2022

PHYSICS

Paper : PHY 522

(Laser Physics)

Full Marks : 50

The figures in the margin indicate full marks.
Candidates are required to give their answers in their own words as far as practicable.

Answer ***any five*** questions.

(a) Explain the first and second-order correlation function. Draw a schematic experimental setup to measure the second-order correlation function. Distinguish between three types of light with the help of the second-order correlation function.

(b) Evaluate the second-order correlation function $g^2(0)$ for a monochromatic light wave with a sinusoidal intensity modulation such that $I(t) = I_0(1 + A \sin \omega t)$ with $|A| \leq 1$.

(c) Write down and explain the total atom-field Hamiltonian for a quantized field interacting with a two-level atom.

(2+1+2)+2+3

(a) Show that the length of the vector that represents the coherent state in a phasor diagram is equal to $\sqrt{\bar{n}}$, where $\bar{n}$ is the mean photon number.

(b) Draw the phasor diagram of a coherent state ($|\alpha\rangle$) and vacuum state ($|0\rangle$) and explain their similarity and dissimilarity.

(c) Show that the superposition state, $|\psi\rangle = \sqrt{3}/2|0\rangle+½|1\rangle$ has squeezing in the X-quadrature but not in the P-quadrature.

(d) Explain the emission and absorption process with the help of quantized interaction Hamiltonian.

3+2+3+2

(a) For a Λ-type three-level atomic system interacting with two resonant e.m. fields, derive the expression of dark-state. Explain the phenomena of coherent population trapping (CPT) with the help of dark state. Distinguish between CPT and Electromagnetically Induced Transparency (EIT).

(b) Show that the photon distribution of the thermal light at a frequency ω can be written as

$$P_{\omega}(n) = \frac{1}{(1+\bar{n})}\left(\frac{\bar{n}}{1+\bar{n}}\right)^n$$

Plot the above function along with Poisson distribution for $\bar{n} = 20$.

(c) Write down the density matrix equation of motion for a stationary two-level atom interacting with a standing wave field considering the decay and incoherent pumping process.

(3+1+1)+(2+1)+2

4. (a) Write down the expression for the scattering force on a two-level atom moving with velocity v and interacting with a counter propagating red detuned laser field. Discuss the effect of the force on the atomic motion if the laser field is blue detuned and counter propagating. What will be the value of the scattering force on the atom in a standing wave laser field? Explain.

(b) How does the lower limit of temperature arise in case of Doppler cooling of atoms? Obtain an expression for the minimum temperature that can be obtained in Doppler cooling. (1+2+1)+(2+4)

5. (a) Calculate the Bose-Einstein condensation temperature (critical temperature) for a free gas of ^{87}Rb atoms with a density of $3\times10^{19}\ m^{-3}$. Derive the necessary formula.

(b) Define the Rabi flopping frequency (Ω_R) for a two-level atom when interacting with a coherent radiation field. Explain the formation of Mollow Triplet in a coherently driven two-level atomic system.

(2+4)+(2+2)

6. (a) Explain the dipole force acting on a two-level atom by an electromagnetic field. Given the dipole force on the atoms in a standing wave laser field :

$$F = -\frac{\hbar\delta}{4}\left(\frac{\nabla\Omega^2}{\delta^2 + (\Gamma/2)^2 + \Omega^2/2}\right)$$ 1

Find out an expression for the optical potential (U_{opt}).

(b) Calculate the ac Stark shift (light shift) in the ground state magnetic sublevels $\left|g_{\pm\frac{1}{2}}\right|$ of the $J_g = ½$ state, and explain its role in the sub-Doppler cooling (Sisyphus Cooling) of atoms. 2

(2+2)+(4+2)

7. Given the expression for the non-linear polarization of the second harmonic field,

$$P_{NL}^{(2)} = (\varepsilon_0 d/2)\left[E_1^2 e^{2i(k_1 z - \omega t)} + c.c.\right]$$

where, E_1 is the electric field and k_1 is the wave vector for the fundamental (ω) frequency.

(a) Derive the differential equation for the second harmonic field (2ω) using non-linear Maxwell's equations.

(b) Using this differential equation, derive the evolution of the amplitude of the second harmonic field E_2 in space (z) for strong pump where E_1 is constant. 3

(c) Calculate the second harmonic power $P(z)$ using the expressions for intensities for E_1 and E_2.

(d) Find the expression for conversion efficiency η from $\omega \to 2\omega$ and discuss its features at $\Delta k = 0$ and $\Delta k \neq 0$ by plotting $\eta(z)$ vs. z.

3+2+2+(1+1+1)

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