2023

PHYSICS — HONOURS

Paper : DSE-B-2.1

(Communication Electronics)

Full Marks : 65

The figures in the margin indicate full marks.

Candidates are required to give their answers in their own words as far as practicable.

Group - A

1. Answer ***any five*** questions : 2×5

(a) The maximum peak to-peak voltage of an AM wave is 16 mV and minimum peak-to-peak voltage is 4 mV. Calculate the modulation index.

(b) Find the Nyquist rate and Nyquist interval for the continuous time signal given below :

$x(t) = \cos(4000\,\pi t)\ \cos(1000\,\pi t)$.

(c) Why companding is needed in PCM system?

(d) What are the advantages of geostationary satellites?

(e) What is multiplexing? Name the types of multiplexing.

(f) How many digits are there in IMEI number? Is it a unique number?

(g) A FM wave is represented by the voltage equation $v(t) = 12\cos[(6\times10^8 t) + 5\sin(1250t)]$.

Determine the (i) Carrier frequency (ω_c), (ii) Modulation index (m_f).

Group - B

2. Answer ***any three*** questions :

(a) (i) How does a phase Discriminator differs from a Ratio Detector in FM demodulation?

(ii) What is the importance of intermediate frequency (IF) in radio receiver? How is it acheived? 2+(2+1)

(b) (i) What do you understand by ASK transmission? How a balanced modulator can be used for ASK generation?

(ii) In a 8-PSK system, how many bits can be transmitted at a time? How does this number differs, if it is a Q-PSK system? Give reason. (1+1)+(1+1+1)

(c) (i) What are the concepts of cell splitting and cell sectoring in mobile communication?

(ii) What is CDMA? What is its advantage? 3+2

(d) Write down the differences between AM and FM. 3+2

(e) (i) Obtain an expression of FM wave.

(ii) A broadcast radio transmitter radiates 10 kW, when the depth of modulation is 60%. How much of this carrier power? 3+2

Group - C

Answer ***any four*** questions.

3. (a) For a carrier $v_c = V_c \cos \omega_c t$ and signal of $v_m = V_m \cos \omega_m t$, show that the frequency modulated signal is represented by the expression, $(v_c)_{FM} = V_c \cos (\omega_c t + m_f \sin \omega_m t)$, where, $m_f = \frac{\Delta f_{max}}{f_m}$ is the modulation index.

(b) Which parameters of a FET / transistor is varied in order to generate FM signal using Reactance Modulator?

(c) Explain with a neat circuit diagram, the principle of operation of a Balanced Slope Detector for FM demodulation. What are its advantages over a Single Slope Detector? 3+2+(4+1)

4. (a) State and explain sampling theorem in pulse communication. For an information / message signal represented by a sine wave, draw the PAM, PWM and PPM waveforms.

(b) With a neat block diagram, show how you can generate PWM (or PDM) signal using comparator. How can you get PPM signal from here?

(c) Explain why the transmission power is very low for PPM transmission. (2+3)+(2+1)+2

5. (a) Distinguish between uniform and non-uniform quantizer in digital communication system. With a neat diagram find out the quantization error in a uniform quantizer.

(b) Write down the expression of A-law of companding. Draw its characteristics for different 'A' values.

(c) What is 'Delta modulation'? What are its advantages over standard PCM? Draw the closed-loop block diagram of a Delta Transmitter. (2+2)+(1+1)+(1+1+2)

6. (a) What is demodulation? Draw the circuit diagram of a diode detector for detection of an AM wave.

(b) A diode detector is used to detect an AM wave. If the maximum modulation factor is m, find the highest modulating frequency which can be detected without excessive distortion.

(c) The value of capacitance of a varactor at the centre of its linear range is 40 pF. This varactor will be in parallel with a fixed 20 pF capacitor. What value of inductance should be used to resonate this combination to 5.5 MHz in an oscillator? (1+2)+4+3

7. (a) Explain the concept of uplink and downlink in satellite communication with a simple block diagram. What are the major components of a earth station?

(b) Give the differences between the network 1G, 2G and 3G mobile communication.

(c) Write down the names of the three main components of GPS Navigation system. (3+2)+2+3

8. (a) Describe FDM and TDM.

(b) What is aliasing? What can be done to reduce aliasing?

(c) Find the Nyquist rate of the following :

$$\frac{\sin(4000\pi t)}{\pi t}.$$

(2½+2½)+(2+2)+1

Paper : DSE-B-2.2

(Advanced Statistical Mechanics)

Full Marks : 65

The figures in the margin indicate full marks.

Candidates are required to give their answers in their own words as far as practicable.

Group - A

1. Answer ***any five*** questions : 2×5

(a) State the two postulates of quantum statistical mechanics.

(b) The mean occupation number of a single particle state for the Fermions and Bosons can be expressed as $n(\epsilon)=\frac{1}{e^{(\epsilon-\mu)/k_BT}\pm 1}$.

Plot the functional behaviour of $n(\epsilon)$ with $(\epsilon-\mu)/k_BT$ for both the cases.

(c) Consider the following density matrix :

$$\rho=\begin{pmatrix}1/2 & 0\\ 0 & 1/2\end{pmatrix}.$$

Does it represent a 'pure state' or a 'mixed state'? Justify your answer.

(d) Define Chandrasekhar limit.

(e) The Hamiltonian of a system is given as $H=Ap_x^{\ 2}+Cx^2+Kx$, where A, C and K are constants. Determine $\langle H\rangle$.

(f) Show that the entropy is given as $S=\Sigma_i P_i \, ln \, P_i$ [When P_i is the probability that any arbitrary system from the ensemble has an energy E_i].

(g) Write the partition function of a two Boson system having single particle energy levels ϵ, 2ϵ and 3ϵ.

Group - B

2. Answer ***any three*** questions :

(a) State Liouville's theorem for the phase space characterized by a probability density $\rho(q, p, t)$. Hence establish the condition required for a system to be in statistical equilibrium. 3+2

(b) Show that the mean number of Bosons in the ground state is (using grand canonical partition function)

$$n(\epsilon_0)=\frac{1}{e^{(\epsilon_0-\mu)/k_BT}-1}.$$

Hence, show that for all finite values of T, the chemical potential μ for the Bosons is always less than the ground state energy ϵ_0. 5

(c) The Hamiltonian for a single particle in an extreme relativistic ideal gas is $H = c\sqrt{p_x^2 + p_y^2 + p_z^2}$. Apply the generalized equipartition theorem to find $\langle H \rangle$. 5

(d) (i) Write the expression of grand canonical partition function of classical ideal gas explaining all the symbols.

(ii) Hence, determine the chemical potential μ for a classical ideal gas. 2+3

(e) Show that for a two-dimensional free electron gas, number of electron per unit area is

$$n = \frac{4\pi mkT}{h^2} \ln\left(e^{E_F/kT} + 1\right)$$ 5

Group - C

Answer ***any four*** questions.

3. (a) Consider a system composed on N non-interacting, distinguishable two-level atoms with energy $+\epsilon$ when they are up and $-\epsilon$ when they are down. Calculate the entropy of this system as a function of energy E. Hence, discuss under what condition can the absolute temperature be negative.

(b) A random walker in one-dimension takes steps to the left or right with equal probability. Calculate the probability that the walker starting from the origin is back to the origin after taking even number of steps N. What will be the probability if N is odd? (4+1)+(4+1)

4. (a) Given that the canonical partition function for classical ideal gas has an expression $Z(N,V,T) = \frac{1}{N!}\frac{V^N}{\lambda^{3N}}$, obtain the partition function for classical ideal gas in grand canonical ensemble. Hence, calculate the mean particle number $\langle N \rangle$ and the chemical potential of the system. Here $\lambda = h/\sqrt{2\pi mk_BT}$ is the mean thermal wavelength of the system.

(b) Show that the fluctuations in the number density (n) in grand canonical ensemble can be expressed as $\langle n^2 \rangle - \langle n \rangle^2 = \frac{k_BT}{V^2}\frac{\partial}{\partial\mu}\langle n \rangle$. Also find the relative root mean square fluctuation in n.

(3+2)+(4+1)

5. (a) Deduce an expression for Bose-Einstein distribution function from the grand partition function of an ideal Bose gas.

(b) What do you mean by Bose-Einstein condensation?

(c) Find the equation of state of an ideal Bose gas in the condensed phase. 3+2+5

6. (a) The Hamiltonian for the Ising model with N spins is

$$H = -J\sum_{\langle ij \rangle} s_i s_j \,,$$

where $s_i = \pm 1$, $J > 0$ and $\Sigma_{\langle ij \rangle}$ is a sum over nearest neighbours.

Show that, within Bragg Williams approximation, the mean magnetization per spin can be expressed as $\bar{m} = \tanh\left(J\gamma\bar{m}/k_B T\right)$, where γ is the number of nearest neighbours. Study the solution graphically for $\bar{m}$ to show that there exists a critical temperature T_C below which the system can have a non-zero spontaneous magnetization and above cannot.

(b) As a simplified model of a binary alloy, consider a square lattice of atoms which can be either of type 1 or type 2. Set spin values $s_1 = +1$ and $s_2 = -1$ and let there be N_1 number of type 1 atoms and N_2 number of type 2 atoms, such that $N_1 + N_2 = N$. Let the interaction energies between two neighbouring atoms be ε_{11}, ε_{22} and ε_{12}, and there be N_{11}, N_{22} and N_{12} bonds of each type. The energy of the binary alloy is thus $E = \varepsilon_{11}N_{11} + \varepsilon_{22}N_{22} + \varepsilon_{12}N_{12}$.

Show that the above expression for E can be written in the following form :

$$E = -J\sum_{\langle ij \rangle} s_i s_j - h\sum_i s_i - cN$$

Find the expression for J, h, and c. 6+4

7. (a) Derive an expression for Fermi energy in terms of particle density.

(b) Show that the degeneracy pressure of a strongly degenerate Fermi gas varies with the number density as $P_0 \sim n^{5/3}$. 5+5

8. (a) For an isolated solid of N molecules, where the molecules are on a fixed 3-dimensional lattice and they vibrate like classical linear harmonic oscillators with a common frequency ν. Determine the entropy S, the internal energy U and the Helmholtz free energy F in terms of N, ν and temperature T. Could the system be treated as entirely a classical system? Justify your answer.

(b) For an isolated ideal gas derive the Sackur Tetrode equation. Is Boltzmann's counting truly justified in this case? (2+2+1+1)+4