# M. Sc. (Physics) 4th Semester Examination 2019 <br> PHY 522 (Adv II: Laser Physics) 



Answer in your own words as far as practicable. The marks on the right-hand margin indicate the full marks for the question.

Full Marks: 50
Time: 2 Hours
Answer Question no. 1 and any three from the rest

1. Answer any five questions:-
$5 \times 4$
a. Explain with examples the homogeneous and inhomogeneous broadening phenomena in laser spectroscopy. Write down the expression for the homogeneously and inhomogeneously broadened line shape functions, explaining all the terms in the expression. $2+2$
b. Show that total Hamiltonian of a two level atom interacting with an electromagnetic field can be written in terms of the Pauli spin operators as
$H=\frac{\hbar \omega}{2} \sigma_{z}-\frac{\mu E_{0}}{2}\left(\sigma_{+} e^{i v t}+\sigma_{-} e^{-i v t}\right)$, here symbols have their usual meaning.
Explain the Rabi oscillation in a two level atomic system. Write the expression of quantized generalized Rabi-frequency.
c. Explain briefly the origin of spontaneous emission. What do you understand by dressed states of an atom? Draw the dressed atom energy level diagram.
d. What are the values of $\mathrm{g}^{2}(0)$ (second order correlation) and $\Delta \mathrm{n}$ (variance) for the Poissonian and sub-Poissonian photon distribution? How are the squeezed states created by using Spontaneous Parametric Down Conversion (SPDC)?
$2+2$
(e) (i) Explain how a laser beam tuned to near resonance with an atomic transition can be used to reduce the temperature of a beam of atoms moving with velocity V toward the laser.
(ii) A beam of ${ }^{133} \mathrm{Cs}$ atoms is emitted in the $+x$ direction from an oven at a temperature of $500^{\circ} \mathrm{C}$ and is cooled by a laser beam directed in the -x direction. The laser is tuned to near resonance with the $5 \mathrm{~s}^{2} \mathrm{~S}_{1 / 2} \rightarrow 5 \mathrm{p}^{2} \mathrm{P}_{3 / 2}$ transition at 852 nm , which has a radiative lifetime of 30 ns . Estimate the time taken to cool the atom to their minimum temperature and the distance the atom travels in this time.
(f) (i) Show that for a centrosymmetric crystal the second order nonlinear susceptibility vanishes.
(ii) Explain how the difference frequency generation in a nonlinear crystal can lead to optical parametric oscillation.
2. a) Obtain an expression for the nonlinear absorption coefficient for a saturable absorber placed inside a Fabry-Perot resonator. Draw the input versus output characteristics curve of a bistable optical device and explain how it can be used in optical switching.
(f) What is the phase matching condition (PMC) in a nonlinear crystal? Show that the sumfrequency generation in such a crystal can be efficient only if the phase matching condition is satisfied.
$(2+1+2)+(1+4)$
3. a) Explain the role of optical pumping and degenerate Zeeman sublevels for a transition $\mathrm{J}_{\mathrm{g}}$ $=1 / 2 \rightarrow \mathrm{~J}_{\mathrm{e}}=3 / 2$ in sub-Doppler laser cooling (Sisyphus cooling) process.
b) Obtain an expression for the ac Stark shift (light shift) of the ground state Zeeman sublevels ( $\mathrm{mg}=+-1 / 2$ ) for a two-level atom interacting with a standing wave formed by two counter propagating laser beams having configuration).
c) Show that in case of large detuning the minimum temperature in Sisyphus cooling i inversely proportional to detuning.
4. Explain what is meant by Bose-Einstein condensation. Draw the schematic diagram of the coil configuration and resulting magnetic lines in a harmonic trap. Show that the critical temperature $\mathrm{T}_{\mathrm{c}}$ for Bose-Einstein condensation in such a trap is proportional to $\mathrm{N}^{1 / 3}$, where N is the total number of particles in the trap. ${ }^{87} \mathrm{Rb}$ atoms in a harmonic trap of angular frequency $10^{3} \mathrm{rad} / \mathrm{s}$. Calculate $\mathrm{T}_{\mathrm{c}}$ for $10,000{ }^{87} \mathrm{Rb}$ atoms $\quad \mathbf{2 + 1 + 5 + 2}$
5. a) Starting from the Planck's law, show that the photon distribution of the thermal light at a frequency $\omega$ can be written as

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

Compare this distribution with a Poisson distribution with the same value of $\bar{n}$.
b) What is the main difference between Michelson Stellar and Hanbury Brown-Twiss (HB-T) interferometer? Which one is more suitable to measure the separation between the stars in a binary star system and why? Draw a schematic diagram of HB-T interferometer. Define the second order correlation function $\mathrm{g}^{2}(\tau)$.
6. a) For a two-level stationary atom in a standing wave $\mathrm{E}(\mathrm{z}, \mathrm{t})=\mathrm{E}_{0} \cos \Omega \mathrm{t}$ sinkz, the density matrix equations are

$$
\begin{aligned}
& \frac{\partial \rho_{22}}{\partial t}=\Lambda_{2}-\gamma_{2} \rho_{22}-\frac{i \mu E_{0}}{\hbar} \sin k z \cos \Omega t\left(\rho_{21}-\rho_{12}\right) \\
& \frac{\partial \rho_{11}}{\partial t}=\Lambda_{1}-\gamma_{1} \rho_{11}+\frac{i \mu E_{0}}{\hbar} \sin k z \cos \Omega t\left(\rho_{21}-\rho_{12}\right) \\
& \frac{\partial \rho_{21}}{\partial t}=-\left(\gamma_{21}+i \omega\right) \rho_{21}-\frac{i \mu E_{0}}{\hbar} \sin k z \cos \Omega t\left(\rho_{22}-\rho_{11}\right)
\end{aligned}
$$

Solve the equations under steady state and show that the population difference is

$$
\rho_{22}-\rho_{11}=N\left[1-\frac{2 I \eta \sin ^{2} k z \gamma_{21}^{2}}{\Delta^{2}+\gamma_{21}^{2}+2 I \eta \sin ^{2} k z \gamma_{21}^{2}}\right]
$$

The symbols have their usual meaning. Plot the population difference against the position 2 .
b) Explain how an absorbing medium becomes transparent in presence of a resonant laser field. Plot the real and imaginary part of the susceptibility of such a medium with the probe detuning. What is the nature of the dispersion slope?
$(4+1)+(3+1+1)$

