M. Sc. (Physics) 4th Semester Examination 2021

PHY 522 Advanced Paper II (Laser Physics)

Full Marks: 50 Time: 2.5 hrs

(*2 hours for answering and 30 minutes for downloading, scanning, and mailing back)*

Answer any *five* questions 5 x 10 = 50

Instructions:

(a) Write your complete *Examination Roll Number* (with college code and subject category) and *Registration Number* (from an earlier admit card) at the top of your answer script.

(b) Do not write your name or class roll number anywhere.

(c) Write page number on top of each page.

(d) Scan the complete answer script into *a single pdf file* and mail it to the e-mail from where you got this question paper.

(e) The answer script file must be named as XXXXXXPHYAAA.pdf, where XXXXXX is the university roll number and AAA is the paper identifier.

For CU students, the filename for the paper PHYAAA must be CUXXXXXXPHYAAA.pdf

For example, for this paper, the answer script coming from CU student of C91/PHS/191099 must be named CU191099PHY522.pdf

For students of Lady Brabourne College, the name should be LBCXXXXXXPHYAAA.pdf, e.g., LBC191098PHY522.pdf

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For students of Vivekananda College, the name should be VCXXXXXXPHYAAA.pdf, e.g., VC191096PHY522.pdf

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1. (a) Explain with diagram how the splitting of the Zeeman sublevels of a two level (J=0→ J=1) atom in an inhomogeneous magnetic field can be utilized to cool and trap the atoms in a magneto optical trap (MOT). What will be the oscillation frequency of the trapped atom in the MOT? **4+3**

(b) Obtain an expression for the lowest temperature that can be achieved by the Doppler cooling method. **3**

2. (a) Derive an expression for the Bose-Einstein condensation temperature (T_C) for a gas of atoms confined in a magnetic trap by a potential of the form given by

$$V_{trap}(r) = \frac{1}{2}k_1x^2 + \frac{1}{2}k_2y^2 + \frac{1}{2}k_3z^2$$

where the symbols have their usual meanings. Also obtain the expression for the condensate fraction, f(T) and plot it. **5+2**

(b) Explain how the evaporative cooling can be used to obtain Bose-Einstein Condensation in a magnetic trap with the help of radio frequency field. **3**

3. (a) Describe how the process of difference frequency generation (DFG) in a nonlinear crystal can be utilized to obtain the optical parametric oscillation. **3**

(b) Assume that infrared radiation of frequency ω_1 is mixed with a laser beam of frequency ω_2 to generate the signal at sum frequency $\omega_3 = \omega_1 + \omega_2$. Obtain an expression for the intensity of the generated filed at frequency $\omega_3 = \omega_1 + \omega_2$. What is the phase matching condition (PMC)? Explain how the PMC can be obtained in non-linear crystals. **4+1+2**

4. (a) Write down the total Hamiltonian of the two-level atom interacting with an electromagnetic field in terms of Pauli spin matrix and spin-flip operators (σ_+,σ_-) semi-classically. **2**

(b) The rate equations for the C-coefficients of a two-level atom interacting with a radiation field may be written as,

$\frac{d\boldsymbol{c}}{dt} = \frac{i}{2}M\boldsymbol{c}$, where $M = \begin{pmatrix} -\delta & \Omega_R \\ \Omega_R & \delta \end{pmatrix}$, Ω_R and δ are the Rabi-frequency and detuning parameter.

Derive the eigenvalue and eigenvector of the matrix M. **3**

(c) Explain the role of optical pumping processes in Sisyphus cooling method. Calculate the lowest temperature that can be achieved by this method for the 3p → 3s transition of sodium at 589nm. **3+2**

5.(a) Derive Liouville's equation of motion including the decay rates phenomenologically starting from the density operator. Explain the physical meanings of density matrix elements ρ_{ii} and ρ_{ij}. Why density matrix approach is more general than the Schrodinger equation? **3+2+1**

(b) Explain physically how the Lamb-dip is observed in a two-level atomic system interacting with an electromagnetic field. **2**

(c) Draw a schematic experimental set up for Saturation Absorption Spectroscopy. **2**

6. (a) What do you understand by Rotating Wave Approximation (RWA)? Explain with an example of a two-level atom interacting with electromagnetic field. **3**

(b) Classify thermal light, coherent light and non-classical light in terms of their photon number distribution (P(n)) and second-order correlation function ($g^2(\tau)$). **4**

(c) Show that the coherent state has Poissonian photon distribution. **3**

7. (a) What is the difference between a coherent state and a quadrature squeezed state? Explain with the phasor diagram an amplitude and phase squeezed light. **2+2**

(b) Drive an expression of Dark state for a Λ-type three-level system interacting with two resonant fields to explain the coherent population trapping phenomena. **3**

(c) Write down the expression of the unperturbed Hamiltonian for a quantized field and explain the terms present in the expression. **2**

(d) What is the difference between bunched and anti-bunched light? **1**