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Archives of Applied Science Research, 2012, 4 (1):28-31
(http://scholarsresearchlibrary.com/archive.html)

ISSN 0975-508X
CODEN (USA) AASRC9

Quantum Zeno Effect in Bloembergen's three level maser

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ABSTRACT

The Quantum Zeno effect is the phenomenon of inhibition of transition between quantum states by frequent measurements. The term Quantum Zeno effect (QZE) was originally introduced by E.C.G.Sudarshan and it may be applied to explain various transitions. In the present work we discuss the essential features of Bloembergen's three level maser and its connection with Quantum Zeno effect.

INTRODUCTION

The Quantum Zeno paradox is concerned with the phenomenon of inhibition of transitions between quantum states by frequent measurements. The term was originally introduced by E.C.G.Sudarshan [1] and it may be applied to explain various transitions and have experimentally been observed. Based on the usual quantum theory of measurement involving projection operators, showed that an unstable particle which was continuously observed to see if it decayed would never be found to do so. Later, several authors [2-5] studied the problem and generalized disturbance introduced into a quantum system by a performed measurements to inhibition of transitions or quantum jumps as the frequency of observation or measurement was increased. This dynamical behavior is widely known as Quantum Zeno effect. The Quantum Zeno Effect is defined as a class of phenomena where the transition is suppressed by an interaction that produces a state that can be interpreted as indicating either "a transition has not yet occurred" or "a transition already occurred". In the present work we discuss that essential features associated with Bloembergen's three level maser which was developed five decades ago and its connection with Quantum Zeno effect. The analysis presented in this paper is approximate. This work can give a new idea about Lasing without inversion.

Quantum Zeno Effect

The Quantum Zeno Effect gets its name from the Greek philosopher Zeno. Recently, renewed attention has been paid to this problem since Itano, Heinzen, Bolingerand Wineland[6] succeeded in observing this effect experimentally. The Zeno effect consists in the impediment of a quantum system's evolution by frequent measurements performed on it. Apart from the generic quantum phenomenon of entanglement, it is probably the most striking difference separating the classical from the quantum world, and an example for the sometimes counterintuitive features of the latter. In the most concise manifestation of the Zeno effect, a decaying state of a quantum system, say an excited state of an atom, is conserved and prevented from decay simply by 'looking at it', i.e., observing the presence of the undecayed state. The Quantum Zeno effect has become a topic of great interest in the areas of polarized light[3],the physics of atoms and atomic ions[5,7-8],neutron physics[8],quantum tunneling[9-11] , Quantum optics[12] and Lasing without inversion[7,13-14] etc.The quantum mechanical view of the world has compelled us to reshape and revise our ideas of reality and notions of cause, effect and measurement. The probability of finding the system in its initial state after being left to itself for a certain period of time t is termed as survival probability and for very short time limit it can be written as

$$P(t) \approx (1-\frac{t^2}{\tau^2}).\ldots$$

For N equal spaced measurements over a time period (0,T). If τ is the time interval between two measurements, then $T = N\tau$. Let us assumed that the measurements are made at times time T/N, 2T/N… (N-1)T/N and T are instantaneous. So the survival probability after N measurements, which is in the limit of continuous measurements

$$Lt_{N\to\infty} P^N(T) = Lt_{N\to\infty}\left(1-\frac{T^2}{N^2\tau^2}\right)^N = 1 \qquad (1)$$

It is seen in equation (1) that the state will survive for a time T goes to 1 in the limit N goes to infinity, means that the continuous measurements actually prevent the system from ever decaying. The seminal formulation of quantum Zeno effect deals with the probability of observing an unstable system in its initial state throughout a time interval.

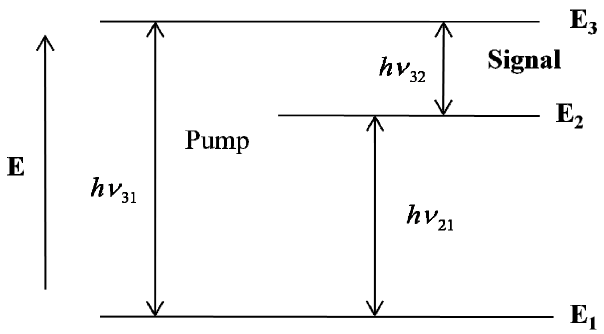

Figure 1: Three level maser scheme

Bloembergen's three level maser

The three level method of population inversion was initially proposed by Basov and Prokhorov [15] who suggested it for application in a molecular beam apparatus. Bloembergen [16] subsequently suggested that the method could be readily applicable to diamagnetic solids containing weak concentration of paramagnetic ions presented the theoretical treatment of the three level maser. Consider a three level system as shown in Fig.1; the stationary states are characterized by energy E and resonant frequencies ν_{ij}.

At thermal equilibrium the populations decrease with increasing energy of state and the assembly will absorb energy from an incident radiation field. Suppose two radiation fields are incident on an assembly, one a very intense one, with frequency near the resonance ν_{31} and a very weak one near ν_{32} If the field at ν_{31} is sufficiently intense (1, 3) transition may be saturated with the result that $n_1 \cong n_2 \cong \frac{1}{2}\left(n_1^{\ e} + n_2^{\ e}\right)$ where $n_1^{\ e}, n_2^{\ e}$ and $n_3^{\ e}$ are the populations in the state 1,2and 3 respectively. Also the total number of atoms N is given by $\mathrm{N} = n_1^{\ e} + n_2^{\ e} + n_3^{\ e}$ Assuming that this saturation process does not disturb the system in state 2,it is reasonable to believe that a condition may be realized in which $n_3^{\ e} \rangle n_2^{\ e}$, in which case the assembly is in a emissive state relative to field at frequency ν_{32}.Further if it is assumed that relaxation processes are operative in the assembly and that they are characterized by transition probabilities $\Gamma_{ij} = \Gamma_{ji} e^{-h\nu_{ji}/kT}$, and i,j=1,2,3. The transition (1, 3) is assumed to be saturated due an intense field at frequency ν_{31} while a weak field frequency ν_{32} is assumed to induce transitions between states 2 and 3.The induced transitions probabilities for the system per unit time are designated as , B_{13}=B_{31}. and $B_{23} = B_{32}$. From the rate of equation it can be obtained that the assembly will emit power at a rate

$$\mathrm{P} = \frac{\mathrm{N}h^2\nu_{32}}{3kT}\left(\frac{\Gamma_{12}\nu_{21} - \Gamma_{23}\nu_{32}}{\Gamma_{12} + \Gamma_{23} + \mathrm{B}_{23}}\right)\mathrm{B}_{23} \tag{2}$$

For B_{23} far from the value required for saturation, and for all Γ_{ij} equal, where $i, j = 1,2,3$ so $\Gamma_{12} = \Gamma_{13} = \Gamma_{23}$ and by neglecting B_{23} in the denominator of the equation (2) then the equation becomes

$$P = \frac{1}{2}\frac{\mathrm{N}}{3}\left(\frac{h\nu_{21}}{kT} - \frac{h\nu_{32}}{kT}\right)\mathrm{B}_{23} h\nu_{32} \tag{3}$$

The net power is positive only when $\Gamma_{23}\nu_{32} \langle \Gamma_{12}\nu_{21}$ or since $\nu_{21} = \nu_{31} - \nu_{32}$ so $\nu_{31} \rangle \nu_{32}(1 + \frac{\Gamma_{23}}{\Gamma_{12}})$ for $\Gamma_{23} = \Gamma_{21}$ it is obtained that $\nu_{31} \rangle 2\nu_{32}$.Thus the three level masers requires sources of saturating or pumping power at frequencies approximately doubles the signal frequency. One of the criteria for maser action may be achieved in three level system is that $\nu_{31} \rangle \nu_{32}(1 + \frac{\Gamma_{23}}{\Gamma_{12}})$.

DISCUSSION

From what has been discussed above it follows that three level system of Bloembergen, We have seen that in this system two fields are allowed to be incident on assembly, a strong field at resonance with frequency ν_{31} (frequency separating the ground level and highest excited level) and the weak signal field at frequency ν_{32}. It may be noted that in this work we have ignored many factors like spectral line shape and life time etc. It will be convenient to present our work in a simplified statement that "Bloembergen's three level maser will tend to acquire the status of two level maser as the energy level representing the signal field goes on decreasing but will never acquire the status of two level maser--- watched pot never boils"

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