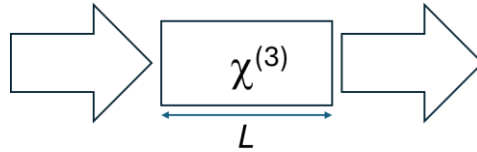
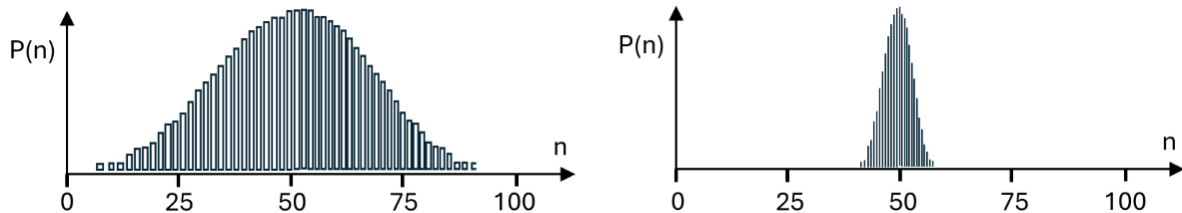


1. The n^{th} -order nonlinear optical susceptibility, $\chi^{(n)}$ is a tensor. What is the rank of the tensor and the total number of components? Explain by giving an example.
2. Write down all possible sum-frequency field outcomes generated due to four-wave mixing involving $\chi^{(3)}$ of a nonlinear medium in presence of three input fields, $E_1(t)$, $E_2(t)$, and $E_3(t)$ at frequencies ω_1 , ω_2 , and ω_3 , respectively.
3. Strong second harmonic radiation generation of a pump field at frequency ω can be obtained by using type-I phase matching in a negative uniaxial crystal. Explain the process and the necessary conditions for it.
4. By using a $\chi^{(2)}$ nonlinear crystal of length L , strong pump $I(\omega_1)$ was used to amplify a weak signal $I(\omega_2)$ via DFG process. Under perfect phase matching condition, power P_1 of the signal $I(\omega_2)$ was recorded when pump was $I(\omega_1)$ and the crystal thickness was L , while power P_2 of the signal $I(\omega_2)$ was recorded for pump $3I(\omega_1)$ and crystal thickness $L/3$. What is the value of the ratio P_1/P_2 ?
5. Complete the following schematic to show self and cross phase modulation processes for optical fields at frequencies of your choice.



In the above, what is the amount of the phase-change due to SPM and the amount of the phase-change due to XPM?

6. A highly sensitive photodetector ($\eta = 20\%$) has dead time of $5\mu s$. What should be the max power with which photons of energy $2eV$ from a random photon source should be delivered so that it can qualify for use in quantum measurements using the above detector.
7. For the probability distributions as shown in the figure below for the photon numbers counted in an experiment, identify the nature of the sources and give one example of each.



8. Describe the Hamiltonian for a radiation mode of frequency ω in terms of ladder operators $\hat{a}$ and $\hat{a}^\dagger$. Also, show the raising and lowering properties of those.
9. A CW and a pulsed laser, both delivering $10mW$ of average power over $1cm$ beam diameter, are used to generate second harmonic of the pump at $\lambda_0 = 800nm$ under

optimized conditions with a $\chi^{(2)}$ nonlinear optical crystal of length L . If the pulsed laser is delivering pulses of full width at half maximum duration of 10ns and at a pulse repetition rate of 100kHz , what would be the ratio between the SHG signal intensities obtained using the CW laser and the pulsed laser?

10. Describe by using the basic definition of an induced polarization that Raman scattering is a linear (1^{st} order) optical process while stimulated Raman scattering is a 3^{rd} -order nonlinear optical process. In those cases, are the energy and momentum conservation conditions satisfied? Explain.

11. The intensity dependent index of refraction of a dielectric medium at frequency ω is given by $n = n_0 + n_2 I$, where $n_2 = \frac{1}{n_0^2 \epsilon_0 c} \chi^{(3)}$. Note that $\chi^{(1)}$ is linear susceptibility, $\chi^{(3)}$ is nonlinear susceptibility and all other symbols have their usual meaning. Determine the SI unit of $\frac{\chi^{(3)}}{\chi^{(1)}}$ and its value at pump intensity of $I = 10^5 \text{W/m}^2$ which is sufficient to enhance the index of refraction by 0.1% of its linear value. Given, $n_0 = 2$, $\epsilon_0 = 8.86 \times 10^{-12} \text{F/m}$, and $c = 3 \times 10^8 \text{m/s}$.