**Quizzes and short questions QUANTUM ELECTRONICS**
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***Module 5: Quizzes and short questions:***

1. A linear harmonic oscillator is prepared in a state such that the probability of finding it with an energy of $5/2\ \hbar\omega$ is 0.2 and with an energy of $11/2\ \hbar\omega$ is 0.8. Write down two possible kets describing the oscillator at $t$ = 0.

2. Q: Consider a single mode radiation in a state given by
$$|\psi\rangle = \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$
Obtain the expectation value of the electric field in the state.
3. Q: Consider a two mode state given by
$$|\psi\rangle = \frac{1}{\sqrt{2}}|0_1, 0_2\rangle + \frac{1}{\sqrt{2}}|1_1, 1_2\rangle$$
Obtain the expectation value of the number of photons in this state.

4. Q: What is the expectation value of energy in a coherent state $|\alpha\rangle$ with $\alpha$ = 5?

5. Q: Consider the following single mode state
$$|\psi\rangle = \frac{1}{\sqrt{0.2}}|n\rangle + \frac{1}{\sqrt{0.2}}|n+1\rangle$$
Obtain the average number of photons in this state.

**Answers of module 5 *Quizzes and short questions*:**

**A1:** $|\psi\rangle_1 = \sqrt{0.2}|2\rangle + \sqrt{0.8}|5\rangle$ and $|\psi\rangle_2 = \sqrt{0.2}|2\rangle - \sqrt{0.8}|5\rangle$
Hence the efficiency for SHG will become zero when $\Delta k = 2\pi/L$ which for the values given gives us $\Delta k$ = 1.26 $cm^{-1}$.

**A2** : The electric field operator is given by

$$\hat{E} = i\sqrt{\frac{\hbar\omega}{2\varepsilon_0 V}}\left[\hat{a}e^{-i(\omega t - kz)} - \hat{a}^\dagger e^{+i(\omega t - kz)}\right]$$

Thus the expectation value of the electric field in the given state will be

$$\langle\psi|\hat{E}|\psi\rangle = \sqrt{\frac{\hbar\omega}{2\varepsilon_0 V}}\, sin(\omega t - kz)$$

**A3**: The expectation value of the number of photons is given by

$$\langle\psi|(\hat{a}_1^\dagger\hat{a}_1 + \hat{a}_2^\dagger\hat{a}_2)|\psi\rangle = \frac{1}{2}\langle 1_1, 1_2|(\hat{a}_1^\dagger\hat{a}_1 + \hat{a}_2^\dagger\hat{a}_2)|1_1, 1_2\rangle = 1$$

**A4** : $\langle\alpha|\hat{a}^\dagger\hat{a}|\alpha\rangle = 5$
Hence $\langle E\rangle = 5.5\ \hbar\omega$

**A5:** A: $\langle\psi|\hat{a}^\dagger\hat{a}|\psi\rangle = \frac{1}{2}[\langle n| + \langle n+1|]\hat{a}^\dagger\hat{a}[|n\rangle + |n+1\rangle] = \left(n + \frac{1}{2}\right)$