

Inhibition of spontaneous decay by continuous measurements: Proposal for realizable experiment.

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Abstract

We propose several multilevel systems that should make possible the experimental verification of the quantum Zeno effect, i.e. the inhibition of exponential *decay* of the population of an atomic level rather than the suppression of a coherent transition. Both numerical and analytical results are presented. Possible ions that realize the required level configurations are presented and we verify for realistic parameters that the quantum Zeno effect should be observable.

I. Introduction

The quantum Zeno effect, although introduced as a suppression of decay, is often defined as the inhibition of the free evolution of a system, e.g. a driven two level system, that is subject to frequent (or in the limiting case continuous) measurements [1]. This behaviour is due to the fact that the transition probability between orthogonal quantum mechanical states is proportional to Δt^2 for sufficiently small times Δt . Let us assume for example that we measure whether the two level system is in its lower state 1 and that we perform this measurement N times at the times $t_m = mT/N$ during the time interval $[0, T]$. If the system is initially in its ground state then for sufficiently large N the probability p_N to find the system, in each of the measurements, in its initial lower state 1 is given by

$$p_N = \left(1 - \alpha \left(\frac{T}{N}\right)^2\right)^N \quad (1)$$

where α does not depend on N but only on parameters such as for example Rabi frequencies. One immediately observes that this expression tends to 1 with increasing N , i.e. the time evolution of the system freezes.

It is not easy to measure this effect and it was not until 1990 that an experiment was performed in which the inhibition of the atomic dynamics due to rapid successive measurements was demonstrated unambiguously [2]. This experiment, originally proposed by Cook [3], has subsequently been analysed theoretically by many authors [4].

In this experiment a two level system initially in its ground state 1 was driven over a long time by a microwave field. The measurement of the ground state population was performed by coupling the ground state via a strong laser for a short time to a third level that strongly decays back to level 1. If photons are observed to be scattered during that pulse, the two level system is inferred to have remained in its ground state, whereas if no photons are

detected the two level system is inferred to have made the transition to its upper state 2. For suitably chosen field strengths of the strong laser and a sufficiently large decay constant of the third level, this pulse can be regarded as an ideal quantum mechanical measurement to an excellent approximation [5]. In practice the experiment is performed by only measuring the population in level 1 at the end of the long microwave pulse [2]. This is because realistic values of the detector photon efficiency mean that not enough photons are detected from the short measurement pulses to determine the population of level 1.

However it has been pointed out that this experiment does not verify the quantum Zeno effect as originally defined, i.e. that a continuously observed state does not decay. It rather shows that the *coherent* Rabi oscillation in the two level system is inhibited due to the strong "measurement" laser pulses. Therefore strictly speaking the quantum Zeno effect within this narrow definition has not been verified by this experiment. The problem in measuring the "true" incoherent quantum Zeno effect lies in the fact that the times for which the spontaneous decay of an excited atomic state is nonexponential (i.e. quadratic) are extremely small, approximately of the order of 10^{-16} s. It seems to be completely impossible to perform repeated measurements on a system that are separated by times less than that and therefore the direct verification of the incoherent quantum Zeno effect seems to be impossible [6].

Therefore one has to look for different schemes in which the nonexponential regime extends to longer times. One possibility is to place the atom in an optical cavity. In such a cavity the modal width and distribution of the quantized radiation field is changed and with it the correlation time of the radiation field which governs the length of the nonexponential regime. However it seems to be extremely difficult to realize this idea in an experiment. Therefore it would be interesting to find different experimental setups or systems which might be more easily implemented in an experiment to verify the incoherent quantum Zeno effect.

In the present paper we propose several different atomic level configurations that have the property that the transition probability from one level starts with a quadratic behaviour which then evolves into an exponential decay law. The length of the quadratic regime as well as the decay constant of the exponential regime can be adjusted by changing the field strengths of the lasers driving the multilevel system.

We present analytical and numerical investigations of these systems as well as atoms or ions that realize the required level configurations. The experimental verification of the incoherent quantum Zeno effect should then be almost as easy or difficult as the original experiment of Itano et al [2].

II. Investigation of possible configurations

In the experiment of Itano et al a two level system was driven by a microwave field with a Rabi frequency Ω_2 causing slow Rabi oscillations in the system. At the beginning all population is assumed to reside in the lower level 1. Strong measurement pulses coupling the lower level to an auxiliary third level 3 were then applied and it was shown that the Rabi flopping was suppressed if the measurement pulses were applied at a sufficiently high rate. This experiment was meant to serve as an experimental verification of the quantum Zeno effect. However the quantum Zeno effect is often understood to be the inhibition of the incoherent exponential decay of a level instead of the inhibition of a coherent Rabi

oscillation. Since the quantum Zeno effect in spontaneous decay is extremely difficult to observe, it is interesting to present alternative multilevel systems in which the population in one of the states decays exponentially with a controllable nonexponential behaviour for short times. This is in fact the case in the configurations we propose in the following. In these configurations we can easily adjust both the length of the nonexponential regime as well as the decay constant of the exponential behaviour by a suitable choice of the laser parameters.

All the configurations that we discuss in the following are based on the same basic idea. If we drive a metastable two level system consisting of levels 1 and 2 by a field, the populations will perform Rabi oscillations. If on the other hand we are able to induce a finite linewidth in the upper level 2 we should expect to find an exponential decrease of the population of level 1 which was assumed to be 1 initially. Such an effective linewidth of the upper level can be achieved in several ways. Possible configurations are depicted in Figs. 2a,2b,2c. In the simplest configuration (2a) the upper level 2 is allowed to decay spontaneously to a third level 3. This configuration however suffers from the drawback that the decay rate on the $2 \leftrightarrow 3$ transition is fixed (and therefore the effective width of level 2) and can only be changed by choosing a different atomic system. Therefore although being a possible configuration in principle it is not very suitable and we will not discuss it further.

A much more interesting configuration which we will discuss both numerically and analytically in the following is the one depicted in Fig. 2b. In configuration (2b) the upper level 2 of the two level system is coupled by a laser of Rabi frequency $\Omega_3 = \mathbf{E} \cdot \mathbf{D}_{31} / \hbar$ to level 3 which can spontaneously decay to level 2 exclusively. There are now two easily adjustable parameters namely the Rabi frequencies Ω_2 and Ω_3 of the two lasers involved. But does the population of level 1 really show the expected exponential decay or will it still exhibit an oscillatory behaviour? In Fig. 3 we have plotted the time evolution of the population ρ_{11} of level 1 as well as the results of analytical approximations given in (5) and (7) for the parameters $\Omega_2 = 0.15 \Gamma_{33}$, $\Omega_3 = 0.0012 \Gamma_{33}$ and the detunings $\Delta_2 = \Delta_3 = 0$. Here Γ_{33} denotes half the Einstein coefficient of the $3 \leftrightarrow 2$ transition. We observe that the population of level 1 falls off exponentially to the value 0.5 for sufficiently large times (here $t > 200 \Gamma_{33}^{-1}$) and that for smaller times ($t < 200 \Gamma_{33}^{-1}$) ρ_{11} has a nonexponential time dependence, namely it obeys a quadratic time dependence.

At this point it should be noted that it is possible in principle to obtain exponential population changes by using a time dependent Rabi frequency $\Omega_2(t)$ instead of an additional coupling to a third level. However apart from the extreme difficulty to realize the required time dependence of the Rabi frequency (as opposed to our easily realizable approach) there are also conceptual differences to our approach. This becomes clear when we go over to the dressed states picture for levels 2 and 3 where we immediately observe that in our approach the the upper levels have a finite width as spontaneous decaying levels. This is not the case for a model with time a dependent Rabi frequency $\Omega_2(t)$.

We are able to give quite simple analytical approximations to the exact time evolution of ρ_{11} . We only give here the expressions for $\Delta_2 = \Delta_3 = 0$ in order to keep them as simple as possible. In the following we assume that the condition

$$\frac{2 \Omega_2^2 \Gamma_{33}}{\Omega_3^2} \cdot \frac{4 \Gamma_{33}^2 + \Omega_3^2}{2 \Gamma_{33}^2 + \Omega_3^2} \ll \frac{\Gamma_{33}}{2} - \frac{1}{2} \sqrt{\Gamma_{33}^2 - \Omega_3^2} \quad (2)$$

is satisfied. This condition assures that the two smallest nonzero eigenvalues of the corresponding Bloch equations of the system (2b) are well separated. Physically this has the

effect that if one would observe the resonance fluorescence of a single system (2b) on its $2 \leftrightarrow 3$ transition one would find long light and dark periods, i.e the time evolution has two largely different time scales. In fact the two eigenvalues

$$\lambda_1 = \frac{2\Omega_2^2\Gamma_{33}}{\Omega_3^2} \cdot \frac{4\Gamma_{33}^2 + \Omega_3^2}{2\Gamma_{33}^2 + \Omega_3^2} \quad (3)$$

$$\lambda_2 = \frac{\Gamma_{33}}{2} - \frac{1}{2}\sqrt{\Gamma_{33}^2 - \Omega_3^2} \quad (4)$$

govern the time evolution of ρ_{11} if (2) is satisfied. We find that

$$\rho_{11}(t) = \rho_{11}^{ss} + (1 - \rho_{11}^{ss}) \left\{ \frac{\lambda_2}{\lambda_2 - \lambda_1} e^{-\lambda_1 t} - \frac{\lambda_1}{\lambda_2 - \lambda_1} e^{-\lambda_2 t} \right\} \quad (5)$$

where

$$\rho_{11}^{ss} = \frac{\Omega_2^2 + 4\Gamma_{33}^2}{2(4\Gamma_{33}^2 + \Omega_2^2 + \Omega_3^2)} \quad (6)$$

If $|\lambda_1|$ becomes comparable to $|\lambda_2|$, then the somewhat more complex approximation

$$\rho_{11}(t) = \rho_{11}^{ss} + (1 - \rho_{11}^{ss} + \alpha_1 + \alpha_2) e^{-\lambda_1 t} - \alpha_1 e^{-\lambda_2 t} - \alpha_2 e^{-(\lambda_1 + \lambda_2)t} \quad (7)$$

where

$$\alpha_1 = \frac{(\lambda_1 + \lambda_2)\lambda_1(1 - \rho_{11}^{ss}) - \Omega_2^2/2}{(\lambda_2 - \lambda_1)\lambda_1} \quad (8)$$

$$\alpha_2 = \frac{-\lambda_1\lambda_2(1 - \rho_{11}^{ss}) + \Omega_2^2/2}{\lambda_1\lambda_2} \quad (9)$$

applies and gives a closer approximation to the exact time evolution. However since it is easy to satisfy condition (2), the approximate result (5) will usually be sufficient. In Fig. 3 both approximations can be compared to the exact result and we see that for the chosen parameters they coincide almost exactly and approximate the exact evolution quite well.

From (5) and (7) one observes that for long times, i.e. $t \gg |\text{Re } \lambda_2|^{-1}$, the population ρ_{11} of level 1 decays exponentially with a decay constant λ_1 . The short time behaviour, i.e. $t \ll |\text{Re } \lambda_2|^{-1}$, is less obvious from the expressions (5) and (7), but one readily verifies that in both cases we find

$$\rho_{11}(t) = 1 - \frac{\Omega_2^2}{4} t^2 \quad (10)$$

i.e. a quadratic time dependence. Therefore we have shown that the population of level 1 in fact obeys an exponential decay law with deviations (quadratic time dependence) for short times.

From the analytical expressions we also see how to influence the length of the quadratic regime and the decay constant of the exponential regime. Since the length of the quadratic regime is approximately given by $|\text{Re } \lambda_2|^{-1}$ which for $\Omega_3 \ll \Gamma_{33}$ is given by

$$|\text{Re } \lambda_2|^{-1} \approx \frac{4\Gamma_{33}}{\Omega_3^2} \quad (11)$$

we can get a prolonged quadratic regime if we decrease Ω_3 . If we also want to decrease the decay constant in the exponential regime we have to decrease the ratio $(\Omega_2/\Omega_3)^2$.

Before we confirm in the next section that rapid measurements of the population of level 1 inhibit its "decay", we briefly treat another slightly more general system depicted in Fig. 2c. Here we allow the additional level 3 not only to decay to level 2 but also to other states. We have introduced another level 4 to which level 3 is allowed to decay spontaneously and from which no repumping takes place. The presence of this additional decay channel alters the time evolution of the population of level 1. For the same laser parameters as in Fig. 3 but now with a decay constant $\Gamma_{44} = 2\Gamma_{33}$ on the $3 \leftrightarrow 4$ transition we have plotted ρ_{11} in Fig. 4. Again one observes the initial nonexponential behaviour and the subsequent exponential decay of the population of level 1. However for large times the population ρ_{11} now tends to zero instead of a finite value as for the system (2b). Of course this is due to the additional loss of population into level 4 from which no repumping takes place. Again we can give useful analytical approximations to the exact time evolution ρ_{11} . We assume that the following conditions

$$\Omega_2^2 \ll \Omega_3^2 \ll 4(\Gamma_{33} + \Gamma_{44})^2 \ll \frac{\Omega_3^4}{2\Omega_2^2} \quad (12)$$

$$\Gamma_{44}\Omega_3^2 \ll 2(\Gamma_{33} + \Gamma_{44})^3 \quad (13)$$

are satisfied. They ensure that all different eigenvalues of the Bloch equations of the system (2c) are well separated. We then find

$$\rho_{11}(t) = \frac{\lambda_2}{\lambda_2 - \lambda_1} e^{-\lambda_1 t} - \frac{\lambda_1}{\lambda_2 - \lambda_1} e^{-\lambda_2 t} \quad (14)$$

with

$$\lambda_1 = \frac{2(\Gamma_{33} + \Gamma_{44})}{\Omega_3^2} \Omega_2^2 \quad (15)$$

$$\lambda_2 = \frac{\Omega_3^2}{4(\Gamma_{33} + \Gamma_{44})} . \quad (16)$$

as a good approximation to the exact time evolution. Again we find for the short time behaviour (quadratic regime)

$$\rho_{11}(t) = 1 - \frac{\Omega_2^2}{4} t^2 \quad (17)$$

as may also be concluded from a power expansion in t of the exact time evolution. The long time behaviour ($t \gg |\text{Re } \lambda_2|^{-1}$) is again governed by the eigenvalue λ_1 .

We have thus shown that in systems (2b) and (2c) the population of level 1 obeys an exponential decay law for large times with a quadratic behaviour for small times as required for those systems that should exhibit the incoherent quantum Zeno effect. In the next section we will show analytically and numerically that the systems (2b) and (2c) indeed show the quantum Zeno effect if the population of level 1 is measured very frequently.

III. The quantum Zeno effect

In the preceding section we have shown that the systems depicted in Figs. 2b and 2c have the property that the population ρ_{11} of level 1 obeys a time evolution similar to that of

a spontaneously decaying excited state in a two level system but with the difference that the regime where the decay of ρ_{11} is nonexponential, i.e. the quadratic regime, is much longer as compared to the case of spontaneous decay. In fact it is easily possible to change the length of that regime. Therefore we have an ideal system for the investigation of the incoherent quantum Zeno effect. A possible experiment may run along the lines of the original experiment of Itano et al [2] where the inhibition of coherent Rabi oscillations due to frequent measurements of the population of one of the two states of a two level system has been verified. Similar to this experiment we imagine that these measurements are performed by coupling level 1 for short times to an auxiliary level which can spontaneously decay to level 1 exclusively and detect the presence or absence of scattered photons on this transition. If the Rabi frequency of the measurement field is sufficiently strong this interaction indeed leads to an excellent approximation to a state reduction which can be described by the von Neumann-Lüders postulate [7]. We therefore consider a configuration as shown in Fig. 5. If we choose $\Gamma_{44} = 0$ we have the configuration (2b) whereas for $\Gamma_{44} \neq 0$ we have configuration (2c). We assume that level 1 can be coupled to level 5 which can only decay to level 1. The $5 \leftrightarrow 1$ transition is the measurement transition whereas the $1 \leftrightarrow 2$ transition is the Zeno transition. In Fig. 6 we have plotted the time evolution of the population ρ_{11} if measurement pulses are applied to system (2b) and we compare this to the evolution of the system without pulses. The Rabi frequency of the measurement pulse was chosen as $\Omega_5 = 4 \Gamma_{33}$ and the decay constant of level 5 is $\Gamma_{55} = \Gamma_{33}$. The other parameters were chosen as in Fig. 3. We applied pulses of length $T_p = 5 \Gamma_{33}^{-1}$ with a separation of the pulses of $\Delta t = 995 \Gamma_{33}^{-1}, 95 \Gamma_{33}^{-1}, 15 \Gamma_{33}^{-1}$.

We observe that the measurement pulses increasingly inhibit the decay of the population ρ_{11} the closer the pulses are spaced. The same results are found in Fig. 7 for the configuration (2c) where $\Gamma_{44} = 2 \Gamma_{33}$ and $\Gamma_{55} = 3 \Gamma_{33}$ and all other parameters are the same in Fig. 6. The relative values for the Γ_{ii} have been chosen to coincide with possible atomic configurations given in Section IV. One can easily find analytically the probability of finding the system in state 1 in all the $N = \frac{T}{\Delta t + T_p}$ measurements performed in the time interval $[0, T]$ since this is just the population $\rho_{11}(T)$ which in turn is well approximated by

$$\rho_{11}(T) \cong \rho_{11}(\Delta t)^N. \quad (18)$$

If Δt is sufficiently small so that each measurement is performed in the quadratic regime we find

$$\begin{aligned} \rho_{11}(T) &\cong \left(1 - \frac{\Omega_2^2}{4}(\Delta t)^2\right)^{\frac{T}{\Delta t + T_p}} \\ &\cong \exp\left(-\frac{\Omega_2^2}{4} \cdot \frac{T \Delta t}{1 + T_p/\Delta t}\right) \end{aligned} \quad (19)$$

for $\Delta t \gg T_p$. This coincides well with the results of Figs. 6 and 7.

IV. Possible atomic configurations

In this paper we have presented multilevel configurations for the verification of the incoherent quantum Zeno effect. In this section we propose two atomic systems that realize the required level configurations. In both cases it is necessary to consider a species which can be held in

some sort of trap configuration as we require a long interaction time between the fields and the atoms. We therefore consider ions which can be trapped and laser cooled in an ion trap, as in the original experiment of Itano et al [2]. In both cases we consider a Penning trap, where a magnetic field has the effect of splitting the energy levels into magnetic sub-levels. *Configuration (2b)*: This might be realized in $^{24}\text{Mg}^+$ in a strong magnetic field of approximately 1 Tesla. In such a field the magnetic sublevels of $3p\ ^2P_{3/2}$ are separated by about $\Delta\nu \approx 10\text{GHz}$ and the sublevels of $3s\ ^2S_{1/2}$ are separated by $\Delta\nu \approx 28\text{GHz}$. As level 1 we choose the $m_J = -1/2$ sublevel of $^2S_{1/2}$. Level 2 is then the $m_J = 1/2$ sublevel of the $^2S_{1/2}$ state and as level 3 we select the $m_J = 3/2$ sublevel of $^2P_{3/2}$ that can only decay back to level 2. As the measurement transition we can use the transition to the $m_J = -3/2$ sublevel of $^2P_{3/2}$ which exclusively decays back to level 1. The decay constant on both the measurement transition as well as the $3 \leftrightarrow 2$ transition are $\Gamma_{33} = \Gamma_{55} \approx 2.7 \cdot 10^8 \text{s}^{-1}$ so that the magnetic sublevels are well resolved.

Configuration (2c): This configuration can be realized in $^9\text{Be}^+$ again in a magnetic field around 1 Tesla. This is similar to the original experiment of Itano et al [2]. We choose in the $2s\ ^2S_{1/2}$ manifold the state $(m_J = 1/2, m_I = 3/2)$ as level 1 and $(m_J = 1/2, m_I = 1/2)$ as level 2. The level spacing between these two levels is about 312MHz. The linewidth in level 2 is induced by coupling it by a laser to a level 3 which is the $(m_J = 1/2, m_I = 1/2)$ sublevel of $2p\ ^2P_{1/2}$ where the spacing between the levels with different m_I quantum numbers is about 59MHz. The coupling of level 2 to different m_I sublevels is very small due to the decoupling of **I** and **J** by the magnetic field and the fact that the other transitions are electric dipole forbidden. The $m_J = 1/2$ levels are separated from the $m_J = -1/2$ levels by about 10 GHz so that the coupling to these levels should be negligible too. The total decay rate of level 3 is $12 \cdot 10^6 \text{s}^{-1}$. Level 3 can decay to level 2 with a rate of $\Gamma_{33} \approx 4 \cdot 10^6 \text{s}^{-1}$ and also with a rate of $\Gamma_{44} \approx 8 \cdot 10^6 \text{s}^{-1}$ to a level 4 which in this case is the $(m_J = -1/2, m_I = 1/2)$ sublevel of the $^2S_{1/2}$ level. For the measurement transition we could use the $m_J = 3/2$ sublevel of the $2p\ ^2P_{3/2}$ level which can be regarded as completely degenerated with respect to the m_I quantum number. One can use circularly polarized light to excite the $m_J = 3/2$ state exclusively which subsequently decays back to level 1 with the decay rate $\Gamma_{55} \approx 12 \cdot 10^6 \text{s}^{-1}$.

V. Summary

The "true" incoherent quantum Zeno effect is sometimes regarded as the inhibition of the incoherent exponential decay of the population of an atomic level due to frequent measurements, as opposed to the inhibition of coherent Rabi oscillations. While the latter has been verified experimentally [2] the former is still regarded as not accessible to experimental verification because the quadratic regime of the time evolution in spontaneous emission is extremely short.

In this paper however we have presented atomic multilevel configurations in which the population of one of the levels decreases exponentially for long times while showing a quadratic time dependence for short times. As opposed to spontaneous decay of a two level system, the duration of the quadratic regime can easily be changed in length and we can also adjust the decay constant of the exponential regime through power-broadening. The principal idea here is to introduce a linewidth in the upper level of a metastable two level system and to pump that system by a weak field. If we start with all the population in the lower level we will find an exponential decay of the population of the lower level instead

of coherent Rabi oscillations. This should make the verification of the incoherent quantum Zeno effect experimentally feasible.

We have also given possible atomic systems in which the required level configurations are realized. For experimentally feasible parameters we have shown analytically and numerically that one should be able to observe the quantum Zeno effect for *decaying* systems in these schemes.

Acknowledgements

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Figure Captions

Fig. 1 : The quantum Zeno experiment of Itano et al. The metastable $1 \leftrightarrow 2$ transition is driven by a weak microwave field. A strong pulsed laser probes the population of the lower state 1 by coupling this level to a third which can spontaneously decay to level 1 again.

Fig. 2 : In (a) the upper level of the Zeno transition $1 \leftrightarrow 2$ can decay to a third level 3 which effectively induces a width in level 2. In system (b) level 2 is coupled to level 3 via a laser field. Level 3 can only decay back to level 2 whereas in configuration (c) decay is also allowed to a fourth level from which no repumping takes place.

Fig. 3 : The time evolution of the population ρ_{11} of level 1 in structure (2b) for the parameters $\Omega_2 = 0.0012\Gamma_{33}$, $\Omega_3 = 0.15\Gamma_{33}$ and $\Delta_2 = \Delta_3 = 0$. The initial quadratic time dependence evolves into an exponential decay to the value 0.5 for larger times. Also plotted are the approximate results of eqns (5) and (7).

Fig. 4 : The time evolution of the population ρ_{11} of level 1 in structure (2c) for the parameters $\Omega_2 = 0.0012\Gamma_{33}$, $\Omega_3 = 0.15\Gamma_{33}$, $\Gamma_{44} = 2\Gamma_{33}$ and $\Delta_2 = \Delta_3 = 0$. The initial quadratic time dependence evolves into an exponential decay for larger times. Also plotted is the approximate result of eqn (14).

Fig. 5 : Configuration (2c) where level 1 can be coupled to an auxiliary level with decay constant Γ_{55} by a laser of Rabi frequency Ω_5 . The presence or absence of resonance fluorescence on the $5 \leftrightarrow 1$ -transition is detected. If the level 3 does not decay to level 4 ($\Gamma_{44} = 0$) then we recover structure (2b).

Fig. 6 : The quantum Zeno effect in structure (2b) for parameters $\Omega_2 = 0.0012\Gamma_{33}$, $\Omega_3 = 0.15\Gamma_{33}$ and $\Delta_2 = \Delta_3 = 0$. The Rabi frequency of the measurement pulse is $\Omega_5 = 4\Gamma_{33}$ and the decay constant of level 5 $\Gamma_{55} = \Gamma_{33}$. The duration of a measurement pulse is $T_P = 5\Gamma_{33}^{-1}$ while the separation is given by Δt . With increasing number of measurements the decay of ρ_{11} is increasingly inhibited.

Fig. 7 : The quantum Zeno effect in structure (2c), $\Gamma_{44} = \Gamma_{33}$, for parameters $\Omega_2 = 0.0012\Gamma_{33}$, $\Omega_3 = 0.15\Gamma_{33}$ and $\Delta_2 = \Delta_3 = 0$. The Rabi frequency of the measurement pulse is $\Omega_5 = 4\Gamma_{33}$ and the decay constant of level 5 $\Gamma_{55} = 3\Gamma_{33}$. Pulse lengths and separations are the same as in Fig. 6. Again the decay of ρ_{11} is increasingly inhibited with growing number of measurements.

Figure 1:

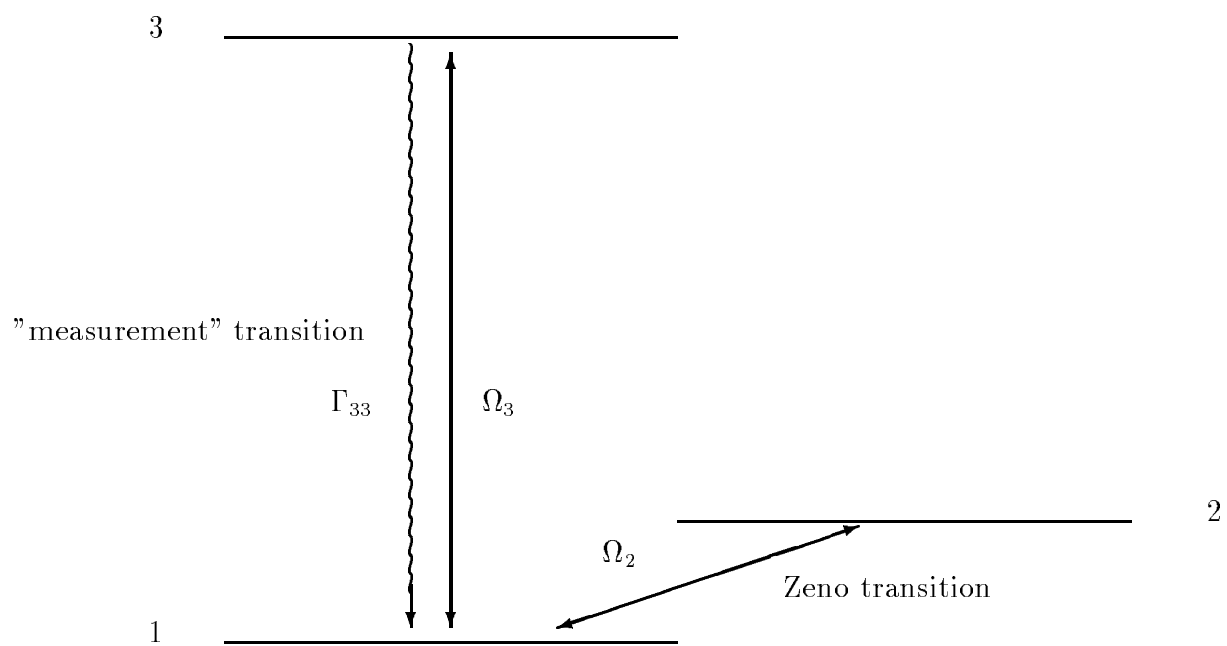


Figure 2a:

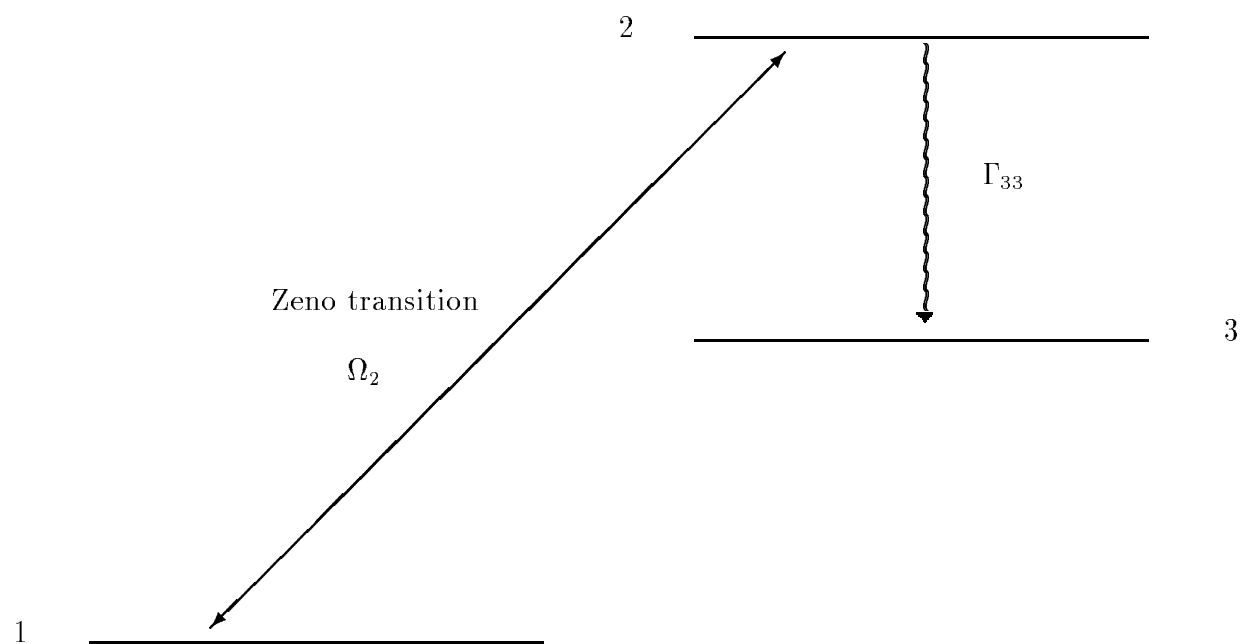


Figure 2b:

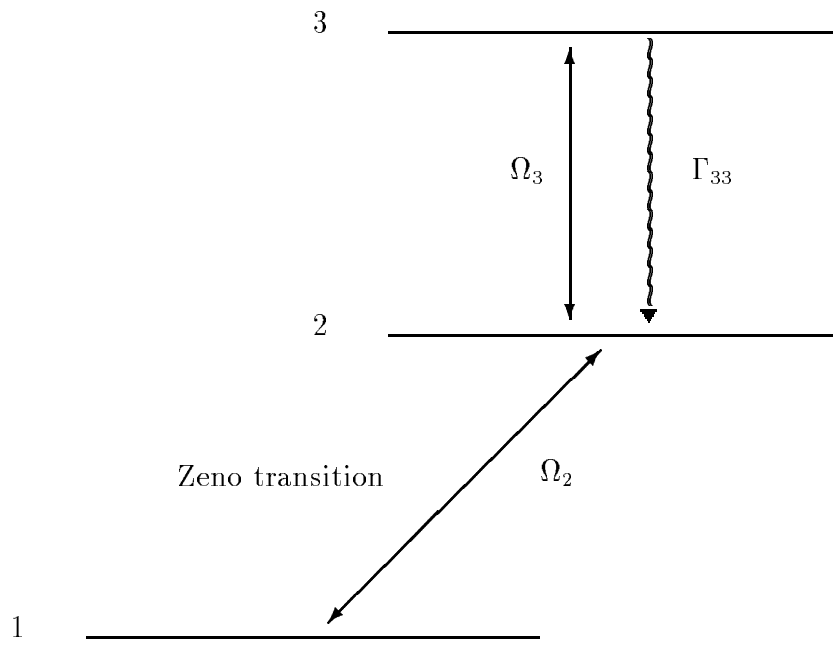


Figure 2c:

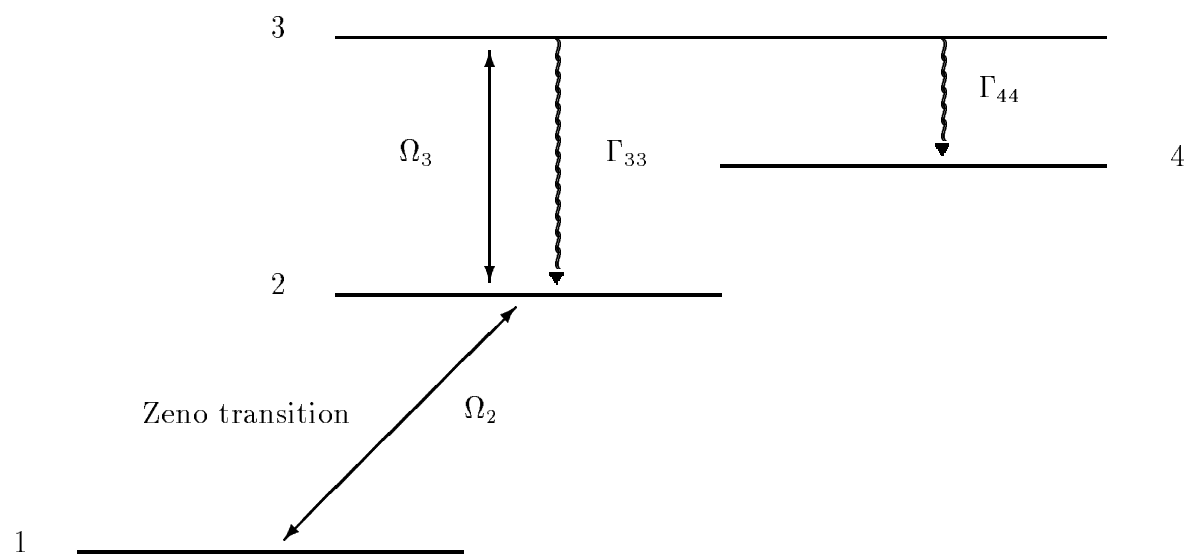


Figure 3:

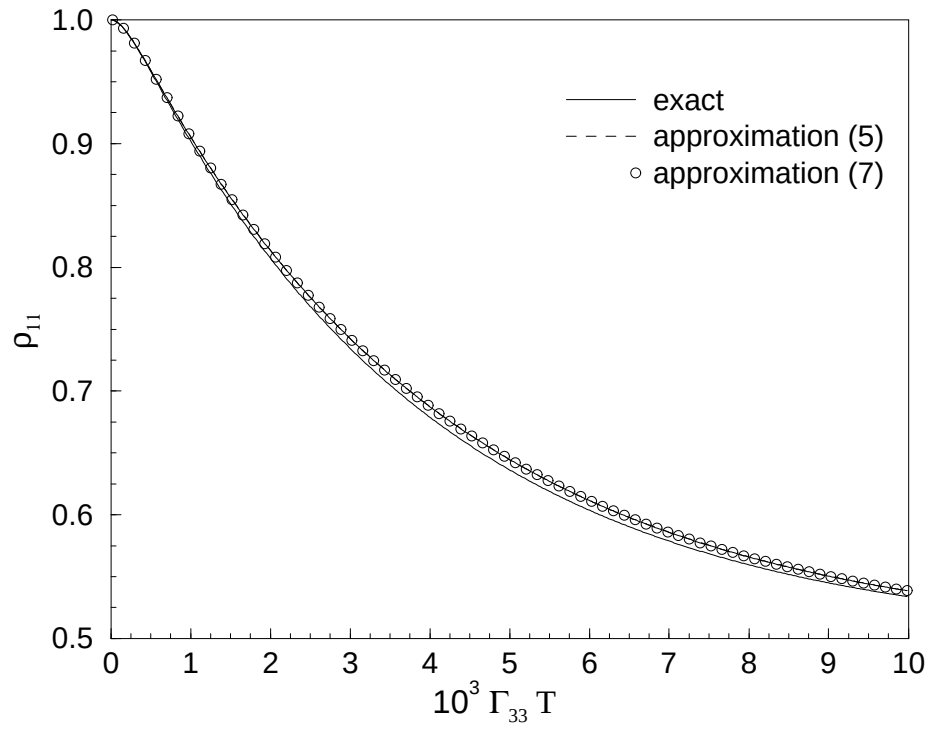


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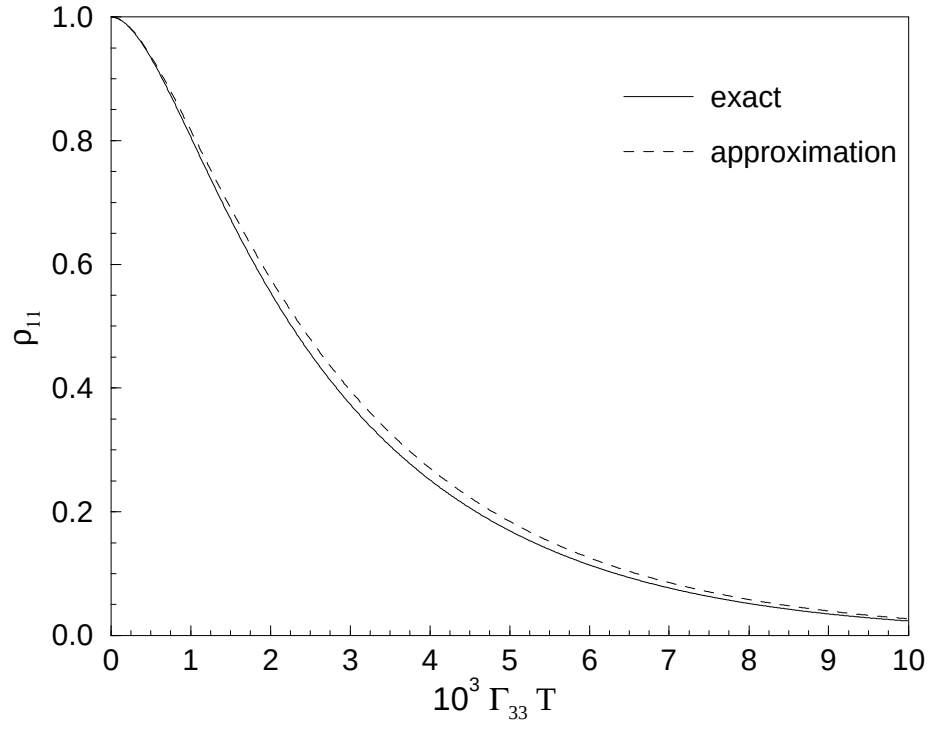


Figure 5:

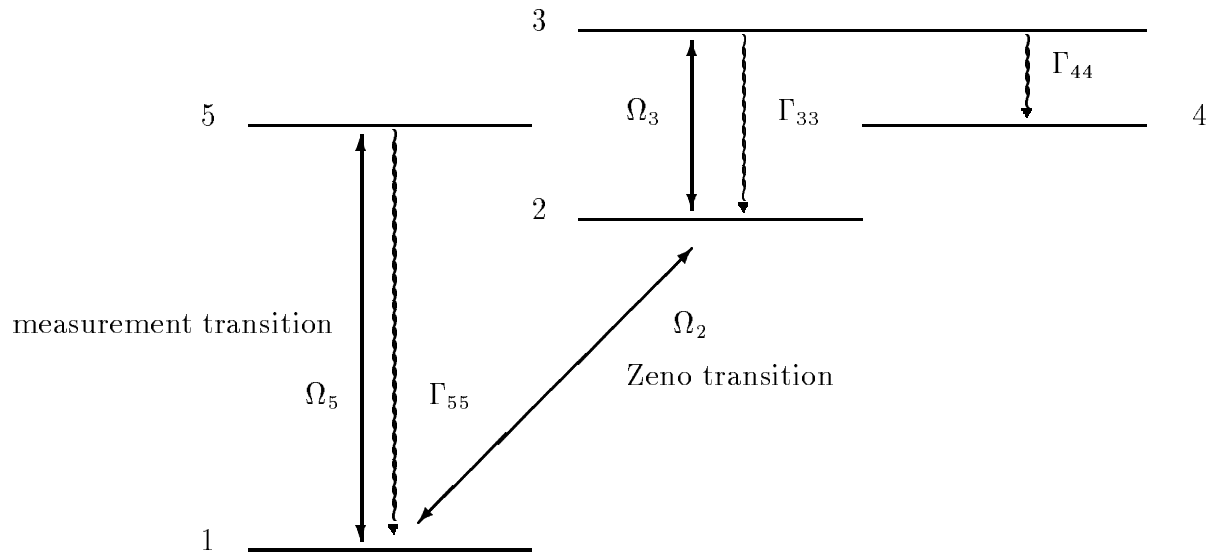


Figure 6:

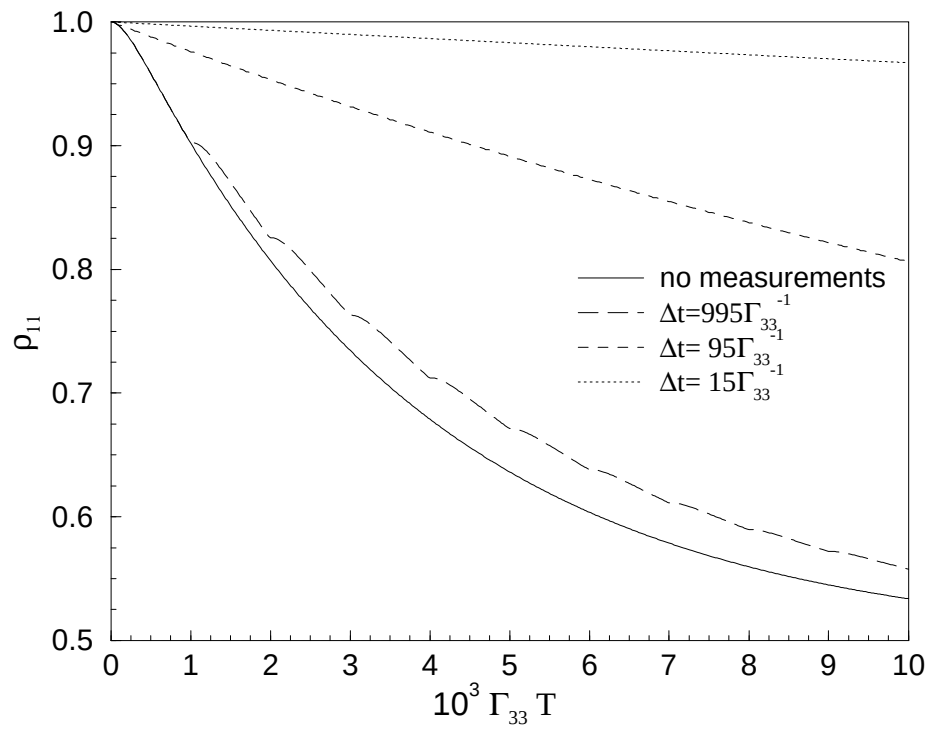


Figure 7:

