Better than Bohm: Preliminary Specification of MQED

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Abstract

One of the three laboratories which has previously produced three entangled photons (the asymmetric GHz state) has performed the triphoton equivalent of the Bell's Theorem experiment. The results so far are inconsistent with the traditional operator projection model of polarizers, which was previously used in mainstream explanations of Bell's Theorem experiments, but consistent with simple local realistic models previously shown to be consistent with Bell's Theorem results and developed by implementing the form of time-symmetric physics which we previously developed [1]. This paper gives a more detailed proposal (MQED1) for a Markovian version of Quantum Electrodynamics (MQED), which it defines as the minimal modification of traditional versions of QED needed to fit the new results, to resolve disagreements between the four mainstream variants of QED used to predict experiments today, and to be consistent with the program of stochastic realism, albeit not a local model. The paper also discusses how MQED1 might be derived as the emergent outcome of a more fundamental local model fulfilling earlier direct discussions between this author and Louis De Broglie, using new statistical distribution functions extending the Glauber-Sudarshan P mapping essential to quantum optics.

1. Specification of the Challenge and Rationale

1a. The Challenge

The purpose of this paper is to provide more details on the specification of MQED, a new variation of quantum electrodynamics (QED). The need for MQED was described in detail in [1]. There are already several respected variations of QED in common use in practical experimental work: (1) KQED (canonical QED, the first successful version of QED); (2) FQED (Feynmann path QED); and (3) CQED (cavity or circuits QED). In addition, there are extensions of QED based on distribution functions which have proven essential to advanced experimental and technological work in quantum optics, such as understanding of how lasers work. [2]. There are many people who assume that differences between quantum theories must be just a matter of interpretation, something to be left to philosophers; however, when different sets of axioms and assumptions really do lead to different predictions, this is not a correct assumption.[3]

The grand challenge here is to produce a new version of QED with three core properties:

(1) In one theory, to retain the key features of the other four essential to their success in predicting experiments in the various domains they are used for.

(2) To correctly predict the new experiments for three entangled photons which older versions of QED do not predict correctly [1]. Correct predictions were already made by local realistic models consistent with the rules of time-symmetric physics *as specified in [1] and [3]*, but these were lumped parameter models and ODE models; the challenge here is to generalize those new models, in effect, for continuous space and time. Different concepts of time symmetric physics have appeared in the literature, and it should not be assumed that they necessarily apply here.

(3) To build a model consistent with *stochastic realism*, the idea that a model should be expressable directly in terms of probability theory predicting possible states or evolutions of the universe over space-time.

Goals (1) and (2), combined, are already important enough. Here I add (3), and I DEFINE MQED (Markov QED) as any theory which meets all three goals. It is natural to add goal (3), as matter of research strategy in trying to attain (1) and (2), because the only models now in existence which correctly predict the new experiments are in the Markovian family, and because realism is a desirable property. This paper and [1] present ideas for what an MQED might be, but I would like to preserve the DEFINITION of MQED as given in this paragraph; the definition should not be confused with the specific proposal.

Please note that I have not included "locality" as a requirement here, in specifying the challenge! Locality is a desirable property, in a theory of the underlying dynamics of nature, a "theory of everything." But QED is not a theory of everything. In QED, the spectrum of hydrogen is predicted based on the assumption that *both* the electron and the proton are perfect point particles, with zero radius; many would argue with my belief that the electron is not really a perfect point particle, but we should all agree by now that the proton has a radius of about one femtometer (a different radius when we measure different properties [4]), and that QED should work reasonably well in general even if the electron has a radius of similar magnitude and variability [5]. QED is an approximate theory, representing emergent stochastic dynamics of some more fundamental system, beyond the scope of this paper. It often happens that systems which obey local underlying dynamics result in emergent statistics which are nonlocal.

The proposal for MQED to be given here is not the same as that given in [1], simply because I have had time to look more deeply into the issue since then. It will indeed be nonlocal, as in all serious Bohmian theories. In fact, this proposal could be considered to be a Bohmian theory, or not; there is no need here to study the semantics of the word "Bohmian"!

1b. Some additional Comments on Goal (1)

See [1] and [3] for more details on the four main existing forms of QED mentioned in 1a. Crudely speaking, that previous work would generally agree with the idea that the dynamics of the universe can be described via the modern "Schrodinger equation":

$$\dot{\Psi} = iH\Psi \qquad (1),$$

where Ψ is a wave function described as a vector in Fock-Hilbert space and H is a Hamiltonian operator over that space. Practical experimental work has demonstrated [1,2,3] the need to account for our uncertainty about the state of the wave function of the universe by working with density operators or matrices ρ defined, crudely, as:

$$\rho(t) = \int \Pr(\Psi, t)\Psi\Psi^H d^\infty\Psi \qquad (2)$$

where $\Pr(\Psi,t)$ is the probability that Ψ is the true wave function at time t, and where superscript H represents the Hermitian conjugate of the vector Ψ. The previous standard versions of quantum field theory (QFT) derive H by "quantizing" the Hamiltonian of some corresponding classical Hamiltonian field theory. For each classical field, there is a corresponding "field operator" defined as a mixture of creation and annihilation operators for that field. But there are two alternative ways to quantize the classical Hamiltonian, which result in different theories about how the universe works:

(1) One may substitute the field operators for the fields, in the classical Hamiltonian, and assume that the multiplications in the classical Hamiltonian should be mapped into ordinary operator multiplication. This results in a raw Hamiltonian, H_r, which contains large zero point energy terms.

(2) One may substitute the field operators for the fields, but assume that the multiplications in the classical; Hamiltonian should be replaced by the normal product, sometimes called the normal ordered product, "N" or ":: ... ::".
This results in the normal form Hamiltonian, H_n.

Feynmann path QFT is usually derived from a very different perspective, but ends up effectively assuming the use of H_r, which includes zero point energy terms [6]. These zero point energy terms predict an attraction between two parallel plates, the Casimir effect, equal to what has in fact been measured in experiments.

The original work on QED [7-9] paid lip service to H_r, the beginning, but argued that terms like the zero point terms should have no important effects in practice. On that basis, they proceeded to use the H_n Hamiltonian in successful prediction of the Lamb shift and other important effects. They did use "vacuum fluctuation" diagrams in their calculations, but there was no need to assume additional zero point terms. More formally, when I refer to "KQED" I am referring to the system of predictions which results when H_n is used as the working starting point for everything, implictly assuming that H in equation 1 is just H_n. I will use "FQED" to the predictions which result when we assume $H = H_r$.

If we consider only the first round of empirical evidence, it seems to favor KQED over FQED. The main, clear area of disagreement is the prediction for the Casimir experiment. But Landau and Lifshitz showed years ago that the usual prediction based on zero point terms also happens to equal the prediction one gets form accounting for the vanderwaals force between the molecules in the two plates. Casimir enthusiasts have sometimes argued that "both theories work, and so it is just a matter of taste." But in fact, vanderwaals forces are not just a matter of theoretical speculation. FQED clearly predicts that the attraction should be the SUM of Vanderwaals forces plus zero point effects – twice what is actually observed! In fact, is we think of Casimir experiments as a way to measure how strong the actual zero point energy terms are (the fluctuations of the vacuum), they measure zero point terms of zero to within the accuracy of the Casimir experiments.

Please note that I do not claim that the zero point fluctuations are actually zero. Based on several lines of empirical work (e.g. [10,11]), I would argue that they are real, but several orders of magnitude smaller than what FQED would call for. New direct measurement at room temperature suggest larger vacuum fluctuations [11], but measurements at temperatures approaching absolute zero would be needed to exclude fluctuations in the EOX measurement crystal. However, since FQED clearly predicts large vacuum fluctuations, the modeling of the small actual fluctuations is an argument for a whole new theory, not for FQED. Since MQED aims at an approximate theory, like what ordinary QED provides, I would not propose to include those effects in MQED as such. I have a better idea of what a more complete theory would be since I last approached that issue [5], but the details are well beyond the scope of this paper.

But – to return to the issue of FQED versus KQED, there is another line of well-established empirical work which seems to point in the opposite direction. In the original texts on QED, based on KQED, it is basically quite embarrassing that rates of spontaneous emission are not well addressed. Spontaneous emission from excited electrons in an atom is as important and fundamental as one can get here, but the usual textbooks on KQED tended to minimize or gloss over the issue. In the end, to make actual predictions in a KQED world, one relies on "Fermi's Golden Rule," which is essentially just an ad hoc additional axiom, analogous to the usual version of the "collapse of the wave function." In FQED, there are principled predictions, based on interaction of the atom with vacuum fluctuations, which hold up in experiment. Modern forms of cavity QED (CQED) have worked very well in predicting spontaneous emission and, more importantly, reductions in the rates of spontaneous emission which have been achieved by engineering cavities to suppress it. Those reductions were proclaimed to be absurd crackpot claims, by those trained in earlier KQED, until the experimental and technological evidence became overwhelming, and CQED grew in popularity.

These (and other) lines of evidence suggest that KQED is right and FQED is wrong for some experiments (like Casimir), while FQED/CQED are right and KQED is wrong for others. As a general matter, in MQED, following time-symmetric physics, we can live without large zero point terms, but use the Pr^- term [1, eq. 10] of continuous-time physics to explain rates of spontaneous emission, following the intuitive description of cavity effects given in [3]. The goal is to produce a theory consistent with both types of experiment, unlike traditional FQED and KQED.

It should also be noted that most textbooks on FQED and KQED assume that we can get correct and complete predictions by relying on Feynmann diagrams made up of lines representing a single charged particle or a single photon. Both FQED and KQED use an interaction Hamiltonian which can represent stimulated emission, where |n> photons come in in some state and |n+1> go out, but it is somehow assumed in such texts that such effects are too unimportant to need representation. I deeply regret the fact that my colleagues in graduate school did not recognize the importance of the new mathematical tools, involving distribution functions like P, Q and W, which are capable of accounting for those terms in the Hamiltonian, and essential to a wide range of core technologies [2].

A family member has noted that the starting point for the true Feynman path version of QED may be exactly equivalent to the usual Feynman diagrams, without a possibility of n-photon lines for n>1. If so, it becomes all the more important to develop a new formulation which does not omit such lines, lines which are so essential in experimental quantum optics.

2. Qualitative Description of the Proposed Form of MQED (MQED1)

2a. General Framework and Analogy to Carmichael

In [3], we proposed that MQED should be something like an extension of the ideas of Howard Carmichael [12,13] to the case of fields over continuous space. That still seems like the right approach, and it calls for me to review some of the basic points in Carmichael's seminal two-volume book on statistical quantum optics [12,13].

Carmichael begins [12] by reviewing earlier work on distribution functions. It shows how one can map two classical variables, like p and q, into a complex variable alpha, and then use the classical Glauber-Sudarshan P mapping to map between probability distributions for classical alpha and density matrices:

$$\rho = \int P(\alpha)\,|\,\alpha >< \alpha^*|\,d\alpha \qquad (3)$$

More precisely, he cites earlier work by Sudarshan showing that any density operator ρ for a bosonic field can be decomposed into a mixture of coherent or classical states, for which $P(\alpha)$ may be interpreted as a kind of probability distribution – but only for states in which $P(\alpha)$ is not less than zero for any value of α. He uses the term "classical states" for density matrices ρ where $P(\alpha)$ is positive or zero for all α. He uses the term "nonclassical states" for all other density matrices. Many quantum systems can be described by classical states, such that a classical dynamical equation for α is enough to reproduce what is seen and predicted in quantum mechanical experiments. The second volume of his work then goes on to discuss what could be done to make calculations as easy, as understandable and as tractable as possible for the case of quantum systems where nonclassical states are important. Our own work [3] shows how to make the calculations relatively simple and tractable for the most important and fundamental nonclassical states, the states of entangled photons encountering polarizers and detectors, but the issue in this paper is how to do that in the more general case.

For those cases where the quantum system can be represented as a (countable set of) variables p and q, Carmichael [13] has presented a new approach, widely respected in quantum optics for quantum computing: the quantum trajectory simulation (QTS) approach. The basic idea is to model the quantum system as a kind of hybrid system, where there are discrete events (quantum transitions) and continuous evolution between them. Carmichael argues that the states between quantum transitions can be represented as a stochastic mixture of a finite number of classical ρ, obeying classical dynamical equations, and that the record (REC) of discrete quantum transitions can capture the essence of the quantum phenomena.

2b. MQED1: A Proposed Form of MQED

For MQED1 (the proposal herein for MQED), I assume essentially the same kind of model, in extended space, using the extension of the P mapping which I derived to map classical fields into density matrices [14]. More precisely, I assume that the state of the (QED) universe at any time t is described by the usual kind of density matrix ρ, as in ordinary QFT, with fermionic terms to represent charged particles such as electron or proton, etc., and bosonic for light (A_μ). Between quantum transitions, I mainly assume that the dynamics of fermionic terms and of A_μ are linear, with one very important exception. I assume that the ordinary small interactions between charged particles and A_μ represented by virtual photons in KQED, such as ordinary Coulomb effects, do exist between quantum transitions, and modify the density matrix dynamics exactly as predicted by classical electrodynamics.

The quantum transitions are events which occur at particular points in space-time x_μ. Again, these are analogous to the quantum transitions which occur at a finite number of times, t, in Carmichael's QTS [13]. In a typical experiment,. There will only be a finite number of these, but of course we do not know the set of x_μ in advance; it is stochastic. The assumption of instantaneous transition from one "basin of attractors" to another is similar to the assumption that the charged particles have a radius of zero; it is a reasonable approximation, consistent with the exquisite work by Carmichael [12] in explaining the empirical details of such transitions in two-level atoms in resonance flourescence.

As in other types of QED (which we follow as closely as possible), there are two general types of event – events in which a photon is created, and events in which a photon is absorbed. For each type of event, the endogenous probability Pr* is essentially just the square of the usual QED interaction term ($e\psi$-bar(x_μ) $\gamma A(x_\mu)\psi(x_\mu)$), multiplied by a delta function enforcing the selection rules, most notably conservation of energy, momentum and angular momentum. This is not a classical stochastic model, because it is necessary to update the partition function Z here, following exactly the equation given for the evolution of Pr^+ in [1] (equation 9 of [1]).

As I type this, I also see a question which needs to be addressed in the mathematics (using the tools of [14]): should the partition function Z also be updated even between quantum transitions, to reflect any statistical skewing effects resulting from the ordinary nonlinear reactions due to virtual photons? Are ordinary Coulomb effects "statistically incompressible" or not? Probably not, I would guess, but logical completion requires making this clear, and the tools to do so are there.

This model, calculated in forward time (Pr^+), is nonlocal in two ways: (1) the partition function Z makes it nonlocal in forwards time, even when local in symmetric time; and (2) the selection rules imply that nature at time x_0 "knows" energy both before and after, for any possible transition. In a classical time-forwards universe, this sounds unnatural, but in a time-symmetric understanding it is quite reasonable, and, in any case, it is the way forward closest to other forms of QED.

Note that this specification does include the usual events changing a photon state from |n> to |n+1>, as the usual photon creation operator provides for, a core aspect of quantum optics [2]. The usual linear dynamics are well-known. The effect of ordinary Coulomb interactions in the extended P formalism [14] are also straightforward.

3. Could MQED1 Be Derived from Something More Basic, ala DeBroglie?

For many practical purposes, QED is already a fundamental theory. In principle, there is no need to "explain" fundamental theories. It is enough to refine them, test them and use them – as with the others forms of QED in serious use today. Such refinement, testing and use is an extremely important activity, which should not be delayed by waiting for parallel efforts to try to explain the theory. Julian Schwinger (in his classes, where I was a student) stressed that all of the quantum field theories we have today are essentially just phenomenological theories, to predict today's experiments, whose deeper truth should not be overestimated (or demanded).

Nevertheless, on a parallel track, many of us naturally wonder how the forces and fields in QED interact at a more fundamental level with nuclear forces, gravity, and dark matter and energy, and how all forms of QED may emerge as an approximation of such a more fundamental theory. Here are my preliminary thoughts on how this might be done.

3a. Background: A Fundamental Track Beyond the Scope of This Paper

One possibility on those lines is to look for a more universal theory, based on a Lagrangian which may be as simple as modified electroweak theory (MEWT) metrified by standard procedures already developed in classical general relativity [5]. By modifying the Higgs terms in the usual EWT Lagrangian, one builds a theory which predicts the existence of topological solitons which could serve as models of what the true elementary particles of physics actually are, with no need for more assumptions or more complexity apriori. This paper will not get into the details of that track of research, except to extract a few comments to modify my previous thoughts in [5]. First, of course, it makes sense to start from the simplest possible Lagrangian which seems to be powerful enough, and add terms (such as explicit gluon fields) only after it is clear that a simpler formulation cannot do the job. Second, I have begun that process, and already have some "next stage" versions in mind to update [5], such as a version in which the Higgs field is replaced by an isotwistor Ω. Third, I no longer would emphasize the Moffat model as a priority alternative to general relativity, because of new considerations mentioned at the end of section 3b.

For purposes of this paper, it is enough to say: one way to try to derive MQED1 as an approximation to something more fundamental is to try to derive it as an approximation to the emergent statistics of MEWT, where MEWT is some classical field theory built up from the fundamental fields W, B and Ω, where the usual A_μ is just a mixture of B and W, as is already well-known in work on EWT [6].

3b. Implementing the De Broglie Picture

Even today, many physicists of the Bohmian schools cite the classical work of DeBroglie and Bohm on a concept called "the pilot wave." Relatively late in life, DeBroglie published a definitive account of what he had in mind here [15]. He did not use the word "soliton", but he pictured the electron as a kind of stable vortex of energy and force which really expresses what we would now call "solitons" or "topological solitons."

He proposed that the electron can be approximated or understood to a relatively high degree of accuracy by viewing it as a combination of a "core," a region of very intense fields which can only be understood in nonlinear terms, together with a large asymptotic region, which he referred to as "the linear wave." Instead of "particle" and "pilot wave," he viewed it more as one nonlinear field system, in which we can roughly distinguish a nonlinear core and linear wave extension.

How big could the core be? As in [5], I would still expect it to be on the order of the Compton radius (3 femtometers), because of fundamental issues about energy, or possibly smaller. But in any case, since QED works for protons, we do not need to know whether it is 3 femtometers, 1 or 0.5; it is enough that it is reasonable to approximate the core as a point particle, following DeBroglie's intuition.

Beyond that, DeBroglie's most crucial speculation is that we can get away with assuming linear dynamics for the rest of the system. But do we really need that, and how could that work?

It is often said that the Bohr atom picture of the electron as an object in orbit about a proton (in the case of H atoms) could not work, because charged particles always radiate energy away when they turn a curve. Yet consider what we learn from studying elementary electrical engineering, from the analysis of what happens to a (direct) electrical current as it is passed through a perfect inductor; the curvature *initially* extracts energy from the current, and thereby builds up a magnetic field around the inductor, but once the magnetic field is strong enough, there is an equilibrium in the sense that no energy is extracted. In a superconducting coil, this can go on for some time. Because A_μ enters into the simple Lorentzian energy for an electron, it is possible for an electron to be in a state of locally minimum energy even in orbit.

This raises the question: do we even need the pilot wave (the linear wave) at all, in order to understand energy levels of hydrogen? What do the energy bands look like for a classic electron bound to a proton, governed by simple Lorentzian rules, easy enough to simulate on a PC (with A_μ modeled by use of Green's functions, time-forwards or symmetric)?

But it seems likely that those energy bands, while interesting and suggestive, would not be good enough, because of the possibility of "orbit decay." More precisely, in that simple classical model, the state of lowest energy would always insert the electron in a static state located right at the proton. In fact, we do observe such a state – the neutron – but the neutron decays into electron plus proton in free space; thus we know that that state is not the state of lowest energy for the electron. It is easy to imagine ways to explain that effect intuitively, involving all kinds of nuclear possibilities, but how do we MODEL the explanation without adding unnecessary complexity to QED, complexity which does not really seem necessary to the task?

The obvious way to overcome this dilemma is to assume a version of DeBroglie's idea. We can assume that there is some other simple mix of B, W and Ω in play, which can be modeled in a good enough approximation as a simple linear field, which results in a repulsion between the electron and proton at small distances, for all possible states of the proton and electron which are close both in space and in velocity. It is natural to assume that mixes other than A_μ itself would be more short-range, because of the well-known exponential term in the Green's function for linear wave equations with a nonzero "mass" term (as in standard EWT).

Even without the addition of that linear wave, it is important to ask how a fermionic density operator could describe the statistics of a small, relatively hard "core" particle. In fact, proving that for the case where the "linear wave" is neglected or does not exist is the natural first step in proving all this.

One way to perform that step would be to use a new mapping, the F mapping, similar in a way to the P mapping in [14], for electrons and protons:

$$\Psi_F^e = \left(\sum_{j=1}^{n} \int b_{\underline{s}_j}^{+}(\underline{x}) \left(\phi(\left|\underline{x} - \underline{q}_j\right|, \alpha) + i\omega(m, \underline{p}_j)\underline{p}_j \cdot \nabla_{\underline{x}} \phi(\left|\underline{x} - \underline{q}_j\right|, \alpha) \right) \right) \left|0\right\rangle \quad , \qquad (4)$$

where b^{+}_{s} is the usual QED fermionic creation operator for an electron or positron of spin $\underline{s}$ (creating a Dirac spinor), where φ is a radially symmetric regularization function (such as a Gaussian, for example, or something like Pauli-Villars regularization) which goes to a Dirac delta function in the limit as α goes to zero, and where ω is the frequency function (as in [14] or in Carmichael's phase space quantization [12]). The "spin vector" $\underline{s}$ is assumed to represent both the classical direction of spin and the information as to whether the particle is an electron or a positron. Here, as in QED, we assume that the perfect point model of the electron and proton is just an approximation, and that fundamental interactions at a deeper level prevent two electrons from being at exactly the same point. More precisely, we assume that electrons are "noncoherent," that the energy in any set of measure zero (such as the set of points $\psi(\underline{q}_j, \underline{q}_k)$ for $\underline{q}_j \neq \underline{q}_k$) will always remain infinitesimal. Notice that both terms in equation 4 have limits as tempered distributions in mathematics, as α goes to zero; the term on the right has an interesting similarity to Gabor wavelets.

The claim here would be the "exact Fermi hypothesis" (EFH), that for field theories with interactions limited to the kind we see in MEWT, that as α goes to zero, our predictions of the exact energy from a Fermi wave calculation go exactly to the correct values assuming eq. 4. In effect, we can ignore the higher statistical moments of the electron fields and still get the correct result.

The extended claim (extended EFH) is simply the same thing, in the presence of an additional linear field, but note that there will be some small approximation error due to our neglect of coherence effects in B and W, especially. However, neglect of those terms is like neglect of B and W terms in electron-electron scattering; under very special experimental conditions, it has measurable consequences, but not in most experiments. In fact, the error here is analogous to the error introduced by using conventional Feynmann diagrams in ordinary QED, neglecting the two-photon and three-photon lines; the error seems to be zero... until we build special devices like lasers or superradiance systems which magnify the effects. For purposes of QED, we expect very small error in ignoring the "two-W coherent lines" – but on another track, perhaps someday people will learn to build W lasers or B lasers, though perhaps such devices would rightly be subject to security controls; still, such possibilities are beyond the scope of QED. Note that the core, not the "pilot wave," is the source of the electromagnetism of the charged particle; linearity implies that the "pilot wave" does not interact with the quantized photons or the virtual photons in Coulomb fields directly.

In the end, one cannot derive equilibrium statistical probabilities or transition probabilities from an underlying theory in a rigorous way without developing some form of Boltzmann equation and invariant statistical measure. In [14], we do that, in a way which can be applied to MEWT, both for static equilibrium and for space-time systems. This appears to predict a statistical mixture of highly interactive quantized modes for A_μ and far less interactive subquantal radiation modes for B and W which might explain part of dark matter and dark energy [10]. The energy density of dark matter in our galaxy is far less than the zero point energy terms predicted by FQED, but still large enough to suggest interesting possibilities. For example, it may be possible after all to squeeze these background fluctuations, as in the suggestions by Leitenstorfer and others to "squeeze the vacuum;" in theory, that might even make it possible to create regions of "negative" (reduced) energy density, as required by Alcubierre's faster than light (FTL) solutions in general relativity. Or perhaps we may someday find a way to extract such energy, after we develop more fully the technology of observing it [11].

In MQED1, the fermionic part of the density operator may be explained as the sum of the point particle core part indicated by equation 4 plus the usual P mapping of the linear "pilot" wave, asymmetrized so as to get rid of the higher order terms needed for a full treatment of coherence effects with photons. The ordinary density function of ordinary QED is then explained, in effect, as the usual density matrix prior to renormalization, plus the density matrix of the "infinite negative mass renormalization" required in ordinary QED to make ordinary QED capable of finite predictions in practice. This density matrix includes the usual cross-correlation terms between two electrons, for example, as required to explain the spectrum of atoms like helium. In a way, this paper is the final outcome of a dialogue between this author and Louis De Broglie in the early 1970s, on the key empirical problem which puzzled us both: how to explain the spectrum of helium in a manner consistent with his mature picture [15] of the electron. His part of that correspondence still exists and has recently been scanned into a private folder on google drive. It was not an easy matter to get this far, though it is obvious that the full program in [1] will require many more years (beyond the remaining lifetime of this author) for its complete fulfillment, as did the work on other forms of QED, and that it requires a full understanding of [1], [3] and [14].

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