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PHYSICS - Optional

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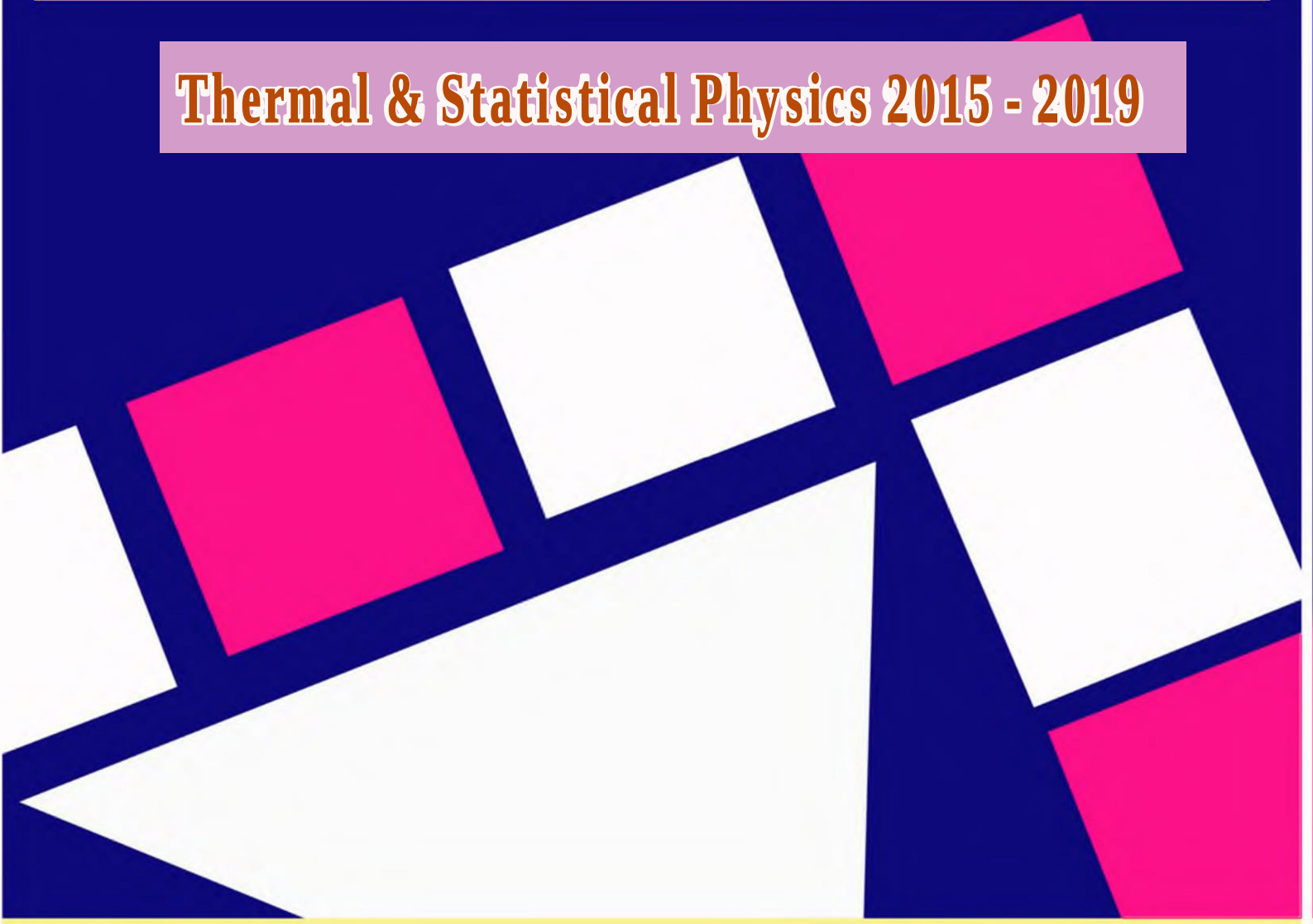
Thermal & Statistical Physics 2015 - 2019



UPSC – PHYSICS Optional – 2015 Questions

1. Using the concept of Einstein's A and B coefficients for a two-level atomic system under thermal equilibrium, determine the ratio of the number of atoms per unit volume in the two levels experiencing spontaneous and stimulated emission. How does the principle of population inversion lead to the gain mechanism in the active medium of the laser? **[20M]**

2. Two spheres A and B having same temperature T are kept in the surroundings of temperature T_0. Consider $T > T_0$. The spheres are made of same material but have different radii r_A and r_B. Using Stefan – Boltzmann distribution, determine which of these will lose heat by radiation faster. **[10M]**

3. A Van der Waals gas undergoes Joule-Kelvin expansion with a pressure drop of 50 atm. If its initial temperature is 300°K, determine its final temperature. (Given Van der Waals constant $a = 0.136\ \text{Pa m}^6\ \text{mol}^{-1}$, $b = 36.5 \times 10^{-6}\text{m}^3\text{mol}^{-1}, C_p = 30\ \text{J}\ K^{-1}\text{mol}^{-1}, R = 8.3J\ K^{-1}\text{mol}^{-1}$) **[10M]**

4. The vapour pressure of an organic substance is 50×10^3 Pa at 40°C. Its normal boiling point is 80°C. If the substance in vapour phase can be treated like an ideal gas, find the latent heat of vaporization of the substance. **[15M]**

5. For a Van der Waals gas, write down the equation of state. Determine the coefficient of critical expansion β. **[15M]**

UPSC – PHYSICS Optional – 2016 Questions

1. m gram of water at temperature T_1 is isobarically and adiabatically mixed with an equal mass of water at temperature T_2. Show that the change in entropy is given by $\Delta S = 2mC_p$ in $\left(\frac{T_{av}}{T_{geo}}\right)$, where $T_{av} = \frac{T_1+T_2}{2}$ and $T_{geo} = \sqrt{T_1 T_2}$ **[10M]**

2. The molecules of a gas obey Maxwell-Boltzmann distribution. Calculate the fraction of molecules of the gas within 1% of the most probable speed at STP. Interpret your result. **[10M]**

3. Write down van der Waals equation of state for n moles of a gas and calculate the temperature at which 5 moles of the gas at 5 atm pressure will occupy a volume of 20 litres. Given, $R = 8.31 \times 10^7 erg\ mol^{-1}K^{-1}$, $a = 1.34 \times 10^{12} dyne\ \ cm^4\ mol^{-2}, b = 31.2 cm^3 mol^{-1}$ and $1\ atm = 1.013 \times 10^6\ dyne\ cm^{-2}$ **[10M]**

4. A student is working in a physics laboratory, which is at temperature $27°C$, on a sonometer to study formation of stationary waves. The cross-sectional area of the sonometer wire is $0.85 \times 10^{-6} m^2$ and a tension of 20 N is applied on it. If the rigid supports are 1.2 m apart and the temperature of the wire drops by $7°C$, calculate the (i) final tension and (ii) fundamental frequency of vibration of the wire. Take, coefficient of linear expansion and isothermal Young's modulus as $1.5 \times 10^{-5} K^{-1}$ and $2.0 \times 10^{11}\ Nm^{-2}$ respectively. **[10M]**

5. What do you understand by the term phase transition? Using Clausius-Clapeyron equation, show that for first-order phase transitions, vapour pressure decreases exponentially with temperature. You can assume that the vapour behaves like an ideal gas and latent heat remains constant with temperature. **[15M]**

6. Consider a system of N particles and a phase space consisting of only two states with energies $0\ and\ \varepsilon(>0)$. Obtain the expressions for the partition function and the internal energy of the system, if it obeys M-B statistics. **[10M]**

7. (i) The viscosity in a liquid arises due to friction between adjacent layers. What causes viscosity in a gas? Explain.

(ii) The molecules of a gas obeying Maxwell-Boltzmann distribution move with an average speed of $450\ \mathrm{ms}^{-1}$. If the coefficient of viscosity of the gas η is $16.6 \times 10^{-6} Nsm^{-2}$, density of the gas ρ is $1.25\ \mathrm{kg}\, m^{-3}$ and number density is $2.7 \times 10^{25} m^{-3}$, calculate the mean free path and diameter of the gas molecules. **[10M]**

UPSC – PHYSICS Optional – 2017 Questions

1. 1 litre of hydrogen at $127°C$ and $10^6\, dynes/cm^2$ pressure expands isothermally until its volume is doubled and then expands adiabatically until its volume is redoubled. Calculate the resulting pressure. ($\gamma = 1.42$) **[10M]**

2. Using the Maxwell-Boltzmann distribution law, show that there cannot be any negative absolute temperature. **[10M]**

3. Write down the physical significance of Maxwell's equations and explain the concept of displacement current by using a proper example. **[10M]**

4. Derive Clausius-Clapeyron equation. How does it explain the effect of pressure on melting point of solids and boiling point of liquids? **[10M]**

5. Write and explain the Maxwell-Boltzmann distribution. Using this distribution, find the expressions for the most probable speed, mean speed and root-mean-square speed. **[15M]**

6. Calculate the critical temperature for helium, given the values for critical constants, $a = 6.15 \times 10^{-5}, b = 9.95 \times 10^{-4}$, where the unit of pressure is atm and the sample is kept at NTP. **[10M]**

7. A reversible engine converts $1/6$ of the heat input into work. When the temperature of the sink is reduced by $62°\mathrm{C}$, its efficiency is doubled. Find the temperatures of source and sink. **[10M]**

8. Explain Bose-Einstein distribution and obtain the same form the grand canonical ensemble. **[15M]**

UPSC – PHYSICS Optional – 2018 Questions

1. One mole of a gas obeys the following equation of state:

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

where v is the molar volume and, a and b are constants. Show that internal energy of the gas increases as the volume increases, with the temperature remaining constant. **[10M]**

2. At 4°C temperature, the density of water is found to be maximum. Prove that heat capacity at the constant pressure (c_p) is equal to the heat capacity at constant volume (c_v) for water at $4°C$. **[10M]**

3. If the temperature variation of heat capacity is known, how do you calculate the change of entropy during an isochoric process? According to Debye's theory of specific heat of a solid, the molar heat capacity of diamond crystal at constant volume varies with temperature (T) as follows:

$$c_v = \frac{12}{5}\pi^4 R\left(\frac{T}{\theta}\right)^3$$

where R is the molar gas constant $= 8.315\ \text{J/mol-K}$ and $\theta = 2230$ K for diamond. Calculate the change in entropy of diamond of 0.36 g mass when it is heated at constant volume form 0 K to 300 K **[20M]**

4. The pressure on 100 g of solid copper is increased quasi-statically and isothermally at 0°C from 0 to 0.5×10^8 Pa. Assuming the density and isothermal compressibility to remain at constant values of $8.96\ \text{g/cm}^3$ and $7.16 \times 10^{-12}\text{Pa}^{-1}$, respectively. Calculate work done. Comment on the sign and magnitude of work. **[15M]**

5. A system having two energy levels, $-\frac{1}{2}\Delta$ and $+\frac{1}{2}\Delta$ with $\Delta = 10$ meV is populated by 1000 particles at a low temperature close to 100 K. Obtain the average energy per particle using classical distribution law. **[15M]**

6. Schematically, show the variation of density of states, $D(\varepsilon)$ and distribution function, $f(\varepsilon, T)$, of particles in a non-relativistic Fermi gas at high temperatures. At a temperature T, an electron occupies a state with energy 100 meV above the Fermi energy (ε_F) with the probability of 1%. Find the temperature T. **[15M]**

UPSC – PHYSICS Optional – 2019 Questions

1. What are the conditions for the change in temperature of a van der Waals gas passing through a porous plug? Prove that the ideal gas passing through the porous plug does not show any change in temperature. **[10M]**

2. A gas has only two particles, a and b. With the help of a diagram, show that how these two particles can be arranged in the three quantum series $1, 2, 3$ using (i) Maxwell-Boltzmann, (ii) Fermi-Dirac, and (iii) Bose-Einstein statistics. **[10M]**

3. What is Gibbs' phase rule? Find the values of degrees of freedom when
(i) only the liquid CO_2 is in equilibrium with the gaseous CO_2.
(ii) water is in the vapour-liquid saturation region.
(iii) water is in a single-phase region.
(iv) water is at the triple point. **[15M]**

4. Obtain the expressions for the cases:
(i) when $T \gg \theta_E$
(ii) when $T \ll \theta_E$
What is the discrepancy of Einstein model to explain the variation of specific heat capacities of solids with the temperature?
The molar specific heat capacity of a solid at constant volume is $2.77\ JK^{-1}$ at 36.8 K. Determine the Debye temperature of the solid. **[20M]**

5. What is carnot's theorem? Prove that Carnot's reversible engine is the most efficient one and no other engine can be more efficient than Carnot's engine. **[15M]**

6. If the partition function for a perfect gas is given by $Z = \frac{V}{h^3}(2\pi\, mkT)^{3/2}$ calculate (i) average kinetic energy per molecule and (ii) specific heat of the gas. **[15M]**

7. Briefly outline the theory of scattering of electromagnetic radiation by a bound electron and hence derive the conditions for Rayleigh scattering. How can you explain the blue of the sky? **[20M]**

8. Explain the effect of pressure on the melting and boiling points of substance using Clapeyron's latent heat equation. Calculate under what pressure, water will boil at $120°C$, if the change in specific volume when 1 gram of water is converted into steam is $1676\ cm^3$. Latent heat of steam $= 540\ cal/g$, 1 atmospheric pressure $= 10^6\ dynes/cm^2$. **[15M]**