A realist view of the electron: recent advances and unsolved problems

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In view of experimentally obtainable resolutions, equal to the Compton wavelength of an electron, the conventional interpretation of quantum mechanics no longer seems to provide a sufficiently subtle tool. Based on the intrinsic properties of extended particles we propose a new theory, which allows to describe fundamental processes with unlimited precision at the microlevel. It is shown how this framework combines classical electrodynamics and quantum mechanics in a single and consistent picture. An analysis of single measurement problems reveals that the theory is suitable to remove some of the most striking paradoxes in quantum mechanics, which are found to originate from obscuring statistical effects with physical reasoning. A possible origin of the infinity problems in relativistic quantum fields is found by analyzing electron accelerations due to photon absorption processes. The current state of the theory and existing problems are discussed briefly.

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I. INTRODUCTION

As long as the size of elementary particles remained somewhat insignificant, the theoretical efforts could be limited to a description of point-like entities with qualities like mass, charge, or spin. The theoretical framework gradually evolving in quantum electrodynamics (QED) or quantum field theory consequently knew little more than these point-particles and their interactions. But experimental methods have developed rapidly. On the one hand, the precision of measurements reaches already far into a regime comparable to the size of particles. The Compton wavelength of an electron, for example, is not smaller than current resolutions in surface science. On the other hand, quantum effects play a major role also in experiments, where the length scale is in the range of centimeters or even meters. This situation makes the development of consistent models of particles, taking into account the relationship between classical and quantum systems, an even more important issue.

Following the traditional method of development, one starts with the definition of e.g. an electron, while the relation between electron properties and electromagnetic fields is determined in a second step. On this basis the treatment of the problem could be commenced with Barut’s assessment of the main problem in electron theory: [If a spinning particle is not quite a point-particle, nor a solid three dimensional top, what can it be? According to Bunge or Recami there are in general only three possibilities: A particle either is (i) strictly point-like, (ii) actual extended, or (iii) a point-like structure in motion within the actual volume of the particle. And the only possible solution for an electron is of type (iii).]

The thesis elaborated in this paper uses a different method, which can be described by four assertions: (i) An electron is determined by its intrinsic properties. (ii) The exact numerical value of these properties, and consequently the actual size of the electron remains undefined. (iii) The statistical ensembles in quantum theory (QT) are based on this indefiniteness. (iv) Quantized properties like mass, charge, or spin are due to a change of intrinsic properties in the presence of external fields. Although the picture is far from complete, it suggests a modification of current concepts in the following sense: even if there are intrinsic properties of single entities called electrons, there may not be single and well defined objects called electrons.

Since the ensembles in QT are related to electrons with a defined range of intrinsic properties, the interaction of a member of the ensemble with exactly determined intrinsic properties is exactly determined. We use the term elementary process in such a case, and the statistical results of measurements in QT are thought to contain an arbitrary number of such processes. This definition of elementary processes implicitly contains the assumption of hidden variables, although the present approach is substantially different from Bohm’s theory: (i) The notion of a particle is not fundamental. (ii) We start with a description of intrinsic properties and relate them only later to the formulations in QT and classical ED. (iii) In this way we regain a statistical (and non-local) interpretation of QT, where the statistical ensembles result from an unknown phase (similar to Bohm’s picture), but also, due to the uncertainty relations, from an unknown energy component.

Especially the latter quality of the ensembles in QT accounts for a fair share of the paradoxes, which have been irritating - or exciting - the physical community for quite some time. And it is exactly this quality of the quantum ensembles which makes QT an incomplete theory. The results are described in view of a non-specialized readership, specialist readers are referred to existing publications, describing all the necessary steps in great detail.
II. THE ELECTRON: INTRINSIC PROPERTIES

There can be no doubt that the electron, of all the elementary particles, is by far the best researched, both experimentally and theoretically. Should it therefore be a mere exaggeration, if a book by MacGregor, appearing in 1992, is entitled: The Enigmatic Electron [13]. Or is there substance to this claim? The main problem with all existing models of the electron (see the introduction) is that none of them can explain all the observed experimental features. An extended particle, for example, is claimed to contradict scattering experiments, a point-particle, on the other hand, leads to the well known infinity problems in QED. Both of these problems have, in the model about to be described, a common solution, which can only be systematically displayed, if we focus our attention on the intrinsic properties of an electron, while we shall recover the solutions to the above problems only afterwards.

We start with a non-relativistic frame of reference, assuming that the electron has a finite volume \( V \), which is not specified, and that it moves with constant velocity \( \vec{u} = u\vec{e}_u \). Its intrinsic structure is described by a wave equation for its density of mass \( \rho(\vec{r}, t) \), and a wave equation for an additional field energy \( \phi(\vec{r}, t) \), which was called the intrinsic potential [13] for two reasons: First, the same model can be used for photons (in this case the particles proceed with \( c \)), the intrinsic field energy \( \phi(\vec{r}, t) \) then is equal in magnitude to the electromagnetic potential \( \vec{A} \). And second, due to electron propagation the energy is shifted from the propagating mass to the correlating intrinsic field energy and vice versa, the field energy therefore behaves like a periodic potential.

The impact of this concept on the fundamental statements in QT is quite substantial: (i) The energy of the electron is double the kinetic energy or equal to \( m_eu^2 \). (The energy is computed by incorporating intrinsic properties over the volume \( V \). The exact value of \( V \) is not required for the integration.)

\[
W_{kin} = \frac{1}{2}m_eu^2 \quad W_{pot} = \frac{1}{2}m_eu^2 \\
W_{tot} = W_{kin} + W_{pot} = m_eu^2 = \hbar\omega \quad (1)
\]

If the total energy is used to satisfy Planck's relation, the dispersion relations for monochromatic plane waves are recovered, then (ii) regarding its intrinsic properties, an electron can be described as a monochromatic plane wave. But this means that (iii) the Schrödinger equation [14], which neglects the intrinsic energy components, is no longer an exact equation [14]. And on this basis it can be deduced that (iv) the Heisenberg uncertainty relations [17] actually describe the errors due to the omission of intrinsic energy.

The latter point is interesting for three separate reasons. First, it is well known that the uncertainty relations are responsible for the spreading of a wave packet (see e.g. [18]). If they are not interpreted as physical causes - as they are thought to be in the standard framework, even if the more innocent term principle is used - then the spreading of a wave packet is not a physical effect, but only a consequence of the logical structure of QT. Second, the result seems to settle the long-standing controversy between the axiomatic and the empirical interpretation of Heisenberg's relation. It is not empirical, since it does not depend on any measurement process; but it is also not a physical principle, because it is due to the fundamental assumptions of QT. Third, if the uncertainty relations are not a universal physical principle, then experiments can be described with unlimited precision also at the microlevel: only in this case does the definition of fundamental processes at all make sense.

![FIG. 1. Intrinsic properties of electrons. The momentum density \( \vec{p} = \rho\vec{u} \) is longitudinal, while the electromagnetic \( \vec{E} \) and \( \vec{B} \) fields are of transversal orientation. The model is valid for electrons and photons, and it can be deduced that the intrinsic magnetic field \( \vec{B} \) is responsible for the magnetic moment of electrons.](image)

So far the proposition of intrinsic structures and intrinsic properties is a mere speculation, which is not very different from other speculations including a more or less substantial part of the known qualities of electrons into a single picture. In particular it is yet unclear, how magnetic properties come into play. This is done in two steps: (i) The intrinsic potential \( \phi \) is interpreted as an electromagnetic property, related to intrinsic electromagnetic fields \( \vec{E} \) and \( \vec{B} \) of transversal orientation, and which comply with a wave equation. The direction of intrinsic fields is shown in Fig. 1. And (ii) it is proved that these conditions are generally sufficient to derive Maxwell's equations [13]. Therefore, the intrinsic structures lie at the bottom of two hitherto separate concepts:

- They are the origin of wave-like qualities of the electrons described by Schrödinger's equation.
- And they are the origin of electromagnetic qualities of electrons (and photons), since they lead to our - to date - best theory of electromagnetic fields.

The peculiar features of spin in QT can only be fully understood from interactions of electrons with external
fields. This will be done in the following sections. Here we wish to add a few remarks on the measurements of Bell type inequalities, performed in ever increasing perfection since the Eighties [20], and which seem to indicate what is usually called action at a distance.

It is a common error, especially among experimenters, to assume that these measurements demonstrate that nature allows action at a distance, that nature is non-local. Without claiming that this is impossible, it can nevertheless be said that it cannot be proven by these - EPR type - measurements due to the fact that a valid measurement of spin correlations violates the uncertainty relations. Why is this decisive? In order to understand the argument, let us analyze the theoretical basis of these measurements. Interpreting a measurement of spin, spin has to be defined, and it can only be defined within QT, but not in classical electrodynamics. For EPR like experiments we also require a conservation principle, since the total spin of two particles must be known. It could be analyzed, furthermore, what theoretical basis is required for the deduction of the Bell inequalities, and it can be argued, that some of the assumptions going into these deductions are a lot less important than locality in physics (see e.g. [21,22]). This is not needed in the present context, since it can be shown that no valid interpretation of spin correlation measurements within QT is possible. To this aim we define the spin of a particle by the magnetic moment \( \vec{\mu} \) and a magnetic field \( \vec{B} \), which shall be determined from intrinsic properties (\( \vec{u} \) is the velocity, \( \rho \) the density of the electron as previously defined):

\[
W = -\vec{\mu} \cdot \vec{B} = \frac{1}{2} \hbar \omega \quad \vec{\mu} = g \frac{e}{2m} \vec{s}
\]

\[
\vec{B} = -\frac{1}{2} \vec{\sigma} \times \rho \vec{u}
\]

\( \vec{\sigma} \) in these relations is a dimensional constant to make mechanical units compatible with electromagnetic variables. Assuming that the kinetic energy \( \frac{1}{2} m \vec{u}^2 \) is due to the interaction of a constant magnetic moment with the intrinsic magnetic field of the electron, we arrive at \( g_e = 2 \) and \( s_e = \hbar/2 \), while the direction of spin is equal to the direction of the intrinsic magnetic field \( \vec{B} \). For photons the same calculation yields \( g_{ph} = 1 \) and \( s_{ph} = \hbar \). These results will be clarified in the calculation of interactions with external fields further down.

If we now consider a correlation measurement of photon spin we are confronted with the problem that spin is parallel to the intrinsic magnetic field, which is a periodic variable: spin therefore cannot be constant but will oscillate from \(+s\) to \(-s\) with a period of half the particle’s wavelength. For a valid correlation measurement the local precision therefore must be higher than \( \lambda/2 \). But it has been demonstrated, in the deduction of the uncertainty relations via the omission of intrinsic potentials and quantum theory for QT, that this is the highest limit of precision possible in QT: thus a valid measurement exceeds the level of precision provided for in QT, thus it is incompatible with the axioms of QT: it can therefore not be consistently interpreted within this same framework. Independently of any other consideration. And since EPR measurements rely on QT for the definition and conservation of spin, they are generally inconclusive.

Returning to Barut’s dilemma quoted in the introduction, it can be said that in this model the electron is neither a spinning top nor any modified point particle: it is an extended structure, and so far it is not clear, which of the intrinsic properties of the electron is actually related to its charge.

III. INTERACTIONS WITH EXTERNAL FIELDS

To elucidate the problem, let us consider the interaction of an electron (density amplitude \( \rho_0 \), charge density amplitude \( \sigma_0 \)) with a photon (density amplitude \( \rho_{ph} \)) under the presence of an external electrostatic field \( \phi_{ext} \). The procedure used for the calculation is pretty standard: we define the Lagrange density of an electron in motion, including an external potential and a presumed photon.

\[
\mathcal{L} := T - V = \rho_0 \dot{x}_i^2 + \rho_{ph} c^2 - \sigma_0 \phi_{ext}
\]

A variation with fixed endpoints and using the principle of least action allows to calculate, by way of a Legendre transformation and in a first order approximation of a Taylor series, the Hamiltonian of the system as [13]:

\[
H = \frac{\partial \mathcal{L}}{\partial \dot{x}_i} \dot{x}_i - \mathcal{L} \approx \sigma_0 \phi_{ext}
\]
by an exchange of photons: the potential of electrostatic fields then is not so much a function of location than a history of interactions. This can be shown by calculating the interaction Hamiltonian \( H_w \):

\[
\begin{align*}
H_0 &= \rho_0 x_i^2 + \sigma_0 \phi \\
H &= \sigma_0 \phi \\
H_w &= H - H_0 = -\rho_0 \dot{x}_i^2 = \rho_{ph} c^2.
\end{align*}
\] (5)

But if electrostatic interactions can be referred to an exchange of photons, and if these interactions apply to accelerated electrons, then an electron in constant motion does not possess an intrinsic energy component due to its electric charge: electrons in constant motion are therefore stable structures.

The photon-interaction model of electrostatic fields allows a further extension of the current framework. Since, what might be called charge, finds its expression in the properties of the emitted and absorbed photons, and since these photons can either lead - by way of their intrinsic properties - to attraction or repulsion of other charges, the sign of the charge is no longer a quantity fixed for all time and under every condition. Although there is, currently, no comprehensive way of describing the origin of a specific charge/anticharge in a specific situation, it seems that the model should also be suitable for questions of this type and which are well beyond the rather phenomenological (Heisenberg) description used in the current standard models of elementary particles.

As a second example we calculate the interaction of an electron with an external magnetic field. The field in this case changes the intrinsic energy components of the electron. The local and deterministic calculation of these interactions is based on the field equations of intrinsic fields. The units of these fields are due to the derivation of the Maxwell equations from intrinsic properties, an analysis of electromagnetic units has been given in [25]:

\[
\begin{align*}
\frac{1}{u^2} \frac{\partial \vec{E}}{\partial t} &= \nabla \times \vec{B} \\
\frac{\partial \vec{B}}{\partial t} &= \nabla \times \vec{E} \\
\phi_{em} &= \frac{1}{2} \left( \frac{1}{u^2} \vec{E}^2 + \vec{B}^2 \right)
\end{align*}
\] (6)

We use a dynamic model by assuming that the external magnetic field is switched on in a finite interval \([0, \tau]\). Then the intrinsic energy component in the magnetic field has changed and will be [10]:

\[
\phi(\vec{B}_{ext}) = \phi_{em} + |\vec{B}_{ext}|^2
\] (7)

The crucial feature of magnetic interaction is, that the acquired energy is independent of the angle \(\theta\) between the intrinsic magnetic field \(\vec{B}\) and the external magnetic field \(\vec{B}_{ext}\) (see Fig.2). It can therefore not be formalized as the scalar product of an intrinsic (and constant) magnetic moment \(\vec{\mu}\) and an external field \(\vec{B}_{ext}\):

\[
W \neq -\vec{\mu} \cdot \vec{B}_{ext} \quad \vec{\mu}, \vec{B}_{ext} \in \mathbb{R}^3
\] (8)

or only, if the magnetic moment is a non-local variable: the non-local definition of particle spin in quantum theory, or the impossibility to describe spin as a vector in \(\mathbb{R}^3\), can only be understood on the basis of interactions. More specifically, it is the - failed - attempt to describe the changes due to magnetic interactions with a formulation inherited from classical electrodynamics. Therefore, spin in quantum theory cannot be a vector, because interactions do not depend on the direction of field polarization. This result, which only applies to free particles, also illustrates the importance of dynamic models of interactions.

As the intrinsic component of particle energy is increased due to external fields, total energy of the particle can either be increased, which should be the case for charged particles like electrons, or it can remain constant, which we, tentatively, assume for neutral particles like neutrons. In any case the kinetic components of particle energy change, and this change corresponds to a changed wavelength of its wavefunction \(\psi\). If the change of the wavelength is calculated and the phase difference to a beam not subjected to this magnetic field estimated, we arrive at the following result for the phase-difference \(\alpha\):

![Fig. 2. The kinetic energy component \(\phi_k\) is changed in a magnetic field due to interaction, the change is independent of the angle \(\theta\) between the external and the intrinsic magnetic field components (top). Due to the interaction the wavelength of the particle wavefunction is changed (bottom).](image)

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\[ \alpha = 2\pi \left( \frac{l}{\lambda} \frac{|\vec{B}_{ext}|}{\sqrt{\mu U}} - n \right) \quad n \in N \quad (9) \]

where \( l \) is the path-length in the field of the magnet and \( \lambda \) the original wavelength of the beam. The result indicates that the phase difference is linear with the intensity of the magnetic field: a result confirmed by neutron interference measurements of Rauch and Zeilinger. A short remark is in place concerning the relation of the present concept to the concept of quantization in QT, which seems to be used in various, and sometimes incompatible meanings. Provided, the structure of matter consists of atoms, every detector and consequently every measurement only yields discrete results: there must, necessarily, exist a threshold which is required to trigger a reaction. On the level of measurements quantization is consequently a necessity (this also applies, for example, to Millikan’s experiments to determine the “elementary charge”). But while this is trivial in the atomic domain, it does not mean that we have to encounter discrete quantities in a point-like volume when electrons are separated from atoms: given the infinity problems connected with such an idea, it seems amazing that it prevailed for so long, even in de Broglie’s “double-solution”. The only real argument, which suggests such an approach, originates from scattering experiments: if electrons were extended structures (three dimensional aggregations of mass) like atomic nuclei, then the scattering cross section would be affected. This has never been observed and it was concluded, therefore, that electrons cannot be extended structures (see e.g. Bender et al. [20]). Comparing with the particle models introduced previously (see the introduction), these experiments only exclude electrons of type (ii): three dimensional tops. They do not exclude any other type, especially not the extended electrons introduced in this paper, where interactions apply to every single point of the internal structure.

It shall not be hidden, though, that a mathematical model for scattering processes based on photon interactions has yet to be developed: not an easy task, it seems, since the reduction to a one body problem in a potential, like in standard solutions, is not generally applicable.

IV. ENSEMBLES IN QUANTUM THEORY

It was already noted by David Bohm that QT does not differ between elementary processes (or physical interactions) and statistical results [22]. Yet it is not immediately clear how the ensembles, to which ... probabilities [in QT] refer, are formed and what their individual elements are. For the very terminology of quantum mechanics contains an unusual and significant feature, in that what is called the physical state of an individual quantum mechanical system is assumed to manifest itself only in an ensemble of systems.

The Copenhagen interpretation seeks to make up for this conceptual deficiency by asserting that nature itself is the origin of this feature. However, we shall try in this section to determine the exact borderline between the elementary processes and the statistical picture in QT. As will be seen presently, the (unusual) statistics of quantum systems have two separate origins: (i) The unknown intrinsic energy components. (ii) Normalization of the wave function. The first accounts for the change of the ensemble structure in measurements, since it affects the range of allowed intrinsic energies, the latter introduces non-locality into the framework of QT, because normalization requires an integral of the wavefunction over the whole system considered: after normalization the amplitude of the wavefunction in one region of the system depends on the potentials and amplitudes of the wavefunction in all the other regions of the system. QT therefore cannot be a local theory. Which does not mean, as demonstrated above, that nature itself must be non-local.

Starting with the ensemble structure in QT pertaining to the omission of intrinsic energy components, let us first consider the situation of a free particle. In this case the external potential \( V(\vec{r}) \) is zero, and the maximum of \( k \), in a plane wave basis of possible solutions of the Schrödinger equation for fixed total energy \( E_T \), is described by \( k^2 = mE_T/h^2 \). Since the phase of the wave-like intrinsic components is unknown, the total energy can be distributed in an unknown manner between the kinetic components, described in QT, and the electromagnetic components, not considered in QT. At a specific point \( \vec{r} \) of our system this means, that we are dealing with a Fourier integral over an allowed range of states, which we called the quantum ensemble of free electrons [4].

\[ \psi(\vec{r}) = \frac{1}{(2\pi)^{3/2}} \int_{0}^{k_0} d^3k \psi_0(k) \exp i\vec{k}\vec{r} \]

\[ k_0 = \sqrt{\frac{m}{\hbar^2}} E_T \quad E_T = ma^2 \quad (10) \]

where \( \psi_0(k) \) is the \( k \)-dependent amplitude. This quantum ensemble, which is defined according to the omission of intrinsic energy and thus according to the uncertainty relations (see above), describes a range of allowed kinetic energies, and it applies to every single point of a given system. In this sense the wavefunction \( \psi(\vec{r}) \), given by Eq. (4), is a statistical measure [22]. The unusual feature, Bohm refers to is thus, on closer scrutiny, removed: although the ensemble is an integral part of QT, it does not mean, that we cannot go beyond the purely statistical picture of e.g. the Copenhagen interpretation [22] to an analysis of the underlying fundamental processes.

This can be done in two steps: (i) The physical environment determines, by way of the potential \( V(\vec{r}) \) and the local boundary conditions the structure of the ensemble, i.e. the range of intrinsic properties in a given environment. A potential \( V(\vec{r}) \), for example, changes the structure of the quantum ensemble, since it affects the range...
of allowed $k$-values. For a negative potential, the range is enhanced, for a positive one, diminished (see Fig. 3). (ii) Once the range of intrinsic properties is determined, the problem for a single member of the ensemble can be treated, at this level we are dealing with a classic physical problem where the interactions and boundary conditions can be included by field theory, e.g. the wave picture of classical electrodynamics.

$$\begin{align*}
\Delta k(E,0) & \quad \Delta k(E,+V) \\
\Delta k(E,-V) & \\
\end{align*}$$

This analysis of the ensemble structure in QT explains also, in a quite natural way, how the statistical picture of QT is related to electrodynamics: the ensembles in classical electrodynamics are in fact quantum ensembles, where the allowed energy range is vanishing, the energy of ensemble members is thus exactly determined, although neither their phase nor their exact location. This is one half of the notorious wave/particle problem, which bounded physics since the establishment of QT (see the collection in [23]): particles, in QT, are an ensemble of wave-like structures of finite volume $V$ and a defined range of energies. It also provides a reason for the validity of von Neumann’s proof, that QT cannot contain a theory of hidden variables, although in quite a different sense than expected by von Neumann [30]: not, because quantum theory is complete, but because quantum theory contains a - in von Neumann’s words - normal ensemble, an ensemble which cannot be described as a sum of members of exactly determined properties (e.g. exact location and exact energy), since the range of allowed energy values pertains to every single point of our system [11].

If we consider a measurement of energy on the quantum ensemble of free electrons, e.g. by a positive potential like in low energy electron diffraction (LEED) experiments, it is immediately clear that the ensemble after the potential, assumed rectangular for simplicity, is diminished compared to the ensemble before it. The wavefunction $\psi(\vec{r})$ has collapsed in $k$-space (see Fig. 3). This process, which cannot be consistently described in the conventional formulation of QT, has led to a host of proposed modifications, among the more daring the many world interpretation of Everett, where every result of a measurement occurs in a different universe [31]: since its publication a continuous source of inspiration for quite a few science fiction authors. The main point here is, that if the wavefunction is interpreted as the wavefunction of one single particle, it must remain a mystery, how - to put it a little sloppily - most of the particle can vanish in the measurement, although the potential, seemingly, is not affected. The effect is only understandable, if the ensembles underneath a specific $\psi$ are considered.

A similar consideration applies to the notorious interaction free measurements, where the wavefunction of a system changes, even if no interaction occurs [32,33]. A paradoxical consequence of this type of measurement would be, that the energy of a system could change, even if that system does not experience any interaction [35]. Within the present theory this behavior is completely understandable, although it points to a statistical, rather than a physical effect: since no interaction with a particle means, in the region where the particle is appreciable, that the wavefunction must necessarily vanish, it excludes the existence of single members of the ensemble in that region. Compared to the case, where no measurement has been performed, the knowledge about the ensemble has been changed. And since energy in QT is computed via the wavefunction, thus the ensemble, the energy in the latter case can be different. Without any spooky physical events, also without assuming, that the apparent lack of interaction ... is only illusionary [35].

As a last example we mention the quantum eraser measurements, where the existence of interference patterns between two orthogonally polarized photons in a double-slit system depends on the insertion of a polarizer with a diagonal plane of polarization [34]. In the conventional

FIG. 3. Quantum ensembles and potentials. A potential at a specific point $\vec{r}$ of the system changes the structure of the ensemble in QT: a negative potential enhances, a positive diminishes the range of allowed $k$-values (top). An energy measurement by a positive potential (a retarding field analyzer) $V_{rf a}$ leads to a collapse of the wavefunction in $k$-space (bottom).
framework, this behavior is attributed to the path information, which, after the diagonal polarizer, is said to have been "erased". In the new framework, an identical result can be computed by estimating the effect of polarizers on the orientation of intrinsic field components [11].

Currently the main focus in developments is on interference measurements, since it has been found, that a local and causal description of this type of measurement can neither be given in QT, nor in classical electrodynamics [11]. The main problem in electrodynamics is the result, that if the extension of wave structures is limited, the scattering amplitude, in a Kirchhoff approximation, contains the final result of measurements already at the moment, when the structure passes the slit environment. It seems therefore, that the mathematical formulation by way of Green’s functions and the scalar theory should be more or less algorithmic, while actual physical processes – the interactions with the atoms of the slit environment – are not described. Which suggests a new theory of interferences including these interactions.

V. A SIDEBVIEW OF SPECIAL RELATIVITY (STR)

It will have been noted that the total energy of an electron, equal to \( m_e u^2 \), bears a slight resemblance to Einstein’s energy expression \([36]\), a resemblance, which becomes especially obvious, if photons are considered in this model, and which possess a total energy of \( m_{ph} c^2 \).

It can be shown that these expressions are more than mere coincidences, they lead, in fact, to one of the most interesting consequences of the theory; touching a problem known for more than fifty years and inciting the late Dirac to qualify QED, in its present form, as a very wrong theory \([37]\).

Since the model starts from a non-relativistic frame of reference, a Lorentz transformation of the fundamental equations into a moving reference frame changes the physical state of the system, because in this case the intrinsic potentials increase with the electron velocity \([8]\). In view of consistency, this result seemed, initially, questionable, since it is incompatible with the relativity principle. As further research revealed, this behavior is closely related to the process of interaction in electrostatic fields.

If electrostatic interactions are accomplished by photons, the absorption of a photon by an electron depends on proper time in the electron system, and the acceleration is then a function of the electron’s velocity. This effect has been known for some time. Adler remarks on that subject that the time kept by the rapidly moving particle is dilated and hence, as the particle’s speed increases, apparently greater intervals are taken to produce the same effect, hence the apparent increase in resistance \([8]\). But if this is the case, then the energy of the electron, in the limit of \( n \to \infty \) absorptions

\[
E_n = \hbar \omega_0 \left[ 1 + \sum_{i=0}^{n-1} \sqrt{1 - \left( \frac{u_i}{c} \right)^2} \right] = m u_n^2 \tag{11}
\]

will not be infinite, but converges to a finite limit, where the total energy of the electron is, incidentally, equal to Einstein’s rest energy term \( m_e c^2 \).

![Graph showing electron energy due to photon absorption](image)

FIG. 4. Electron energy due to photon absorption. Top: while in Special Relativity (ES) the energy of the electron becomes infinite in the limit \( u \to c \), it remains finite in the photon interaction model (EI). Bottom: due to changed frequencies in the electron frame accelerations decrease with increasing electron velocity. The decrease leads to an observed but virtual increase of inertial mass. The difference between Einstein’s \( \gamma \) (g) and \( \alpha \) (a) is insignificant over the whole velocity range from \( u = 0.05 \) to \( u = 0.99 \).

By comparing the classical interactions due to electrostatic fields with the interactions pertaining to photon absorption with dilated proper time it can be established that the electron mass seems enhanced, and that this enhancement is equal to the mass effect in STR \([14]\). To prove the equivalence we have calculated the (virtual) mass enhancement due to time dilation, described by a variable \( \alpha(u) \)

\[
m(u) = m_e \sqrt{\frac{m}{m_U}} \sqrt{1 - \frac{\sqrt{n}}{n} \frac{u_n}{u_{n-1}}} \quad \alpha = \sqrt{\frac{\hbar \omega_0}{m}} \frac{\sqrt{1 - \frac{u_n}{u_{n-1}}} u_n}{u_{n-1}} \tag{12}
\]
where \( u_n^e \) and \( u_n^r \) denote the classical and the interaction model velocities of the electron in an electrostatic field, and compared \( \alpha \) to Einstein’s \( \gamma \). The results of these (numerical) calculations are displayed in Fig. 1. It should be noted that for reasons of comparison we have taken only the kinetic energy of the electron and added the rest energy. As can be seen, the mass effect in STR coincides nicely with the virtual mass enhancement due to time dilation.

From a physical point of view, the result means that the relativistic mass formulas, in STR artifacts of the kinematical transformation of space and time [35], are an expression of changed interaction characteristics, described by the time dilation in moving frames. That the result is consistent with measurements has been shown elsewhere [36]. In addition, it sheds a new light on the so called renormalization procedures in QED, which were the reason for Dirac’s uneasiness. As Weisskopf showed in his treatment of the free electron, the infinite contributions to the self energy of the electron have two origins: (i) the electrostatic energy, diverging with the radius \( a \) of the electron, and (ii) the energy due to vacuum fluctuations of the electromagnetic fields. For these two energies \( W_{st} \) and \( W_{fluct} \) he found [37]:

\[
W_{st} = \lim_{a \to 0} \frac{e^2}{a} \quad W_{fluct} = \lim_{a \to 0} \frac{e^2 h}{\pi m c a^2} \quad (13)
\]

The electrostatic contribution vanishes, if an electron in constant motion is considered, since in this case no emission or absorption of photons will occur. The second contribution, the vacuum fluctuations, sums up the energies due to the interaction of the electron with its own created and annihilated photons in a statistical picture which considers all possible events.

In the first calculation to master the infinity problems of quantum electrodynamics Bethe derived the following expression for the Lamb shift of the hydrogen electron in an s-state [38]:

\[
W_{ns} = C \cdot \ln \frac{K}{\langle E_n - E_m \rangle_{AV}} \quad (14)
\]

where \( C \) is a constant \( \langle E_n - E_m \rangle_{AV} \) the average energy difference between states \( m \) and \( n \), and \( K \) determined by the cutoff of electromagnetic field energy. The prime refers to mass renormalization, since the - infinite - contribution to the electron energy due to electrostatic mass has already been subtracted. The second infinity, the infinity of vacuum fluctuations, is discarded by defining the cutoff \( K \), which in Bethe’s calculation is equal to \( mc^2 \). But while the energy of the field could have any value, if the actual energy of the electron has a singularity at \( u = c \) (and \( K \) could therefore be infinite), this is not the case if the energy remains finite in this limit: in this case the total energy difference between a relativistic electron and an electron at rest is \( mc^2 \) according to our calculations. This is, incidentally, equal to the rest energy of the electron. It seems, therefore, that the renormalization procedures [1] may have their ultimate justification in finite electron energy.

It should be noted that it is not yet sufficiently clear, from the viewpoint of this new theory, how the more subtle theoretical developments of QED shall be put into the new framework. In addition, it has been seen by reanalyzing experiments and their description in the standard theory, that progress in not to be expected by an equation for everything. Rather by careful revision of experimental evidence and subtle speculation within the new framework: a tedious task, it seems, but which is the price paid for the insight gained into fundamental processes.

VI. CONCLUSIONS

We have shown in this paper that a new theoretical framework, based on the intrinsic properties of electron, is suitable to remove the notorious infinity problems in QED and to describe a realistic electron in accordance with experimental data. Electrostatic and magnetic interactions have been treated in this framework, and the origin of the non-local properties of particle spin has been determined. We have also described the borderline between the usually statistical interpretation of the wavefunction and the, physically relevant, intrinsic wave properties. In this case a novel structure of the ensembles in quantum theory was proposed, which is due to the omission of intrinsic energy components. Finally, we have described how the theory treats photon absorption processes in a relativistic context, which led to the conclusion that the mass enhancement in the electron system is only virtual and an effect of time dilation. It was shown, how this result lies underneath the hitherto unexplained renormalization procedures in relativistic quantum field theory.

VII. ACKNOWLEDGEMENTS

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