black hole.
Pressure > Gravity: The internal pressure overcomes gravity, causing the star to expand and potentially evolve into a red giant.
Thus, stellar evolution is governed by this ongoing competition between gravitational compression and internal pressure.

SLO BASED SHORT QUESTION ANSWERS + PAST PAPERS MCQs OF PUNJAB BOARDS

Brownian Motion

9. What does Brownian motion show about the motion of molecules in a fluid? 12113052

Ans. Brownian motion is the random and irregular motion of tiny particles in a fluid. It happens because the particles are continually struck by moving molecules from all sides. This proves that molecules in a fluid are always in motion.

10. Why do tiny particles follow a zig-zag path in Brownian motion? 12113053

Ans. The tiny particle receives unequal collisions from the surrounding fluid molecules. These collisions keep changing its direction again and again. As a result, the motion becomes zig-zag and irregular instead of smooth.

11. How does the viscosity of a fluid affect Brownian motion? 12113054

Ans. A fluid with lower viscosity offers less resistance to motion, so Brownian motion becomes faster. In a more viscous fluid, internal friction is greater and the random motion slows down. Thus, viscosity and Brownian speed are inversely related.

Kinetic Theory of Gases

12. State any three assumptions of the kinetic theory of gases. 12113055

Ans. The gas consists of a very large number of tiny particles that are far apart compared with their size. The particles are in constant random motion in all directions. Their collisions are perfectly elastic and there are no forces of attraction or repulsion between collisions. The average kinetic energy depends only on temperature.

13. Why is gas pressure produced when molecules strike the walls of a container? 12113056

Ans. When gas molecules strike the walls, their momentum changes. This change in momentum produces a force on the walls. The force spread over the wall area gives the pressure of the gas.

14. Why is the ordinary average velocity of gas molecules not used in kinetic theory? 12113057

Ans. The velocities of molecules are in opposite directions, so the ordinary average becomes nearly zero. To avoid this cancellation, we use the squares of the speeds first and then take the square root. This gives a meaningful measure of molecular motion.

15. Write the relation between pressure and mean square speed of a gas. 12113058

Ans. The relation is

$$P = (1/3)\rho \langle v^2 \rangle$$

It connects pressure with density and mean square speed. So, greater density or faster molecular motion produces greater pressure.

Gas Speed and Kinetic Energy

16. What is root mean square speed and why is it used? 12113059

Ans. The root mean square (rms) speed is the square root of the average of the squares of molecular speeds. It is used because gas molecules move randomly, so simple averaging of velocity gives zero. The rms speed gives a useful measure of molecular motion.

17. Why do all gases have the same average translational kinetic energy at the same temperature? 12113060

Ans. The average translational kinetic energy depends only on temperature, not on the type or mass of gas molecules. Therefore, two different gases at the same temperature have the same mean kinetic energy per molecule. This is a key result of kinetic theory.

18. State the relation between average translational kinetic energy and temperature. 12113061

Ans. The chapter gives the relation between average translational kinetic energy and temperature as follows:

$$\langle K.E. \rangle = (3/2)\, K_B T$$

This equation shows that average translational kinetic energy is directly proportional to absolute temperature. So, higher temperature means greater molecular kinetic energy.

19. Mention two daily life applications of kinetic theory given in the chapter. 12113062

Ans. One example is popcorn popping, where heating turns trapped moisture into steam and increases pressure. Another example is air in car tyres, where more molecules increase collisions and make the tyre harder. These examples show the effect of molecular motion in daily life.

Statistical Physics and Stellar Evolution

20. What does Boltzmann distribution law tell us about particle populations in different energy states? 12113063

Ans. The Boltzmann distribution law states that particles are not equally distributed among all energy states. More particles stay in lower energy states than in higher ones. The probability of finding particles in a state decreases exponentially as energy increases.

21. How does hydrostatic equilibrium keep a star stable? 12113064

Ans. A star stays stable when the inward gravitational force is balanced by the outward internal pressure. This balance is called hydrostatic equilibrium. It prevents the star from collapsing inward or expanding without limit.

22. What happens when a star's gravitational force becomes greater than its internal pressure? 12113065

Ans. The star contracts inward because gravity is stronger than the outward pressure. As it contracts, the core density and temperature rise. Depending on the mass of the star, it may later form a neutron star or a black hole.

23. Why are neutron stars very difficult to study directly? 12113066

Ans. Neutron stars are extremely dense and have very strong gravitational fields. Their matter behaves like a degenerate gas, which makes them difficult to model. Many are also very far away, so scientists usually study them through indirect observations such as pulsars.

24. How was the Sun formed and what is its present stage? 12113067

Ans. The Sun formed about 4.6 billion years ago from a huge cloud of gas and dust called a solar nebula. Gravitational contraction raised the core temperature until nuclear fusion began. The Sun is now in the main sequence stage.

CONSTRUCTED RESPONSE QUESTIONS

1. What will be the kinetic energy near absolute zero? Explain. 12113068

Ans. Near absolute zero, the kinetic energy of gas molecules approaches zero.

Reason: According to the kinetic theory of gases, the average translational kinetic energy of gas molecules is given by:

$$<K.E.> = (3/2)\, K_B\, T$$

As the temperature T approaches absolute zero (0 K), the product K_BT approaches zero, and therefore the average kinetic energy also approaches zero. This means the molecules have virtually no translational motion. Since temperature is a direct measure of the average translational kinetic energy of molecules.

2. What is the average kinetic energy of the oxygen and nitrogen molecules in a room at room temperature? 12113069

Ans. The average translational kinetic energy of any gas molecule at temperature T is:

$$<K.E.> = (3/2)\, k_B\, T$$

At room temperature, T = 300 K and $K_B = 1.38 \times 10^{-23}$ J K^{-1}:

$$<K.E.> = (3/2) \times (1.38 \times 10^{-23}) \times 300$$

$$<K.E.> = (3/2) \times 4.14 \times 10^{-21}$$

$$<K.E.> \approx 6.21 \times 10^{-21} \text{ J}$$

Since this formula depends only on temperature and not on the type of molecule, both oxygen (O_2) and nitrogen (N_2) molecules have the same average kinetic energy of 6.21×10^{-21} J at room temperature.

3. Consider a gas enclosed in a sealed container. By what factor does the gas temperature change if: (a) the volume and pressure are both doubled? (b) the volume is halved and the pressure is tripled? 12113070

Ans. Using the ideal gas law: PV = nRT, so T = PV / nR

(a) Volume and pressure are both doubled (P → 2P, V → 2V):

$$T' = (2P)(2V) / nR = 4PV / nR = 4T$$

The temperature increases by a factor of 4.

(b) Volume is halved and pressure is tripled (P → 3P, V → V/2):

$$T' = (3P)(V/2) / nR = (3/2)(PV/nR) = (3/2)T$$

The temperature increases by a factor of 3/2 (i.e., 1.5 times the original temperature).

4. Is it possible to boil water at room temperature without heating? Explain. 12113071

Ans. Yes, it is possible to boil water at room temperature without heating.

Reason: Boiling occurs when the vapor pressure of the liquid equals the surrounding (external) pressure. Normally, water boils at 100°C at standard atmospheric pressure. However, if the external pressure above the water is reduced significantly the boiling point of water decreases. When the external pressure is lowered to match the vapor pressure of water at room temperature, the water will begin to boil without any heating.

5. Explain how the drop of ink in a beaker containing water will behave. 12113072

Ans. The drop of ink spreads slowly through the water and finally mixes uniformly.

Explanation:

When a drop of ink is placed in a beaker of water, the ink molecules gradually and randomly spread throughout the water. This behavior is due to **Brownian motion**. Water molecules are

in constant random motion so the water molecules bombard the ink molecules from all directions with varying forces. As a result, the ink molecules follow a zig-zag (random) path, gradually diffusing through the entire volume of water. Over time, the ink distributes itself uniformly throughout the liquid.

COMPREHENSIVE QUESTIONS

Q.1 Derive the expression of pressure exerted by the gas on the walls of the container. 12113073

Ans. See Q No. 4 of theory

Q.2 Write the expression for rms speed, and most probable speed of a gas molecule. 12113074

Ans. See Q No. 4 of theory

Q.3 Explain the Boltzmann distributions law on the basis of statistical physics. 12113075

Ans. See Q No. 4 of theory

Q.4 Describe the pressure role on the neutron star. 12113076

Ans. See Q No. 7 of theory

Q.5 Show that temperature of a gas is a direct measure of the average translational K.E. of its molecules. 12113077

Ans. See Q No. 5 of theory

Q.6 Explain stellar evolution in terms of the balance between gravitational pressure and internal pressure, and how stellar mass determines whether a star ends as white dwarf, neutron star or black hole. 12113078

Ans. See Q No. 7 of theory

NUMERICAL PROBLEMS

Problem 13.1 **Calculate the rms velocity of hydrogen molecules at standard temperature and pressure (STP). Density of hydrogen at STP;** $\rho = 8.957 \times 10^{-2}\, kgm^{-3}$ **Density of mercury** $= 13600 kg\, m^{-3}, g = 9.8 m s^{-2}$ 12113079

Solution:

Density of hydrogen at STP:

$$\rho_{H2} = 8.957 \times 10^{-2} \text{ kg m}^{-3}$$

Density of mercury: $\rho_{Hg} = 13600 \text{ kg m}^{-3}$

Acceleration due to gravity: $g = 9.8 \text{ m s}^{-2}$

Height of mercury column at STP: h = 0.76m

Root-mean-square velocity: $v_{rms} = ?$

Formulae:

$$P = \rho_{Hg} \times g \times h$$

$$P = \frac{1}{3}\rho_{H_2} < v^2 >$$

$$< v^2 > = \frac{3P}{\rho_{H_2}}$$

$$v_{rms} = \sqrt{\frac{3P}{\rho_{H_2}}}$$

Step-by-Step Calculation:

Step 1: Calculate atmospheric pressure at STP

$$P = \rho_{Hg} \times g \times h$$

$$P = 13600 \times 9.8 \times 0.76$$

$$= 1.013 \times 10^5\, Pa$$

Step 2: Calculate mean-square speed

$$< v^2 > = \frac{3P}{\rho_{H_2}} = \frac{3 \times 1.013 \times 10^5}{8.957 \times 10^{-2}}$$

$$< v^2 > = 3.392 \times 10^6\, m^2\, s^{-2}$$

Step 3: Take the square root

$$v_{rms} = \sqrt{3.392 \times 10^6}$$

$$v_{rms} = 1842\, m\, s^{-1}$$

$$\approx 1.84 \times 10^3\, m\, s^{-1}$$

$v_{rms} = 1.84 \times 10^3 \text{ m s}^{-1}$

Problem 13.2 **Determine the pressure of oxygen gas at 0°C if the density of oxygen is 1.44 kg m^{-3} at STP and rms speed at STP is 456.4 ms^{-2}.** 12113080

Solution:

Density of oxygen at STP:

$$\rho_{O2} = 1.44 \text{ kg m}^{-3}$$

rms speed of oxygen at STP:

$$v_{rms} = 456.4 \text{ m s}^{-1}$$

Temperature: T = 0°C = 273 K

Pressure of oxygen at STP: P = ?

Formula:

$$P = \frac{1}{3}\rho v_{\text{rms}}^2$$

Substituting values:

$$P = \frac{1}{3} \times 1.44 \times (456.4)^2$$

$$P = \frac{1}{3} \times 1.44 \times 208{,}380.96$$

$$P = \frac{300{,}068.58}{3} = 100{,}022.86\ N\ m^{-2}$$

$$P \approx 1.0 \times 10^5\ N\ m^{-2}$$

$P = 1.0 \times 10^5$ N m^{-2}

Problem 13.3 **At what temperature will the rms speed of the molecules of gas be three times its value at STP?** 12113081

Solution:

Temperature at STP: $T_1 = 0°C = 273$ K

Ratio of rms speeds: $v_{rms2} / v_{rms1} = 3$

Temperature T_2 at which rms speed triples= ?

Formula:

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

$$\frac{v_{\text{rms2}}}{v_{\text{rms1}}} = \sqrt{\frac{T_2}{T_1}} \qquad \text{As } v_{\text{rms}} \propto \sqrt{T}$$

$$\frac{T_2}{T_1} = \left(\frac{v_{\text{rms2}}}{v_{\text{rms1}}}\right)^2$$

Substituting values:

$$\frac{T_2}{273} = 9$$

$$T_2 = 9 \times 273 = 2457\ K$$

$$T_2 = 2457 - 273 = 2184\ °C$$

$T_2 = 2184$ °C

Problem 13.4 **If a gas is at temperature 80°C and pressure 5×10^{-10} Nm^{-2}, having 1 m^3 volume, what is the number of molecules per cubic metre, where Boltzmann's constant is 1.38×10^{-23} JK^{-1}.** 12113082

Solution:

Temperature: T = 80°C = 80+273=353 K

Pressure: P = 5 × 10^{-10} N m^{-2}

Volume: V = 1 m^3

Boltzmann's constant: $k_B = 1.38 \times 10^{-23}$ J K^{-1}

Number of molecules per cubic metre: N = ?

Formula:

$$PV = Nk_BT$$

$$N = \frac{PV}{k_BT}$$

Substituting values:

$$N = \frac{5 \times 10^{-10} \times 1}{1.38 \times 10^{-23} \times 353}$$

$$N = \frac{5 \times 10^{-10}}{4.871 \times 10^{-21}}$$

$$= 1.026 \times 10^{11}\ molecules$$

$N = 1.02 \times 10^{11}$ *molecules*

Problem 13.5 **The temperature and pressure in the Sun's atmosphere are 2.00×10^6 K and 0.0300 Pa respectively. Calculate the rms speed of free electrons (mass of the electron $= 9.11\times10^{-31}$ kg).** 12113083

Solution:

Temperature of Sun's atmosphere:

T = 2.00 × 10^6 K

Pressure in Sun's atmosphere: P = 0.0300 Pa

Mass of electron: m = 9.11 × 10^{-31} kg

Boltzmann's constant: $k_B = 1.38 \times 10^{-23}$ J K^{-1}

rms speed of free electrons: v rms = ?

Formula:

$$v_{\text{rms}} = \sqrt{\frac{3\ k_BT}{m}}$$

Substituting values:

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$$v_{rms} = \sqrt{\frac{3 \times 1.38 \times 10^{-23} \times 2.00 \times 10^{6}}{9.11 \times 10^{-31}}}$$

$$v_{rms} = \sqrt{\frac{8.28 \times 10^{-17}}{9.11 \times 10^{-31}}}$$

$v_{rms} \approx 9.53 \times 10^{6}\ m\ s^{-1}$

$v_{rms} = 9.5 \times 10^{6}$ m s^{-1}

Problem 13.6 **A star has a mass enclosed within radius *r* equal to 2.0×10^{30} kg, density 1500 kg m^{-3} and radius 7.0×10^{8} m. Calculate the gravitational force inside the star.** **12113084**

Solution:

Mass enclosed within radius r:

$M_r = 2.0 \times 10^{30}$ kg

Density of star: $\rho = 1500$ kg m^{-3}

Radius of star: $r = 7.0 \times 10^{8}$ m

Gravitational constant: $G = 6.67\times10^{-11}$ Nm^{2}kg^{-2}

Gravitational force on a test mass m at the surface: F = ?

Solution:

Formulae:

$$M_r = \frac{4}{3}\pi r^3 \rho$$

$$F = \frac{GM_r m}{r^2}$$

$$\frac{F}{m} = \frac{GM_r}{r^2}$$

Step-by-Step Calculation:

Step 1: Calculate M_r from density and radius

$$M_r = \frac{4}{3} \times 3.14159 \times (7.0 \times 10^{8})^3 \times 1500$$

$$r^3 = (7.0)^3 \times 10^{24} = 343 \times 10^{24} = 3.43 \times 10^{26}\ m^3$$

$$M_r = 4.189 \times 3.43 \times 10^{26} \times 1500 = 2.155 \times 10^{30}\ kg$$

Step 2: Calculate gravitational acceleration at the surface

$$\frac{F}{m} = \frac{GM_r}{r^2} = \frac{6.67 \times 10^{-11} \times 2.155 \times 10^{30}}{(7.0 \times 10^{8})^2}$$

$$\frac{F}{m} = \frac{14.374 \times 10^{19}}{49 \times 10^{16}} = 293.3\ N\ kg^{-1}$$

Step 3: Gravitational force on test mass m

$$F = 293.3 \times m \approx 2.94 \times 10^{2} \times m\ N$$

$F = 2.94 \times 10^2$ N (on unit test mass m)

IMPORTANT BOARD QUESTIONS

(i) Drive an expression for pressure exerted by gas on the walls of the container.

(ii) Show that pressure of a gas is directly proportional to the average translational K. E of its molecules.

(iii) State kinetic theory of gases. Describe basic postulates of kinetic theory of gases.

MPORTANT SHORT QUESTIONS OF BOARD EXAMINATIONS

(i) State any three assumptions of the kinetic theory of gases.

(ii) Write the relation between pressure and mean square speed of a gas.

(iii) What is root mean square speed and why is it used?

(iv) Why do all gases have the same average translational kinetic energy at the same temperature?

(v) State the relation between average translational kinetic energy and temperature.

(vi) How does hydrostatic equilibrium keep a star stable?

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