Source Field Effects and Wave Function Collapse

Atilla Gurel atillag@physics-qa.com
Hektas Ticaret TAS GOSB Gebze Kocaeli Turkey
Zeynep Gurel zgurel@marmara.edu.tr
Marmara University, Faculty of Education, Physics department,
Fikirtepe Istanbul Turkey

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To E.T. Jaynes, in memoriam.

Abstract
Detection of a material particle is accompanied by emission of bremsstrahlung. Thus the dynamics of the energy loss of the particle is determined by radiation reaction force. The description of radiation reaction is a difficult problem still being subject of ongoing debates. There are problems of runaway solutions, preacceleration already in classical description of radiation reaction. Additional complications in quantum mechanical description arise because of the infinite source field energy term in hamiltonian for a point charge. There is still no general consensus on an appropriate quantum mechanical description. Neither the achievements of the radiation theory on the subject nor the problems associated with it are sufficiently taken into account in context with measurement problem. Radiation reaction doesn’t effect free particle wave packets, but it favors stationary states of the “wave function of the measured particle” in presence of a potential gradient. We suggest therefore that radiation reaction may play a significant role in the dynamics of the wave function collapse.

keywords: wave function collapse, interpretation, randomness, Jaynes Cummings dynamics, spontaneous emission, source field effects, radiation reaction, quantum measurement, decoherence
1 Introduction

1.1 Current situation on quantum measurement problem

There are basically two different viewpoints (1.1.a and 1.1.b) regarding the problem of wave function dynamics during a quantum measurement.

1.1.a “There is no problem at all. The wave function is not a physical entity in classical sense but it is only a mathematical construction that allows us to calculate the probability to observe a particular outcome in a measurement. It represents therefore not “actual reality” but only “potential realities”. The “collapse” therefore is not a continuous time evolution of a physical entity but only a “sudden(?)” actualization of one of these potential realities. The dynamical laws of physics (QM) describe only the time evolution of this probability amplitude but not its “collapse”. Therefore, there is no sense in looking for a dynamical description of this process. We have to accept this new reality however discomforting it may be philosophically. ”

This mental attitude is expressed most clearly by R.P. Feynman who said in one of his popular lectures (Dudley J.M et al. (1996)):

"You will have to accept it. Because it is the way nature works. If you want to know the way nature works, we looked at it carefully. Looking at it, that is the way it looks. You dont like it? Go somewhere else. To another universe, where the rules are simpler, philosophically more pleasing, more psychologically easy. I cant help it,okay ?”

1.1.b “There is a problem. The measuring device itself is obviously nothing but a physical system. Which aspect is so fundamentally different in the interaction between particle and measuring device so that laws of dynamics of quantum mechanics (that preserve the superpositions of wave function) are interrupted during this interaction so that all components in the initial superposition should vanish except the actual outcome.”

If an electron beam goes between two plates of a capacitor, it interacts with the electrostatic field. The beam changes its direction, but there is no collapse. We can verify this by the fact that the capability of interference of the beam is still there after it comes out of the capacitor. Ultimately, what happens in a measuring device is nothing but the interaction of the beam with the electromagnetic field of the atoms. Thus, basically there is no qualitative difference between the two processes but only a quantitative difference regarding the number of interacting particles, the strength of the electromagnetic field etc. Thus, there is no reason that something qualitatively different like “actualization of one of the potential realities” should occur only in one process but not in the other. Notice that the problem of
Copenhagen interpretation is not the supposedly fundamental randomness, but the problem is the lack of physical or objective criteria that allows us to determine under which physical circumstances "one of the potential realities becomes actualized". Thus, in our opinion, there is indeed a problem. With all respect to Feynman’s creativity and his extraordinary mind that made great achievements in physics possible, his words cited above are unacceptable because they ignore the inherent potential in science for continuous progress. There is no philosophical argument that justifies the idea “what is not known now, should remain unknown for ever”.

The suggested solutions to the problem can be classified into two groups(1.1.c and 1.1.d).

1.1.c Some physicists try to solve the problem by importing new elements or mechanisms into the theory. Bohmian trajectories(Bohm,(1993)), spontaneous collapse hypothesis of Girhardi Rimini and Weber (1986), and all hidden variable theories in general belong to this group.

1.1.d Other physicists try to find solutions within known QM without adding new elements or mechanisms to the known equations. Decoherence theories of measurement(Zurek(1982)), relative state interpretation(Everett,(1957)), and consistent histories approach (Griffiths (1984)) belong to this group. They all seem to converge into a single picture of decoherent histories approach that J.Bub calls "the new orthodoxy" (Bub (1997)page 207).

In this paper we will not discuss the alternative theories mentioned under 1.1.c, but our discussions will remain within the boundaries of the established theory.

Decoherence\(^1\) seems to explain why we do not observe a superposition of the macroscopically distinct states of the measuring device corresponding to different values of the pointer variable in an individual measurement\(^2\)(Zurek(1982)). However, it does not explain at first sight why the observed outcome is the actual one and not another one. This problem is "solved" by interpreting each diagonal element as parallel evolving but non-interacting branches of classical reality so that in each branch it appears as if only one particular outcome is actualized. What we experience as actual "we" is only one of these branches. Thus the decoherence is considered as the

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1 the vanishing of the off diagonal elements of the density matrix in pointer variable basis

2 the term decoherence is a very general term referring to loss of interference. It is sometimes used also to refer to the destruction of the interference pattern that emerges as a result of large number of measurements. For example, the interference pattern on the scintillating screen is lost when electrons are disturbed while passing through the slits. This should not be confused with the decoherence between the collective states of the measuring device representing the pointer variable in an individual measurement.
intrinsic mechanism that leads to branching of histories that was suggested by Everett. There is still no consensus whether the decoherence mechanism is sufficient to explain the unique outcome in a measurement or not (Bub (1997) page 231, Adler (2003)). A detailed discussion of the arguments on this subject is beyond the scope of this paper; however we want to present one argument as to why we think that decoherence does not explain the unique outcome in a measurement:

The more the wave function of a particle is localized in space, the broader its Fourier spectrum is; namely the less localized it becomes in momentum space. We experience this experimentally as the uncertainty principle between position and corresponding momentum. According to the decoherence picture, on the other hand, the measurement of position doesn’t mean an actual localization of particle wave function in position space, but it is merely a slicing of measuring device states each corresponding to detection at different position into noninterfering branches of classical reality. Thus, even after the measurement, the state in the total configurations space (that contains the measured particle and all particles that make up the measuring device) continues to contain all positions of the measured particle that were held by the particle immediately prior to measurement. If this were correct, measurement of transversal position with a detector would have no effect on the sharpness of the transversal momentum of the particle. This contradicts the experience. A measurement of transversal momentum immediately after position measurement on a large number of identically prepared particles would indeed show that the transversal momentum of the particle would fluctuate randomly in accordance with Heisenberg uncertainty principle when it comes out of a thin detector after being detected. This shows that detection is not merely a slicing of the total wave function, but that it is an actual localization of the particle wave function. One can find arguments to overcome this difficulty but it takes us further and further away from beautiful simplicity of the known foundations of QM.

One may ask whether known quantum mechanics provides a mechanism that actually destroys the initial superposition? The general argument used to rule out this possibility is:

“This is principally not possible because QM is linear and the conservation of superpositions is the direct consequence of this linearity”

Quantum measurement is a QED problem. In QED the Hamiltonian contains not only the energy of the particle, but also the energy of the electromagnetic field; and the wave function in QED is not the “particle wave function” of the ordinary QM anymore but a more abstract wave function

3prepared with sufficiently sharp momentum prior to measurement (plane wave)
that describes the whole system consisting of material particle(s) and electromagnetic field. In fact, the term “particle wave function” is not appropriate because this wave function cannot be written as a product of two wave functions because of the correlated states between electromagnetic field and particle. We will continue to use the term “particle wave function” in quotes for practical purposes. We will discuss in subsection 3.2 and in paragraph 4.a in section 4 why this linearity argument is incorrect if the subject of interest is not the time evolution of the whole system but the time evolution of a subsystem like “wave function of measured particle” (as it is the case in a measurement) or more correctly expressed the time evolution of particle position operator in Heisenberg picture if we consider the source field of the particle in total hamiltonian.

1.2 Radiation reaction and quantum measurement

In quantum mechanical terms, the detection of an electron is an inelastic scattering process in presence of large number of scattering centers accompanied by emission of bremsstrahlung and the transversal localization of “particle wave function”. The scattering theory focuses on differential cross section of emitted bremsstrahlung based on incoming and outgoing electronic momentum eigenstates. (Itzykson, C.;Zuber, JB. p.238 (1985)) It neither focuses on the very mechanism of the energy dissipation as a consequence of source field dynamics during the short time period while interacting with the scattering center, nor does it focus on the effect of this process on the spatial transversal form of the wave function.

The dynamic localization of the particle wave function without explicit presence of radiation field is not something completely unknown to quantum mechanics. Consider, for example, the transition of an atom from an excited state in discrete spectrum region to the ground state by spontaneous emission. The spatial extension of the initial electronic state can be arbitrarily large if its energy quantum number n is very large. The role of radiation reaction in QED description of spontaneous emission was first realized in the seventies (Ackerhalt et.al.(1973)) and an intensive discussion regarding the respective roles of vacuum fluctuations and radiation reaction followed. (Milonni et.al (1973); Senitzky (1973); Milonni Smith (1975); Milonni (1976)). Milonni (1976) (1980). According to the currently accepted picture, spontaneous emission is triggered by vacuum fluctuations and proceeds under combined effect of vacuum field and radiation reaction (Dalibard et. al. (1982)(1984); Cohen-Tannoudji (1986)). Considering the zero expectation value of transversal momentum and the obvious role of radiation reaction in the detection process, one wonders whether the transversal localization
during detection may have some aspects common with spontaneous emission so that there may be no need to import an additional ad hoc spontaneous localization mechanism as suggested by Girardi Rimini and Weber (1986). A problem is that there is still no general consensus on an accurate quantum mechanical description of radiation reaction so that it can be applied to a realistic model of quantum measurement. Discussions and controversies on the subject continue. Rohrlich (2001)(2002) Ribarič (2002) Baylis (2002) O’Connel (2003) Heras(2003)). It is a complicated subject already in classical description because of problems of runaway solutions and preacceleration. The problem becomes more complicated in quantum mechanics if one tries to solve it starting from first principles because of infinite source field energy in hamiltonian for a point charge. The price we have to pay to overcome this difficulty by renormalization in perturbative QED is that the effect of self retardation is lost in description (Grotch et.al.(1982)).

Considering the mentioned difficulties related to quantum mechanical description of source field effects, it is clear that realistic modeling of a quantum measurement is a very difficult problem to solve. Current decoherence models of measurement are, on one hand, far from reflecting this complex aspect of the process because they ignore source field effects, but on the other hand, they complicate the problem in a wrong direction by including the macroscopic measuring device with its huge number of particles into the total wave function and going to a configurations space with huge dimensions. This is somewhat a misleading model, for example, for position measurement with a scintillating screen, where the real problem gets out of focus. The significant role of the screen is merely providing a strong electrostatic field of a particular (quasi-periodic) form that decelerates the particle so that it emits Bremsstrahlung. It is the emission of this radiation from a localized spot that makes up the measurement, and it is the high initial energy of the particle that leads to the high intensity of the emitted radiation and to the macroscopicality, thus to the observability of the effect and not the motion of the pointer of a fictious macroscopic measuring device.

The following points are certain:

1.2.a Energy exchange with radiation field without explicit presence of external radiation field can proceed only under the influence of two factors in QED: Vacuum fluctuations and/or source field effects.

1.2.b Detection is essentially an energy exchange between material system and radiation field without explicit presence of external radiation field(except thermal background fluctuations and vacuum fluctuations). Detection has not occurred unless energy exchange with radiation field has occurred.

The consequence of 1.2.a and 1.2.b is: If it should be possible at all to
understand collapse within laws of QED, without introducing new elements or mechanisms, it must be a consequence of fluctuations and/or source field effects.

1.3 The organization of this paper

1. In section 2 we introduce the problem of radiation reaction in quantum mechanics, and we try to outline why do we think that the consideration of radiation reaction on the dynamics may have a potential value to open new perspectives for understanding the mechanism of collapse.

2. In section 3 we go to the history of quantum mechanical description of radiation reaction to understand why radiation reaction has not been discussed sufficiently in context with quantum measurement despite its relevance. In section 4 we summarize possible reasons.

3. Any successful dynamical collapse theory (based on whatever mechanism) would make the probability amplitude interpretation superfluous and would automatically impose a realistic interpretation of wave function. Therefore, proposing any type of dynamical collapse mechanism requires the discussion of the arguments that are raised against any type of realistic interpretation and against any type of dynamic collapse approach in general. This is done in section 5.

2 Radiation reaction in quantum mechanics

2.1 The problem

We will introduce the problem of radiation reaction from the perspective of ordinary QM without intentionally first going to a QED hamiltonian. The reasons will be clear later.

Schroedinger equation for a particle with electric charge $e$ and mass $m$ in an external electrostatic potential $V(x,y,z)$ has the form:

$$-\frac{\hbar^2}{2m} \nabla^2 \Psi(x,y,z) + eV(x,y,z)\Psi(x,y,z,t) = i\hbar \frac{\partial}{\partial t} \Psi(x,y,z,t)$$

(1)

using the Ansatz

$$\Psi(x,y,z,t) = \psi(x,y,z)e^{-i\omega t}$$

(2)

one can obtain the eigenvalue equation

$$-\frac{\hbar^2}{2m} \nabla^2 \psi(x,y,z) + eV(x,y,z)\psi(x,y,z) = \hbar\omega \psi(x,y,z)$$

(3)

$^4$we mean not a “slicing” as suggested by decoherence mechanism but an actual collapse
Equation (3) has an infinite number of solutions $\psi_k$ with corresponding $\omega_k$ such that $E_k = \hbar \omega_k$ is the energy of each particular solution. These solutions are stationary, which means that $|\Psi|^2$ is time independent. The most general solution of equation (1) can be written as

$$\Psi(x, y, z, t) = \sum_k a_k \psi_k(x, y, z) e^{-i\omega_k t}$$

(4)

where $a_k$ are constant. The $a_k$ satisfy the normalization condition: $\sum |a_k|^2 = 1$ (The sum should be replaced by an integral for continuous energy regions in the spectrum). The time evolution of the expectation value of the position $\langle r \rangle = \int \psi^* r \psi \ dr$ of a localized wave packet that can be constructed using (4), is given by Newton’s equation of motion

$$m \frac{d^2}{dt^2} \langle r \rangle = -\nabla V$$

(5)

This correspondence with classical mechanics is known as the Ehrenfest theorem. An important property of the solution (4) is that, since $a_k$ are time independent in a static potential, the expectation value of particle’s energy is conserved, namely:

$$\frac{d}{dt} \langle E \rangle_{\text{particle}} = \frac{d}{dt} \sum_k |a_k|^2 E_k = 0$$

(6)

There is no dissipation of energy in this model. Classically, however, accelerated charges radiate and the energy of the particle decreases because of radiation. One may expect that this should also occur for an accelerated quantum mechanical wave packet. That this expectation is justified is verified by synchrotron radiation. Thus, obviously eq. (1) is sufficient only as long as the energy dissipation rate by radiation reaction is negligible.

2.2 Potential relevance for quantum measurement

Although it is clear that radiation reaction is involved in measurement, we may ask: “Are there any indications that its consideration may have any potential value for a better understanding of collapse or can it provide at most only a more refined description of the process but without providing any clues for how collapse occurs?”

2.3.a Since there must be an energy dissipation from particle to electromagnetic field in the case of accelerated wave packet eq(6) cannot be valid. To allow this energy dissipation, the coefficients $a_k$ in (4) must be time dependent; thus the solution cannot be written in form of (4) with constant
While the superposition of the form (4) representing a free particle wave packet (outside the measuring device) is not effected by radiation reaction, since there is no acceleration \( \langle d(r)/dt = \text{const.} \rangle \), it begins to decay to lower energies if it enters a region with a nonzero potential gradient (an measuring device) because of energy dissipation by radiation even in the absence of external radiation field! Thus it is obvious that the initial weights of the particle energy eigenfunctions in the superposition are not conserved. Thus radiation reaction destroys the superposition of “particle wave function” that enters the measuring device. This is good news and shows why a simple “linearity of QM” argument as mentioned at the end of the subsection 1.1 is incorrect. This is, however, not enough because what we need is not merely the non-conservation of the weights in the superposition, but what we need is that some states are preferred so that they can be chosen during measurement.

2.3.b We may suspect that stationary states of eq.(1) in presence of a potential gradient (like bound atomic energy eigenstates in detector) should not be affected by radiation reaction because \( d\langle r \rangle/dt = 0 \). Since there is no truly static field in a real world we may say, the closer the particle is to a stationary state of the quasi-static potential of measuring device the smaller the radiation reaction force is on the “particle wave function” so that these constitute (relatively) stable islands in the function space of particle.

The consideration of 2.3.a and 2.3.b together indicate that if the wave function comes somehow close to a quasi stationary state during the dissipative time evolution, it will stay there much longer because of minimal radiation reaction when compared to a state in full superposition. Thus, the likelihood to be found in such a quasi-stationary state is greater then the likelihood to be found in a full superposition. This indicates that it may be worth studying its possible role in collapse.

There are of course spatially extended stationary electronic states in a static potential created by an array of atoms so that one may doubt whether the above considerations may provide an understanding of localization. These are however only theoretically stationary in an ideal case of perfectly static potential. In a real world the relative positions of atoms fluctuate because of thermal vibrations so that such spatially extended electronic states are practically nonstationary and unstable because of radiation reaction. It is conceivable therefore that the electron would become localized in the energetically most favorable location under these conditions.

To prevent a misunderstanding for a reader with a background in QED and radiation theory we want to make some remarks in advance. One may ask “Is this expectation in accordance with QED or is this a semiclassical assumption that uses implicitly the already refuted Schroedinger interpretation of the wave function where \( |\Psi|^2 = \text{charge density} \)”. As we will see in subsec-
tions 3.4 to 3.7, the presence of radiation reaction in presence of a potential gradient doesn’t rely on a semiclassical assumption, but it is the direct consequence of time evolution for particle position operator in Heisenberg picture if one takes the source field dynamics into account without leaving the operator formalism of QED and without using extra semiclassical assumptions.

Before exploring alternatives like modifying Schroedinger equation (SE) by nonlinear or ad hoc stochastic terms, it is important to be aware that SE as it is, neither includes the effect of vacuum fluctuations that can be a possible candidate for providing the necessary stochasticity naturally from within QED, nor does it include the effect of radiation reaction on particle wave function. Thus vacuum field and source field dynamics may already provide the necessary modification to SE naturally. In consideration of the principle of Ockham’s razor it is obviously preferable to look for a solution within QED before considering ad hoc modifications to SE. These alternatives should be explored only if the possibilities within QED are fully exhausted and proven to be not a solution to the problem.

To understand why the role of radiation reaction has not been considered in context with the dynamics of wave function collapse until now despite these indications, let’s take a look at the history of quantum mechanical description of radiation reaction that is full of controversies on the interpretation of wave function.

3 History: Relation between the quantum description of radiation reaction and the interpretation problem

3.1 Radiation reaction: a problem that is still unsolved classically

Classically the effect of the energy loss by radiation of an accelerated charge on the motion of the charge is described by the well known Abraham-Lorenz equation:

$$m_{\text{eff}} \frac{d^2 r}{dt^2} = F(t) + \frac{2e^2}{3c^3} \frac{d^3}{dt^3} r$$

(7)

where $m_{\text{eff}}$ is the effective mass $m_{\text{eff}} = m + \delta m$ and $\delta m$ is the contribution of electromagnetic self energy to the effective mass. $\delta m$ depends on the size of the charged particle. The second term on the right describes radiation reaction and acts similar to a friction force. There is, however, a problem
with the equation (7). It allows runaway solutions, namely, solutions where
the acceleration increases exponentially even in the absence of external forces.
If one tries to eliminate the runaway solutions by the imposition of a suitable
boundary condition for $t \to \infty$, one obtains the acausal behavior known as
preacceleration. The particle accelerates namely before the force acts. The
problem doesn’t disappear in relativistic treatment of Dirac either.

3.2 Things become even more complicated in quantum
description

We may ask now, for example, how we should modify equation (1) so that
a quantum mechanical equivalent corresponding to the second term on the
right side of eq. (7) automatically emerges on the right side of the equation
(5).

If we want to develop a quantum description, the problems we face are:

3.2.a How do we avoid infinite self energy and runaway problems?

3.2.b We have only time evolution of the particle wave function, but no
definite trajectory. How do we calculate the changes in the source field if we
don’t know how the source particle precisely moves?

There has been basically two different approaches to the source field prob-
lem in the history of quantum mechanics(3.2.c and 3.2.d).

3.2.c. Quantum electrodynamics (QED) includes the energy of the elec-
tromagnetic field in the hamiltonian operator as in eq.(10). This proce-
ss is called quantization. Including source field energy into the hamiltonian
in this way requires that it has to be written as an integral over $E^2$. This
presents difficulties for a pointlike charge because it leads to infinite self en-
ergy. The fact that the runaway solutions are eliminated for particles with
a sufficient size was not known until the seventies( Moniz and Sharp (1974);
Levine et al (1977)). QED expects that if source field energy is inclu-
ded in hamiltonian, quantum mechanical description of radiation reaction must
follow automatically.

3.2.d. Semiclassical theories (SCT) describe material particles quantum
mechanically, but to avoid the infinite self energy problem and as a simple
solution to problem 3.2.b they use the Schrödinger interpretation (SI) of
particle wave function (where $\Psi$ is not merely probability amplitude but
$|\Psi|^2 = \text{classical charge density}$). Electromagnetic field is not quantized (E
and B are not operators but c-number fields) and the internal dynamics of
electromagnetic field is described by Maxwell equations. Thus we have a
system of coupled nonlinear equations that determine the dynamics of the
whole system.
3.3 The first steps in QM: Source field in semiclassical and neoclassical radiation theory (NCT)

Because of the difficulty of infinite source field energy for a pointlike particle, the quantization of the electromagnetic field was applied only to free field, and the source field problem couldn’t be attacked by QED approach for a long time. In 1927, two papers appeared both describing the radiation of an atom but representing the mentioned two different viewpoints (3.2.c and 3.2.d). Dirac took Fourier spectrum of the electromagnetic field and used the time dependent perturbation theory to calculate its effect on the atom. Fermi used the Schrödinger interpretation of the wave function and added a nonlinear term containing the expectation value of dipole moment operator describing the energy dissipation by radiation reaction. Fermi’s model is discussed by Wodkiewicz (1980). Fermi found that an excited two level atom would decay to the lower state with a time dependence that has the following form

\[
|a_2(t)|^2 = \frac{1 - |a_1(0)|^2}{1 - |a_1(0)|^2 + |a_1(0)|^2 e^{At}}
\]

(8)

where \(a_2(t)\) is the weight of the excited state \(\psi_2\) and \(a_1(t)\) is the weight of the lower state \(\psi_1\) in the superposition. For \(a_1(0) = 0\) there is no decay. For \(a_1(0) > 0\) the decay starts with an initial slope that depends on \(a_1(0)\) (small for small \(a_1(0)\)), it reaches a turning point (the smaller \(a_1(0)\), the longer it takes) and reaches asymptotically \(e^{-At}\) after the turning point. Interestingly, the decay rate \(A\) in Fermi’s formula (8) that determines the exponential tail (long term behaviour) agrees with the decay rate in Dirac’s exponential decay and it has the following form:

\[
A = \left(\frac{e^2}{3\pi \epsilon_0 c^3 \hbar}\right) [(E_2 - E_1)^3 / \hbar^3] \left(\int \psi_1^* \psi_2 \, dr\right)^2
\]

(9)

where \(E_2\) and \(E_1\) are the eigenenergies of \(\psi_2\) and \(\psi_1\) respectively.

After the successful calculation of the emission line width in exponential decay by Weisskopf and Wiegner in 1930 on the basis of Dirac’s model of quantized light field and after Weltons successful interpretation of Lamb shift as a direct observable effect of vacuum fluctuations in 1948, the folk theorem “vacuum fluctuations cause the spontaneous emission” established itself in text books (see Baym (1969) p. 276), and radiation reaction became more and more to be regarded rather as a classical concept that is superfluous in quantum mechanics. In the fifties and sixties, semiclassical models (par. 3.2.d) in connection with masers became popular again because the Dirac’s transition probabilities were not sufficient for describing phenomena where
phase relations between radiation field and atom’s wave function played an important role because of long term coherences. In these semiclassical models, one tried to find sufficiently accurate solutions of the Schrödinger equation for the given boundary conditions. (Shimoda et al. (1956)). Jaynes at al. enhanced semiclassical theory by including the effect of source field back on the electromagnetic field in the cavity and called it neoclassical theory (NCT). What they wanted to do was not merely to develop a better description of cavity phenomena, but to challenge the established “probability amplitude” interpretation and to restore Schrödinger’s realistic interpretation of wave function. The model successfully described the cavity dynamics.

3.4 Correspondence and discrepancy between nonlinear NCT and linear QED

The success of NCT led to the following question: “What is the degree of correspondence or discrepancy between the nonlinear neoclassical equations and linear QED?” This was the question that was addressed by Jaynes and Cummings in the (1963) paper. They calculated the time evolution of an atom’s dipole-moment and electric field in a resonant cavity using the two competing models, namely according to NCT based on Schrödinger interpretation of the wave function on one hand and pure quantum mechanically using the commutators in Heisenberg picture on the other hand.

They showed that the time evolution of the operators in Heisenberg picture agreed to a great extent with the time evolution predicted by coupled nonlinear semiclassical equations (p.101 fig.4) even in the few photon region. (p. 97). The main difference between QED and NCT seemed only the lack of correlated states in NCT. In NCT product of expectation values appear where the expectation value should be taken after the multiplication of the operators according to QED. The actual time evolution was differing only slightly in the two models(p.101 fig.4). Thus calculations indicated that Schrödinger interpretation was not as in contrast to QED as previously thought. Thus Fermi’s nonlinear model of spontaneous emission (8) is not a mutually exclusive alternative to Dirac’s description, inconsistent with principles of QM but it is an incomplete approximate model that reflects only a partial aspect of the process.

In 1969 Crisp and Jaynes calculated lamb shift and spontaneous emission

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\textsuperscript{5}There is a typographical error on page 97 regarding the equation number referred in the text. In the phrase ”...which is to be compared to (12c). If we interpret (12c)as the expectation value of (20)......” the authors refer in truth to (69c) instead of (12c) and to (77) instead of (20)
using the semiclassical model where the lamb shift and spontaneous emission appear merely as a consequence of radiation reaction. In 1970 Stroud and Jaynes presented an improved semiclassical model taking the results of 1969 paper into account. There were only some small differences between predictions of QED and the NCT.

3.5 Source field in perturbative QED

The success of NCT led to controversies because of the fundamental difference in the interpretation of wave function when compared with QED. This success of NCT motivated QED defenders to take a closer look at the mechanism of spontaneous emission. Based on pure QED calculations, Ackerhalt et.al.(1973) suggested that radiation reaction should play the dominating role in spontaneous emission. Detailed calculations later showed that one could see vacuum fluctuations and radiation reaction as two faces of the same reality and the interpretation one may adopt depend on the ordering of the operators. (Milonni et.al (1973); Senitzky (1973); Milonni Smith (1975); Milonni (1976)). Milonni (1976) (1980) suggested that spontaneous emission should be considered as a result of the combination of both effects. Milonni showed also that although the interpretation of the cause of line shift may depend on ordering of the operators, the role of radiation in dynamics of energy loss does not depend on ordering. This combined role of vacuum fluctuations and radiation reaction in spontaneous emission is widely accepted today. (Dalibard et. al. (1982)(1984); Cohen-Tannoudji (1986)).

Despite the great success of NCT, there were early signs of conflicts with experiments regarding correlated outcomes in measurements (Kocher (1967), Clauser(1972)). There were also discrepancies regarding emission line shape. As time passed and experiments improved, QED won the battle over NCT on these issues\(^6\). However NCT served a great purpose in the history of physics: By stimulating the reconsideration of source field effects in QED, it helped the physics community to realize that the consideration of source field effects does not necessarily need semiclassical assumptions and it stimulated the efforts to find solutions to source field problem beyond perturbative QED.

3.6 Source field dynamics beyond perturbative approach

In all these discussed QED models, the potential energy of the dipole is considered in the Hamiltonian by a potential term of the form \(1/(r_1 - r_2)\)

\(^6\)except one prediction of NCT defenders regarding quantum beats in Λ type atoms that we will discuss in paragraph 5.f in section 5. This was however not the deficiency of QED itself but the misinterpretation of QED by its defenders.
and not as an integral over $E^2$. It is only the free radiation field that is expanded in terms of creation and annihilation operators. The role of radiation reaction can be identified only by the interpretation of the dynamics after appropriate ordering of operators. However we know that a potential term in form $1/(r_1 - r_2)$ has only approximate validity because it implies that the Coulomb field immediately changes over the whole space when the position of the particle changes. This is not true from the relativistic point of view and one has to take the retardation into account. That energy is transported away by electromagnetic radiation indicates that the energy is indeed in the electromagnetic field and not in the charges so that we have to write it as an integral over $E^2$. The following example shows that we cannot escape this: Consider, for example, a charged particle with mass $m_1$ in the gravitational field of a neutral massive object with mass $m_2$. The Hamiltonian must contain a gravitational potential term of the form $gm_1m_2/(r_1 - r_2)$, but there is no electrostatic potential term of the type $1/(r_1 - r_2)$ because there is only one charged particle. The particle has obviously a Coulomb field however unsharp its value is according to QM, and it radiates because of acceleration as it is assumed to happen when x-rays are emitted while plasma from neighboring star is falling into a black hole. There are no electrical dipoles in synchrotron radiation either. Thus, we must somehow find a way to describe radiation reaction quantum mechanically even for a single particle wave packet independent of the nature of the force that accelerates it.

Sharp and Moniz were aware of this problem and turned their attention to a purely quantum mechanical nonperturbative treatment of radiation reaction of a single particle (Moniz and Sharp (1974)(1977); Sharp (1980)). Their starting point was the following Hamiltonian:

$$H = \frac{1}{2m}[\mathbf{p} - \frac{e}{c}\mathbf{A}(r)]^2 + \frac{1}{8\pi} \int d\mathbf{R} \{E^2(\mathbf{R}, t) + (\nabla \times \mathbf{A}(\mathbf{R}, t))^2\}$$

where

$$\mathbf{A}(r) = \int d\mathbf{R} \rho[\mathbf{R} - \mathbf{r}(t)]\mathbf{A}(\mathbf{R}, t)$$

and

$$\mathbf{E} = E_{\text{long.}} + E_{\text{transv.}}$$

$r$ is the operator for particle coordinate and $\mathbf{R}$ is the general space coordinate. The electron is assumed to have a spherical charge distribution $\rho$ so that $\int \rho(\mathbf{r} - \mathbf{R}) = 1$. Thus, unlike the potential term in the Hamiltonian of a two particle system, the Coulomb energy in the field is written as an integral over the field. They obtained the operator form of the Lorentz equations in
Heisenberg picture. As a result of rigorous calculations, quantum mechanical equivalent of the second term in the operator equation corresponding to the classical equation (7) automatically appears on the right side plus some purely quantum mechanical smaller terms with higher powers of $c$ in denominator. If one takes the point charge limit at an appropriate stage, it turns out that additional purely quantum mechanical smaller terms generate an effective charge distribution spread out over a compton wavelength. This eliminates automatically the unphysical runaway solutions (Moniz and Sharp (1974); Levine et al (1977)). If we take the expectation values of the operator $r$ on both sides we obtain the desired modified form of eq.(5). Rohrlich (1980) emphasizes the importance of their results in context with fundamental problems of QED. Grotch et.al.(1982) discussed the relation between perturbative approach and the work of Sharp and Moniz and emphasized the fact that perturbative approach can account only for the effects related to retardation between two particles and the contribution of self retardation cannot be accounted for because of renormalization.

3.7 Present situation

After the work of Sharp and Moniz the problem of radiation reaction has been recognized as a problem by itself in QED, and several works on the subject appeared since then classically as well as quantum mechanically (Jiménez (1987); Lozada (1989); Ianconescu et.al.(1992); Ford et.al (1991) (1993); Kim (1999); de Parga et.al (2001)). There is still no general consensus and discussions continue (Rohrlich (2001)(2002) Ribarič (2002) Baylis (2002) O’Connel (2003) Heras(2003)). Unfortunately discussions on the quantum measurement problem seem to proceed without taking all these developments into account despite the relevance as mentioned in the introduction. Let us summarize the possible reasons for this.

4 Why has it not been considered in context with the collapse problem until now?

In the light of the above discussion, the possible reasons can be summarized as follows:

4.1. The structure of QM and QED is linear. Thus it was assumed that any effect that can be described within the framework of QED cannot be a candidate to explain the wave function collapse and that one has to undertake modifications like making it slightly nonlinear (Weinberg (1989)(1993)) or adding ad hoc stochastic terms to achieve this.
In QED the Hamiltonian does not contain only the energy of the particle, but also the energy of the electromagnetic field; and the wave function in QED is not “particle wave function” of the ordinary QM anymore, but a more abstract wave function that describes the whole system consisting of material particle(s) and electromagnetic field. Although the linearity and superposition principle still holds for the time evolution of this whole abstract wave function, what we measure in a measurement is a particular variable like the position of the “particle” or frequency of emitted “radiation” etc. Therefore, we have to focus on the dynamics of the subsystem like, for example, “wave function of the measured particle”. However, such an exact separation of the total wave function is not possible in QED (although we will use the term “particle wave function” in approximate sense). Nevertheless we can use Heisenberg picture and focus on time evolution of the operator corresponding to the particular variable of interest during the interaction of radiation with matter. As the work of Jaynes Cummings have shown, the back coupling of the atom’s source field to radiation field in the cavity leads to effective nonlinearity of time evolution of the atomic operator.

Thus, if one focuses on time evolution of a subsystem like “particle wave function” as we implicitly do in a discussion of quantum measurement, then the linearity of the QED is a wrong argument to principally discard the possibility that the dynamics of the collapse can be described within laws of QED.

Whether the destruction of superposition of ”particle wave function” by radiation reaction proceeds sufficiently fast to amplify initially small differences rapidly enough, to explain the collapse is still an open question that requires further research to clarify, in particular it requires the consideration of the results of theoretical papers about quantum mechanical description of radiation reaction in measurement theories.

4.2. Radiation reaction was considered for long as a semiclassical concept. It was believed that its consideration necessarily uses implicitly the mental picture “$|\Psi|^2 = \text{classical charge density}$” that is inconsistent with fundamentals of QED where $\Psi$ should be interpreted only as a probability amplitude but not as something physically real that carries the charge (see paragraph 5.f in the next section). Thus it was assumed that the dynamics of this probability wave could not lead to some real physical event. The role of radiation reaction in QED description was realized relatively late, namely in the seventies in connection with spontaneous emission. Not only was Copenhagen interpretation already well established at this time but the skeleton of the most of the well known alternatives to Copenhagen interpretation (like Bohmian mechanics, Everett’s relative state interpretation, von Neumann approach that led to decoherence theories etc.) had already been formed and
started an evolution of their own.

Thus, the situation is that, on one hand scientists working on decoherence approach to quantum measurement seem not sufficiently familiar with all this complicated aspects of radiation theory related to source field effects. On the other hand, scientists working in radiation theory in general and on quantum mechanical description of source field effects in particular have not explored the consequences of their calculations for the measurement problem. Thus what is needed seems to be an inter(sub)disciplinary cooperation.

4.3. The calculation of source field effects starting from first principles is not an easy task. Calculations are already complicated enough in a nonrelativistic treatment as the work of Sharp and Moniz show. Most of the papers on the subject that followed this work use ad hoc introduction of a form factor to avoid infinities. The appealing property of the work of Sharp and Moniz is that it doesn’t rely on ad hoc introduction of finite particle size. Therefore, it can be considered as a milestone on the subject and calculations must be extended into the relativistic region. Discussions on the quantum mechanical description of radiation reaction continue and there is still no general consensus on the subject. The lack of general consensus and the complexity of the calculations even for a single particle prevents its application to more complicated problems like interaction with a measuring device. It seems the solution requires a numerical approach and computer simulations.

4.4. Compared to other radiative phenomena, radiation reaction is considered as a weak process that can be ignored. Although this is true for a typical transition between two atomic bound states, it is not generally true as one can see in formula (9) that gives the magnitude of radiation reaction for a transition between two stationary states. Even for slightest energy differences ($E_2 - E_1$) that can emerge by a slightest removal of degeneration between involved states by fluctuations, large spatial extension of the involved states (as we have when the particle wave function with large transversal extension enters the measuring device) may lead in general to large transversal dipole moment matrix elements ($\int \psi_1 \mathbf{r} \psi_2 d\mathbf{r}$). This large dipole moment may lead to rapid decay rate towards states that are more stable with regard to radiation reaction(namely more stationary or more localized). Consider also that it is not only the dipole moment that contributes to decay but the third time derivative of all position operator matrix elements that contribute to radiation reaction in the case of a spatially extended wave function according to nonperturbative QED calculations of Sharp and Moniz.

So far we have discussed the detection of material particles. We want to make a short remark about the detection of photons. Based on the considerations above one may suggest that simultaneous excitation of multiple
detector atoms by a single photon\(^7\) is not principally impossible because there is a particle-like(pointlike) aspect of the photon complementary to its wave like aspect\(^8\) but it is merely extremely unlikely because if two distant atoms are halfway excited by a single photon, both atoms are in a nonstationary superposition so that such a state would be instable because of source field effects.

## 5 Discussion of general arguments against dynamical collapse or against physically real wave function

Based on whatever mechanism, if you can fully describe with your deterministic wave equation why only one of the possible outcomes is observed you don’t need to attach a special ambiguous ontological status of “probability amplitude” to the wave function. The observed apparently probabilistic behaviour is then only a consequence of dynamics but not an inherent property of the wave function itself. We must note that this doesn’t only apply to a real collapse towards a unique outcome as we suggest, but it applies also to the decoherence picture where the wave function is “sliced” into noninterfering outcomes. In decoherence picture, for example, the pointlike detection of an electron on a scintillating screen at a particular position does not indicate the existence of a pointlike aspect complementary to wavelike aspect but it represents only one of the decohering branches of the detector states corresponding to detection at different locations.(see paragraph on decoherence in subsection 1.1). Thus, there is no need for a pointlike entity to understand pointlike scintillations and thus no wave particle duality if we accept the logical consequences of any type of dynamic collapse within laws of QED.

Obviously a succesful deterministic dynamic collapse theory within QED would explain how the magnitude of the wave function makes the corresponding outcome more probable. This would make the probability amplitude interpretation superfluous and impose automatically a realistic interpretation of the wave function. If we suggest such a possibility in principle we have

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\(^7\)Here we use the term photon in the field theoretical sense namely “n photon state” referring to the “n’th energy eigenstate of the field” in a particular vibration mode and not in the sense used in wave particle duality of old QM

\(^8\)Consider the excitation of vibrational modes of a water molecule in microwave range. The whole molecule as a single multiparticle quantum system absorbs the energy of a single photon over many cycles. We cannot say that the incoming photon is absorbed by the oxygen atom or by the hydrogen atom. There is no evidence that there is a pointlike entity that disappears suddenly at some point during detection(absorption)
to discuss in advance general arguments (5.a to 5.g) that have been used against realistic interpretation and against dynamic collapse.

5.a “Ψ is complex. Real physical entities should be represented by real numbers” The complex value indicate that we have not only a magnitude but also a cyclic property we call phase. The absolute value of the phase has no physical meaning. One can rotate the phase everywhere at the same amount and the physics remains the same. Consequently, the absolute values of real and imaginary parts don’t have physical meaning. However, we don’t see any philosophical reason why even this should not be possible in nature. See arguments under 5.b regarding the relationship between observed reality and deeper reality.

5.b “For n particles the wave function is defined in 3n dimensional configurations space but real physical space is 3 dimensional and therefore the wave function cannot be a physical entity”. It is surprising that the defenders of Copenhagen interpretation are on one hand so “open-minded” to accept totally new concepts like probability wave or mutually exclusive aspects that reveal themselves depending on performed experiment (complementarity) that are alien to classical understanding of nature and the concept of objective reality, but on the other hand they consider this as one of the arguments against a realistic interpretation. The elements of the “deeper reality” (described by operators and the wave function) have neither to be similar to our macroscopic reality nor should they be directly observable, but it is enough if we can deduce directly observable macroscopic experience described by eq.(5) from the equations that describe this “deeper reality”, however strange this “deeper reality” may appear when viewed within a conceptual framework built upon our daily macroscopic experience. This is why a physical theory is not merely an empirical recipe to correlate collected data but it represents a “deeper insight” about how nature works. The correspondence in form of eq.(5) does not only work for a single particle but it works also for n particle system.

5.c “Quantum mechanical wave packets spread in time but macroscopic objects do not.” If one considers, for example, the two particle system of the hydrogen atom, the spatial wave function is in 6 dimensional configurations space and one can separate the Schrödinger equation into two equations, one with the relative coordinates \( r = r_p - r_e \) and the reduced mass, and the other one with center of mass coordinates and the total mass representing the center of mass motion of the whole atom as a free particle. What we experience as size of an hydrogen atom is the spatial extension of the ground state in relative coordinate subspace, but this is of course independent of the wave length or size of the wave packet corresponding to the center of mass motion. It is the type of the involved interaction that deter-
mines which part reveals itself in the experiment. What we experience as the size of a macroscopic object in daily life is the spatial extension of the bound state of the n particle system in relative coordinate subspace. This is why macroscopic objects do not spread. The free wave packet corresponding to center of mass motion of a macroscopic (n particle) object is simultaneously present in a different subspace of the 3n dimensional configurations space.

5.d “One can never observe wave function in its entirety directly. What we can observe/detect directly are only localized entities (particles). We can only calculate the wave function by evaluating a large number of measurements conducted on identically prepared particles. Thus, we don’t have direct observational evidence for the physical reality of the wave function” In contrast to the interference pattern on the scintillating screen in a double slit experiment that emerges as a result of large number of individual pointlike detections, the interference pattern in the Bose Einstein condensate (Andrews et.al (1997)) continue to exist however we lower the number of the atoms in the condensate, (as long as we keep the temperature deep enough) and we don’t encounter pointlike entities representing individual atoms in the condensate. Indeed, any localization of the individual atoms would mean the destruction of BE condensate. In the double slit interference experiment we can not observe the electron while passing as a wave through both slits simultaneously because electron wave collapses due to interaction with photon to a localized state. Therefore, it passes either through one or the other slit so that we loose the interference pattern. In the case of Bose Einstein condensate light is reflected from condensate to the camera without destroying its coherent quantum state as long as the temperature remains sufficiently low. Thus the photographs of interference patterns in a Bose Einstein condensate are in a sense direct observation of the wave function of the condensate without collapse. It seems that although the wave function is more strange than (or less similar to) a classical field in ordinary three dimensions as Schrödinger originally hoped, it is nevertheless physically more real then the defenders of the Copenhagen interpretation had assumed.

5.e “The form of the potential energy operator for two particles has the form $1/(r_1 - r_2)$. If the wave function were something physically real then we would have to write the potential energy term as integral between two continuous charge distributions. This is however not the case.” This argument implicitly assumes that a realistic

\footnote{do not confuse this with grained structure in the photograph related to individual detection of reflected photons. We are not talking here about the wave function of detected photons but about the condensate namely the “entity” that reflects photons}
interpretation is automatically equivalent to Schrödinger interpretation. The error in this assumption is reading the correspondence principle in a wrong direction by assuming that $|\Psi|^2$ must be something like classical charge density. The correct reading of correspondence principle is “what we experience as classical charge density in ordinary 3 dimensional space is the result of the form of the wave function in 3n dimensional configuration space that evolves according to purely quantum laws”.

One should not confuse between two opposite directions of correspondence between classical physics and quantum mechanics, namely

i. How we discover the form of the operator in quantum mechanics by looking at the corresponding classical expression

ii. How classical laws emerge as a consequence of quantum laws as in equation (5)

It is obvious that only one of them can be fundamental so that the other one must be the logical consequence of the more fundamental one. Obviously, what counts is not how we discover the laws but how nature works. The nature works according to ii not i. The reason why two localized quantum mechanical wave packets move in first approximation similar to classical bodies with a classical potential term $1/(r_1 - r_2)$ is because the quantum mechanical operator for potential term has the form $1/(r_1 - r_2)$ and not the other way round\(^{10}\). Since it is only the dynamics of the continuous entity wave function (or operators in Heisenberg picture) what QM is about, the mathematical form of any quantum operator can not be an argument for the existence of a pointlike entity.

The correspondence in form of ii can be confirmed experimentally in Rydberg atoms, where one can excite the electrons wave function to arbitrarily sharp localized wave packets in an elliptical orbit by adjusting the shape of the laser pulse accordingly. All these support the assumption that localized detections may be a spontaneous emission type rapid (3.2) but continuous transition from a spatially extended state to a localized one\(^{11}\) and not a ”sudden revealing of particle aspect that remains hidden until it is measured”.

5.f. "Neoclassical theory (NCT) was developed on the basis of a realistic interpretation of the wave function. It was not in agreement with experiments regarding emission line shape and correlations between individual measurement results. This shows that the realistic interpretation is inconsistent with observations”.

The problem of semiclassical or neoclassical model was not the realis-
tic interpretation of particle wave function but associating a classical charge density with it and rejecting the operator nature (quantization) of the EM field. Thus the error was the wrong reading of the correspondence principle we mentioned in first paragraph under 5.e The resulting difference between QED and NCT as a consequence of this is that in NCT product of expectation values appear where the expectation value should be taken after multiplication of operators according to QED. There is nothing in equations of QED that says wave function is only probability amplitude and it cannot be something real. It is only the speculation “collapse can principally not be described as a dynamical process within QED” that leads to the assumption that probability amplitude interpretation is an inseparable part of QED. A good example of how this assumption could mislead even the experts is the discussion on quantum beats in Λ type atoms\textsuperscript{12} in the seventies that couldn’t be observed at that time(Jaynes (1980), Scully (1980). QED defenders claimed that expecting beats in Λ type atoms is based on the realistic Schrödinger interpretation and the missing of the beats verify the invalidity of it and confirm probability wave interpretation. The beats in Λ type atoms were actually observed in 1995 (Schubert et.al (1995)).

All problems mentioned above are, therefore, not real problems in our opinion; however it seems the following problem is a serious one that has to be solved.

5.g “Correlations between space-like separated measurement outcomes conducted on entangled particles point to a conflict with special relativity if we want to describe collapse as a rapid but continuous dynamic process occurring at the very moment of detection.” (Aspect et.al (1980)) Although there are still discussions about possible loopholes, each and every improved experiment seems to continue to confirm the violation of Bell inequalities(Chiao et.al (1993), Tittel et.al (1998), Chiao et.al (2002)). The usual reconciliation of nonlocal correlations with special relativity goes as follows(summarized by us)(see for example Chiao et.al (1993)): “Each individual measurement on a single particle is random. This is independent of whether the particle is entangled with another particle or not. Thus the measurements on an individual particle do not reveal any information about entanglement with another particle. The correlations become apparent only after the measurement results are brought together or communicated via usual means with subluminal speed. Therefore, there is no superluminal information flow”. Fundamental randomness is a

\textsuperscript{12}A three level atom that is excited to the upmost level initially and decays spontaneously to the lower levels. NCT defenders expected variation of the emitted intensity due to interference between two concurrently occurring transitions.
necessary condition for such a reconciliation. Thus denying the ontological status of the wave function (Stenger (1995) p. 196) and interpreting it only as a probability amplitude, namely merely as a mathematical function determining the probability of an outcome is the essence of the reconciliation. Any deterministic mechanism \(^{13}\)would invalidate it.

How can we resolve the conflict with special relativity? Is there something going on similar to the propagation of electromagnetic waves in matter with superluminal phase velocity? Or is the process similar to faster than light motion of wave packet maxima (Friedrich (1995)) despite subluminal group velocity? Is it because the continuity equation does not hold for each subsystem (particle or electromagnetic field) separately (because an exact separation of wave function is not possible) but it holds only for some type of total density with subluminal currents so that we may have a change of particles \(|\Psi|^2\) without a corresponding current\(^{14}\)? Does the relativistic form of the operators automatically assure that quantummechanical density currents remain subluminal? Is it possible that Lorentz invariance of the equations is lost because of the necessary modifications we have to make to describe the source field effects? Some of these alternatives may sound dangerous at first sight since they seem to jeopardize the established relativistic view of space time but we must bear in mind that Lorentz transformations (LT) have two different interpretations. In his original derivations of LT, Lorentz considered the time dilation (Larmor dilation) and length contraction (Lorentz-Fitzgerald contraction) as physical effects due to a motion relative to a preferred frame\(^ {15}\). The time dilation leads to an inevitable time difference between distant clocks (symbolized by \(t'\) and called by Lorentz as “local time”) in the moving frame when clocks are separated after synchronization because of different absolute velocities in opposite directions during separation. The time difference is the same, one obtains if one tries to synchronize them by light signals in moving frame because of different velocities of light in different directions in moving frame. Thus it is impossible to check one method against the other, and therefore there is no way to verify this asynchrony. The reason why all the effects of time dilation and length contraction seem to be reversed when viewed from moving frame is essentially the fact that the moving observer is fooled by assuming his distant clocks all to be synchronous clocks. A Lorentzian derivation of LT can be found in our opinion including decoherence contrary to the claims of decoherentists because decoherence is a local process and there is no mechanism that assures that space-like separated correlated outcomes remain in the same branch of history.

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\(^{13}\)nonrelativistically \(\Psi^* \nabla \Psi - \Psi \nabla \Psi^*\) in the absence of electromagnetic field

\(^{14}\)that could be well understood by Maxwell equations
in Kennedy and Thorndike’s (1932) paper\textsuperscript{16}. For Einstein the symmetry between considered reference frames was a too precious a property to sacrifice its physical reality by interpreting it as merely observational or apparent. He sacrificed rather the established view about absolute time and absolute simultaneity to save the interpretation of the symmetry as physically real. Thus, in his interpretation simultaneity is relative and the symmetry between the reference frames is real and reflects the very structure of space time, namely its Minkowskian type geometry. The Einsteinian interpretation is preferred and has been established because of 3 reasons:

\begin{enumerate}
  \item It doesn’t refer to a concept of undetectable preferred frame, thus better in accordance with the principle of Ockham’s razor.
  \item Symmetry is an appealing property for a fundamental law.
  \item From Lorentzian view it seems mysterious why the velocity of electromagnetic waves should enter in all the fundamental equations, namely even the equations that seem to have (at least at first sight) nothing to do with electromagnetism, like for example gravitation or velocity dependence of the mass of neutral particles etc. Einstein provides a simple answer to this question. Since everything occurs in space-time and since the geometry of space-time is Minkowskian, the physical equations have to be Lorentz invariant.
\end{enumerate}

However, despite the appealing properties of Einsteinian view, Lorentzian interpretation may be worth being reconsidered in context with the problem of quantum nonlocality as a last resort because although a superluminal speed is associated necessarily with backwards flowing of time and leads to problems of causality in Einstein’s interpretation of LT, this problem doesn’t exist in Lorentzian interpretation where time is absolute. We must be open-minded enough not to raise the Einsteinian interpretation to a taboo and not to principally discard the theoretical possibility that the Lorentz invariance of the fundamental equations may not be related to the geometry of space

\textsuperscript{16}The Lorentzian derivation is given in the last two pages. Interestingly in some relativity text books and on some web pages teaching special relativity it is mentioned that “Although Lorentz Fitzgerald length contraction hypothesis could explain Michelson Morley experiment it cannot explain Kennedy and Thorndike experiment”. This creates the wrong impression that Kennedy Thorndike experiments impose Einsteinian interpretation and invalidates the Lorentzian view. What Kennedy Thorndike experiment has shown is merely that the absolute length contraction is not enough and one has to add an absolute time dilation to explain the experiment. Kennedy and Thorndike derive LT starting with these two assumptions as Lorentz had done it previously. It seems that there is a general lack of information about the degree of observational equivalence between these two interpretations and about the reasons why Einstein’s interpretation was preferred. One example of this is the wrong expectation of observation of a torque in Trouton Noble experiment.
time but the reason may well be that all different types of quants are merely
different types of excitations of the same field (similar to different phonon
modes in a crystal) in a galilean space time and that the intrinsic fundamental
properties of this unified field (like elastic constants in a solid) reflects itself
in dispersion relations $\omega(k)$ of different type of excitations $^{17}$ in form of rest
masses of different type of excitations (namely $\omega$ at $k = 0$) and in form of an
asymptotical upper limit for group velocity $d\omega/dk$ for $k \to \infty$ for all type of
excitations. Although Einstein’s decision to sacrifice the established view of
space and time and to replace it by a relativistic space-time was favorable be-
cause of the strong arguments; if the new upcoming tough decision should be
between either sacrificing mathematically pleasing relativistic view of space
time or loosing the boundary between objective reality and our knowledge on
it, between physics and metaphysics so that we may be in danger of loosing
even the notion of objective reality itself it should be the notion of objective
reality that should be saved from being sacrificed if science should continue
to be science and not turn into “mediaval necromancy” as Jaynes called it
in 1980 (p.43).

To address all these questions we must reach a consensus on the quantum
mechanical description of radiation reaction$^{(}$see recent references on radiation
reaction in subsection 3.7$^{)}$. Then we have to look at the Lorenz invariance
of the obtained equations to address problem 5.g. Then we have to put the
acquired knowledge into the theories of quantum measurement. Probably it
would be appropriate to apply all these first to a simple case of an electron
wave packet of large spatial extension approaching two attractive potential
centers A and B to see whether small initial asymmetries prevent it from
evolving to a superposition of the states localized at A and B so that it
rather evolves almost directly to the energetically more suitable one for large
A-B distance$^{18}$.

$^{17}$that we experience as relativistic energy momentum relation $E(p)$

$^{18}$By applying Fermi’s semiclassical idea (eq.(8) that ignores vacuum photons and con-
siders merely radiation reaction) to a three level atom (Gürel, A.; Gürel, Z.(1998))that
is initially in the excited state $|3\rangle$, one can actually demonstrate how the differences
between initial small contributions of the two lower states $|2\rangle$ and $|1\rangle$ determine whether there is
a transition directly from $|3\rangle$ to $|1\rangle$ or whether there is a cascade in form $|3\rangle \to |2\rangle \to |1\rangle$.
A transition to a superposition of $|2\rangle$ and $|1\rangle$ occurs only if the initial contributions of $|2\rangle$
and $|1\rangle$ have the same order of magnitude. This may explain why the quantum beats for
A type atoms couldn’t be observed for a very long time until 1995 although they were
predicted by defenders of NCT in 1970’s.
6 Summary and conclusion

Detection of a material particle is always associated with radiation reaction. The consideration of source field dynamics in the calculation of time evolution of particle position operator in nonpertubative QED indicates that stationary particle states remain unaffected by radiation reaction so that they are favored in presence of a potential gradient (subsection 3.6 and 3.7). Therefore it is necessary to investigate its possible role in the destruction of superpositions of “particle wave function” during a measurement. Unfortunately, there are several historical and technical reasons why radiation reaction is not discussed in context with quantum measurement until now (section 4).

A realistic modeling of a quantum measurement that contains all the complicated aspects related to radiation reaction seems difficult analytically. In particular, there are still different approaches to the problem of quantum mechanical description of radiation reaction and discussions continue (see references in subsection 3.7). We think that decoherence is not a solution to measurement problem (subsection 1.1). The most important next step needed in our opinion is the collaboration between scientists that work on measurement theory and scientists who try to find an appropriate quantum mechanical description of radiation reaction so that the results can be applied to a sufficiently realistic model of a simple measurement probably numerically. Contrary to the opinion expressed by Fuchs et.al (2000) we think that a realistic interpretation of all the quantum mechanical entities (wave function, operators, vacuum fluctuations etc.) would be the true “QM without interpretation” and not the established interpretation. Before exploring alternatives like modifying Schroedinger equation (SE) by nonlinear or ad hoc stochastic terms, it is important to be aware that SE as it is, neither includes the effect of vacuum fluctuations that can be a possible candidate for providing the necessary stochasticity naturally from within QED, nor does it include the effect of radiation reaction on particle wave function. Thus vacuum field and source field dynamics may already provide the necessary modification to SE naturally. In consideration of the principle of Ockham’s razor it is obviously preferable to look for a solution within QED before considering ad hoc modifications to SE. These alternatives should be explored only if the possibilities within QED are fully exhausted and proven to be not a solution to the problem. One wonders whether it may be one of the cases where the equations themselves turn out to be smarter or the elements of the theory turn out to be more real then they were suggested initially by

\footnote{equations of QED including the description of source field effects} \footnote{wave function, operators}
scientists who discovered them\textsuperscript{21}. \textsuperscript{22}

\textsuperscript{21}Einstein added cosmological constant to the general relativistic equations to prevent the universe from expanding in the model but then removed it when it was discovered that universe expands. He called this ”the biggest error in my life”

\textsuperscript{22}Dirac discarded negative energy solutions of his equation as unphysical. It was later found that they describe antiparticles
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