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QUANTUM REALITY IN A UNIVERSE WHERE THE PHOTON CARRIES THE ARROW OF TIME

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ABSTRACT

We show how the new observer-participant paradigm of Measurement Color Quantum Electrodynamics (MC-QED) discussed earlier (Leiter, D., Journal of Cosmology, 2009, Vol 3, pp 478-500) can resolve the fundamental problem of the asymmetry between microscopic quantum objects and macroscopic classical objects inherent in the laws of quantum physics. Since spontaneous CPT violation implies that the photon carries the arrow of time in MC-QED, the total Hamiltonian operator in the Schrodinger Picture contains quantum potentia and quantum measurement interaction operator components which are time reversal violating. The quantum measurement interaction operator component contains causal retarded light travel times that are related to the physical sizes and/or spatial separations associated with the physical aggregate of Measurement Color symmetric fermionic states into which the fermionic sector of the state vector is expanded.

For light travel time intervals *in between* the preparation *and* the measurement, the expectation values of the time-reversal violating retarded quantum measurement interaction operator will be negligible compared to the expectation values of the time reversal violating quantum evolution operator, and the net effect generates the "quantum potentia" of what may occur. On the other hand for light travel time intervals *corresponding to* the preparation *and/or* the measurement, the expectation values of the time-reversal violating retarded quantum measurement interaction operator will be dominant compared to the expectation values of the time reversal violating quantum evolution operator, and the net effect causes the "quantum potentia" to be converted into the "quantum actua" of observer-participant measurement events.

For sufficiently large aggregates of atomic "systems" described by the bare state component of the total Hamiltonian, which are assumed to exist in an "environment" associated with the quantum measurement interaction component of the total Hamiltonian, the net effect of the quantum measurement interaction generates time reversal violating decoherence-dissipation effects on the reduced density matrix in a manner which can give large aggregates of atomic systems apparently classical properties. In this context MC-QED obeys a "dynamic form of Macroscopic Realism" in which the classical level of physics emerges dynamically in the context of local intrinsically time reversal violating quantum decoherence-dissipation effects. Because of the intrinsic time reversal violating quantum decoherence-dissipation effects generated by its time reversal violating photon structure, MC-QED does not require an independent external complementary classical level of physics obeying strict Macroscopic Realism in order to obtain a physical interpretation. Hence a resolution of the fundamental problem of the asymmetry between microscopic quantum objects and macroscopic classical objects inherent in the laws of quantum physics can be found in the MC-QED formalism. This offers the possibility of new insights into the emergence of macroscopic conscious observers in an observer-participant universe where the photon carries the arrow of time.

I. INTRODUCTION

The Copenhagen Interpretation of Quantum Mechanics (CI-QM) contains an inherent logical asymmetry between object and observer which leads to contradictions. This problem is associated with the circular reasoning associated with the two assumptions in CI-QM that: a) "conscious observers" are associated with macroscopic measuring systems which have local objective properties and, b) "microscopic quantum systems" have non-local properties which do not have an objective existence independent of the irreversible "act of observation" generated by its interaction with the macroscopic measuring instruments associated with "conscious observers". Because of this problem the CI-QM leads to contradictory predictions when macroscopically objective systems become directly coupled to microscopically non-objective quantum systems in a superposition of states. This problem occurs because "conscious observers" and their "macroscopic measuring instruments" are made up of large numbers of quantum micro-systems. This problem cannot be avoided since the direct coupling of macro-aggregates of quantum systems to nonlocal micro-quantum systems must occur in Nature.

In an attempt to better understand the full implications of the quantum measurement process described by the CI-QM John Wheeler pioneered the development of the "Observer Participant Universe" (OPU). Within the OPU macroscopic conscious observers directly participate in the process of irreversibly actualizing the elementary quantum phenomena which make up the universe. Wheeler emphasized this point in his well known dictum that "No elementary quantum phenomenon is a phenomenon until it is an irreversibly recorded phenomenon". However the logical asymmetry between the observer and the object associated with the CI-QM remained in Wheeler's Observer-Participant Universe, since the dynamical manner in which macroscopic living conscious observers irreversibly actualize microscopic elementary quantum phenomena was still unexplained.

In order to solve this problem a new observer-participant paradigm of the quantum measurement process is needed which generalizes Wheeler's concept of the observer-participant universe into a microscopic quantum operator form that is symmetric in regard to the definition of the "observer" and the "object". In a recent paper (Leiter, D., Journal of Cosmology, 2009, Vol 3, pages 478-500) it was shown that this new paradigm could be found by incorporating an Abelian operator gauge symmetry of microscopic operator observer-participation called "Measurement Color" into the operator equations of Quantum Electrodynamics in the Heisenberg picture. This was shown to require that the Measurement Color labeling symmetry be imposed onto the quantum field theoretic structure of <u>both</u> the electron-positron operators <u>and</u> the electromagnetic field operators in the QED formalism. The resultant formalism, called Measurement Color Quantum Electrodynamics (MC-QED), took the form of a non-local quantum field theory which described the quantum measurement process in terms of myriads of microscopic electron-positron quantum operator fields undergoing <u>mutual</u> microscopic observer-participant quantum measurement processes mediated by the charge-field photon quantum operator fields through which they interact.

Since the time-symmetric free photon operator could not be given a Measurement Color description within the microscopic observer-participant operator symmetry in MC-QED, it was automatically excluded from the formalism, Instead the photon operator in MC-QED was given by the nonlocal Measurement Color Symmetric "Total Coupled Radiation" charge-field photon operator, which carried a negative time parity under the Wigner Time Reversal operator. In this context, applying the same time-symmetric Asymptotic

Conditions to the non-local MC-QED operator equations of motion as was done for the local operator equations of motion in standard QED, the physical requirement of a stable vacuum state in MC-QED dynamically required that the MC-QED Heisenberg operator equations must contain a causal retarded quantum electrodynamic arrow of time.

It was shown that this surprising result could be better understood in a broader context by noting that, within the nonlocal quantum field theoretic structure of the MC-QED formalism, the physical requirement of a stable vacuum state generated a spontaneous symmetry breaking of both the T and the CPT symmetry. Spontaneous symmetry breaking of the T and the CPT symmetry occurred in MC-QED because the nonlocal photon operator acting within it has a negative parity under Wigner time reversal. In this manner the requirement of a stable vacuum state dynamically selected the operator solutions to the MC-QED formalism that contain a causal, retarded, quantum electrodynamic arrow of time, independent of any external thermodynamic or cosmological assumptions (Zeh, D., 2007).

Spontaneous CPT breaking in MC-QED implies that the photon carries the arrow of time. In this paper we will show that this fact implies that MC-QED contains both the Von Neumann Type 1 and Von Neumann Type 2 of time evolution of the state vector. For this reason we will find that MC-QED contains its own microscopic observer-participant description of the quantum measurement process, independent of the use of the Copenhagen Interpretation or the Everett “Many Worlds Interpretation”. It is for this reason that the paradigm of MC-QED can be used to solve the problem of macroscopic quantum reality.

The origin of the problem of macroscopic quantum reality lies in the nature of Copenhagen Interpretation of QED. This is because within the QED formalism macroscopic bodies, associated with macroscopic measuring instruments and macroscopic conscious observers, are assumed to obey a strict form of “Macroscopic Realism” on a complementary classical level of physics external to the microscopic quantum electrodynamic system. Macroscopic bodies that satisfy the strict form of Macroscopic Realism are assumed have the property that they are at all times in a macroscopically distinct state which can be observed without affecting their subsequent behavior.

In this paper we will show that strict Macroscopic Realism is not valid for MC-QED. This is because its Measurement Color symmetry implies that the photon operator carries the arrow of time. This fact will be shown to have a profound effect on the nature of the time evolution of the state vector in the Schrodinger Picture of the MC-QED formalism, since it causes the total Hamiltonian operator acting on the state vector in the Schrodinger Picture of MC-QED to become a differential-delay equation containing time reversal violating quantum evolution and quantum measurement interaction components.

The time reversal violating quantum measurement interaction part of the Hamiltonian operator will be shown to contain causal retarded light travel times, which are connected to the values of the physical sizes and/or spatial separations associated with the physical aggregate of Measurement Color symmetric fermionic states into which the fermionic sector of state vector is expanded. For the retarded light travel time intervals in between the preparation and the measurement, the expectation values of the time-reversal violating retarded quantum measurement interaction operator will be negligible compared to the expectation values of the quantum evolution operator which generates the “quantum potentia” of what may occur. On the other hand for retarded light travel time intervals corresponding to the preparation and/or the measurement, the expectation values of the time-reversal violating retarded quantum measurement interaction operator will be dominant compared to the expectation values of the quantum evolution operator and this will cause the “quantum potentia” to be converted into the “quantum actua” of observer-participant measurement events.

In this context we will show that for a sufficiently large aggregate of atomic systems, described by the by the bare state component of MC-QED Hamiltonian and assumed to exist in an “environment” associated with the time reversal violating quantum measurement interaction component of the total Hamiltonian operator, the effects of the quantum measurement interaction will *generate time reversal violating decoherence and dissipation effects* on the reduced density matrix in a manner which will give these large aggregates of atomic systems apparently classical properties. This *dynamic form of Macroscopic Realism* within the MC-QED formalism is in stark contrast to the Copenhagen Interpretation of QED with its *strict form of Macroscopic Realism.*

Since MC-QED obeys a dynamic form of Macroscopic Realism, the classical level of physics emerges dynamically in the context of local intrinsically time reversal violating quantum decoherence effects which project out individual states since they are generated by the time reversal violating quantum measurement interaction in the formalism. Hence MC-QED does not require an independent external complementary classical level of physics obeying strict Macroscopic Realism in order to obtain a physical interpretation. This is in contrast to the time reversal symmetric case of QED where the local quantum decoherence effects only have the appearance of being irreversible because a local observer does not have access to the entire wave function and, while interference effects appear to be eliminated, individual states have not been projected out.

Hence while MC-QED uses standard canonical quantization methods in the development of its observer-participant time reversal violating microscopic operator equations of motion in the Heisenberg Picture, it does not require an independent external complementary classical level of physics in order to obtain a physical interpretation of the quantum measurement process. For this reason the Copenhagen Interpretation division of the world does not play a role in the MC-QED formalism. Hence the MC-QED formalism represents a more general observer-participant approach to quantum electrodynamics in which a consistent description of quantum electrodynamic measurement processes at both the microscopic and macroscopic levels can be obtained. Because of this we will find that the paradigm of Measurement Color in Quantum Electrodynamics represents a new observer-participant quantum field theoretic language in which both microscopic and macroscopic forms of quantum de-coherence and dissipation effects may be studied in a relativistically unitary, time reversal violating quantum electrodynamic context.

The structure of this paper is as follows: Section II discusses the structure of the microscopic, time reversal violating, observer-participant quantum measurement process in the MC-QED formalism. Section III discusses how the time reversal violating quantum measurement process in MC-QED acts to convert the “quantum potentia” of potential events into the “quantum actua” of actual events. Section IV discusses how the time reversal violating, observer-participant quantum measurement process in MC-QED leads to a well-defined dynamic description of the transition from the quantum to the classical level. Finally Section V concludes with discussions about the possible extension of the new paradigm of MC-QED into the broader realms of physical phenomena associated with emergence of macroscopic conscious observers in an observer-participant universe where the photon carries the arrow of time.

For the convenience of readers with higher levels of expertise who want more technical information about the arguments underlying the general discussions given in Sections II - IV of this paper, more detailed analysis in support of these sections is given in Appendices I –VI.

II. THE OBSERVER-PARTICIPANT QUANTUM MEASUREMENT PROCESS

In this section we continue the development of the time reversal violating Measurement Color Quantum Electrodynamics (MC-QED) formalism published earlier (Leiter, D., Journal of Cosmology, 2009, Vol 3, pages 478-500). For the convenience of those readers who are not familiar with this paper, a brief summary of the MC-QED formalism has been given in Appendix I.

Previously we have shown how MC-QED can resolve the apparent asymmetry in the description of the microscopic and macroscopic “Arrows of Time” in the universe. In this section we will show how MC-QED can resolve the problem of the asymmetry between microscopic quantum objects and macroscopic classical objects inherent in the laws of quantum physics.

We begin our discussion by noting that the origin of this problem lies within the nature of Copenhagen Interpretation itself. This occurs in the Copenhagen Interpretation of QED because within it macroscopic bodies are assumed to obey a strict form of “Macroscopic Realism” on a complementary classical level of physics external to the microscopic quantum electrodynamic system. Macroscopic bodies that satisfy this strict form of Macroscopic Realism must have the property that they are at all times in a macroscopically distinct state which can be observed without affecting their subsequent behavior.

Since the Measurement Color symmetry in MC-QED implies that the photon operator carries the arrow of time this has a profound effect on the nature of the time evolution of the state vector in the Schrodinger Picture of the MC-QED formalism such that the assumption of Macroscopic Realism is not required in the MC-QED formalism. The fact that the photon carries the arrow of time causes the Hamiltonian operator in the Schrodinger Picture of MC-QED to contain quantum evolution and quantum measurement interaction components which are both time reversal violating. This causes the time reversal violating quantum measurement interaction part of the Hamiltonian operator to contain components which have causal retarded light travel times, which are connected to the values of the physical sizes and/or spatial separations associated with the physical aggregate of Measurement Color symmetric fermionic states into which the fermionic sector of state vector is expanded.

For the retarded light travel time intervals in between the preparation and the measurement, the expectation values of the time-reversal violating retarded quantum measurement interaction operator will be negligible compared to the expectation values of the time reversal violating quantum evolution operator and the net effect generates the “quantum potentia” of what may occur. On the other hand for the retarded light travel time intervals corresponding to the preparation and/or the measurement, the expectation values of the time-reversal violating retarded quantum measurement interaction operator will be dominant compared to the expectation values of the time reversal violating quantum evolution operator and the net effect causes the “quantum potentia” to be converted into the “quantum actua” of observer-participant measurement events.

Let us now discuss the above comments in more technical detail. We begin by recalling that in MC-QED the reason why the Photon carries the arrow of time is because of the effects of spontaneous CPT symmetry breaking inherent within the formalism. In this context the expectation value of the electron-positron operator equations of motion in the Heisenberg Picture, whose Wigner time reversal violating structure is determined by the Asymptotic Condition requirement that a stable vacuum state exists, are ($k= 1,2, \dots , N \quad (2 \leq N \to \infty)$

$$<(-i\hbar\gamma^{\mu}\partial_{\mu} + m - e/c\gamma^{\mu}A_{\mu}{}^{(k)}{}_{(obs)})\psi^{(k)}> = 0$$

where

$$<A_{\mu}{}^{(k)}{}_{(obs)}> = < \sum_{(j \neq k = 1\dots , N)}A_{\mu}{}^{(j)}(ret) + A_{\mu}{}^{(k)}(-)>,$$

The expectation value of the <u>time reversal violating MC-QED operator equations of motion</u> describe the Universe as being made up of an infinitely large number of countable ($2 \leq N \to \infty$) microscopic observer-participant quantum measurement interactions, in the context of which:

a) charge field photons are causally being emitted and absorbed between the $\psi^{(k)}$ and $\psi^{(j)}$ fermions ($k \neq j = 1,2, \dots , N$) , and

b) charge field photons are spontaneously being emitted into the vacuum by each of the $\psi^{(k)}$ fermions $k = 1,2, \dots , N$),

In the Heisenberg picture the Total Heisenberg State Vector $|\psi_H>$ obeys $\partial_t|\psi_H> = 0$, and the Total Heisenberg Hamiltonian Operator $H = H^{\dagger}$ obeys $dH / dt = 0$. Since they are both conserved in time then it follows that both $|\psi_H>$ and $H = H^{\dagger}$ are time reversal invariant. In the Heisenberg picture the MC-QED Hamiltonian operator H can be written as

$$H = H^{\dagger} = [H_0 + V_{qp} + V_{ret\text{-}qa}]$$

where H_0 is the bare fermion and bare hamiltonian operator given by

$$H_0 = H_f + H_{ph}$$

Inside of H_0 we have that:

H_f is the bare electron-positron Hamiltonian operator given by

$$H_f = \sum_{(k)} \{: \int dx^3 [\psi^{(k)\dagger}(\alpha.\bullet \mathbf{p} + \beta m - e\varphi^{(k)}{}_{(ext)})\, \psi^{(k)}] + J^{\mu(k)} A_{\mu}{}^{(k)}{}_{Breit}{}^{(obs)} :\}$$

(where ($k =1,2, \dots , N\to \infty$, the symbols **: :** represent the use of normal ordering, $A_{\mu}{}^{(k)}{}_{Breit}{}^{(obs)} = \sum_{(j) \neq (k)} \int dx^3 J_{\mu}{}^{(j)}(x',t) / 4\pi |x-x'|$ represents the Breit vector potential operator, and the external potential $\varphi^{(k)}{}_{(ext)}$) represents the lowest order Coulombic effects of baryonic nuclei).

and H_{ph} is the MC-QED charge-field photon hamiltonian operator given by

$$H_{ph} = -1/2 \int dx^3[\sum_{(k)} \{:[(\partial_t A_{\mu\,(rad)}{}^{(k)}\, \partial_t A^{\mu}{}_{(rad)}{}^{(k)(obs)} + \nabla A_{\mu\,(rad)}{}^{(k)} \bullet \nabla A^{\mu}{}_{(rad)}{}^{(k)(obs)})]:\}$$

where

$$A_\mu{}^{(k)}{}_{(rad)} = (\alpha_\mu - A_\mu{}^{(k)}{}_{(-)})$$

$$\alpha_\mu = \sum_{(j)} A_\mu{}^{(j)}(-)/(N-1)$$

$$A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)} = \sum_{(j)\neq(k)} A_\mu{}^{(j)}{}_{(rad)} = A_\mu{}^{(k)}{}_{(-)}$$

and $A_\mu{}^{(k)}{}_{(-)}$ is the non-local, negative time parity, Heisenberg picture operator

$$A_\mu{}^{(k)}{}_{(-)} = \int dx'^4 (D_{(-)}(x-x')\;\; J_\mu{}^{(k)}(x') \qquad (k=1,2,\ldots,N\rightarrow\infty)$$

In this context the <u>time reversal violating</u> "quantum potentia interaction operator" V_{qp} is given by

$$V_{qp} = \sum_{(k)} :\int dx^3\, J\mu^{(k)} A^{\mu}{}_{(rad)}{}^{(k)(obs)}:$$

where

$$A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)} = \sum_{(j)\neq(k)} A_\mu{}^{(j)}{}_{(rad)} = A_\mu{}^{(k)}{}_{(-)}$$

and the <u>time reversal violating</u> "retarded *quantum actua* interaction operator" $V_{ret\text{-}qa}$ is given by

$$V_{ret\text{-}qa} = :\{\int dx^3 \sum_{(k)} [J_\mu{}^{(k)} (A^{\mu(k)}{}_{(ret)}{}^{(obs)} - A_\mu{}^{(k)}{}_{Breit}{}^{(obs)})]$$

$$-1/2\,[\partial_t A^{\mu}{}_{(ret)}{}^{(k)}\, \partial_t A_{\mu\,(ret)}{}^{(k)\,(obs)} + \partial_t A^{\mu}{}_{(ret)}{}^{(k)} \partial_t A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)} + \partial_t A^{\mu}{}_{(rad)}{}^{(k)}\, \partial_t A_{\mu\,(ret)}{}^{(k)(obs)}$$

$$+ \nabla A^{\mu}{}_{(ret)}{}^{(k)} \bullet \nabla A_\mu{}^{(k)}{}_{(ret)}{}^{(obs)} + \nabla A^{\mu}{}_{(ret)}{}^{(k)} \bullet \nabla A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)} + \nabla A^{\mu}{}_{(rad)}{}^{(k)} \bullet \nabla A_{\mu\,(ret)}{}^{(k)(obs)}]\}:$$

where inside of the expression for the quantum measurement interaction operator $(V_{ret\text{-}qa})$

$$(A^{\mu(k)}{}_{(ret)}{}^{(obs)} - A_\mu{}^{(k)}{}_{Breit}{}^{(obs)}) = \sum_{(j)\neq(k)} (A_\mu{}^{(j)}{}_{(ret} - A_\mu{}^{(j)}{}_{Breit})$$

Since the above quantum measurement interaction operator $V_{ret\text{-}qa}$ involves $(k \neq j = 1,2,\ldots,N)$ retarded electromagnetic operators, then the "quantum actua states" that it selects out of the available "quantum potentia states" generated by V_{qp}, will be restricted to those which contain $(k \neq j = 1,2,\ldots,N)$ measurement color labels.

The total Hamiltonian $H = H^{\dagger} = H_S$ is conserved in time as

$$idH / dt = i\partial H / dt + [H, H] = i\partial H / dt = 0$$

Hence it follows that the total Hamiltonian operator H is invariant under the action of the Wigner Time Reversal operator T_w in the MC-QED theory as

$$[H, T_w] = [(H_0 + V_{qp} + V_{ret\text{-}qa}), T_w] = 0$$

which implies that

$$[H_0, T_t] = - [V_{qp} + V_{ret\text{-}qa}, T_t]$$

However because of the presence of nonlocal charge-field charge field photon operators with negative parity under Wigner time reversal T_w , the operator $[V_{qp} + V_{ret\text{-}qa}]$ violates Wigner time reversal Invariance as

$$[V_{qp} + V_{ret\text{-}qa}, T_w] \neq 0$$

Hence from the above equations this implies that H_0 violates Wigner time reversal as well

$$[H_0, T_t] \neq 0$$

Now since the MC-QED Heisenberg density matrix operator $\rho_H = |\psi_H\rangle\langle\psi_H|$ obeys $\rho_H = (\rho_H)^2$ and $Tr(\rho_H) = 1$), then the expectation value the H operator given by $\langle\psi_H|H|\psi_H\rangle = Tr(\rho_H H)$ evolves in a time reversal invariant unitary manner.

However in this context the expectation value of the operator $[V_{qp}(t) + V_{ret\text{-}qa}(t)]$ given by

$$\langle\psi_H [V_{qp}(t)+ V_{ret\text{-}qa}(t)] |\psi_H\rangle = Tr(\rho_H[V_{qp}(t) + V_{ret\text{-}qa}(t)])$$

violates Wigner time reversal, and hence follows that the time evolution of the expectation value of the operator $H_0(t)$

$$\langle\psi_H| H_0(t)|\psi_H\rangle = Tr(\rho_H H_0(t))$$

also violates Wigner time reversal.

However this internal time reversal violating process still preserves global unitarity, since it dynamically preserves the value of the total energy associated with the quantity $\langle\psi_H|H|\psi_H\rangle = Tr(\rho_H H)$.

III. CONVERSION OF "QUANTUM POTENTIA" INTO "QUANTUM ACTUA"

Since the above MC-QED time reversal violating property is valid in the Heisenberg Picture, it must also be true in both the Schrodinger Picture and the Interaction Picture as well. To see this more explicitly we transform the total Heisenberg picture state vector $|\psi_H>$ into the total Schrodinger picture state vector $|\psi_S(t)>$ by the unitary time transformation $\exp[-iH(t-t_o)]$

$$|\psi_S(t)> = \exp[H(t-t_o)/ih]\,|\psi_H>$$

From which it follows that

$$ih\partial_t|\psi_S> = H_S\,|\psi_S>$$

where

$$H = H_S = (H_0)_S + (V_{qp})_S + (V_{ret\text{-}qa})_S$$

$$(V_{qp})_S = \sum_{(k)} \{:(\int dx^3\, J\mu^{(k)}\, A^{\mu}{}_{(rad)}{}^{(k)(obs)})_S :\}$$

and

$$(V_{ret\text{-}qa})_S = \{: \int dx^3 \sum_{(k)} [J_\mu{}^{(k)} (A^{\mu(k)}{}_{(ret)}{}^{(obs)} - A_\mu{}^{(k)}{}_{Breit}{}^{(obs)})]$$

$$-1/2\, [{}_tA^{\mu}{}_{(ret)}{}^{(k)}\, \partial_tA_{\mu\,(ret)}{}^{(k)\,(obs)} + \partial_tA^{\mu}{}_{(ret)}{}^{(k)}\partial_tA_\mu{}^{(k)}{}_{(rad)}{}^{(obs)} + \partial_tA^{\mu}{}_{(rad)}{}^{(k)}\, \partial_tA_{\mu\,(ret)}{}^{(k)\,(obs)}$$

$$+ \nabla A^{\mu}{}_{(ret)}{}^{(k)}\bullet\nabla A_\mu{}^{(k)}{}_{(ret)}{}^{(obs)} + \nabla A^{\mu}{}_{(ret)}{}^{(k)}\bullet\nabla A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)} + \nabla A^{\mu}{}_{(rad)}{}^{(k)}\bullet\nabla A_{\mu\,(ret)}{}^{(k)\,(obs)}]_S :\}$$

and inside of the expression for the quantum measurement interaction operator $(V_{ret\text{-}qa})_S$ we have

$$(A^{\mu(k)}{}_{(ret)}{}^{(obs)} - A_\mu{}^{(k)}{}_{Breit}{}^{(obs)})_S = \sum_{(j)\neq(k)} (A_\mu{}^{(j)}{}_{(ret} - A_\mu{}^{(j)}{}_{Breit})_S$$

$$(A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)})_S = (\sum_{(j)\neq(k)} A_\mu{}^{(j)}{}_{(rad)})_S = (A_\mu{}^{(k)}{}_{(-)})_S$$

$$(A_\mu{}^{(k)}{}_{(rad)})_S = (\alpha_\mu - A_\mu{}^{(k)}{}_{(-)})_S$$

Hence in the same manner as occurred in the Heisenberg Picture, it follows in the Schrodinger Picture the relativistic, time reversal violating property of

$$Tr(\rho_S[V_{qp}(t) + V_{ret\text{-}qa}(t)]_S) = <\psi_S(t)|\,[V_{qp} + V_{ret\text{-}qa}]_S\,|\psi_S(t)>$$

dynamically causes the value of

$$Tr(\rho_S[H_0]_S) = <\psi_S(t)|\,[H_0]_S\,|\psi_S(t)>$$

to change in a time reversal violating manner which is unitary since it preserves the value of the total energy associated with $Tr(\rho_S H_S) = <\psi_S(t)|\,|\,[H]_S\,|\psi_S(t)>$.

The dynamic source of this time reversal violating property can be seen more explicitly by examining the form of the non-local Schrodinger state vector potential operators $(A^{\mu(j)}{}_{(ret)})_S$, $(A^{\mu(j)}{}_{(adv)})_S$, and $(A^{\mu(j)}{}_{(-)})_S$ given respectively by

$$(A^{\mu(j)}{}_{(ret)})_S = \left(\int dx'^3 \exp(-iHR/hc)\, J^{\mu(j)}(\mathbf{x}')\, \exp(iHR/hc) / 4\pi R\right)_S$$

$$(A^{\mu(j)}{}_{(adv)})_S = \left(\int dx'^3 \exp(iHR/hc)\, J^{\mu(j)}(\mathbf{x}')\, \exp(-iHR/hc) / 4\pi R\right)_S$$

and

$$(A^{\mu(j)}{}_{(-)})_S = [(A^{\mu(j)}{}_{(ret)})_S - (A^{\mu(j)}{}_{(adv)})_S] / 2$$

where $R = |\mathbf{x} - \mathbf{x}'|$.

Since linear combinations of these nonlocal time reversal violating Schrodinger operators and their derivatives appear inside of the $(V_{ret\text{-}qa})_S$ operator component of H_S in the Schrodinger Picture equation of motion for the MC-QED state vector, they influence time evolution of the MC-QED state vector. In this context since

$$|\psi_S(t)> = \exp(-i/hH_S t)|\psi_S(0)>$$

then it follows that

$$\exp(+iHR/hc)\, |\psi_S(t)> = \exp(H_S[t\text{-}R/c]/ih)|\psi_S(0)> = |\psi_S(t - R/c)>$$

$$\exp(-iHR/hc)\, |\psi_S(t)> = \exp(H_S[t\text{+}R/c]/ih)|\psi_S(0)> = |\psi_S(t + R/c)>$$

Hence we see that the effects of the non-local Schrodinger state vector potential operators $(A^{\mu(j)}{}_{(ret)})_S$, and $(A^{\mu(j)}{}_{(-)})_S$ inside of the Hamiltonian equation of motion for the Schrodinger Picture state vector $|\psi_S(t)>$, convert it into a retarded time-irreversible integro-differential-delay equation for the Schrodinger state vector $|\psi_S(t)>$ which contains nonlocal-in-time volume integrals over the state vector quantities $|\psi_S(t - R/c)>$ and $(|\psi_S(t - R/c)> - |\psi_S(t - R/c)>) / 2$.

Since the Schrodinger Hamiltonian operator H_S in MC-QED contains components which are nonlocal in time, this prevents locally defined eigenstates $|E_S>$ of the total Schrodinger Picture Hamiltonian H_S operator from being able to be defined at finite time t = to.

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However since the bare state hamiltonian operator H_0 is local-in-time then, as shown in Appendices III and IV, locally defined bare states $|E_o> = |E_{fermion}>|E_{photon}>$ can be defined for finite times t = to and the total MC-QED state vector in the Schrodinger Picture $|\psi_S(t)>$ can be expanded into these bare local-in-time microscopic observer-participant eigenstates $|E_0>$ of the local-in-time bare hamiltonian operator H_0 as

$$|\psi_S(t)> = \sum_{(Eo)} C_{(Eo)} |E_o>$$

where|

$$H_o |E_o> = E_o |E_o>$$

Then from the Schrodinger state vector equation of motion

$$ih\partial_t|\psi_S(t)> = H_S |\psi_S(t)>$$

we find that the time dependent coefficients $C_{(Eo)}(t)$, of the observer-participant bare states $|E_o>$ into which $|\psi_S(t)>$ was expanded, obeys a time irreversible, retarded, integro-differential equation.

Hence in the context of the expectation value associated with states $|E_o>$ given by

$$Tr(\rho_S[H_0]_S) = <\psi_S(t)| [H_0]_S |\psi_S(t)> = \sum_{(Eo)} E_o |C_{(Eo)}(t)|^2$$

the time irreversible, retarded, integro-differential equation obeyed by the $C_{(Eo)}(t)$ physically represents the fact that there exist characteristic light travel time intervals $\Delta E/h < (t-t_o) < (t - R/c)$, in between the creation of "quantum potentia" by the action of $V_{qp}(t)$ and their conversion into "quantum actua" by the time irreversible action of $V_{ret-qa}(t)$. In the context of these characteristic time intervals, the $|C_{(Eo)}(t)|^2$ can be interpreted as the relative probabilities, associated with *observer-participant quantum-potentia*, of potential events being converted into actual events associated with *observer-participant quantum-actua*.

We now transform back from the Schrodinger Picture in MC-QED to the Interaction Picture in MC=QED as

$$|\psi_I(t)\rangle = \exp[i(H_0)_S(t-t_o)]\,|\psi_S(t)\rangle$$

Then we can write

$$|\psi_I(t)\rangle = U(t, t_o)\,|\psi_H\rangle$$

where $U(t-t_o)$ is the unitary operator given by

$$U(t-t_o) = \exp[i(H_0)_S(t-t_o)]\,\exp[-iH(t-t_o)]$$

and $(H_0)_S$ and $H=H_S$ are constant in time. (The more technical oriented reader can look at Appendix II for a more detailed discussion of the Interaction Picture in the MC-QED formalism)

In this context it follows from the Schrodinger Picture state vector equation

$$i\partial_t|\psi_S(t)\rangle = H_S\,|\psi_S(t)\rangle$$

that the Interaction Picture state vector equation which $|\psi_I(t)\rangle$ obeys is given by

$$i\partial_t|\psi_I(t)\rangle = [V_{qp}(t) + V_{ret\text{-}qa}(t)]_I\,|\psi_I(t)\rangle$$

This can be formally integrated as

$$|\psi_I(t)\rangle = |\psi_I(t_o)\rangle + (1/ih)\int_{to}^{t} dt'[V_{qp}(t') + V_{ret\text{-}qa}(t')]_I\,|\psi_I(t')\rangle$$

where

$$[V_{qp}(t) + V_{ret\text{-}qa}(t)]_I$$

$$= U(t-t_o)\,[V_{qp}(t) + V_{ret\text{-}qa}(t)]_H\,U(t-t_o)^{-1}$$

$$= \exp[i(H_0)_S(t-t_o)]\,[(V_{qp})_S + (V_{ret\text{-}qa})_S]\,\exp[-i(H_0)_S(t-t_o)]$$

Since the above equations are also nonlocal in time, retarded, integro-differential equations then within them there exist characteristic light travel times $\Delta E/h < (t-t_o) < (t - R/c)$ in between the creation of the "quantum potentia" by the action of the $V_{qp}(t)$ and their conversion into "quantum actua" by the time irreversible action of $V_{ret-qa}(t)$.

In this context let us define the quantities R_i , i = 1,2,.. as representing the various values of the physical sizes and/or spatial separations associated with the physical aggregate of Measurement Color symmetric fermionic states, which contribute to the local-in-time bare observer-participant quantum states $|Eo>$ into which the state vector $|\psi_I(t)>$ is expanded.

Then in the context of the $|Eo>$ states the expectation value of the relativistic, retarded effects of $V_{ret-qa}(t)_I$ will be negligible compared to $V_{qp}(t)_I$ for light travel time intervals $-(R_i /c) < t < (R_i /c)$, $|(R_i /c)| >>> |(h / \Delta E)|$. These light travel time intervals can be thought of as occurring "in-between" the "preparation of quantum states" by the action of $V_{ret-qa}(t)_I$ at $t \sim (-R_i /c)$ and the "measurement of quantum states" at $t \sim (R_i /c)$, (after which time the $V_{ret-qa}(t)_I$ then acts to convert the "quantum potentia" generated by $V_{qp}(t)_I$ into the "quantum actua" of observer-participant measurement events).

Hence for light travel time intervals $-(R_i /c) < t < (R_i /c)$, $|(R_i /c)| >>> |(h / \Delta E)|$, during which the operator $V_{qp}(t)_I$ dominates $V_{ret-qa}(t)_I$, the state vector in the Interaction Picture can be approximated by $|\psi_I(t)> \approx |\psi_I(t)>_{qp}$ where $|\psi_I(t)>_{qp}$ is the state vector which represents the "quantum potentia" state of the system and obeys the equation of motion

$$i\partial_t|\psi_I(t)>_{qp} = [V_{qp}(t)]_I \; |\psi_I(t)>_{qp}$$

Then during the light travel time intervals $-(R_i /c) < t < (R_i /c)$, which occur in between preparation and measurement, the above equation can be formally iterated using the Wick "time ordered product operator" T to obtain the S-matrix approximation, associated with the "quantum potentia" created $V_{qp-in}(t)_I$ as

$$|\psi_I(t)>_{qp-out} = \left\{T\left(\exp[(-i/h)\int_{-(R_i/c)}^{t<(R_i/c)} dt' V_{qp-in}(t')_I\right\} \; |\psi_I(-R_i /c)>_{qp-in} = S \; |\psi_I(-R_i /c)>_{qp-in}$$

where for $|(R_i /c)| >>> |(h / \Delta E)|$ the S-matrix in MC-QED is given by

$$S = \left\{T\left(\exp[(-i/h)\int_{-(R_i/c)}^{t<(R_i/c)} dt' V_{qp-in}(t')_I\right\}$$

The above expression represents the S-matrix approximation in MC-QED for the time evolution of the state vector in the Interaction Picture. (see Appendix V for a further more technical discussion of the structure of the S-matrix in the MC-QED formalism)

In the language of von Neumann this would be called PROCESS 2 evolution from which the probability of events associated with quantum potentia can be calculated.

We emphasize that the above described S-matrix approximation to MC-QED is valid only for the characteristic time intervals $-(R_i /c) < t < (R_i /c)$, $|(R_i /c)| >>> |(h / \Delta E)|$, which occur in between quantum state preparation and measurement. In this context the R_i represent the various values of the physical sizes and/or spatial separations associated with the aggregate of Measurement Color symmetric fermionic states, which contribute to the local-in-time bare observer-participant quantum states $|Eo>$ into which the state vector $|\psi_I(t)>$ is expanded.

On the other hand for the characteristic time intervals $t > (R_i /c)$ the equation for $|\psi_I(t)>$ becomes

$$i\partial_t|\psi_I(t)> = [V_{qp}(t) + V_{ret\text{-}qa}(t)]_I \ |\psi_I(t)> \qquad t > (R_i /c)$$

which can be formally integrated as

$$|\psi_I(t)> \ = \ |\psi_I(R/c))>_{qp} \ + (1/ih)\int_{(Ri / c)}^{t} dt'[V_{ret\text{-}qa}(t')]_I \ |\psi_I (t')>$$

For characteristic time intervals $t > (R_i /c$, the above equation formally describes how the superposition of “quantum potentia” states in the MC-QED S-matrix associated with

$$|\psi_I(R/c))>_{qp} \ = \ \{T(\exp[(-i/h)\int_{-(Ri / c)}^{(Ri / c)} dt' V_{qp\text{-}in}(t')_I \,)\} \ |\psi_I(-R_i/c)>_{qp}$$

are converted, by the time reversal violating quantum measurement interaction operator $[V_{ret\text{-}qa}(t)]_I$, into the “quantum actua” state of an observer-participant measurement event.

In the language of von Neumann this would be called PROCESS 1 evolution where the probability of events associated with the quantum potentia are time irreversibly converted into the quantum actua of real events.

IV. DYNAMIC TRANSITION FROM THE QUANTUM TO THE CLASSICAL LEVEL

In this section we will now show that for a sufficiently large aggregate of atomic systems, described by the by the bare state component of MC-QED Hamiltonian and assumed to exist in an "environment" associated with the retarded quantum measurement interaction component of the Hamiltonian, the net effect of the quantum measurement interaction in MC-QED will generate time reversal violating decoherence effects on the reduced density matrix in a manner which can give large aggregates of atomic systems apparently classical properties.

Hence, in contradistinction the Copenhagen Interpretation of QED with its strict form of "Macroscopic Realism", it follows that MC-QED obeys a dynamic form of Macroscopic Realism in which the classical level of physics emerges dynamically in the context of local intrinsically time reversal violating quantum decoherence effects which can project out individual states since they are generated by the time reversal violating quantum measurement interaction in the formalism.

This is in contrast to the time reversal symmetric case of QED where the local quantum decoherence (Schlosshauer, M., 2007) effects only appear to be irreversible. This occurs in the time symmetric description of decoherence in QED because a local observer does not have access to the entire wave function and, while interference effects appear to be eliminated, individual states have not been projected out.

Hence we conclude that the resolution of the problem of the asymmetry between microscopic quantum objects and macroscopic classical objects inherent in the laws of quantum physics can be found in the MC-QED formalism, because the intrinsically time reversal violating quantum decoherence effects inherent within it imply that MC-QED does not require an independent external complementary classical level of physics obeying strict Macroscopic Realism in order to obtain a physical interpretation.

In the Heisenberg picture the MC-QED Hamiltonian operator H is

$$H = [H_0 + (V_{qp} + V_{ret\text{-}qa})] = [H_0 + (V)]$$

Now the successive state vector transformations on the Heisenberg Picture State vector $|\psi_H>$, through the Schrodinger Picture state vector $|\psi_{S}>$, that finally leads to the Interaction Picture state vector $|\psi_I>$ can be formally represented by $|\psi_I(t)> = U(t-t_o)\ |\psi_H>)$ where the unitary operator $U(t-t_o)$ is given by

$$U(t-t_o) = \exp\ [i(H_0)_S(t-t_o)]\ \exp\ [-iH(t-t_o)]$$

where the Schrodinger Hamiltonian operators $(H_0)_S$ and $H=H_S$ are constant in time. It then follows that the equation of motion of the state vector in the Interaction Picture is

$$i\partial_t|\psi_I(t)> / dt = [V(t)]_I\ |\psi_I(t)>$$

and that the density matrix operator $\rho_I(t) = |\psi_I(t)><\psi_I(t)|$ obeys the equation of motion

$$id\rho_I(t)/dt = i\partial_t\rho_I(t) = [V(t), \rho_I(t)]_I$$

where

$$[V(t)]_I = \exp[i(H_0)_S(t-t_o)] \; [V]_S \exp[-i(H_0)_S(t-t_o)]]_S$$

which is time-reversal violating because $[V]_I = [(V_{qp} + V_{ret\text{-}qa})]_I$ is not invariant under Wigner time reversal. However time reversal violating time evolution of $\rho_I(t)$ is unitary because conserves the total hamiltonian operator H. Because of this fact that the full density matrix satisfies the two conditions required for unitarity to hold, namely

$$Tr_{|Eo>}\{\rho_I(t)\} = <\psi_I(t)|\psi_I(t)> = 1 \qquad (\text{where } H|E_o> = E_o|E_o>)$$

and

$$\rho_I(t)^2 = \rho_I(t)$$

In standard QED the local Wigner time reversal invariant properties of the Hermetian Hamiltonian operator guarantees a unitary, time reversal invariant evolution of the state vector $|\psi_I(t)>$ of the quantum system. For this reason, in Copenhagen Interpretation of standard QED, macroscopic bodies associated with measuring instruments and observers are assumed to obey a strict form of “Macroscopic Realism” on a complementary classical level of physics external to the microscopic quantum electrodynamic system. Macroscopic bodies which satisfy the concept of classical “Macroscopic Realism” are assumed to have the property that they are at all times it is in one of their macroscopically distinct states. In addition it is also assumed that one can observationally determine that the macroscopic system is in a particular macroscopically distinguishable state without affecting its subsequent behavior.

However in contradistinction to standard QED we have that in MC-QED the nonlocal, time-reversal violating, observer-participant structure of MC-QED does not require an independent external complementary classical level of physics obeying “Macroscopic Realism” in order to obtain a physical interpretation. This is because the Hermetian Hamiltonian operator in MC-QED maintains unitary time evolution of the state vector $|\psi_I(t)>$ in the context of Wigner Time reversal violating, nonlocal, observer-participant interaction operators, associated with the quantum measurement interaction given by

$$Tr_{|Eo>}\{\rho_I(t)[V_{in\text{-}qp}(t) + V_{ret\text{-}qa}(t)]_I\} = <\psi_I(t)|\{V_{in\text{-}qp}(t) + V_{ret\text{-}qa}(t)\}_I|\psi_I(t)>$$

$$= <\psi_I(t)| \int dx^3 \Sigma_{(k)} \{J\mu^{(k)} A\mu^{(k)} obs\}_I |\psi_I(t)>$$

where

$$\int dx^3 \Sigma_{(k)} \{J\mu^{(k)} A\mu^{(k)} obs\}_I = \int dx^3 \Sigma_{(k)} \Sigma_{(j)\neq(k)} \{J\mu^{(k)} [A\mu^{(k)}(-) + A\mu^{(j)}(ret)]\}_I$$

Hence in MC-QED the action of the relativistic, time reversal violating property of the quantum measurement interaction $<\psi_I(t)| \ [V_{in-qp}(t) + V_{ret-qa}(t)]_I \ |\psi_I(t)>$ dynamically causes the value of the quantity $<\psi_I(t)| \ [H_0(t)]_I \ |\psi_I(t)>$ to change in a time reversal violating manner while still preserving the expectation value of the energy of the total hamiltonian $<\psi_I(t)| \ | \ [H(t)]_I \ |\psi_I(t)>$ and hence the unitarity of the total state vector $|\psi_I(t)>$.

Now inside of $<\psi_I(t)| \ | \ [H_0(t)]_I \ |\psi_I(t)>$ let the R_i represent the values of the various physical sizes and/or spatial separations associated with the aggregate of Measurement Color symmetric fermionic states, which contribute to the local-in-time bare observer-participant quantum states $|Eo>$ into which the state vector $|\psi_I(t)>$ is expanded.

Then the photons associated with the electromagnetic radiation emitted and absorbed within the context of these observer-participant states will occur:

a) in a highly efficient manner in the "wave-zone" after a light travel time $\Delta t \sim R_i /c >> (h / \Delta E)]$ if the characteristic spatial dimension of the observer-participant fermion states within $|Eo>$ are $R_i >> \lambda \sim hc / \Delta E$, and

b) in a relatively inefficient manner in the "induction-zone" over time intervals $(h / \Delta E) < \Delta t << R_i /c$ if the characteristic spatial dimension of the observer-participant system is $R_i \sim \lambda \sim hc / \Delta E$,

Hence in $<\psi_I(t)| \ | \ [H_0(t)]_I \ |\psi_I(t)>$ the relativistic, retarded effects of the operator $V_{ret-qa}(t)_I$ will be negligible compared to the effects of the operator $V_{in-qp}(t)$ for the light travel time intervals $(h / \Delta E) < t << (R_i /c)$, which occur in between the creation of the "quantum potentia" by the action of $V_{in-qp}(t)$ and their conversion into "quantum actua" by the action of $V_{ret-qa}(t)$ after the light travel time intervals $t \geq (R_i /c)$.

In this manner the action of operator $V_{ret-qa}(t)$ is responsible for the "preparation" of the quantum state which occurs at $t = t_o \sim -(R_i /c)$ as well as the "measurement process" which acts on the quantum state at $t = t_o \sim (R_i /c)$ and converts the quantum potentia (which exist during the intermediate time intervals $(h / \Delta E) < t << (R_i /c)$ within which the operator $V_{in-qp}(t)$ dominates the state vector equation of motion).

Hence in MC-QED it follows that macroscopic bodies do not obey a *strict form of Macroscopic Realism*, because in the context of this formalism they are considered to be fully quantum mechanical. However within the context of MC-QED it is possible for macroscopic bodies to obey a *"Dynamically Conditional Form of Macroscopic Realism"* in the following sense:

a) If the physical dimension of the correlation length of the currents contained within the "object" is <u>larger</u> than the physical dimension of the wave-zone associated with its internal radiation fields, the physical effects of the time reversal violating “induced emission” interaction term will dominate the “spontaneous emission” interaction term inside of < $\sum_{(k)}$ $\{J\mu^{(k)} A\mu^{(k)} obs\}$>. Then the resultant time reversal violating evolution of $<\psi_I(t)| \, | [H_0(t)]_I |\psi_I (t)>$ will lead to the generation of a rapid time reversal violating quantum de-coherence effect which will ultimately lead to $<\psi_I(t)| \, | [H_0(t)]_I |\psi_I (t)>$ being in a “pointer-basis defined” classical state.

(e.g. if Ls ~ Ns(ao) >> λ ~ (c/ν) ~ 10^{-5} cm; Ns >> 10^3 atoms)

b) On the other hand if the physical dimension of the correlation length of the currents contained within the “object” is <u>smaller</u> than the physical dimension of the wave-zone associated with its internal radiation fields, the physical effects of the time reversal violating “induced emission” interaction term will be dominated by the “spontaneous emission” interaction term inside of < $\sum_{(k)}$ $\{J\mu^{(k)} A\mu^{(k)} obs\}$>. Under these conditions the resultant time reversal violating unitary evolution of the density matrix <u>will not lead</u> to the generation a rapid quantum de-coherence effect on $<\psi_I(t)| \, | [H_0(t)]_I |\psi_I (t)>$. *Instead* $<\psi_I(t)| \, | [H_0(t)]_I |\psi_I (t)>$ will be in a quantum superposition of states with a lifetime associated with the spontaneous decay of its internal states if they are unstable.

(e.g. if Ls ~ Ns(ao) << λ ~ (c/ν) ~ 10^{-5} cm; Ns << 10^3 atoms)

These sizes associated with classical–quantum threshold of 10^{-5} cm and 10^3 atoms are consistent those calculated on page 135, tbl 3.2, of the book by M. Schlosshauer “Decoherence And The Quantum To Classical Transition” as follows:

$$a_{(dust)} \sim 10^{-3} \text{ cm} > Ls \sim 10^{-5} \text{ cm} > a_{(Large\ molecule)} \sim 10^{-6} \text{ cm})$$

In this context the process of decoherence in MC-QED will always accompanied by the time reversal violating effects of dissipation. This phenomenon what produces such a profound effect on the physical nature of the transition from quantum to classical in the MC-QED formalism.

To see this more specifically we note that by virtue of its Measurement Color labeling structure, the total MC-QED Hamiltonian H is

$$H = \left(H_{0(sys)} + H_{0(env)}\right)_I + (V)_I$$

where $H_{0(sys)I} = \sum_{(k)} (H_f^{(k)})$ will be associated with Measurement Color fermion operators (k=1,2,…N $\geq$2) and the environment will be associated with the charge-field Hamiltonian $(H_{ph})_I$. In this context the bare state Hamiltonian operators $H_{0(sys)I}$ and $H_{0(env)I}$ can be used to define the bare states associated with the system and the environment respectively as

$$H_{f(sys)I} |E_f> = E_f |E_f>$$

$$H_{ph(env)I} |E_{ph}> = E_{ph} |E_{ph}>$$

Now choosing to = 0 and noting that $|E_{env}\rangle = |E_{ph}\rangle$ and $|E_{sys}\rangle = |E_f\rangle$, it follows that the reduced density matrix associated with the fermion "system" obtained by tracing over the "environment" is

$$\rho_I(t)_f = Tr_{|Eph>}\{\rho_I(t)\}$$

$$= Tr_{|Eph>}\{\exp [i(H_0)_S\, t]\ \rho_S(t) \exp [-iH_0\, t]\}$$

$$= \exp [i(H_f)t] \quad [Tr_{|Eph>}\{\exp [i(H_{ph})\, t]\ \rho_S(t) \exp [-i(H_{ph})t]\}] \quad \exp [-i(H_f)t]$$

$$= \exp [i(H_f)t] \quad [Tr_{|Eph>}\{\rho_S(t)\}] \quad \exp [-i(H_f)t]$$

Hence for MC-QED we see that the reduced fermion density matrix of the system is

$$\rho_I(t)_f = Tr_{|Eph>}\{\rho_I(t)\} = \exp [i(H_f)t] \quad [Tr_{|Eph>}\{\rho_S(t)\}] \quad \exp [-i(H_f)t]$$

On the other hand while the reduced density matrix of the fermion system $\rho_I(t)_f = Tr_{|Eph>}\{\rho_I(t)\}$ obeys the time reversal violating time evolution equation given by

$$d\rho_I(t)_f / dt = -i\, Tr_{|Eph>}\{ [V(t), \rho_I(t)]_I \}$$

the time reversal violating evolution of the reduced density matrix is non-unitary.

This is because now the second of the two conditions for unitarity to hold is violated since now

$$Tr_{|Eph>}\{\rho_I(t)_f\} = Tr_{|Eo>}\{\rho_I(t)\} = 1$$

and

$$\rho_I(t)_f{}^2 = (Tr_{|Eph>}\{\rho_I(t)\})^2 \neq \rho_I(t)_f = Tr_{|Eph}\{\rho_I(t)^2\}.$$

It is important to note that the above result is formally the same as that shown in section 8.4 and Appendix I of the book by M. Schlosshauer "Decoherence And The Quantum To Classical Transition", except now for the case of MC-QED the operator $(V)_I = (V_{qp} + V_{ret\text{-}qa})_I$ is both non-local-in-time and time reversal violating.

V. CONCLUSIONS

In order to describe the microscopic quantum electrodynamic measurement process in a relativistic, observer-participant manner, an Abelian operator symmetry of “microscopic observer-participation” called Measurement Color (MC) was incorporated into the field theoretic structure of the Quantum Electrodynamics (QED).

Within the multi-field-operator theoretic Measurement Color paradigm upon which MC-QED was based, a microscopic, causal, electrodynamic arrow of time was found to exist in the universe, independent of any additional external thermodynamic or cosmological assumptions. This occurred because the Measurement Color symmetry dynamically prohibited the free photon operator from the formalism. Instead the physical effects of photons were generated by the measurement color symmetric, negative time parity Total Coupled Radiation Charge-Field Photon operator in the MC-QED formalism.

In contradistinction to the standard local formulation of quantum electrodynamics, this caused the phenomenon of spontaneous symmetry breaking with respect to CPT invariance to occur the MC-QED formalism. This occurred because MC-QED was a non-local quantum field theory in which the photon carried the arrow of time. In this manner the physical requirement of a stable vacuum state spontaneously broke the CPT symmetry and led to operator solutions which were CP invariant but not T invariant.

In the context of the MC-QED formalism, the empirically observed invariance of CP in quantum electrodynamics does not imply T invariance. Hence for the MC-QED formalism the C, P, and CP symmetry will be preserved but the CPT symmetry will be spontaneously violated. This implies, within the context of MC-QED, that the CPT transformation cannot turn our universe into its "mirror image" because the photon carries the arrow of time. Hence MC-QED implies that the flow of time in the universe can run forward in a causal sense but cannot not backward in an acausal sense.

Since the microscopic observer-participant paradigm of Measurement Color with its dynamically generated microscopic dynamic arrow of time is a general concept, its application can be applied to quantum gauge field theories which are more general than Quantum Electrodynamics. Hence Measurement Color generalizations of higher symmetry quantum gauge particle field theories associated with the Standard Model and Grand Unified Models should be attainable, within which the gauge bosons as well as the photon would carry the Arrow of Time.

In this manner we see that the dynamic existence of the microscopic arrow of time in MC-QED represents a fundamentally quantum electrodynamic explanation for irreversible phenomena associated with the Second Law of Thermodynamics, which complements the one supplied by the well-known statistical arguments in phase space (Zeh, D., 2007). This occurs because MC-QED dynamically generates a causal radiation arrow in the universe which dynamically implies that the entropy, associated with spontaneous emission of a cloud of photons from a aggregate of fermions, will always increase.

Hence the dynamic radiation arrow of time, caused by the spontaneous CPT violation in the MC-QED formalism, can be used to derive the Second Law of Thermodynamics, in the fundamental form which states that the heat associated with radiation is an irreversible process which spontaneously flows from hot bodies to cold bodies and not the other way around.

Since the MC-QED formalism resolved the apparent asymmetry in the description of the microscopic and macroscopic “Arrows of Time” in the universe, this allowed us to use it to solve the problem of the asymmetry between microscopic quantum objects and macroscopic classical objects inherent in the laws of quantum physics. We began by first noting that the origin this problem lies within the nature of Copenhagen Interpretation of QED. This is because within QED macroscopic bodies, associated with macroscopic measuring instruments and macroscopic conscious observers, are assumed to obey a strict form of “Macroscopic Realism”, on a complementary classical level of physics external to the microscopic quantum electrodynamic system.

Because its Measurement Color symmetry implied that the photon operator carries the arrow of time, this concept of strict Macroscopic Realism was shown to not be valid for the case of MC-QED. This was because the photon carrying the arrow of time was shown to have a profound effect on the nature of the time evolution of the state vector in the Schrodinger Picture of the MC-QED formalism.

In particular we found that this caused the total Hamiltonian operator in the Schrodinger Picture of MC-QED to contain a time reversal violating quantum evolution component as well as a time reversal violating quantum measurement interaction component. The time reversal violating quantum measurement interaction part of the Hamiltonian operator was shown to have components which contained causal retarded light travel times, connected to the values of the physical sizes and/or spatial separations associated with the physical aggregate of Measurement Color symmetric fermionic states into which the fermionic sector of the state vector was expanded.

For retarded light travel time intervals *in between the preparation and the measurement*, the expectation values of the time-reversal violating retarded quantum measurement interaction operator was found to be negligible compared to the expectation values of the time reversal violating quantum evolution operator, and the net effect generated the “quantum potentia” of what may occur in the form of the S-matrix approximation to the formalism.

On the other hand for the retarded light travel time intervals *corresponding to the preparation and/or the measurement,* the expectation values of the time-reversal violating retarded quantum measurement interaction operator was found to be dominant compared to the expectation values of the time reversal violating quantum evolution operator. and the net effect caused the “quantum potentia” of what may occur to be converted into the “quantum actua” of actual observer-participant measurement events.

In this context it was found that for a sufficiently large aggregate of atomic systems, described by the bare state component of total MC-QED Hamiltonian and assumed to exist in an “environment” associated with the remaining time reversal violating components of the total Hamiltonian, the net effect of the quantum measurement interaction in MC-QED generated time reversal violating decoherence-dissipation effects on the reduced density matrix in a manner which could dynamically give large aggregates of atomic systems apparently classical properties.

Hence, in contradistinction the Copenhagen Interpretation of QED with its strict form of "Macroscopic Realism", we found that MC-QED obeyed a dynamic form of Macroscopic Realism in which the classical level of physics emerged dynamically in the context of non-local intrinsically time reversal violating quantum decoherence effects which were able to project out individual states associated with specific diagonal elements of the density matrix. This result was in stark contrast to that of QED, where local quantum decoherence effects only appeared to be irreversible since a local observer did not have access to the entire wave function and, while interference effects appeared to be eliminated, individual states associated with specific diagonal elements of the density matrix had not been projected out (Schlosshauer, M., 2007).

In this manner we showed that the intrinsically time reversal violating quantum decoherence effects inherent within MC-QED implied that it did not require an independent external complementary classical level of physics obeying strict Macroscopic Realism in order to obtain a physical interpretation. In this way we have been led to the conclusion that an elegant resolution of the problem of the asymmetry between microscopic quantum objects and macroscopic classical objects inherent in the laws of quantum physics could be found within the context of the MC-QED formalism.

This result has broader implications since it leads to the possibility of finding a physical explanation of how living, macroscopic conscious observers emerge from the microscopic laws of quantum physics. This is because the observer-participant nature of MC-QED, with its intrinsic arrow of time dynamically generated by spontaneous CPT violation, opens up the possibility of two possible approaches to explain the apparently spontaneous emergence of macroscopic conscious minds in the universe from the microscopic laws of quantum physics. .

The first approach is a local one which can be found by extending the Measurement Color paradigm into the recently developed quantum field theoretic domain of consciousness research called Quantum Brain Dynamics QBD, (Jibu, M., and Yasue, K., 1995) , (Vitiello, G., 2001). Since MC-QED is a quantum field theoretic formalism which contains both the effects of quantization and dissipation, it may be possible that the ideas underlying QBD can be consistently generalized into a (MC-QBD) formalism. In this way it may be possible to find a local cybernetic description of how macroscopic conscious observer-participant entities emerge in a microscopic observer-participant universe.

The second approach is a global one which can be found by noting the fact that MC-QED describes the universe in terms of myriads of microscopic, time reversal violating, observer-participant quantum field theoretic interactions which span both the classical and the quantum world. On the other hand living, macroscopic conscious observers also appear to have physical properties which simultaneously span both the classical and the quantum world. Because of this similarity the MC-QED formalism has the capability of being able to explain how macroscopic conscious observer-participant entities emerge in a microscopic observer-participant universe. Since this would occur in a Measurement Color quantum field theoretic manner, a global quantum holographic description of consciousness may exist which connects the "minds of conscious observers" to the "mind of the observer-participant universe" as a whole.

APPENDIX I. MEASUREMENT COLOR QUANTUM ELECTRODYNAMICS

Measurement Color Quantum Electrodynamics (MC-QED) is constructed by imposing an Abelian operator gauge symmetry of microscopic operator observer-participation called Measurement Color onto the operator equations of Quantum Electrodynamics (QED) in the Heisenberg picture. We do this by defining an Abelian quantum field operator labeling symmetry associated with the integer indices k = 1,2, …, N (where in the limit we will let N --> ∞) and then imposing this integer labeling in an operational manner onto the quantum field structure of the standard QED formalism. In doing this we use the metric signature (1,-1, -1,-1), and $(h/2\pi) = c = 1$ units and the relativistic notation, operator sign conventions, and operator calculation techniques, used to generalize and extend the standard QED formalism into the MC-QED theory, are formally similar to those used in Chapters 8 and 9 of "Introduction to Relativistic Quantum Field Theory" by Sylvan. S. Schweber, Harper & Row 2nd Edition (1962).

The MC-QED formalism which emerges operationally describes the microscopic observer-participant quantum electrodynamic process, between the electron-positron quantum operator fields $\psi^{(k)}$ and the charge field photon quantum operator fields $A_\mu^{(j)}$ $(k \neq j)$ which they interact with, in the Heisenberg Picture operator field equations. Since MC-QED is a theory of mutual quantum field theoretic observer-participation, its action principle must be constructed in a manner such that time-symmetric self-measurement interaction terms of the form $J_\mu^{(k)}A^{\mu(k)}$ (k=1,2,… , N→ -∞) are dynamically excluded from the formalism.

In the Heisenberg picture this is dynamically accomplished by means of the charge-conjugation invariant MC-QED action principle given by (k, j =1,2,… , N→ -∞)

$$I = \{- \int dx^4 \ [\Sigma_{(k)} \left(1/4[\psi^{(k)\dagger}\gamma^o, (-i\gamma^\mu\partial_\mu+m)\psi^{(k)}] + \text{hermetian conjugate}\right)$$
$$+ \Sigma_{(k)} \Sigma_{(j \neq k)} (1/2\partial_\mu A^{\nu(k)} \partial^\mu A_\nu^{(j)} + J_\mu^{(k)}A^{\mu(j)})]\}$$

In the Heisenberg picture, following the standard second quantization methods taken in generating QED from CED to the above action for MC-QED, we find that the MC-QED Heisenberg operator equations of motion are given by

$(-i\gamma^\mu\partial_\mu + m - e\gamma^\mu A_\mu^{(k)}{}_{(obs)})\psi^{(k)} = 0$ (Heisenberg equation for $\psi^{(k)}$ fermion operator)

$A_\mu^{(k)}{}_{(obs)} = \Sigma_{(j \neq k)} A_\mu^{(j)}$ (electromagnetic operator field $A_\mu^{(k)}{}_{(obs)}$ *observed* by $\psi^{(k)}$)

$\Box^2 A_\mu^{(k)} = J_\mu^{(k)} = -e\,[\psi^{(k)\dagger}\gamma^o, \gamma_\mu\psi^{(k)}]$ (Heisenberg equation for the $A_\mu^{(k)}$ operator)

where the Measurement Color labels on the operator fields $\psi^{(k)}$, and $A_\mu^{(k)}$ range over (k= 1,2, , N --> ∞). In the context of an indefinite metric Hilbert space, the Subsidiary Condition

$$<\psi| (\partial^\mu A_\mu^{(k)}) |\psi> = 0 \qquad (k =1,2, \dots , N\text{-->} \infty))$$

must also be satisfied.

Then the expectation value of the Heisenberg Picture operator equations of MC-QED are will be invariant under the Abelian Measurement Color gauge transformation

$$\psi^{(k)'}(x) = \psi^{(k)}(x)\exp(ie\Lambda(x))$$

$$A_\mu^{(k)'}(x)_{obs)} = A_\mu^{(k)}(x)_{(obs)} + \partial_\mu\Lambda(x)$$

where $\Lambda(x)$ is a scalar field obeying $\Box^2\Lambda(x) = 0$ (k =1,2, … , N→ -∞). Hence the individual Measurement Color currents $J_\mu^{(k)}$ are conserved as $\partial^\mu J_\mu^{(k)} = 0$ (k =1,2, … , N→ -∞) which implies that the individual Measurement Color charge operators $Q^{(k)} = \int dx^3\, J_0^{(k)}$ (k =1,2, … , N→ -∞) commute with the total Hamiltonian operator of the theory.

Following the standard procedures for the canonical quantization of fields applied to MC-CED leads to the canonical equal-time commutation and anti-commutation relations in the MC-QED formalism as

$$\begin{aligned}
&[A_\mu^{(k)}(x, t), \partial_t A_\nu^{(j)}{}_{(obs)}(x', t)] = i\eta_{\mu\nu}\delta^{kj}\,\delta^3(x' - x)\\
&\{\psi^{(k)}(x, t), \psi^{(j)\dagger}(x', t)\} = \delta^{kj}\,\delta^3(x' - x) \qquad\qquad (k, j = 1,2, \dots, N\rightarrow \infty)\\
&[A_\mu^{((k)}(x, t), \psi^{(j)}(x', t)] = [A_\mu^{((k)}(x, t), \psi^{(j)\dagger}(x', t)] = 0
\end{aligned}$$

where $sig(\eta_{\mu\nu})$ = (1, -1, -1, -1, with other equal-time commutators and anti-commutators vanishing respectively, (k, j =1,2, … , N→ ∞).

In this context the structure of the MC-QED operator equations of motion and the equal-time commutation and anti-commutation relations dynamically enforces a form of mutual operator observer-participation which dynamically excludes time-symmetric Measurement Color self-interaction terms of the form $e\gamma^\mu A_\mu^{(k)}\psi^{(k)}$ (k =1,2, … , N→ ∞) from the operator equations of motion.

The N ≥ 2 Maxwell field operator equations must be solved for the charge-field operator solutions $A_\mu^{(k)}$ within the context of the multi-operator field theoretic Measurement Color paradigm upon which MC-CED is based. Hence the MC-QED paradigm excludes the local time-symmetric free radiation field operators $A_\mu^{(0)}$ from contributing to the $A_\mu^{(k)}$ charge-field operator solutions, because the $A_\mu^{(0)}$ field operators cannot be defined in terms of Measurement Color charge-field operator currents. This is in contrast to the case of QED where the local time-symmetric free radiation field operators $A_\mu^{(0)}$ cannot be excluded from A_μ since Measurement Color does not play a role in the Maxwell field operator structure in QED. Hence in solving the N ≥ 2 Maxwell field operator equations for the charge-field operators $A_\mu^{(k)}$ the MC-CED paradigm implies that a universal time-symmetric boundary condition, which mathematically excludes local time reversal invariant free uncoupled radiation field operators $A_\mu^{(0)}$ from contributing to the N ≥ 2 charge-fields $A_\mu^{(k)}$, has been imposed on <u>each</u> of the $A_\mu^{(k)}$ operator solutions to the N ≥ 2 Maxwell operator field equations.

Hence "free uncoupled radiation field operators" are excluded from MC-QED and in their place the physical effects of radiation are operationally described in a microscopic observer-participant manner by the "nonlocal, time anti-symmetric, total coupled radiation charge-field operator" $A_\mu^{(TCRF)}$

$$A_\mu^{(TCRF)} = \Sigma_{(j)} A_\mu^{(j)}(-) = \int dx^{4'} D_{(-)} (x-x') \, \Sigma_{(j)} J_\mu^{(j)}(x') \qquad (k = 1,2, \ldots, N \dashrightarrow \infty))$$

where

$$D_{(-)} (x-x') = (D_{(ret)} (x-x') - D_{(adv)} (x-x')) / 2$$

The $A_\mu^{(TCRF)}$ operator is a real, nonlocal operator which has a negative parity under Wigner time reversal T_W (defined as the product of the Hermetian complex conjugate operator and the operator which takes t into –t) It has the unique property of being non-locally coupled to the sum of all of the current operators while still obeying the charge field photon operator equation $\Box^2 A_\mu^{(TCRF)} = 0$

Now within the operational observer-participant context of the MC-QED Heisenberg operator field equations, the electron-positron operator fields $\psi^{(k)}$ (k = 1,2, … N) "observe" the electromagnetic operator field $A_\mu^{(k)}{}_{(obs)}$ field, where $A_\mu^{(k)}{}_{(obs)}$ is given by the superposition of the "time-symmetric" electromagnetic field operators $A_\mu^{(j)}(+) = 1/2 \int dx^{4'} (D_{(ret)} (x-x') + D_{(adv)} (x-x'))J^{(k)}(x')$, ($j \neq k$ =1,2, …N) and the "time-anti-symmetric" total coupled radiation field operator $A_\mu^{(TCRF}$ as

$$A_\mu^{(k)}{}_{(obs)} = \Sigma_{(k \neq j)} A_\mu^{(j)} = \Sigma_{(j \neq k)} A_\mu^{(j)}(+) + (2p-1) A_\mu^{(TCRF)} \qquad (k = 1,2, \ldots, N \dashrightarrow \infty))$$

where p is a c-number whose value, in the absence of "free radiation field operators", determines nature of the Arrow of Time in the MC-QED formalism independent of any external cosmological or thermodynamic assumptions.

To see this more explicitly we re-write the operator equations for $A_\mu^{(k)}{}_{(obs)}$ in the following form as

$$\begin{aligned} A_\mu^{(k)}{}_{(obs)} &= pA^{(k)}{}_{(obs)}(ret) + (1-p)A^{(k)}{}_{(obs)}(adv) + A^{(k)}{}_{(obs)}(in\text{-}p) \\ &= pA^{(k)}{}_{(obs)}(adv) + (1-p)A^{(k)}{}_{(obs)}(ret) + A^{(k)}{}_{(obs)}(out\text{-}p) \end{aligned}$$

where the negative time parity coupled charge field photon "in and out" operators are

$$A^{(k)}{}_{(obs)}(in\text{-}p) = (2p - 1)\, A^{(k)}(-)$$

$$A^{(k)}{}_{(obs)}(out\text{-}p) = A^{(k)}{}_{(obs)}(in\text{-}p) + 2(2p - 1)\, A^{(k)}{}_{(obs)}(-)$$

$$A^{(k)}(-) = 1/2 \int dx^{4'} (D_{(ret)} (x-x') - D_{(adv)} (x-x'))J^{(k)}(x')$$

Now, in the absence of non-operational free radiation fields, the presence of the negative time parity Total Coupled Radiation Field operator $A_\mu^{(TCRF)}$ in MC-QED implies that the MC-QED operator equations violate both the T_p and the T_W symmetry operations defined as follows:

a) The "Radiation Flow Symmetry Operator" T_p , for which $p \rightarrow (1-p)$ occurs, is violated in the operator equations (3) since they have a negative parity under the T_p operation

b) The Wigner Time Reversal operator symmetry T_W , for which Hermetian complex conjugation and $t \rightarrow -t$ occurs, is violated in the operator equations since by virtue of the presence of the Total Coupled Radiation Field operator $A_\mu^{(TCRF)}$ they have a negative parity under the T_W operation

However, even though equations separately violate the T_p and the T_W symmetry, they are still invariant under the generalized Time Reversal operator $T = T_W \times T_p$ which is the product of the Wigner Time Reversal Operator T_W and the Radiation Flow Symmetry Operator T_p . Since the operator field equations of motion of the MC-QED formalism in the Heisenberg Picture are also invariant under the respective action of the Charge Conjugation operator C, and the Parity operator P, then even though it violates the T_W time reversal symmetry, we find that MC-QED is still CPT invariant where the T symmetry is generalized to become $T = T_W \times T_p$.

Now in the context of the Heisenberg Picture state vector $|\psi>$ one defines the "in-out" operator field solutions by imposing the "In-Asymptotic Condition" as $\psi^{(k)}(x, t \rightarrow -\infty) = \psi^{(k)}(in)$ $(k = 1, 2, \ldots, N \dashrightarrow \infty))$

(In-kinematic condition)

$$< A_\mu^{(k)}{}_{(obs)}(x, t \rightarrow -\infty)> = <(\int dx^3 (J_\mu^{(k)}{}_{(obs)}(x', t \rightarrow -\infty) / 4\pi |\mathbf{x-x'}|) + A^{(k)}{}_{(obs)}(in)>$$

(in-dynamic stability condition)

$$<\partial_t J_\mu^{(k)}(x, t \rightarrow -\infty)> = 0$$

in the limit as $t \rightarrow -\infty$ of the operator equations (1) as

$$<(-i\gamma^\mu\partial_\mu + m - e\gamma^\mu A_\mu^{(k)}{}_{(obs)}(x, t \rightarrow -\infty))\psi^{(k)}(in)>= 0$$
$$<\Box^2 A_\mu^{(k)}(in)> = <J_\mu^{(k)}(in)> = -e <[\psi^{(k)}(in)^\dagger \gamma^o, \gamma_\mu\psi^{(k)}(in)]>$$

and also imposing "Out-Asymptotic Condition" as $\psi^{(k)}(x, t \rightarrow +\infty) = \psi^{(k)}(out)$ $(k = 1, 2, \ldots, N \dashrightarrow \infty))$

(out-kinematic condition)

$$< A_\mu^{(k)}{}_{(obs)}(x, t \rightarrow +\infty)> = <(\int dx^3 (J_\mu^{(k)}{}_{(obs)}(x', t \rightarrow +\infty) / 4\pi |\mathbf{x-x'}|) + A^{(k)}{}_{(obs)}(out)>$$

(out-dynamic stability condition)

$$<\partial_t J_\mu^{(k)}(x, t \rightarrow +\infty)> = 0$$

in the limit as t $\rightarrow +\infty$ of the operator equations (1) as

$$<(-i\gamma^{\mu}\partial_{\mu} + m - e\gamma^{\mu}A_{\mu}{}^{(k)}{}_{(obs)}(x, t \rightarrow +\infty))\psi^{(k)}(out)> = 0$$

$$<\Box^{2}A_{\mu}{}^{(k)}(out)> = <J_{\mu}{}^{(k)}(out)> = -e <[\psi^{(k)}(out)^{\dagger}\gamma^{o}, \gamma_{\mu}\psi^{(k)}(out)]>$$

Now by applying the Asymptotic Conditions to the MC-QED operator equations of motion it follows that a retarded quantum electrodynamic arrow of time emerges dynamically. This is because in the absence of "free uncoupled radiation field operators":

a) the kinematic component of the Asymptotic Condition formally determines two possible values for the c-number p which controls the arrow of time in the operator equations to be either p =1 or p = 0, and
b) the dynamic component of the Asymptotic Condition associated with the stability of the vacuum state dynamically requires that the physical value of the c-number p which appears in the operator equations to be p=1 associated with a retarded, causal, quantum electrodynamic arrow of time.

To see this more specifically note that for the case of p =1 the Heisenberg Picture operator equations of motion have the form

$$<(-i\gamma^{\mu}\partial_{\mu} + m - e\gamma^{\mu}A_{\mu}{}^{(k)}{}_{(obs)})\psi^{(k)}> = 0$$

$$<A_{\mu}{}^{(k)}{}_{(obs)}> = <\sum_{(j \neq k)}A_{\mu}{}^{(j)}(ret) + A^{(k)}(-)> \qquad (k, j = 1,2, \ldots , N\text{-->} \infty))$$

The expectation value of the above operator equations physically describe the situation where charge field photons are causally emitted and absorbed between the $\psi^{(k)}$ and $\psi^{(j)}$ $k \neq j$ fermion operators, while being spontaneously emitted into the vacuum by the $\psi^{(k}$ fermion operators, $(k, j = 1,2, \ldots , N\text{-->} \infty))$. For this reason these operator equations predict that electron-positron states can form bound states which spontaneously decay into charge field photons. Hence these operator equations will satisfy the dynamic stability component of the Asymptotic Condition because they predict that their expectation values imply that a stable vacuum state exists.

On the other hand for the case of p =0 the Heisenberg Picture operator equations of motion have the form

$$<(-i\gamma^{\mu}\partial_{\mu} + m - e\gamma^{\mu}A_{\mu}{}^{(k)}{}_{(obs)})\psi^{(k)}> = 0$$

$$<A_{\mu}{}^{(k)}{}_{(obs)}> = <\sum_{(j \neq k)} A_{\mu}{}^{(j)}(adv) - A^{(k)}(-)> \qquad (k, j = 1,2, \ldots , N\text{-->} \infty))$$

On the other hand the expectation value of these operator equations physically describe the situation where charge field photons are causally absorbed and emitted between the $\psi^{(k)}$ and $\psi^{(j)}$ $k \neq j$ fermion operators, while being spontaneously absorbed from the vacuum by the $\psi^{(k}$ fermion operators, $(k, j = 1,2, , N\text{-->} \infty))$. For this reason these operator equations predict that electron-positron states will be spontaneously excited from the vacuum.

Hence these operator equations cannot satisfy the dynamic stability component of the Asymptotic Condition because they predict that their expectation values imply that a stable vacuum state cannot exist. In addition, because of the operational presence negative time parity Total Coupled Radiation Charge-Field $A_\mu^{(TCRF)}$ in the MC-QED formalism, the dynamic component of the time-symmetric Asymptotic Condition, which requires that a stable vacuum state must exist, dynamically determines a retarded quantum electrodynamic Physical Arrow of Time associated with p =1 independent of any Thermodynamic or Cosmological boundary conditions. Hence this implies that MC-QED has a negative parity under the T_w and T_p operations while still remaining Invariant under the CPT symmetry operation where T is generalized to become $T = T_w \times T_p$.

APPENDIX II . OBSERVER-PARTICIPANT FORMALISM IN THE MC-QED INTERACTION PICTURE

The S-matrix approximation to MC-QED, which holds for time intervals $|(h / \Delta E)| < t << |(R/c|$, and its connection to the well-known Feynman diagrammatic explanations of quantum electrodynamic processes, will now be discussed in more detail in the this section where the observer-participant bare state structure of MC-QED will be developed.

In the Heisenberg picture the MC-QED Hamiltonian operator $H = H_S$ is

$$H = H^{\dagger} = [H_0 + V_{qp} + V_{ret\text{-}qa}]$$

where H_0 contains the bare fermion and bare components of H

$$H_0 = (H_f + H_{ph})$$

In H_0 the Measurement Color symmetric bare electron-positron Hamiltonian operator H_f is given by $(k = 1,2, \ldots , N \rightarrow \infty)$

$$H_f = \sum_{(k)} \{ : \int dx^3 [\psi^{(k)\dagger} (\alpha . \bullet \mathbf{p} + \beta m - e\varphi^{(k)}{}_{(ext)}) \psi^{(k)} + J^{\mu(k)} A_\mu{}^{(k)}{}_{Breit}{}^{(obs)}] : \}$$

(where the Breit potential operator is given by $A_\mu{}^{(k)}{}_{Breit}{}^{(obs)} = \sum_{(j) \neq (k)} \int dx^3 J_\mu{}^{(j)}(x',t) / 4\pi |x-x'|$ and an external potential $\varphi^{(k)}{}_{(ext)})$ has been included in order to represent the lowest order Coulombic effects of baryonic nuclei in the MC-QED) and the Measurement Color symmetric bare electromagnetic field Hamiltonian operator where H_{ph} is given by $(k = 1,2, \ldots , N \rightarrow \infty)$

$$H_{ph} = -1/2 \sum_{(k)} \{ : \int dx^3 [(\partial_t A^{\mu(k)}{}_{(rad)} \partial_t A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)} + \nabla A^{\mu(k)}{}_{(rad)} \bullet \nabla A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)})] : \}$$

where

$$A_\mu{}^{(k)}{}_{(rad)} = (\alpha_\mu - A_\mu{}^{(k)}{}_{(-)})$$

$$\alpha_\mu = \sum_{(j)} A_\mu{}^{(j)}(-) /(N-1)$$

$$A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)} = \sum_{(j) \neq (k)} A_\mu{}^{(j)}{}_{(rad)} = A_\mu{}^{(k)}{}_{(-)}$$

and $A_\mu{}^{(k)}{}_{(-)}$ is the non-local, negative time parity, Heisenberg picture operator defined as

$$A_\mu{}^{(k)}{}_{(-)} = \int dx'^4 (D_{(-)} (x-x') \; J_\mu{}^{(k)}(x') \qquad (k = 1,2, \ldots , N \rightarrow \infty)$$

Note that the $A_\mu{}^{(k)}{}_{(rad)}$, $A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)}$, α_μ all have a negative parity under Wigner Time reversal since they are linear functions of $A_{\mu\,(-)}{}^{(k)}$.

The operators V_{qp} and $V_{ret\text{-}qa}$ are given ($k = 1,2, \ldots , N \rightarrow \infty$) by

$$V_{qp} = \sum_{(k)} \{ : \int dx^3 J\mu^{(k)} A^{\mu(k)}{}_{(-)} : \}$$

and

$$(V_{ret\text{-}qa}) = \sum_{(k)} \{ : \int dx^3 \left[J_\mu{}^{(k)} (A^{\mu(k)}{}_{(ret)}{}^{(obs)} - A_\mu{}^{(k)}{}_{Breit}{}^{(obs)}) \right]$$

$$-1/2 \left[{}_tA^\mu{}_{(ret)}{}^{(k)} \partial_t A_{\mu\,(ret)}{}^{(k)\,(obs)} + \partial_t A^\mu{}_{(ret)}{}^{(k)} \partial_t A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)} + \partial_t A^\mu{}_{(rad)}{}^{(k)} \partial_t A_{\mu\,(ret)}{}^{(k)\,(obs)} \right]$$

$$+ \nabla A^\mu{}_{(ret)}{}^{(k)} \bullet \nabla A_\mu{}^{(k)}{}_{(ret)}{}^{(obs)} + \nabla A^\mu{}_{(ret)}{}^{(k)} \bullet \nabla A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)} + \nabla A^\mu{}_{(rad)}{}^{(k)} \bullet \nabla A_{\mu\,(ret)}{}^{(k)\,(obs)} \Big] : \}$$

where

$$A_\mu{}^{(k)}{}_{(ret)}{}^{(obs)} = \sum_{(j) \neq (k)} A_\mu{}^{(j)}{}_{(ret)}$$

where $J\mu^{(k)} = -e[\psi^{(k)\dagger}\gamma^o, \gamma_\mu \psi^{(k)}]$ and the symbols **:** **:** indicate that normal ordering of operators has been taken. In the Heisenberg Picture the MC-QED *equal-time* commutation and anti-commutation relations for ($k, j = 1,2, \ldots , N \rightarrow \infty$) are given, ($k, j = 1,2, \ldots , N \rightarrow \infty$), $sig(\eta_{\mu\nu}) = (1, -1, -1, -1)$, by

$$[A_\mu{}^{(k)} (\mathbf{x}, t), \partial_t A_\nu{}^{(j)}{}_{(obs)} (\mathbf{x'}, t)] = -i\eta_{\mu\nu}\delta^{kj} \delta^3(\mathbf{x'} - \mathbf{x})$$
$$[A_\mu{}^{((k)} (\mathbf{x}, t) , \psi^{(j)}(\mathbf{x'}, t)] = 0$$
$$[A_\mu{}^{((k)} (\mathbf{x}, t) , \psi^{(j)\dagger}(\mathbf{x'}, t)] = 0$$
$$\{\psi^{(k)} (\mathbf{x}, t) , \psi^{(j)\dagger}(\mathbf{x'}, t)\} = \delta^{kj} \delta^3(\mathbf{x'} - \mathbf{x})$$
$$\{\psi^{(k)} (\mathbf{x}, t) , \psi^{(j)} (\mathbf{x'}, t)\} = 0$$
$$\{\psi^{(k)\dagger}(\mathbf{x}, t) , \psi^{(j)\dagger}(\mathbf{x'}, t)\} = 0$$

All other equal-time commutators and anti-commutators vanishing respectively.

Now the successive state vector transformations on the Heisenberg Picture State vector $|\psi_H>$, through the Schrodinger Picture state vector $|\psi_{S>}$, that finally leads to the Interaction Picture state vector $|\psi_I>$ can be formally represented by $|\psi_I(t)> = U(t-t_o) |\psi_H>)$ where the unitary operator $U(t-t_o)$ is

$$U(t-t_o) = \exp [i(H_0)_S(t-t_o)] \exp [-iH(t-t_o)]$$

and Schrodinger Hamiltonian operators $(H_0)_S$ and $H=H_S$ are constant in time. It then follows that the equation of motion of the state vector in the Interaction Picture is

$$i\partial_t|\psi_I(t)> / dt = [V_{qp}(t) + V_{ret\text{-}qa}(t)]_I \; |\psi_I(t)>$$

where Interaction Picture operators $O_I(x, t)_I$ are related to Heisenberg Picture operators $O_H(x, t)$ as

$$O_I(x,t)_I = U(t-t_o)\, O_I(x,t)_H\, U(t-t_o)^{-1} = U(t-t_o)\, O_I(x,t)_H\, U(t-t_o)^{\dagger}$$

The Interaction Picture the S-matrix approximation to the MC-QED is applicable during the time intervals for which $V_{qp}(t)_I$ dominates $V_{ret\text{-}qa}(t)_I$ in the state vector equation of motion. The S-matrix approximation is valid during the time intervals $-(R / c) < t < (R / c)$ in between *preparations* occurring at t = $-(R/c)$ and *measurements* occurring at t = (R/c), (where $|(R / c)| >>>> (h / \Delta E)$ is the magnitude of the characteristic size and/or spatial separation of the physical components associated with observer-participant quantum states of the bare hamiltonian operator H_0). In this context it follows that the Interaction Picture Hamiltonian operator is given by $H_I = (H_0)_I + (V_{qp})_I$

<u>For simplicity of notation, the subscript</u> " $_I$ " <u>will be dropped and understood to hold for all equations in what follows</u>. In this context we have

$$H = H_0 + V_{qp}$$

where

$$H_0 = H_f + H_{ph}$$

and the bare fermion Interaction Picture Hamiltonian operator $H_{in\text{-}f}$ is $(k =1,2, \ldots , N\rightarrow$

$$H_f = \sum_{(k)} \{: \int dx^3 \, [\psi^{(k)\dagger}(\alpha.\bullet \mathbf{p} + \beta m - e\varphi^{(k)}{}_{(ext)})\, \psi^{(k)} + J^{\mu(k)} A_\mu{}^{(k)}{}_{Breit}{}^{(obs)}] :\}$$

and the bare Interaction Picture Hamiltonian operator H_{ph} is $(k =1,2, \ldots , N\rightarrow$

$$H_{ph} = -1/2 \sum_{(k} \{: \int dx^3 \,[\, (\partial_t A^{\mu(k)}{}_{(rad)}\, \partial_t A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)} + \nabla A^{\mu(k)}{}_{(rad)} \bullet \nabla A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)})]:\}$$

In H_{ph} the operators $A_\mu{}^{(k)}{}_{(rad}$ and $A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)}$ are given by

$$A_\mu{}^{(k)}{}_{(rad)} = (\alpha_\mu - A_\mu{}^{(k)}{}_{(-)})$$

$$A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)} = \sum_{(j) \neq (k)} A_\mu{}^{(j)}{}_{(rad)} = A_\mu{}^{(k)}{}_{(-)}$$

where $\alpha_\mu = \sum_{(j)} A_\mu^{(j)}{}_{(-)} /(N-1)$ and $A_\mu^{(k)}{}_{(-)}$ is given by

$$A_\mu^{(k)}{}_{(-)} = \left(\int dx'^4\, D_{(-)}(x-x')\, U(t)U(t')^{-1}\, J^{\mu(k)}(x')\, U(t')U(t)^{-1}\right)$$

where

$$U(t)U(t')^{-1} = \left(\exp[i(H_0)_S\, t] \exp[-iH_S\, t]\right) \left(\exp[-i(H_0)_S\, t'] \exp[iH_S\, t']\right)$$

The "quantum potentia" Interaction Picture operator which couples H_f to H_{ph} is given by

$$V_{qp} = \sum_{(k)} \{ \mathbf{:} \int dx^3\, J\mu^{(k)} A^{\mu(k)}{}_{(-)} \mathbf{:} \} = \sum_{(k)} Vqp^{(k)} \qquad (k=1,2,\ldots,N \text{ --- } > \infty)$$

The Interaction Picture operator equations of motion for MC-QED are given by

$$(-i\gamma^\mu\partial_\mu + m - e\varphi^{(k)}{}_{(ext)} - e\gamma^\mu A_\mu^{(k)}{}_{(Breit\text{-}obs)})\psi^{(k)} = 0$$

$$\Box^2 A_\mu^{(k)}{}_{(-)} = 0 \qquad (k, j = 1,2, \ldots, N \rightarrow -\infty)$$

where

$$A_\mu^{(k)}{}_{(Breit\text{-}obs)} = \sum_{(j \neq k)} A_\mu^{(j)}{}_{(Breit)}$$

$$A_\mu^{(j)}{}_{(Breit)}(x,t) = \int dx'^3\, J\mu^{(j)}(x', t) / 4\pi\, |x - x'|$$

and the Coulombic effects of baryonic nuclei in the MC-QED formalism is represented to lowest order by the external potential $\varphi^{(k)}{}_{(ext)}$). The *equal-time commutation and anti-commutation relations* in the Interaction Picture are (k, j =1,2, … , N→ ∞), $\mathrm{sig}(\eta_{\mu\nu}) = (1, -1, -1, -1)$, (REF SCHWEBER PG 242)

$$[A_\mu^{(k)}(\mathbf{x}, t), \partial_t A_\nu^{(j)}{}_{(obs)}(\mathbf{x'}, t)] = -i\eta_{\mu\nu}\delta^{kj}\, \delta^3(\mathbf{x'} - \mathbf{x})$$
$$[A_\mu^{((k)}(\mathbf{x}, t), \psi^{(j)}(\mathbf{x'}, t)] = [A_\mu^{((k)}(\mathbf{x}, t), \psi^{(j)\dagger}(\mathbf{x'}, t)] = 0$$
$$\{\psi^{(k)}(\mathbf{x}, t), \psi^{(j)\dagger}(\mathbf{x'}, t)\} = \delta^{kj}\, \delta^3(x' - x)$$
$$\{\psi^{(k)}(\mathbf{x}, t), \psi^{(j)}(\mathbf{x'}, t)\} = 0$$
$$\{\psi^{(k)\dagger}(\mathbf{x}, t), \psi^{(j)\dagger}(\mathbf{x'}, t)\} = 0$$

All other equal-time commutators and anti-commutators vanishing respectively, (k, j =1,2, … , N→ ∞).

Using the operator equations of motion the above equal time commutation and anti-commutation relations can be solved for the general commutation and anti-commutation relations in the Interaction Picture as

(k, j =1,2, … , N→ ∞) , sig($\eta_{\mu\nu}$) = (1, -1, -1, -1)

$$[A_\mu^{(k)}(x), A_\nu^{(j)}{}_{(obs)}(x')] = \delta^{kj}[i\eta_{\mu\nu}D(x'-x)] = \delta^{kj} D_{\mu\nu}(x'-x)$$
$$[A_\mu^{((k)}(x), \psi^{(j)}(x')] = [A_\mu^{((k)}(x), \psi^{(j)\dagger}(x')] = 0$$
$$\{\psi^{(k)}(x), \psi^{(j)\dagger}(x')\} = \delta^{kj} S(x'-x)$$
$$\{\psi^{(k)}(x), \psi^{(j)}(x')\} = 0$$
$$\{\psi^{(k)\dagger}(x), \psi^{(j)\dagger}(x)\} = 0$$

where $D_{\mu\nu}(x'-x) = [i\eta_{\mu\nu}D(x'-x)]$ and $D(x'-x) = (1/2\pi)\,\varepsilon(x_0)\delta(x) = -D_{(-)}(x'-x)$, and all other equal-time commutators and anti-commutators vanishing respectively, (k, j =1,2, … , N→ ∞).

When the relationships

$$A_\mu^{(k)}(x) = (\alpha_\mu(x) - A_\mu^{(k)}{}_{(-)}(x))$$
$$\alpha_\mu(x) = \textstyle\sum_{(j)} A_\mu^{(j)}{}_{(-)}(x) \,/(N-1)$$
$$A_\mu^{(k)}{}_{(obs)}(x) = \textstyle\sum_{(j)\neq(k)} A_\mu^{(j)}(x) = A_\mu^{(k)}{}_{(-)}(x)$$

are inserted, the commutation relations for $A_\mu^{(k)}{}_{(-)}(x)$, $A_\nu^{(k)}(x')$, and $\alpha_\mu(x)$ become (k, j =1,2, … , N→ ∞).

$$[A_\mu^{(k)}{}_{(-)}(x), A_\nu^{(j)}{}_{(-)}(x')] = (1 - \delta^{kj})(D_{\mu\nu}(x'-x))$$
$$[\alpha_\mu(x), A_\nu^{(k)}{}_{(-)}(x')] = (D_{\mu\nu}(x'-x))$$
$$[\alpha_\mu(x), \alpha_\nu(x')] = (N/N-1)(D_{\mu\nu}(x'-x)) \dashrightarrow D_{\mu\nu}(x'-x))$$
$$[\alpha_\mu(x), A_\nu^{(k)}(x')] = (1/N-1)(D_{\mu\nu}(x'-x)) \dashrightarrow 0$$
$$[A_\mu^{((k)}{}_{(-)}(x), \psi^{(j)}(x')] = 0$$
$$[A_\mu^{((k)}{}_{(-)}(x), \psi^{(j)\dagger}(x')] = 0$$

where $D_{\mu\nu}(x'-x) = [i\eta_{\mu\nu}D(x'-x)]$ and $D(x'-x) = (1/2\pi)\,\varepsilon(x_0)\delta(x) = -D_{(-)}(x'-x)$, and all other equal-time commutators vanishing (k, j =1,2, … , N→ ∞).

APPENDIX III. PHOTON BARE STATE STRUCTURE IN THE MC-QED INTERACTION PICTURE

We now consider the quantum state structure associated with the MC-QED charge field photon Hamiltonian operator

$$H_{ph} = \sum_{(k} \{ : \int dx^3 \, [-1/2 \, (\partial_t A^{\mu(k)}{}_{(rad)} \, \partial_t A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)} + \nabla A^{\mu(k)}{}_{(rad)} \bullet \nabla A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)})] : \}$$

(k=1,2,…,N --- > ∞)

where

$$A_\mu{}^{(k)}{}_{(rad)} = (\alpha_\mu - A_\mu{}^{(k)}{}_{(-)})$$
$$A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)} = \sum_{(j) \neq (k)} A_\mu{}^{(j)}{}_{(rad)} = A_\mu{}^{(k)}{}_{(-)}$$

and

$$\alpha_\mu = \sum_{(j)} A_\mu{}^{(j)}{}_{(-)} /(N-1)$$

are linear functions of the negative time parity operator $A_\mu{}^{(k)}{}_{(-)}(x)$ which obeys $\Box^2 A_\mu{}^{(k)}{}_{(-)}(x) = 0$ then

$$\Box^2 A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)} = \Box^2 A_\mu{}^{(k)}{}_{(rad)} = \Box^2 \alpha_\mu(x) = 0$$

Hence the operators $A_\mu{}^{(k)}{}_{(rad)}$, $A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)}$ and α_μ (k =1,2, … , N→ ∞) can be respectively expanded as

$$A_\mu{}^{(k)}(x) = (\alpha_\mu(x) - A_\mu{}^{(k)}{}_{(-)}(x)) = \int d\lambda^3 / \sqrt{[2(2\pi)^3 \lambda^2)]} \, \{ a_\mu{}^{(k)}(\lambda) \, e^{-i\lambda \bullet x} + a_\mu{}^{(k)}(\lambda)^\dagger e^{i\lambda \bullet x} \}$$
$$A_\mu{}^{(k)}{}_{(rad)}{}^{(obs)}(x) = A_\mu{}^{(k)}{}_{(-)}(x) = \int d\lambda^3 / \sqrt{[2(2\pi)^3 \lambda^2)]} \, \{ a_\mu{}^{(k)}{}_{(-)}(\lambda) \, e^{-i\lambda \bullet x} + a_\mu{}^{(k)}{}_{(-)}(\lambda)^\dagger e^{i\lambda \bullet x} \}$$
$$\alpha_\mu(x) = \sum_{(j)} A_\mu{}^{(j)}{}_{(-)}(x) /(N-1) = \int d\lambda^3 / \sqrt{[2(2\pi)^3 \lambda^2)]} \, \{ \alpha_\mu(\lambda) \, e^{-i\lambda \bullet x} + \alpha_\mu(\lambda)^\dagger e^{i\lambda \bullet x} \}$$

where in the above

$$a_\mu{}^{(k)}{}_{(-)}(\lambda) = a_\mu{}^{(k)}{}_{(rad)}{}^{(obs)}(\lambda), \quad \alpha_\mu(\lambda) = \sum_{(j)} a_\mu{}^{(j)}{}_{(-)}(\lambda) /(N-1) = \sum_{(j)} a_\mu{}^{(j)}(\lambda)$$
$$a_\mu{}^{(k)}(\lambda) = (\alpha_\mu(\lambda) - a_\mu{}^{(k)}{}_{(-)}(\lambda)) = (\sum_{(j)} a_\mu{}^{(j)}{}_{(-)}(\lambda) /(N-1) - a_\mu{}^{(k)}{}_{(-)}(\lambda))$$

In the context of the above operator equations and their commutation relations, will now show that the time reversal violating Measurement Color symmetric operators $\alpha_\mu(\lambda)$ and $\alpha_\mu(\lambda)^\dagger$ *act respectively as destruction and creation operators for Measurement Color symmetric charge field photon states in MC-QED which have a negative parity under the Wigner Time Reversal operator* T_w.

We begin by substituting the above representations of $A_\mu{}^{(k)}(x)$, $A_\mu{}^{(k)}{}_{(obs)}(x)$, and $\alpha_\mu(x)$ into the above MC-QED commutation relations to find (k, j =1,2, … , N→ ∞) that

$$[a_\mu{}^{(k)}{}_{(-)}(\lambda),\ a_\nu{}^{(j)}{}_{(-)}{}^{\dagger}(\lambda')] = (1 - \delta^{kj})\,(-\eta_{\mu\nu}\lambda_0\,\delta^3(\lambda - \lambda'))$$
$$[\alpha_\mu(\lambda),\ a_\nu{}^{(j)}{}_{(-)}{}^{\dagger}(\lambda')] = -\eta_{\mu\nu}\lambda_0\,\delta^3(\lambda - \lambda')$$
$$[\alpha_\mu(\lambda),\ \alpha_\nu(\lambda')] = (-\eta_{\mu\nu}\lambda_0\,\delta^3(\lambda - \lambda'))(N / (N-1))$$
$$[\alpha_\mu(\lambda),\ a_\nu{}^{(k)}(\lambda')^{\dagger}] = 0$$
$$[a_\mu{}^{(k)}{}_{(-)}{}^{\dagger}(\lambda),\ a_\nu{}^{(j)}{}_{(-)}{}^{\dagger}(\lambda')] = 0$$
$$[a_\mu{}^{(k)}{}_{(-)}(\lambda),\ a_\nu{}^{(j)}{}_{(-)}(\lambda')] = 0$$

where $\lambda_0 = \sqrt{(\lambda^2)} = \omega(\lambda)$ and all other commutators vanish. Next we substitute above representations of $A_\mu{}^{(k)}(x)$ and $A_\mu{}^{(k)}{}_{(obs)}(x)$ into the charge field photon hamiltonian H_{ph} which gives the charge field photon hamiltonian as

$$H_{ph} = \sum_{(k)} \{\colon [- \int d\lambda^3 / \lambda_0 \ \ (\omega(\lambda) a^{\dagger}{}_{(\lambda)\mu}{}^{(k)}(\lambda))\ a^{\mu(k)}{}_{(-)}(\lambda)]\colon\}$$

and normal ordering of operators inside of the symbols $\{\colon\ \colon\}$ has been taken. H_{ph} is Hermetian since by inserting $a_\mu{}^{(k)}(\lambda) = (\alpha_\mu(\lambda) - a_\mu{}^{(k)}{}_{(-)}(\lambda))$ and $\alpha_\mu(\lambda) = \sum_{(j)} a_\mu{}^{(j)}{}_{(-)}(\lambda)/(N-1)$ into the above expression we find that it can also be written as

$$H_{ph} = \sum_{(k)} \sum_{(j \neq k)} \{\colon [- \int d\lambda^3 / \lambda_0 \ (\omega(\lambda)\ a_{(\lambda)\,(-)}{}^{\dagger\mu(k)}\ a_{(\lambda)(-)\mu}{}^{(j)}(\lambda)]\colon\} = H_{ph}{}^{\dagger}$$

In this context if the bare MC-QED charge field photon vacuum state |0ph> is defined by

$$a_\mu{}^{(k)}{}_{(-)}(\lambda)\ |\ 0_{ph} > = 0 \qquad (k = 1, 2, \ldots, N \to \infty)$$

this implies that $H_{ph}\ |\ 0_{ph} > = 0$ as required. Now since $\alpha_\mu(\lambda) = \sum_{(j)} a_\mu{}^{(j)}{}_{(-)}(\lambda)/(N-1)$ the above definition of |0ph> also implies that the bare charge field photon vacuum state also obeys

$$\alpha_\mu(\lambda)\ |\ 0_{ph} > = 0$$

In this context the bare single charge-field photon in MC-QED can be defined as

$$|\lambda\mathbf{1}_\mu> = \alpha_\mu(\lambda\mathbf{1})^{\dagger}|0> = (1 / (N-1) \sum_{(j)} a_\mu{}^{(j)}{}_{(-)}{}^{\dagger}(\lambda\mathbf{1})^{(j)}\ |0>$$

This can be seen by calculating

)

$$H_{ph}\,|\lambda_1> \;=\; -\sum_{(k))}\int d\lambda^3/\lambda_0 \;\; (\omega(\lambda)\, a_\nu{}^{(k)}{}_{(\lambda)}{}^{\dagger} a^{\nu(k)}{}_{(-)(\lambda)}\, \alpha_{\mu(\lambda\mathbf{1})}{}^{\dagger}\,|0>$$

Then using the fact that $[\alpha_\mu(\lambda),\; a^{\nu(j)}{}_{(-)}{}^{\dagger}(\lambda')] = -\delta_{\mu\nu}\lambda_0\,\delta^3(\lambda - \lambda')$ and $\alpha_\mu\,(\lambda\mathbf{1}) = \sum_{(J)} a_\mu{}^{(j)}(\lambda\mathbf{1})$ in the above equation we have that

$$\begin{aligned} H_{ph}\,|\lambda_1> \;&=\; \sum_{(J)}\int d\lambda^3\,(\omega(\lambda) a_\nu{}^{(j)}{}_{(\lambda)}{}^{\dagger})\,(-\delta_\mu{}^\nu)\delta^3(\lambda - \lambda\mathbf{1})\,|0> \\ &=\; \omega(\lambda\mathbf{1})\,\sum_{(J)} a_\mu{}^{(j)\dagger}(\lambda\mathbf{1})\,|0> \\ &=\; \omega(\lambda\mathbf{1})\;(\alpha_\mu\,(\lambda\mathbf{1})^{\dagger}\;|0> \\ &=\; \omega(\lambda\mathbf{1})\,|\lambda\mathbf{1}> \end{aligned}$$

as required.

Hence multiple bare charge-field photon states in MC-QED are defined as

$$|\lambda_{\alpha 1},\, \lambda_{2\beta},\;\lambda_{3\gamma},\;\ldots.\;> \;=\; 1/\sqrt{(N_p!)}\;\alpha_{\alpha(\lambda_1)}{}^{\dagger}\alpha_{\beta(\lambda_2)}{}^{\dagger}\alpha_{\gamma(\lambda_3)}{}^{\dagger}\;\ldots.\;|0>$$

In a similar manner as that of the covariant form of QED, consistency with the expectation value of the operator form of Maxwell equations in the covariant form of MC-QED requires that an Indefinite Metric Hilbert space must be used. <u>Note that the time parity of the N-photon state $|\lambda_{\alpha 1},\, \lambda_{2\beta},\;\lambda_{3\gamma},\;\ldots.\;>$ is $(-1)^N$ and that the coherent state defined by $\exp(\alpha_\mu)\,|0>$ is not symmetric under time reversal in</u>

In the context of an Indefinite Metric Hilbert space, the subset of physical bare charge field photon states in MC-QED contained within the above set of multiple charge field photon eigenstates of H_{ph} are required to obey the Weak Subsidiary Condition

$$\lambda^\mu\, a_\mu{}^{(k)}\,(\lambda)\,|\psi> = 0$$

where $a_\mu{}^{(k)}{}_{(\lambda)} \;=\; (\alpha_{\mu(\lambda)} \;-\; a_\mu{}^{(k)}{}_{(obs)}) \;=\; (\sum_{(j)} a_\mu{}^{(j)}{}_{(-)}/(N\text{-}1) - a_\mu{}^{(k)}{}_{(-)})$

which requires them to contain equal numbers of timelike and longitudinal charge field photons. Since the Indefinite Metric Hilbert space implies that charge field photon states with an odd number of time-like charge field photons have an additional negative sign associate with their inner product, the combination of the Weak Subsidiary Condition and the Indefinite Metric Hilbert space together imply that the physical bare charge field photon states have a positive semi-definite norm and energy momentum expectation values. Hence from the above analysis we conclude that the Measurement Color symmetric bare charge field photon state structure of MC-QED is similar to that of QED, with the key exception being that the Measure Color symmetric bare charge field photon creation and annihilation operators $\alpha_{\mu(\lambda)}{}^{\dagger}$ and $\alpha_{\mu(\lambda)}$ have a negative parity under Wigner Time reversal T_w.

APPENDIX IV. FERMION BARE STATE STRUCTURE IN THE MC-QED INTERACTION PICTURE

We next discuss the bare state electron-positron structure associated with the fermion Hamiltonian operator in the context of the Furry Interaction Picture, (where an external potential $\varphi^{(k)}{}_{(ext)}$) has been included in order to represent the lowest order Coulombic effects of baryonic nuclei in the MC-QED) given by

$$H_f = \, : \int dx^3 \sum_{(k)} [\psi^{(k)\dagger}(\alpha\bullet \mathbf{p} + \beta m - e\varphi_{(ext)})\,\psi^{(k)}] + J^{\mu(k)} A_\mu{}^{(k)}{}_{Breit}{}^{(obs)} :$$

where (k =1,2, … , $N\rightarrow \infty$) and

$$A_\mu{}^{(k)}{}_{Breit}{}^{(obs)} = \sum_{(j) \neq (k)} \int dx^3 J_\mu{}^{(j)}(x',t) / 4\pi\, |x-x'|$$

(k, j =1,2, … , $N\rightarrow \infty$)

and the equal time anti-commutation relations in the Furry Interaction Picture are

$$\{\psi^{(k)}(\mathbf{x}, t) , \psi^{(j)\dagger}(\mathbf{x'}, t)\} = \delta^{kj}\,\delta^3(x' - x)$$
$$\{\psi^{(k)}(\mathbf{x}, t) , \psi^{(j)}(\mathbf{x'}, t)\} = 0$$
$$\{\psi^{(k)\dagger}(\mathbf{x}, t) , \psi^{(j)\dagger}(\mathbf{x'}, t)\} = 0$$

All other equal-time anti-commutators vanishing respectively, (k, j =1,2, … , $N\rightarrow \infty$).

Since the bare fermion Hamiltonian operator H_f is summed over all of its internal Measurement Color indices (k =1,2, … , $N\rightarrow \infty$) it does not single out any particular Measurement Color label and hence it is a Measurement Color scalar. This implies that the multi-electron-positron eigenstates of H_f must be $N_f \geq 2$ Measurement Color singlet states which are symmetric in their Measurement Color labels.

In the Furry Interaction Picture, the MC-QED fermion operator equations of motion, and their charge-conjugate equations of motion respectively have positive energy operator solutions (denoted by $\psi^{(k)}{}_{(+)}{}^{\dagger}$, $\psi^{(k)}{}_{(+)}$ and $\psi^{c(k)}{}_{(+)}{}^{\dagger}$, $\psi^{c(k)}{}_{(+)}$) which, when acting on the vacuum state |0> respectively annihilate and create electrons and positrons in a manner formally similar to that of QED. in this context the equal-time anti-commutation relations and the Measurement Color symmetry property of H_f work together to generate Measurement Color symmetric electron-positron eigenstates.

Here we will start first by considering case of $N_f \geq 2$ electrons interacting with each other in the presence of an external field since $N_f = 1$ fermion states are ruled out by the requirement of Measurement Color symmetry. In this context it follows that the equal-time anti-commutation relations and the Measurement Color symmetry property of H_f imply that the *Measurement Color symmetric* multi-electron eigenstates for $N_f = N_e \geq 2$ bare electrons in the Furry Interaction picture for MC-QED has the form

$$|E, (N_1),(N_2),..(N_e)\rangle = (1 / N_e !) \int dx_1{}^3 .. dx_{Ne}{}^3 \sum (s_1 .\, s_{Ne})\, \chi_E(\mathbf{x}_1,s_1 ... \mathbf{x}_{Ne},s_{Ne})\, \psi(\mathbf{x}_1,s_1)^{(1)}{}_{(+)}{}^{\dagger} \ldots \psi(\mathbf{x}_{Ne},s_{Ne})^{(Ne)}{}_{(+)}{}^{\dagger} |0\rangle$$

Note that in the $|E, (N_1),(N_2) \ldots (N_e)>$ state the combination of the anti-commutation properties of the $\psi in^{(k)}{}_{(+)}{}^{\dagger}$, with the requirement of measurement color symmetry of the $|E, (N_1),(N_2) \ldots (N_e)>$ state imposed by H_f, automatically requires that the wave function for the Ne electrons given by $\chi_E(\mathbf{x}_1,s_{1\ldots}\,\mathbf{x}_{Ne},s_{Ne})$ must be anti-symmetric in the configuration space and spin coordinates $(\mathbf{x}_1,s_{1\ldots}\,\mathbf{x}_{Ne},s_{Ne})$ consistent with the Pauli Exclusion Principle.

The anti-symmetric Ne-electron wave function $\chi_E(\mathbf{x}_1,s_{1\ldots}\,\mathbf{x}_{Ne},s_{Ne})$ is given by the positive energy eigenstate solution to the configuration space Hamiltonian for Ne electrons in an external field given by

$$H_{cs}\,\chi_E(\mathbf{x}_1,s_{1\ldots}\,\mathbf{x}_{Ne},s_{Ne}) = E\,\chi_E(\mathbf{x}_1,s_{1\ldots}\,\mathbf{x}_{Ne},s_{Ne})$$

where $Ne \geq 2$ and $(k, j = 1,2, \ldots, Ne)$

$$H_{cs} = \sum_{(k)} \Lambda^{\mathbf{k}}{}_{+} (\alpha^{\mathbf{k}}\bullet \mathbf{p}^{\mathbf{k}} + \beta^{k} m - e\varphi^{(k)}{}_{(ext)})\, \Lambda^{\mathbf{k}}{}_{+} + (e^2/4\pi) \sum_{(k)} \sum_{(j \neq k)} [\Lambda^{\mathbf{k}}{}_{+} \Lambda^{\mathbf{j}}{}_{+} (1 - \alpha^{\mathbf{k}} \bullet \alpha^{\mathbf{j}})\, \Lambda^{\mathbf{k}}{}_{+} \Lambda^{\mathbf{j}}{}_{+}] \,/\, |\mathbf{x}^{\mathbf{k}} - \mathbf{x}^{\mathbf{j}}|$$

and the $\Lambda^{\mathbf{k}}{}_{+}$ which appear in H_{cs} are appropriately chosen positive energy projection operators for the kth electron interacting with the $j \neq k$ other electrons in the presence of an external field. For example in the simplest case of Ne = 2 electrons, depending on the choice of the external field representing the lowest order coulomb coupling of the nucleus, the measurement color symmetric |Ne =2 electron> state could describe either the quantum states of either a Helium atom or the quantum states of two spatially separated Hydrogen atoms

In a similar manner Measurement Color symmetric $N_p \geq 2$ positron states involving operator products of $\psi^{C(k)}{}_{(+)}{}^{\dagger}$ acting on |0>, and Measurement Color symmetric $(N_e + N_p) \geq 2$ electron-positron states, involving products of both $\psi^{(k)}{}_{(+)}{}^{\dagger}$ and $\psi^{C(k)}{}_{(+)}{}^{\dagger}$ acting together on |0>, can be constructed in the MC-QED formalism.

APPENDIX V. ON THE CALCULATION OF THE S-MATRIX OF QUANTUM POTENTIA IN MC-QED

In the context of the previous discussion of the bare charge field photon and bare electron-positron state structure in the MC-QED Interaction Picture, we demonstrated that the predictive properties of the Measurement Color symmetric bare charge field photon and bare electron-positron state structure were similar to that of QED.

In this appendix we will show how these bare states can be used in calculating the S-matrix in the quantum potentia approximation to MC-QED. However in this context we will see that differences in the dynamic description of the source of radiative corrections will occur between QED and MC-QED. This is because, instead of being defined by local in time free charge field photon operators as in the case of QED, the observed bare in-field charge field photon operators in MC-QED are described by non-local in time operators with a negative parity under Wigner Time Reversal T_w given by (k =1,2, … , N→ ∞)

$$A_\mu{}^{(k)}{}_{(-)} = \left(\int dx'^4\, D_{(-)})(x-x')\, U(t)U(t')^{-1}\, J^{\mu(k)}(x')\, U(t')U(t)^{-1}\right)$$

where

$$U(t)U(t')^{-1} = \left(\exp [i(H_0)_S\, t] \exp [-iH_S\, t]\right) \left(\exp [iH_S\, t']\exp [-i(H_0)_S\, t']\right)$$

Now recall that the successive state vector transformations on the Heisenberg Picture State vector $|\psi_H>$, through the Schrodinger Picture state vector $|\psi_{S}>$, that finally lead to the Interaction Picture state vector $|\psi_I>$ can be formally represented by $|\psi_I(t)> = U(t\text{-}t_o)\, |\psi_H>)$ where the unitary operator $U(t\text{-}t_o)$ is

$$U(t-t_o) = \exp [i(H_0)_S(t-t_o)] \exp [-iH_S(t-t_o)]$$

where the Schrodinger Hamiltonian operators $(H_0)_S$ and $H_S = H$ are constant in time. It then follows that the equation of motion of the state vector in the Interaction Picture is

$$i\partial_t|\psi_I(t)> / dt = [V_{qp}(t) + V_{ret\text{-}qa}(t)]_I\, |\psi_I(t)>$$

and the Interaction Picture operators $O_I(x, t)_I$ are related to Heisenberg Picture operators $O_H(x, t)$ as

$$O_I(x,t)_I = U(t-t_o)\, O_I(x,t)_H\, U(t-t_o)^{-1} = U(t-t_o)\, O_I(x,t)_H\, U(t-t_o)^{\dagger}$$

Now setting to = 0 for simplicity in what follows we have

$$J^{\mu(k)}(x)_I = U(t)\, J^{\mu(k)}(x)_H\, U(t)^{-1}$$

$$(A^{\mu(k)}(x)_{(-)})_I = U(t)(A^{\mu(k)}(x)_{(-)})_H U(t)^{-1}$$

Note that since

$$(A_\mu{}^{(k)}(x)_{(-)})_I = \int dx'^4\, D_{(-)})(x-x')\, U(t)U(t')^{-1}\, J_\mu{}^{(k)}(x')_I\, U(t')U(t)^{-1}$$

is a nonlocal in time operator functional of the current operator then the commutation relations

$$[\, A_\mu{}^{((k)}{}_{(-)}\ (x)\, ,\, \psi^{\,(j)}(x')]_I = [\, A_\mu{}^{((k)}{}_{(-)}\ (x)\, ,\, \psi^{\,(j)\dagger}(x')]_I = 0$$

(required for the existence of the bare local-in-time fermion-charge field photon "in-states") creates a nonlocal in time operator constraint relationship, involving a spacetime integration over the Green functions $D_{(-)}(\, x' - x)$ *and* $S(\, x' - x)$ whose form is required to be consistent with the anti-commutation relations

$$\{\psi_{in}{}^{(k)}\, (x)\, ,\, \psi_{in}{}^{(j)\dagger}(x')\}_I = \delta^{\,kj}\, S(\, x' - x)$$

Hence in the Wick T-product decomposition of the S-matrix in the Interaction Picture, this leads to two different kinds of Wick contraction terms associated with the $J_\mu{}^{(k)}(x)$ and the $A_\mu{}^{(k)}{}_{(-)}(x')$ operators:

1) the first kind are local contractions between the $J_\mu{}^{(k)}(x)$ operators and the $A_\mu{}^{(k)}{}_{(-)}(x')$ operators as a whole which vanish as

$$(\overbrace{J_\mu{}^{(k)}\, (x)\, A_\mu{}^{(k)}}\,{}_{(-)}\, (x')) = 0$$

2) the second kind are contractions between the $J_\mu{}^{(k)}(x)$ operators and the nonlocal functional dependence of the $J_\mu{}^{(jk}(x)$ operators which appear inside of the $A_\mu{}^{((k)}{}_{(-)}\, [J_\mu{}^{(k)}\, (x')]$ operators which generates two types of non-zero contraction terms

$$\overbrace{J_\mu{}^{(k)}\, (x)\, A_\mu{}^{((k)}{}_{(-)}\, [J_\mu}{}^{(k)}\, (x')] \neq 0$$

$$J_\mu{}^{(k)}\, (x)\, A_\mu{}^{((k)}{}_{(-)}\, [\underbrace{J_\mu{}^{(k)}}\, (x')] \neq 0$$

These contractions of the second kind, which are nonlocal since they involved spacetime integrations over products of $S_F(\, x' - x)$ and $D_{(-)}(\, x' - x) = (D_{(ret)}(\, x' - x) - D_{(adv)}(\, x' - x)\ \ )\, /\, 2$ are time reversal violating and generate time reversal violating radiative corrections to the bare fermion states which occur in the MC-QED S-matrix. The details associated with the calculation of the S-matrix in MC-QED will be presented elsewhere in future papers.

APPENDIX VI. EFFECTS OF SPONTANEOUS CPT SYMMETRY BREAKING IN MC-QED

From the above discussion we see that the Measurement Color symmetry in MC-QED automatically excluded time-symmetric free photon operators from the formalism. Instead the photon operator in MC-QED was described by a nonlocal Measurement Color Symmetric "Total Coupled Radiation" charge-field photon operator which carried a negative time parity under Wigner Time Reversal. In this context the physical requirement of a stable vacuum state dynamically required that the Heisenberg operator equations for fermions must contain a causal retarded quantum electrodynamic arrow of time, independent of any external thermodynamic or cosmological assumptions. Hence this dynamically implied that the photon carries the quantum electrodynamic arrow of time in the MC-QED formalism.

This result is better understood in a broader context by noting that, within the nonlocal quantum field theoretic structure of the MC-QED formalism, the physical requirement of a stable vacuum state generated a spontaneous symmetry breaking of both the T and the CPT symmetry. Spontaneous symmetry breaking of the T and the CPT symmetry occurred in MC-QED because the nonlocal photon operator acting within it has a negative parity under Wigner time reversal. In this manner the requirement of a stable vacuum state dynamically selected the operator solutions to the MC-QED formalism that contained a causal, retarded, quantum electrodynamic arrow of time, independent of any external thermodynamic or cosmological assumptions. In this manner the existence of the causal microscopic arrow of time in MC-QED represents a fundamentally quantum electrodynamic explanation for irreversible phenomena associated with the Second Law of Thermodynamics which complements the one supplied by the well-known statistical arguments in phase space [Zeh, 2007].

The fact that the Measurement Color symmetry in MC-QED implies that the photon operator carries the arrow of time has a profound effect on the nature of the time evolution of the combination of "systems + environment" in the Interaction Picture of the formalism (Leiter, 2010). This is because it causes the reduced density matrix of the "system" in the presence of its "environment" to contain both Von Neumann Type 2 (quantum potentia) time evolution of the state vector as well as Von Neumann Type 1 (quantum actua) time evolution.

This is because the reduced density matrix of the system takes the form of a differential-delay equation containing time reversal violating quantum evolution and quantum measurement interaction components. The time reversal violating quantum measurement interaction part of the quantum interaction has components that contain causal retarded light travel times, which are connected to the values of the physical sizes and/or spatial separations associated with the physical aggregate of Measurement Color symmetric fermionic states into which the fermionic sector of state vector is expanded.

For the retarded light travel time intervals in between the preparation and the measurement, the expectation values of the time-reversal violating retarded quantum measurement interaction operator will be negligible compared to the expectation values of the quantum evolution operator which generates the "quantum potentia" of what may occur. On the other hand for retarded light travel time intervals corresponding to the preparation and/or the measurement, the expectation values of the time-reversal violating retarded quantum measurement interaction operator will be dominant compared to the expectation values of the quantum evolution operator and this will cause the "quantum potentia" to be converted into the "quantum actua" of observer-participant measurement events.

Hence in this manner MC-QED contains its own time reversal violating microscopic observer-participant description of the quantum measurement process, independent of the Copenhagen Interpretation or the Everett "Many Worlds Interpretation". It is for this reason that the paradigm of MC-QED can be used to solve the problem of macroscopic quantum reality.

This is because Measurement Color Quantum Electrodynamics (MC-QED) has the form of a non-local quantum field theory which describes the quantum measurement process in terms of myriads of microscopic electron-positron quantum operator fields undergoing spontaneous CPT symmetry breaking time observer-participant quantum measurement interaction processes mediated by the charge-field photon quantum operator fields through which they interact.

In this context it has been shown (Leiter, 2010) for a sufficiently large aggregate of atomic systems, described by the bare state components of MC-QED Hamiltonian and interacting with each other through the effects of the time reversal violating quantum measurement interaction operator, that the effects of the CPT violating quantum measurement interaction will generate time reversal violating (Quantum Decoherence + Dissipation) effects on the reduced density matrix in a manner which will give these large aggregates of atomic systems apparently classical properties.

Since MC-QED obeys a dynamic form of Macroscopic Realism, the classical level of physics emerges in the context of local intrinsically time reversal violating quantum decoherence effects which project out individual states since they are generated by the time reversal violating quantum measurement interaction in the formalism. Hence MC-QED does not require an independent external complementary classical level of physics obeying strict Macroscopic Realism in order to obtain a physical interpretation.

Since it does not require an independent external complementary classical level of physics in order to obtain a physical interpretation of the quantum measurement process, the MC-QED formalism represents a more general observer-participant approach to quantum electrodynamics in which a consistent description of quantum electrodynamic measurement processes at both the microscopic and macroscopic levels can be obtained.

This is in contrast to the time reversal symmetric case of QED where the local quantum decoherence effects only have the appearance of being irreversible because a local observer does not have access to the entire wave function and, while interference effects appear to be eliminated, individual states have not been projected out.

The phenomenon of Quantum Decoherence in MC-QED is described in terms of quantum systems interacting with their environments, in a time irreversible manner which prevents different components in the quantum superposition of the wave function of the (system + environment) from interfering with each other. However MC-QED differs from QED in that the phenomenon of Quantum Decoherence occurs in the context of a microscopic, time irreversible, process generated by spontaneous CPT breaking in the MC-QED formalism.

Hence the phenomenon of Quantum Decoherence in MC-QED always includes the effects of Quantum Dissipation. This is due to the fact that spontaneous CPT symmetry breaking in the MC-QED formalism causes the photon to carry the arrow of time. The combination of (Quantum Decoherence + Quantum Dissipation), created by the spontaneous CPT symmetry breaking inherent in the MC-QED formalism, generates an overall time reversal violating process.

This causes the reduced density matrix of the system to become diagonalized by Quantum Decoherence effects over a “decoherence time period” after which the effects of Quantum Dissipation over a “relaxation time period” >> “decoherence time period” causes specific diagonal elements of the of the reduced density matrix to become equal to unity with all others equal to zero. In this manner the quantum field theoretic dynamics of the reduced density matrix of the system by itself will be both microscopically time irreversible as well as being non-unitary.

The combination of microscopically time reversal violating (Quantum Decoherence + Quantum Dissipation), generated by the spontaneous CPT symmetry breaking inherent in the MC-QED formalism, predicts both the probability of an outcome (i.e. a quantum potentia) as well as an actual outcome (i.e. a quantum actua). Because of this fact the well known paradox of the “problem of outcomes”, associated with the process of Quantum Decoherence in QED [Schlosshauer, 2007], can resolved in the context of the MC-QED formalism

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