A critical view of quantum physics

Jorma Jormakka
Vantaa, Finland
jorma.o.jormakka@gmail.com

Abstract: The article explains issues that I see as problems in quantum mechanics and quantum field theory. The first section briefly reminds of the main errors in the Relativity Theory that I noticed in earlier papers. Sections 2-5 discuss why I consider wave-particle dualism and wavefunction as incorrect concepts. Section 6 looks at some problems in QED and explains why the theory is not verified by measurements of anomalous magnetic moments and the fine structure constant. Section 7 gives a few comments about the Standard Model and addresses the question why false theories have been accepted in theoretical physics.

Keywords: Quantum Mechanics, Wave-particle dualism, Quantum Electrodynamics, anomalous magnetic moment, Standard Model.

1. Why to reconsider quantum physics?

Quantum mechanics started from Max Planck's black body radiation formula of 1900, but Planck did not consider his quantum hypothesis as anything more than a mathematical artifact. Albert Einstein was the first to state that Planck's quantum hypothesis implies completely new physics. Quantum physics and Einstein's Relativity Theory are the pillars of this new physics. The reason to recosider quantum physics is that there are many errors in Einstein's Relativity Theory, see my findings in papers referred to in [1]. Quantum mechanics not only is formulated to be compatible with the Relativity Theory but also the concept of a wavefunction originally derives from Einstein's view of a photon as a particle-wave, a view that this article will identify as false and the source of the errors in quantum physics. Let us start by mentioning Einstein's main errors in the Relativity Theory.

Hendrik Lorentz and others noticed that electrons accelerated to speeds rather close to the speed of light in a cathode ray tube seemed to have a larger mass. When a fast electron with speed v_L from the anode to the cathode was deviated with a static magnetic field, i.e., by the Lorentz force, to a direction that was transverse to the velocity of the electron, it seemed to have a mass $\gamma_L m_e$ where $\gamma_L = (1 - {v_L}^2/c^2)^{-1/2}$. This mass was named apparent transverse mass. This (correct) finding was one of the direct inspirations to Einstein in the Special Relativity Theory.

Notice that the transverse apparent mass alone refutes Einstein's relativistic kinetic energy formula. In the measurement of transverse mass of an electron, the electron deviated from from its straight path from the anode to the cathode gets a small velocity v_T in the transverse direction. The square of the total velocity of the electron is therefore $v^2 = v_L^2 + v_T^2$. Einstein's formula for the kinetic energy is

$$E_k = (\gamma - 1)m_e c^2 \tag{1}$$

where

$$\gamma = \left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}} = \gamma_L \left(1 - \frac{v_T^2}{c^2}\gamma_L^2\right)^{-\frac{1}{2}}. \tag{2}$$

Expanding the square root into a Taylor series and taking the first order approximation gives

$$E_k = (\gamma_L - 1)m_e c^2 + \frac{1}{2}\gamma_L^3 m_e v_T^2 + O(v_T^4/c^4). \tag{3}$$

The first order approximation of the first term in the right side gives the kinetic energy in the longitudinal direction. The second term should be the first order approximation of kinetic energy in the transverse direction, but it is not. According to the measurements by Lorentz and others the second term in the right side should have the apparent mass $\gamma_L m_e$, i.e., the term should be $\frac{1}{2}\gamma_L m_e v_T^2$. (Or, if the transverse mass that Lorentz noticed is mass in momentum $p = \gamma_L mv$, it also does not give this kinetic energy.) The second term to the right has the apparent mass as $\gamma_L^3 m_e$. This means that Einstein's relativistic kinetic energy formula is wrong. Olinto de Pretto's formula $E = mc^2$ is correct, as is verified by nuclear energy, but Einstein did not prove this formula correctly.

The second finding that lead to the Relativity Theory was the Michelson-Morley experiment. The Michelson-Morley experiment was incorrectly made, it necessarily had to give a null-result. The error in this experiment can be seen by thinking of two men with wrist watches that are synchronized to show the same time. These two men pass place A and meet later in another place B. They move from A to B along different ways and have different speeds. To what directions do the second hands in their watches point when the men meet at B? Naturally to the same direction because the second hands all the time point to the same direction and different ways from A to B and different speeds have nothing to do with the direction of the second hands in their wrist watches. In the Michelson-Morley experiment a beam of light arrives to a place A at some time moment and is split into two beams. We can for simplicity assume that the beam has only one frequency. The frequency is the same in both beams and in A the beams are synchronous as they come from the same beam. Therefore these beams are synchronous at any time moment, just like the wrist watches. There cannot be any phase difference at B and different ways of gettig from A to B and different speeds on these ways do not cause any phase difference. But if the beams meet at B, they are at B at the same time moment. If one beam had a higher speed and the length of the two ways from A to B are equal, as in the experiment, then these beams did not pass A at the same time moment. The confusion that a different speed should cause a phase difference in B comes from thinking that the two beams that split at some time moment in A are the two beams that meet at B at a later time moment. The two beams that are synchronous at A do not arrive to B at the same time and they cannot have interference with each other, while the two beams that do meet at B did not pass A at the same time and they had a phase difference in A, but at a different time moment.

Einstein denied that the Michelson-Morley experiment had any major role in his invention of the Special Relativity, but it did because this experiment led Lorentz to make his transform.

Lorentz accepted the result of the Michelson-Morley experiment experiment as correct. In a sense the result of the experiment is correct, though the experiment is incorrectly made: it is today possible to measure the one-way speed of light in satellite communications over a long distance and directly verify that the local speed of light in (near) vacuum is the same to all directions. This locally constant speed of light is not explained by a coordinate transform, it shows that there is a local ether that moves with the Earth, possibly the gravitational field plays the role of the local ether.

Einstein modified Lorentz' transform into a slightly different (and incorrect) transform that he named Lorentz transform. The error in the Lorentz transform is easy to find. Solving x' from $x' = \gamma(x - vt)$ and inserting to $t' = \gamma(t - (v/c^2)x)$ gives $t' = \gamma^{-1}t - (v/c^2)x'$. This is a local time formula: time t' depends on the place x'. This is seen by noticing that only the present time exists. The future does not exist because the future is not determined and the past cannot exist because if a moment in the past exists, then the present moment is future to this past moment. It follows that in the whole universe only the present moment exists. There is no four-dimensional space-time, there is three-dimensional space and change. If t is the present moment in the fixed frame of reference in the Lorentz transform, it is the only moment that exists in the whole universe. At this present moment t, the time t'_1 at the place x'_1 in the moving frame of reference is different than the time t'_2 at another place x'_2. As only one time moment exists, only one time moment exists in the moving frame of reference. The clock at x'_1 shows a different time than the clock at x'_2, but the present moment is the same at both places. That means that t' is a local time, similar to our time-zone time. In a local time coordinate system the time difference between two events happening at two different places is not calculated by subtracting local times. It is necessary to project the local times to the t' coordinate axis and then subtracting the times. Thus, whatever two places x'_1 and x'_2 are, the time difference $t'_1 - t'_2$ is $\gamma^{-1}(t_1 - t_2)$. Making this projection and calculating the time differences in the moving frame correctly shows that the speed of light in the moving frame is $c' = \gamma^2(c \pm v)$ depending on which direction the light is sent. The result of this error is that Einstein's Special Relativity Theory is incorrect in almost all of its claims.

The General Relativity Theory is also incorrect: there does not exist any solution to the Einstein equations that approximate Newtonian gravity in a situation of a point mass in otherwise empty space, a situation that well applies to the Earth's and the Sun's gravity. The Schwarzschild solution is the only radially symmetric stationary solution of the Einstein equations for this situation, but it is not a valid solution because of two reasons: 1) it does not have locally constant speed of light to every direction, and even if this condition is dropped, there is the second error: 2) the spatial part of the Schwarzschild metric is not a Riemannian metric, i.e., there is no inner product in the tangent space that gives this 3-dimensional metric. Therefore one cannot in a valid way even write down the Einstein equations. There are many more problems in the Relativity Theory, they are described in [1] and its references.

2. The origin of the problems in quantum mechanics

It will be argued that there are errors in quantum physics and they originate from Einstein's understanding of light having both a wave and particle character. This lead to matter-waves and to a wavefunction which is not limited to local space coordinates, a reason for two paradoxes in quantum mechanics. This caused viewing space and momentum coordinates as conjugate coordinates in a Fourier transform, which lead to the Heisenberg inequality, a source of a third paradox in quantum mechanics. An effort to align quantum physics with Special Relativity led to to the Dirac equation, which is based in the incorrect relativistic kinetic energy formula. Formulating quantum physics as relativistic quantum field theories implied that the Fourier transform must be four-dimensional causing divergence of Feynman diagrams for propagators and other issues. But let us explain this sad story in steps.

In Planck's derivation of the black body radiation formula it is assumed that light is emitted and absorbed in discrete units of energy. The formula can be explained by assuming that an atomic oscillator with frequency ν emits a run of n wavelengths having the energy $E_n = nh\nu$ and the distribution of runs of n wavelengths is p^n for some probability $1 > p > 0$. Energy of an electromagnetic wave depends on the frequency and amplitude, thus for some reason the amplitude is always the same in waves produced by atomic oscillators. This is not especially mysterious. The present theory of Quantum Physics has many unexplained constants: why the spin of fermions is half-an-integer? Why electron has a fixed charge? And so on.

There would have been many ways to make a model for an atom giving these discrete energy levels, but one particular way was chosen, largely because of Niels Bohr. Niels Bohr and Arnold Sommerfeld tried solar system type models, but such models disagreed with experiments. Bohr proposed that the angular momentum of an electron is quantized as $m_e vr = \hbar$. As a solar system model did not work, de Broglie proposed that the electron is a wave with the orbit being a standing wave of wavelength $\lambda = 2\pi r$. Inserting to Bohr's quantization rule for angular momentum, this gives de Broglie wavelength $\lambda = h/p$ where $p = m_e v$. Louis de Broglie presented this formula as a matter-wave formula: all matter has also a wave form.

The matter-wave idea was inspired by Einstein's proposal that electro-magnetic wave is a particle. This interpretation is in Einstein's explanation for the photoelectric effect. Einstein used Planck's quantum hypothesis in his explanation of the photoelectric effect. He defined a new concept, later called photon, a wave packet of light that behaves like a particle and has energy $E = h\nu$ and momentum $p = h/\lambda$. As light also behaves as a wave, e.g., creates interference patterns, a photon was both a wave and a particle, different aspects shown in different experiments.

A reality check, is a photon a wavepacket? A photon has the energy $E = h\nu$, it is a wave with one wavelength. We can consider it as a part of a wave which is a run of n wavelengths, but is it a wave packet? If there is a single frequency, it is a wave of one wavelength, not in my opinion a wave packet. If there are multiple frequencies, it is a wave packet, but it is not a photon as it does not have a single frequency and energy $h\nu$. Atomic oscillators in Planck's blackbox generate waves with n wavelengths. If n is larger than one, we can see such a wave as a concatenation of n photons.

Can there be fractional photons, i.e., waves that do not have a full wavelength? Atomic oscillators apparently cannot produce waves which have fractional wavelengths, but it can be done with a sending circuit for radiowaves. If the wavelength for a radio wave is long enough, there is no difficulty in sending a wave with the length of a fraction of the wavelength. There is also no difficulty in sending a continuous wave having an indefinitely long run of wavelengths.

These issues mean that a photon is not a fundamental concept. It is not really a particle. If the sender of the wave sends a run of n-wavelengths, then this wave can be considered as a concatenation of n photons, but it is simply a wave. Light does not have wave-particle dualism. Light is a wave, not a particle. In many calculations the concept of a photon can be used and treated as a particle for mathematical convenience.

Photon is a mathematical artifact. Very often mathematical calculations have mathematical artifacts. As an example of a mathematical artifact, consider the sinusoidal components of a Fourier series. We can send at some time t_1 a wave and stop sending it at time t_2. The Fourier series decomposition of this wave has components that start at time $-\infty$ and continue to the time $+\infty$. They are not any physical waves, they are mathematical artifacts, but very useful in calculations.

3. On wave-particle dualism of matter waves

Let us start with a brief look at an Euler-Lagrange equation. Light has speed c in vacuum, but more generally, let the propagation speed of the wave be v. In the one-dimensional Euler-Lagrange equation

$$\frac{\partial}{\partial s}L(s,v,t) - \frac{d}{dt}\frac{\partial}{\partial v}L(s,v,t) = 0 \tag{4}$$

for $L = E_p(s) + E_k(v)$ the first term is clearly force. Therefore the second term must also be a force, it is the force from kinetic energy. Let a mass have the kinetic energy $E_k(v)$ and let is slow down to rest by doing work $W = W(s)$. By conservation of energy $E_k(v) = W(s)$ and

$$F = \frac{d}{ds}W(s) = \frac{d}{dt}\frac{\partial}{\partial v}E_k(v) = \frac{d}{dt}\frac{d}{dv}E_k(v) \tag{5}$$

$$F = \frac{d}{ds}E_k(v) = \frac{d}{dt}\frac{d}{dv}E_k(v). \tag{6}$$

This gives

$$F = \frac{dt}{ds}\frac{dv}{dt}\frac{d}{dv}E_k(v) = \frac{dv}{dt}\frac{d}{dv}\frac{d}{dv}E_k(v). \tag{7}$$

Cancelling $\frac{dv}{dt}$ from both sides and writing $y(v) = dE_k(v)/dv$ gives

$$\frac{1}{v}y(v) = \frac{dy}{dv} \tag{8}$$

which has the solution $y = m_0 v$ and thus $E_k(v) = \frac{1}{2}m_0 v^2$ where m_0 is a constant. Especially, kinetic energy does not have the relativistic mass formula. We can see what changes if the mass is moving with a speed close to c and the force that accelerates it is from a field with the propagation speed c. The mass does not feel the full force from the field. We have to write the Euler-Lagrange equation with a weakened force F_w

$$F_w = \frac{d}{dt}\frac{\partial}{\partial v}E_k(v). \tag{9}$$

In the case of a transverse force deviating an electron in a cathode-ray tube $F_w = \gamma^{-1}F$. We can interpret the result also as the mass appearing as larger:

$$F = \gamma\frac{d}{dt}\frac{\partial}{\partial v}E_k(v) = \gamma m_e\frac{dv}{dt}. \tag{10}$$

and $m = \gamma m_e$ is the transverse apparent mass that early researchers like Lorentz found. If the force is in the longitudinal direction, the apparent mass is different: it is about $m = \gamma^{1.5}m_e$ and the reason why the longitudinal mass differs from the transverse mass is that the degree how well a force can accelerate the mass depends on the direction of the force.

What is important here is that the momentum is always obtained from energy $E_k(v)$ by taking the derivate with respect to v. Thus, if kinetic energy is $E_k = h\nu = hv/\lambda$ and if ν is constant, then the momentum is $p = \frac{d}{dv}hv/\lambda = h/\lambda$, just like Einstein set in the formula for the momentum of a photon. But if the kinetic energy is $E_k = \frac{1}{2}mv^2$, then the momentum is $p = \frac{d}{dv}\frac{1}{2}mv^2 = mv$. As the above calculation shows, the mass is constant. Only the apparent mass that the force sees depends on velocity.

Notice what this means to wave-particle dualism. The energy must be the same whether the wave-particle is viewed as a wave or as a particle, and the momentum must be the same. But this is not possible. If $E_k = hv/\lambda = pv$ and $E_k = \frac{1}{2}mv^2$, then

$$E_k = pv = (mv)v = \frac{1}{2}mv^2 \tag{11}$$

which is a contradiction.

One may object to the use of the Euler-Lagrange equation for a small mass like that of an electron. Let us discuss this objection. The Euler-Lagrange equation is a mathematically correct way to minimize the action integral. The action integral is an integral from time t_1 to time t_2 of the Lagrangean, which in physical applications is often the total energy. The idea is that the path can vary and the Euler-Lagrange equations give the path of minimum energy. But in quantum physics it is not assumed that a particle always follows the path of minimum energy. The action integral is formulated differently: paths with smaller energy are given higher probability: if the energy on a path is $< \psi|H|\psi >$, then the probability of the path could be something like $\exp(-(1/2) < \psi|H|\psi >)$. No Euler-Lagrange equation is used and no action integral is minimized. Instead, a calculation of the path integral is made and it gives the probabilities of different paths. A path integral can be formulated in many ways, not only as Dirac and Feynman realized it. A path integral is something like an integral from t_1 to t_2 of all paths that can happen, something like $\int d\psi \exp(-(1/2) < \psi|H|\psi >)$. The minimum energy path is the most probable path, but the particle can also take other paths. There is no mimimization of the path as in calculus of variations. There is no force in this concept. A force is a mathematical artifact but what actually happens is that a particle interacts with external fields and they change the momentum of the particle, and the result looks like if there is a force. Could the origin of the problem in (11) be the use of the Euler-Lagrange equation?

No. Though the path integral method is a reasonable way of imagining what happens to a particle on its path, it does not solve the problem in (11). From bubble chamber pictures of the paths of charged particles (like electrons) in external fields we know that an elementary particle does behave very much like a mass in an Euler-Lagrange equation for energy. The kinetic energy of a particle can be sufficiently well calculated from the Newtonian formula with a real or apparent mass, or from the relativistic kinetic energy formula if one refuses to accept that this formula is incorrect. The contradiction that was derived in (11) is still there. There cannot be contradictions in a theory. Particles are not waves. The wave-particle dualism in matter-waves is false.

4. On Niels Bohr's influence

Not only Einstein caused quantum physics to take a wrong term. Some of the blame goes to the Copenhagen interpretation by Bohr, Heisenberg and Born, but that is Denmark.

Much of the early work on quantum mechanics was performed under the leadership of Niels Bohr. Bohr seems to have dealt out tasks to other researchers or accepted their research projects, for instance Dirac was asked by Bohr what he intends to do, Dirac answered that he intends to create a relativistic wave equation, Bohr answered that Kein and Gordon already did it, to which Dirac responded by showing that the Klein-Gordon equation has a problem. Stories like this, Bohr was some kind of a manager of early quantum research. Heisenberg and Born worked with Bohr in the Copenhagen interpretation.

I have the feeling that Bohr was the main force behind quantum mechanics, there were a few good ideas in that theory but also paradoxes. Maybe it was not Bohr, maybe it was de Broglie's hypothesis, but the paradoxes in quantum mechanics came from the Copenhagen interpretation. The main paradoxes were the Schrödinger cat, a cat is both dead and alive, the double-slit paradox that requires future to change the past, and the Bell inequalities which claim that basic mathematics fails. A theory with a valid paradox is false, yet in the Relativity Theory it was denied that the twin paradox refuted Special Relativity and in Quantum Mechanics the paradoxes were explained off as apparent mysteries coming from our inability to understand quantum physics and not errors. But they are paradoxes and they derive from the wavefunction concept.

The claim that matter does have a wavefunction is said to be proven by double-slit experiments, but is it? Are they not experiments that show scattering behavior? The formula for de Broglie wavelength

$$\lambda = \frac{h}{mv} \tag{12}$$

has a certain similarity with the formula for the Compton wavelength

$$\lambda = \frac{h}{m_0 c}. \tag{13}$$

Compton wavelength does not say anything of matter being waves, it says something of scattering. In a similar way de Broglie's wavelength may also say something mainly of scattering, not that matter is waves. Let us check how the double-slit experiments verified that matter is waves.

In a double-slit experiment there are two slits close to each other and a screen behind them. Particles are sent towards the slits, they pass through one of the two slits (they do not go through both slits at the same time) and they reach the screen making a dot, so they are very localized when hitting the screen. When the experiment is run for a long time, the dots show an interference pattern with some areas having been hit many times and other areas seldom. Interference patterns are obtained from electrons, protons, atoms and even molecules. The usual interpretation is that the particles leaving the slit behave as waves and the wave fronts expand according to Huygen's principle. In some areas the two waves amplify and in other areas they cancel each others resulting to the interference pattern, but there are two experiments that show that this explanation is false.

There is a double-slit experiment [5] where one of the two slits is closed and one open at each time moment, which one is closed and which one is open changes in a rather slow time scale. Electrons that are sent towards this double-slit show an interference picture. This is not possible if the interference picture comes from interference of two beams as there cannot be two beams at any time moment.

Maybe we can think of this situation in the following way. An atom can be modelled as a state machine that makes transitions between states and receives or transmits a wave of one wave length, or it may absorb or emit particle(s). If atoms get energy from outside temperature, like the atoms in the walls of Planck's black box, they repeatedly make transitions to a higher state and repeatedly fall back to a lower state, which results to emission of a run of n wavelengths of electromagmetic radiation corresponding to Planck's energy levels $nh\nu$.

When a particle comes to a double-slit, it interacts with the atoms on the borders of the slit. It is a type of electron scattering. We can first remind of photon scattering by matter. If photons are scattered by free electrons, the collision can be elastic, Thomson scattering, or inelastic where the photon loses energy, Compton scattering. If photons are scattered by electrons bound to atoms or molecules, the collision can be elastic, Rayleigh scattering, or inelastic, Raman scattering. Particles like electrons, positrons or neutrinos are also scattered in collisions with matter. If electrons are scattered by free atoms, like in the Franck-Hertz experiment, the collision can be elastic if the colliding electron does not have enough energy to cause a transition of an electron in the atom to a higher energy level. If the colliding electron has enough energy, the collision is inelastic: the electron first gets absorbed to some energy level in the electron belt of the atom, immediately re-emitted, also a photon gets emitted and some energy, and some momentum goes to the atom that changes its direction. If a fast electron collides with an atom that is not free but bound to a double-slit, what one should expect to happen is that the electron gets absorbed, immediately re-emitted with changed energy level and momentum, and electromagnetic radiation is emitted. This should happen even if the colliding particle is much larger than an electron, it can be an atom or a molecule. Matter particles of any size do so, we can even take a hand-size stone, hit another stone with it, and often there comes a sparkle of light showing that some electrons were absorbed, re-emitted and photons were emitted.

In the case of electrons scatterig from a double-slit, the atom and consequently electrons in the atom are tied to the fixed slit. Therefore they cannot obtain the additional energy that is left by the particle into their momentum. This is why the additional energy must be emitted as electromagnetic radiation. Electromagnetic radiation from the two slits creates an interference pattern, but the screen shows only electrons that are hitting it and are visible as dots.

Maybe the electromagnetic radiation creates an electromagnetic field behind the slit and the field influences electrons that pass the slit by electromagnetic forces. The result would be that the electrons create a pattern of dots on the screen that corresponds to the interference pattern.

When sufficiently many electrons have passed though one of the slots, we can expect that the space behind the slots has a field that can direct electrons to directions that give the interference pattern. There is no need for a wavefunction that reaches far from the double-slit.

We should expect to see de Broglie wavelength in scattering. A minor comment on de Broglie wavelength may fit in this discussion. Planck in his atomic model gave the rule of angular momentum quantization for electrons in the electron orbits of an atom as $p = m_e vr = \hbar$. de Broglie replaced Plack's circular orbits by a full wavelength of a matter wave, i.e., the electron on an orbit was seen as a wave, throung the formula $\lambda = 2\pi r$. Inserting Planck's angular moemntum quantization rule to this formula gives de Broglie wavelength: $\lambda = 2\pi\hbar/p$ is $p = h/\lambda$. Notice that here $p = m_e v$ and not $p = \gamma m_e v$. Indeed, $p = \gamma m_o v$ seems incorrect. If so, then using electrons with a speed very close to c should give very close to zero de Broglie wavelength and an extremely high resolution in an electron microscope. I do not think this is possible. The momentum should be $p = m_0 v$ as that is the real momentum of a mass m_0 and $\gamma m_0 v$ is the apparent transverse momentum.

The other experiment that seems to point to the same explanation is tracking the distribution of the dots that electrons make when they hit the sceen behind the double slit [6]. In the beginning the dots look rather random, but when there are more dots the distribution shows a clear interference pattern. If the interference picture is caused by a wavefunction, we would expect that the interference picture appears earlier than it does. It is not so that at the beginning of the experiment the dots are completely random. They are not quite random, but they also do not look like early forms of the final interference pattern. We should expect that there is an equation giving the probability of scattering to some direction. This scattering formula does not know that there is the other slit and therefore it does not know in what areas the two waves amplify and in what areas they cancel each others. However, electrons that pass the double-slit may gradually build up a field in the space behind the slit and this field could be responsible for the gradual appearance of the interference picture.

Based on these two experiments it looks to me that a wavefunction does not exist. This would solve Schrödinger's cat paradox where the paradoxical living and dead cat is a result of extending the quantum system to the cat.

In quantum mechanics first Heisenberg and then Schrödinger took another approach. They did not model an atom as a state machine that receives and sends waves when making transitions, though later, in the second quantization, there is a state machine idea in some form. Heisenberg created a matric operator formalism and Schrödinger made a differential equation. Both approaches give the same model and this model implies that a particle, indeed any mass, is a matter wave, a wavefunction. I do not see this approach as a correct one. An electron in a bubble chamber, in a cathode ray tube and in a linear particle accelerator seems to behave as a particle: it follows a track that seems to come from a solution of an Euler-Lagrange equation. Only when the electron interacts with matter we see effects that suggest that it is a matter wave. But in such a case an electron gets first absorbed into an atom and very soon re-emitted. The situation is scattering and if the energy or momentum of the electron is changed and the matter is fixed and cannot turn this momentum into its own momentum, there will be emission of electromagnetic radiation. There is no need for a wavefunction.

The main problem in the wavefunction concept is that it requires the concept of the collapse of the wavefunction. This leads to several paradoxes. One of these paradoxes is explained in the thought experiment where a photon passes point A and can reach point B by using two different ways. According to the Copenhagen (i.e., Bohr's) explanation of this thought experiment, a single photon can take one way or two ways at place A. If the photon takes two ways, the ways join at place B and produce an interference pattern. However, if one way is observed so that we can tell which way the photon took, this observation collapses the wave function of the photon and it must take only one way, therefore there is no interference pattern. The paradox is that the observation takes place after the time moment when the photon has chosen to use one or two ways, i.e., future changes the past.

The problem with this thought experiment is that it cannot be made in practice: a photon cannot be obserbed without absorbing it. Despite claims in university textbooks, this phenomenon has not been empirically verified. Instead, it is logically impossible: the observation happens after the photon has chosen whether to take one path or two paths, a later event influences what happened before it. This is impossible and there are no real paradoxes, the Copenhagen interpretation must be incorrect.

Let us also notice that as in the Michelson-Morley experiment, the beams that meet at B are synchronous and they cannot produce an interference pattern, and the beams that split at A are not passing A at the same time. Therefore it is not possible that a single photon chooses two ways at the place A and joins again at the place B. The scenario in this thought experiment is incorrect.

There have been several experiments that have tried to resolve this question. For instance in 1987 a real experiment was made, it got partial information which path a particle took and yet the interference pattern remained. In 2012 there was an experiment called Weak measurement. There were Wheeler's delayed-choice experiments. I do not think that any of these experiments have thrown much light on the issue, instead one may question the whole concepts of a wavefunction and wavefunction collapse.

Another paradox arising from the wavefunction is the Bell inequality. Bell made an experiment where the analysis of the experiment shows that if quantum mechanics is correct, then a correct and elementary theorem in probability theory is wrong, i.e., the experiment does not violate any theorem in probability theory, only the analysis of quantum mechanics violates it. The elementary theorem in the probability theory is not wrong, the error must be in quantum mechanics.

The error can be localized to the Bohr rule, or it can be localized more generally to the existence of a wavefunction. If the error is located to the Bohr rule as in Chapter 4 of [4], the explanation is as follows. Max Bohr explained the wavefunction as probability distribution and normalized this probability so that the sum of the probabilities of pure states is assigned to one. This is not necessarily a correct normalization in all situations. While a measurement must always give a pure state and a measurement eventually gives a result, it does not follow that at any given time moment the sum of the probabilities of pure states should be one. This is because a measurement takes time. Chapter 4 in [4] also discusses some form of entanglement (the ERP paradox), but this topic will be omitted in this paper.

A phenomenon that has also been given as a verification of the existence of a wavefunction is tunneling. A charged particle, like an electron, can move across a potential barrier. The explanation of this by a wavefunction is that a wavefunction extends to the whole space and therefore a particle can be found also in the space behind the potential barrier. There are simpler explanations that do not need the wavefunction concept. For instance, there probably are atoms in the other side of the barrier and they can lose an electron and become positively charged ions that can pass the negatively charged potential barrier. We can imagine that positive ions pass the barrier to both directions. These ions capture electrons and turn into noncharged atoms. If there is a larger negative charge in one side of the barrier, the flows of positive ions are not equal: more positive ions flow to the side with a higher negative charge. This is seen as negative charge tunneling across the potential barrier.

5. On Heisenberg's incertainty and the Fourier transform $x \to p$

Heisenberg's incertainty principle between p and x is a consequence of de Broglie's wavelength and Schrödinger's momentum substitution. Consider the following simple example. Let the energy be a sum of Newton's kinetic energy and de Pretto's rest mass energy:

$$E = \frac{1}{2}m_0 v^2 + m_0 c^2 = \frac{p^2}{2m} + m_0 c^2. \tag{14}$$

In canonical quantization of this energy equation the momentum is substituted by

$$p^2 = -\hbar^2 \frac{\partial^2}{\partial x^2} \tag{15}$$

and the eigenvalue equation for energy is

$$\hat{H}\Psi = E_n \Psi \tag{16}$$

where

$$\hat{H} = -\hbar^2 \frac{\partial^2}{\partial x^2} + m_0 c^2. \tag{17}$$

An eigenfunction has the form

$$\Psi = e^{i(k_n x - \omega t)}. \tag{18}$$

Inserting the eigenfunction gives the equation

$$k_n^2 = \hbar^{-2}(E_n - m_0^2). \tag{19}$$

There are countably infinitely many eigenvalues E_n, $n = 1, 2, ...$ and each corresponds to one eigenfunction. Every solution to the wavefunction equation can be expressed as a linear combination of these eigenfunctions. In Heisenberg's matric formulation the Hamiltonian operator $\hat{H}$ is Hermitian and for a Hermitian operator eigenfunctions form a basis for the solution space.

In Ψ the wavenumber k and space coordinate x are conjugate variables in the same way as ω and t are. Just like we can make a Fourier transform between t and ω, we can make a Fourier transform between x and k. General properties of conjugate variables give Heisenberg's incertainty equation between x and k and de Broglie wavelength relation allows writing $p = \hbar k$, leading to Heisenberg's incertaintly relation between x and p.

The are two issues that can be criticized. The first one is that the space where the wavefunction exists need not be the external three (or four) dimensional space. It can be the finite space inside a particle. If the particle is an atom, then de Broglie's way of requiring that the length of the orbit of an electron is full wavelengths (which gives de Broglie wavelength) means that the space coordinates are confined to orbit lengths. If so, this space is limited and instead of making a Fourier transform, one could make a Fourier series. This space is not the external space and there is no Heisenberg inequality where the momentum and external space coordinates are conjugate coordinates.

The second issue that can be critizised is that p from de Broglie wavelength is not the momentum of the mass m_0, but in some way Heisenberg's matrix formulation works. It gets much worse when the momentum is three or four dimensional as in quantum field theory. Let us see where the problem is.

We extend the momentum and space to three dimensions: $\vec{k} = (k_1, k_2, k_3)$ $\vec{x} = (x_1, x_2, x_3)$ and find an eigenfunction of the form

$$\Psi = e^{i(\vec{k}_n \cdot \vec{x} - \omega t)}. \tag{20}$$

for a Hamiltonian of the form

$$\hat{H} = -\hbar^2 \sum_{i=1}^{3} \frac{\partial^2}{\partial x_i^2} + m_0 c^2. \tag{21}$$

Calculating

$$\hat{H}\Psi = E_n \Psi \tag{22}$$

gives the equation

$$\sum_{i=1}^{3} k_{n,i}^2 = \hbar^{-2}(E_n - m_0^2). \tag{23}$$

For each energy eigenvalue E_n there are uncountably infinite number of linearly independent eigenfunctions. The fact that the Hamiltonian operator is a Hermitian matric and for a Hermitian matrix eigenfunctions form a basis does not help much: the basis is uncountably infinite. Additionally, in order to get a Fourier transform form $\vec{x}$ to $\vec{p}$ we have to use de Broglie's wavelength formula, and the momentum it gives is not the momentum of the mass.

This problem appeared first time in the Klein-Gordon equation where Schrödinger's momentum substitution is extended to three dimensions. This incorrect substition was later followed by Dirac in the Dirac equation. Dirac made many unfortunate choices in his equation: he wanted to make a wavefunction equation that is fully compatible with Special Relativity, but Special Relativity Theory is seriously incorrect, and the Dirac equation is not even Lorentz invariant. Secondly, Dirac followed Klein in generalizing the momentum substitution to higher dimensions (in his case, to four). This generalization is incorrect, indeed if the direction of r stays constant

$$\sum_{i=1}^{3} \frac{\partial}{\partial x_i} = \frac{1}{r^2} \frac{\partial}{\partial r} r^2 \frac{\partial}{\partial r} \tag{24}$$

and not

$$\frac{\partial^2}{\partial r^2} \tag{25}$$

as it should be if the Schrödinger substition is expressed in three dimensions.

The third issue in the Dirac equation is not so much an error than a questionable choice: Dirac followed Pauli's approach and expressed Dirac matrices by vectors (i.e., matrices) in a four dimensional complex space. While this can be done, the question is what sense does it have. The fourth issue is that in my opinion a free electron does not have a wavefunction. The Dirac equation is the standard representation of a spin 1/2 particle in quantum field theories, so any error in the Dirac equation affects quantum field theories.

6. Problems in Quantum Electrodynamics

Werner Heisenberg made the first steps towards a quantum field theory. Paul Dirac continued to this direction and proposed the path integral method and solving it by developing a Green function into a perturbation series. When tried, it was noticed that some terms in the perturbation series diverge. Especially, the first term in the perturbation series, the Green function of the Dirac equation, later named as the Dirac propagator, gives an infinity when transformed to the space coordinates. This happens because the Dirac equation is a first order polynomial of p in the momentum coordinates. The inverse operator in the momentum coordinates has a first order pole of p, so it is first order in $|p|$, absolute value of p. The four-dimensional Fourier transform back to space coordinates has the differential d^4p which is of the order $|p|^3d|p|$ in absolute value. The integral over the momentum space to infinity is necessarily infinite.

The Fourier transforms of the Green functions in the momentum space to the space coordinates give the expectation values, i.e., probabilities, of the paths that the terms in the perturbation series describe. Especially, the Fourier transform of the Dirac propagator should give the probability of the electron simply moving from place A to place B, not having any interactions with fields. This is the most probable event that should happen. The probability if this event should be a bit under 1. But it is infinite. This shows why the path integral method did not work. The error is in the four-dimensional Fourier transform, see my comments in [2].

The path integral method was discarded, but in 1947 Hans Bethe proposed a way to cope with this problem. The method is called renormalization, adding to the perturbation series terms that cancel too low order poles and rescale the other terms. For a theory to be renormalizable there can only be finitely many poles that must be cancelled by additional terms. The problem with this method is that there are many possible ways to renormalize a theory and it adds freedom to get a result that one wants. Anyway, renormalization was accepted. Richard Feynman and Julius Schwinger formulated Quantum Electrodynamics (QED) and shared a Nobel Prize for it with Sin-Itiro Tomogana in 1965. This theory has a kind of path integral, Feynman path integral, the Dirac equation as the representation of spin 1/2 particle, Maxwell's equations in the Lorentz covariant Lagrangean form as the electromagnetic field and renormalization as a way to remove divergent Green functions (i.e., Feynman diagrams).

QED is described as a highly precise theory, even praised as the most precise theory there is. This claim is justified by explaining that QED predicts the anomalous magnetic moment of an electron to some parts in a trillion, and also predicts very well the Lamb shits in a hydrogen atom. I will not look at the Lamb shift case as the anomalous magnetic moment case will already show all that needs to be shown.

The claim that QED predicts very precisely the anomalous magnetic moment of the electron comes from Julius Schwinger. His gravestone has engraved the following formula

$$a_e = \frac{\alpha}{2\pi} \tag{26}$$

where a_e is the anomalous magnetic moment of an electron and α is the fine-structure constant. Schwinger presented a calculation of Feynman diagrams to the first loop-order relating the anonymous magnetic moment of an electron to the fine-structure constant, the equation above.

Let us first check if this equation is exact. Article [7] from 2023 measured the anomalous magnetic momentum of an electron as

$$a_e = 0.00115965218059(13). \tag{27}$$

The (13) at the end means the standard deviation of the error in the last two digits.

Article [8] from 2020 measured the value for the inverse of the fine-structure constant as

$$\alpha^{-1} = 137.035999206(11). \tag{28}$$

NIST recommends the value of α^{-1} as

$$\alpha^{-1} = 137.035999177(21) \tag{29}$$

this value is combined from measurements and theoretical calculations.

Schwinger's gravestone formula for the 2023 measurement gives a calculated α as

$$(2\pi a_e)^{-1} = (2*3.14159265358979328...*0.00115965218059)^{-1} = 137.24368889... \tag{30}$$

This value is too large, Schwinger's formula is not exact, but it is a good initial approximation. More terms in the perturbation series improve the approximation.

Article [9], originally from 2012, calculated Feynman diagrams to the tenth loop order, 12672 diagrams. The version in arxiv is dated to November 2024 and seems to be the latest state-ot-the-art study on this topic, but it uses a_e measurements from 2011. The theoretical value for the inverse of the fine structure constant in this study is from the h/m_{Rb} measurement where the Rydberg constant is very precisely known. The value of α used in the study is

$$\alpha^{-1} = 137.035999049(90). \tag{31}$$

In the Standard Model a_e gets contributions from electromagnetic, hadronic and electroweak interactions. $a_e(QED)$ is the electromagnetic contribution. The article calculates the perturbation series as

$$a_e(QED) = \sum_{n=1}^{\infty} \left(\frac{\alpha}{\pi}\right)^n a_e^{(2n)}. \tag{32}$$

The coefficients in the perturbation series depend on the mass ratios of electron, muon and tau, the article uses latest estimates for these. The theoretical a_e value calculated from QED and α is

$$a_e = 0.00115965218178(77). \tag{33}$$

The article says that even the best available estimate for α that is not calculated from QED is too unprecise to verify QED to the precision that a_e has been measured. Therefore the article tests QED by comparing α^{-1} from the Rydberg constant and h/m_{Rb} measurements with α^{-1} calculated from QED and measured a_e. This leads to a theoretical value of α^{-1} which still has a certain error range. It is not possible to make this verification of QED significantly more precise before some extremely precise non-QED measurement for α is invented.

Theoretical a_e in (33) is very close to the measured a_e in the 2023 article in (27). Does this excellent match verify QED and the Standard Model? No, the article refutes both QED and the Standard Model. This is easily noticed, it is simple reasoning.

Article [9] includes in the calculation from QED other effects than only electromagnetic fields, i.e, hadronic and electroweak interactions. This means that without these other effects QED does not give a sufficiently good prediction to a_e even though the perturbation series is calculated to the tenth order, it converges fast as α is small. What is wrong with this is that there should not be hadronic and electroweak interactions in a scenario where a_e appears. Magnetic dipole moment causes torsion for a magnet in an external magnetic field. Thus, electrons in the Stern-Gerlach experiments show effects of magnetic dipole moment of free electrons. The magnetic moment is linearly related to the spin angular momentum of an electron by the formula

$$m_S = -\frac{g_S \mu_B S}{\hbar} \tag{34}$$

where $S = \hbar/2$ is the spin anglular momentum of the electron, μ_B is the Bohr magneton and $(g_S - 2)/2 = a_e$. There are no hadrons for hardonic interactions and there are no neutrinos indicating electroweak interactions. This situation should be described only with electromagnetic interactions, but [9] shows that it cannot be explained with QED only. That means, QED is refuted.

Let us look at a textbook on the Standard Model to find more problems. Textbook [10] explains how the formula from QED connecting a_e and α is derived. The problem is formulated in a more general way, for any simple gauge group. Page 131 equation (11.2) in [10] gives the Lagrangean of a simple gauge group as

$$\mathcal{L} = -\frac{1}{4}F_a^{\mu\nu}F_{\mu\nu}^a - \frac{1}{2\xi}(\partial_\mu A_a^\mu)^2 \tag{35}$$

$$+ \partial_\mu \mu_a^* \left(\partial^\mu \eta_a + g f_{abc} \eta_b A_c^\mu\right) \tag{36}$$

$$+ \bar{\psi}\left(i\delta^\mu D_\mu - m\right)\psi. \tag{37}$$

For QED the first term to the left is the Lagrangean of the Maxwell's equations in a Lorenz covariant form. The second is the gauge fixing term given as a Lagrange multiplier in the corresponding Euler-Lagrange equations. This gauge fixing term gives the Lorenz gauge (after Ludwig Lorenz) for the vector potential A_μ. The third is the Faddeev-Popov ghost term. This ghost term is not coupled to the gauge field in the Abelian case, as in QED, and it can be omitted, i.e., included in the normalization of the generating functional. The last term has the gauge group covariant derivative of the Lagrangean of the Dirac equation in a more general form:

$$D_\mu \psi = \left(\partial_{mu} + ig\mathbf{T} \cdot A_{mu}\right)\psi. \tag{38}$$

For QED the group $\mathbf{T}$ is 1.

The calculation is on pages 141 and 142 in [10]. The part with the Lagrangean of the Dirac equation equation can be calculated exactly, gives the Dirac propagator, shown in (8.30) and (8.35) on pages 100 and 101. The first term is calculated in (10.10) using the result (8.20). The gauge fixing term and the covariant derivative is in (10.68). Using these results [10] calculates the Feynman diagrams of the first-loop order approximation. The only diagram that is needed is diagram 6 in equation (11.62) on page 138 in [10]. It is written as a formula in (11.63). Simplifying this formula in section 11.3 gives the equation for the anomalous magnetic momentum of an electron in the first order of perturbation theory in (11.87)

$$\mu_{AMM} = \frac{\alpha}{2\pi}\frac{e}{2m}. \tag{39}$$

In [10] the fine-structure constant is expressed in high energy physics normalized constants ($\hbar = c = \varepsilon_0 = 1$) and has the formula

$$\alpha = \frac{e^2}{4\pi}. \tag{40}$$

In SI units

$$\alpha = \frac{e^2}{4\pi\varepsilon_0\hbar c}. \tag{41}$$

Thus, equation for the anomalous magnetic moment is actually

$$\mu_{AMM} = \frac{\alpha}{2\pi}\mu_B \tag{42}$$

where μ_B is the Bohr magneton

$$\mu_B = \frac{e\hbar}{2m_e}. \tag{43}$$

As

$$\mu_e = \frac{g}{2}\mu_B = (1 + a_e)\mu_B. \tag{44}$$

$$\mu_{AMM} = a_e\mu_B. \tag{45}$$

That is, as expected from a first loop-order approximation, [10] gives Schwinger's formula

$$a_e = \frac{\alpha}{2\pi}. \tag{46}$$

The interesting part is to see what actually happens in the calculation. Initially the Lagrangean in [10] does not have any coupling constant in the QED case. There is a coupling constant only for a non-Abelian gauge group. The coupling constant appears in renormalization. Textbook [10] makes dimensional renormalization with the SM renormalization scheme (usually SM means Standard Model). This renormalization only cancels the pole in the Dirac propagator and gives a constant to the finite diagrams. This constant is a renormalization mass and it is unspecified. Just before the last step this constant is fixed to $(\alpha/2\pi)\mu_B$ and it is very unsurprising that the result gives $\mu_{AMM} = (\alpha/2\pi)\mu_B$. The integration of the (single) Feyman diagram (diagram 6) does not give the anonymous magnetic moment, it only scales the coupling constant.

There is no explanation why the Feynman diagrams that were obtained by making a perturbation series from the Lagrangean for QED should in any way be related to the anomalous magnetic moment of an electron. The same perturbation series should come from every case of an electromagnetic field interacting with a free electron, for instance, it could be electrostatic effect of a field to a moving electron. The only place where this calculation gives a chance to address a specific situation is the renormalization step. Textbook [10] explains that instead of only cancelling the infinity coming from the Dirac propagator as in the SM renormalization scheme, the scheme can also include a term that remains finite. This means freedom to match the result to what is wanted. In article [9] the matching is improved by introducing hadronic and electroweak interactions. Feynman's path integral method with renormalization allows tuning the theory to match with measurements. Verifying that the prediction from QED matches well with measurements is not any valid test of the theory.

Additionally, the perturbation series itself is not necessarily as sound as one might imagine. In [9] the perturbation is simply given as a series, but in QED the perturbation series is derived from Feynman's path integral with the help of the functional derivative.

Textbook [10] gives the derivation of the perturbation series from the Feynman path integral for a scalar field and this derivation said to go in a similar way in the derivation of the perturbation series used in the formula for the anomalous magnetic momentum of the electron.

The essential part of the calculation in page 56 in [10] is as follows. It is the derivation of the perturbation series for Feynman's path integral, so, it is the most important part of the whole path integral method because when we get to the perturbation series, the rest is only calculation of Feynman diagrams, a step that [9] made with a program.

Starting from

$$\mathcal{L} = \mathcal{L}_0 + \mathcal{L}_1(\varphi). \tag{47}$$

Here φ is a function

$$\varphi = \varphi(x). \tag{48}$$

For easier notations, we name the functional derivative with respect to the current J as

$$z = z(x) = -i\frac{\delta}{\delta J(x)}. \tag{49}$$

The definition of the functional derivative is

$$\frac{\delta}{\delta J(x)} e^{i\int dx(\mathcal{L}_0 + J\varphi)} = i\varphi(x) e^{i\int dx(\mathcal{L}_0 + J\varphi)} \tag{50}$$

Therefore for any n holds

$$\frac{1}{n!}\left(\frac{\delta}{\delta J(x)}\right)^n e^{i\int dx(\mathcal{L}_0 + J\varphi)} = \frac{1}{n!}\left(i\varphi(x)\right)^n e^{i\int dx(\mathcal{L}_0 + J\varphi)}. \tag{51}$$

Summing over n gives

$$\sum_{n=0}^{\infty}\frac{1}{n!}\left(\frac{\delta}{\delta J(x)}\right)^n e^{i\int dx(\mathcal{L}_0+J\varphi)}=\sum_{n=0}^{\infty}\frac{1}{n!}\left(i\varphi(x)\right)^n e^{i\int dx(\mathcal{L}_0+J\varphi)} \tag{52}$$

which can be written as

$$e^{\frac{\delta}{\delta J(x)}}e^{i\int dx(\mathcal{L}_0+J\varphi)}=e^{i\varphi(x)}e^{i\int dx(\mathcal{L}_0+J\varphi)}. \tag{53}$$

Using z for more clarity, we rewrite this equation as

$$e^{-iz}e^{i\int dx(\mathcal{L}_0+J\varphi)}=e^{i\varphi(x)}e^{i\int dx(\mathcal{L}_0+J\varphi)}. \tag{54}$$

On page 56 $\mathcal{L}_1$ is defined as

$$\mathcal{L}_1=-\frac{\lambda}{4!}y^4=a\varphi^k \tag{55}$$

where $a=-\frac{\lambda}{4!}$ and $k=4$. For any a, k and n holds an equation similar to (48)

$$\frac{1}{n!}\left(ia\left(-i\frac{\delta}{\delta J(x)}\right)^k\right)^n e^{i\int dx(\mathcal{L}_0+J\varphi)}=\frac{1}{n!}\left(i\left(a\varphi(x)\right)^k\right)^n e^{i\int dx(\mathcal{L}_0+J\varphi)}. \tag{56}$$

Summing n from zero to infinity gives

$$e^{i\mathcal{L}_1(z)}e^{i\int dx(\mathcal{L}_0+J\varphi)}=e^{i\mathcal{L}_1(\varphi(x))}e^{i\int dx(\mathcal{L}_0+J\varphi)}. \tag{57}$$

Textbook [10] defines

$$S_0[J,\varphi_0]=\int\mathcal{D}\varphi e^{i\int(dx\mathcal{L}_0+J\varphi)} \tag{58}$$

$$S[J,\varphi_0]=\int\mathcal{D}\varphi e^{i\int dx(\mathcal{L}+J\varphi)}. \tag{59}$$

The textbook claims that

$$S[J,\varphi_0]=e^{i\int dx\mathcal{L}_1\left(-i\frac{\delta}{\delta J(x)}\right)}S_0[J,\varphi_0] \tag{60}$$

and expanding the exponent into a formal series gives the perturbation series from which the Feynman diagrams come

$$S[J,\varphi_0]=\sum_{n=0}^{\infty}\frac{1}{n!}\left(i\int dx\mathcal{L}_1\left(-i\frac{\delta}{\delta J(x)}\right)\right)^n S_0[J,\varphi_0]. \tag{61}$$

We simplify the right side of this equation. Expressing the sum as an exponent and inserting (50) shows that the right side is

$$e^{i\int dx(\mathcal{L}_1(z))}S_0[J,\varphi_0]=e^{i\int dx(\mathcal{L}_1(z))}\int\mathcal{D}\varphi e^{i\int dx(\mathcal{L}_0+J\varphi)}. \tag{62}$$

As z does not depend on φ we can move the term with z inside the path integral

$$= \int \mathcal{D}\varphi e^{i \int dx(\mathcal{L}_1(z))} e^{i \int dx(\mathcal{L}_0 + J\varphi)}. \tag{63}$$

With this simiplification of the right side and by inserting (51), equation (53) gets the form

$$\int \mathcal{D}\varphi e^{i \int dx(\mathcal{L} + J\varphi)} = \int \mathcal{D}\varphi e^{i \int dx \mathcal{L}_1(z)} e^{i \int dx(\mathcal{L}_0 + J\varphi)}. \tag{64}$$

Expressing the left side as a product

$$\int \mathcal{D}\varphi e^{i \int dx \mathcal{L}_1(\varphi)} e^{i \int dx(\mathcal{L}_0 + J\varphi)} = \int \mathcal{D}\varphi e^{i \int dx \mathcal{L}_1(z)} e^{i \int dx(\mathcal{L}_0 + J\varphi)}. \tag{65}$$

Compare this equation to (49)

$$\int \mathcal{D}\varphi e^{i \mathcal{L}_1(\varphi)} e^{i \int dx(\mathcal{L}_0 + J\varphi)} = \int \mathcal{D}\varphi e^{i \mathcal{L}_1(z)} e^{i \int dx(\mathcal{L}_0 + J\varphi)}. \tag{66}$$

Equation (57) is almost like (58), but not quite. There is an integral over x in the expression of the operator z in (57). I do not see any justification for claiming that (57) holds, i.e., that the claim (52) in the book holds. On page 56 this calculation is made for a scalar field theory, but the same calculation is referred to in the calculation for QED. Based on the calculation in the textbook [10] it is not clear that the perturbation series in QED is correctly derived.

Can it be that the textbook [10] has an incorrect calculation but the theory of QED has a correct derivation for the perturbation series? Textbooks do have errors, but the theory of QED does seem to have an error in derivation of the perturbation series. A discrepancy of the theoretical and measured anonymous magnetic moment of the muon was found some years ago. According to the Wikipedia, a large group of experts on Feynman diagrams took part into an effort to solve this problem and they changed Feynman diagrams in order to get the theoretical α to match with the measured α. How could any error made by some physicist who incorrectly calculated Feynman diagrams need to be addressed by a large group of experts? Of course not, one expert could have spotted the error. The calculation giving a result that conflicts with measurements must have been correctly done according to the theory of QED and the theory had an error. These many experts patched an incorrect theory to look correct in this special case that revealed the error in the QED theory. In a similar way [9] added hadronic and electroweak interactions to get the excellent match between the theory and measurements.

The g-factor of the electron g_e is the coupling constant in QED. The anomalous magnetic moment a_e is related to the g_e by

$$a_e = \frac{g_e - 2}{2} \tag{67}$$

and this explains why the anomalous magnetic moment of an electron can be related to the fine-structure constant by QED by including Feynman diagrams, selecting renormalization masses, and even by including other interactions. But there are errors in the path integral method, like in the derivation of the perturbation series, in the Dirac equation that is based on the incorrect relativistic kinetic energy formula and in the four-dimensional Fourier transform that caused the Dirac propagator to diverge in the inverse transform.

The relativitic kinetic energy formula is incorrect as was explained in Section 2 in (4)-(8), and it contradicts with Bertozzi's measurements [11] as is explained in [12], see the following figure from [12] plotting Bertozzi's measurements:

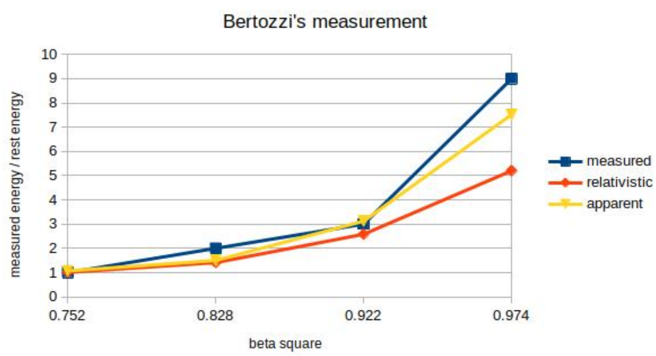

Figure 1. The figure plots E_k/m_ec^2 (measured), $0.5\gamma^{1.5}m_ev^2$ (kinetic energy of the apparent mass) and $\gamma - 1$ (relativistic kinetic energy) as an function of $v^2/c^2 = \beta^2$. The y-axis gives the ratio of energy and the rest energy of an electron.

See also the problems mentioned in [3].

Notice more generally that QED, or any theory, is not verified by showing that calculations made from it are correct. In the case of QED, at least in the derivations in the textbook [10] there are mathematical errors, but even if a theory does not have mathematical errors and gives correct results, the concepts in the theory can be mathematical artifacts. Mathematical artifacts are very common in theories in physics, as an example Dirac explained antimaterial as holes in a cloud of electrons. Calculations worked the same way with this explanation as with the explanation that antimaterial is real matter. Today antimateria is not understood as holes in a cloud of matter particles. What really happens in a physical situation is relevant, it is not only a question of getting some results correct. Real insight to the physical situation leads to advances in the field.

In QED there are concepts that seem like artifacts, like matter waves and wavefunctions, but we can find more concrete examples: Feynman diagrams do not describe what actually happens. For instance, in the first loop-order approximation for the anomalous magnetic moment calculation from the textbook [10] there is a Feynman diagram of a spin-1/2 particle moving directly from time t_1 to time t_2, but this diagram has a pole and is cancelled by a counter term. Yet, in reality, the most probable way is that the electron moves directly from time t_1 to time t_2 and it is not any infinite term that is or should be cancelled by a counter term. The need for cancelling the term by a counter term means that the method incorrectly gives this diagram a pole. The Feynman diagram of the interaction of a electro-magnetic field with the electron is in diagram 6 in [10]. This diagram seems to show that an electron splits into two photons that later again joint to an electron. Nothing like this happens. Feynman diagrams correspond to the terms in the perturbation series, but they do not correspond to anything physical. The method uses mathematical artifacts. It does not give insight. For instance, it does not give insight to why the fine-structure constant has the value that it has, as was often mentioned by Feynman.

7. Comments on the Standard Model and Conclusions

This final section contains some comments about the Standard Model, like the electro-weak theory and the Higgs mechanics, but not any deeper discussion of these issues. The conclusion part of this section tries to formulate some understanding of what happened in theoretical physics, notably, how could false theories become accepted and stay accepted. First, I give my comments.

A particle accelerator is producing an enourmous number of collisions and only those of interest are analysed. Filtering is used to select interesting events for analysis. This means that when Z and W^+, W^- particles were announced found by CERN, not all collisions were analyzed: the measurement was tuned for finding verification of a theory, not for refuting the theory, but basically experiments can only refute a theory, not verify it.

A neutrino sending a Z (or $W^\pm$) to an electron describes the way how it is shown in a Feynman diagram, but a Feynman diagram does not describe what actually happens. Feynman diagrams are for calculation of the cross section of an event to happen, not a model for what actually happened. What actually happened cannot be that a neutrino simply sent a particle to an electron. The neutrino had to know that the electron was able to receive it because if it was not, the particle - being unstable - would have broken into other particles, and this probably could have been observed. Such events (probably) were not observed. (We cannot know if they were observed as the filter to select interesting events may have screened them out.) In order for a neutrino to know that the electron can receive a particle in weak interaction, it needs to know the helicity of the electron. This means, if CERN did find Z and $W^\pm$ particles, they also found some mechanism (i.e., a two-way particle exchange) that gave the neutrino this knowledge. No such particles are in the Standard Model and here is one issue for Beyond Standard Model: interactions cannot be so simple as Feynman diagrams show them. There is some exchange of information in the phenomenon of apparent mass and there is some exchange of information in the case of correct helicity being crucial for the interaction. There is nothing in the Standard Model that tries to model what an interaction really can be.

The Higgs particle was found, but it does not seem to have any connection to the gravitational field. This is strange because in the Standard Model the Higgs mechanism gives the mass to elementary particles. This mass is the inertial mass, but inertial mass should be the same as gravitational mass according to Newton's gravitational law, and also according to Einstein's intuition. The gravitational field must be a scalar field, not a tensor field, see the references in [1]. There certainly should be some connection between the Higgs field and a scalar gravitational field, but it requires changes to the Standard Model.

The electro-weak theory is largely based on parity violation in weak interactions. This parity violation is placed in the theory to the weak interaction rather than to elementary particles. It could also be in elementary particles, like most screws that we can find are tightened by clock-wise rotation, but that does not mean that the force would not be able to turn screws counter-clock-wise. Neutrinos may have in our part of the universe only one chirality, but is it not also true that spin 1/2 particles, when rotated by 360 degrees turn to mirror images and when rotated 720 degrees return to the same chirality.

Quantum Color Dynamics (QCD) is not a good a theory. The perturbation series does not converge fast enough and a force that does not decrease with distance seems strange, but the actual problem is that it does not seem to model strong interactions at all, only the mechanism that keeps quarks together (this mechanism does not need to be a force at all). QCD has massless glue bosons. Massless bosons do not explain what mass turns into energy in strong interactions.

The Standard Model and especially in Unified Field Theories there is an effort to model interactions with a Lagrangean of the form (35)-(38), i.e., a Yang-Mills field. There is a gauge group of invariances. We would expect that there is a group in a theory as leptons and hadrons so nicely divide into six elementary particles that might make a group, but it is not these flavors that make the gauge groups. In the electroweak theory the group corresponds to parity and vector potential, while in QCD the gauge group describes three colors that each quark can have, i.e., keeping quarks together to form hadrons. It is not describing the strong force keeping hardons together. I do not think (35)-(38) is a good starting point for any theory except for electromagnetism. In [4] Chapter 7 I made a small study of Yang-Mills fields with tensor calculus, without focusing on the gauge group and working with classical fields. Then I had to quantize the fields and noticed that both the canonical and path integral quantization methods have a wavefunction and momentum substitution. These two methods leads to problems. The only reasonable quantization method is the one used by Planck, Bohr and Sommerfeld: quantization by rules. One should return to that idea.

Let's continue to conclusions. Lorentz covariance is unnecessary, a four-space is unnecessary, Fourier transform between momentum and space coordinates is not correct. Gauge symmetry idea is probably not correct. The whole theory should be reworked from very beginning and that means from the ideas of early quantum physics. How did we get here?

The Michelson-Morley experiment was incorrectly made. Michelson got a Nobel Prize, Morley did not. The Relativity Theory by Einstein is incorrect. Einstein got a Nobel Prize, not from the Relativity Theory. When I looked at the Relativity Theory (see the references in [1]), I found only errors, but the theory got accepted and remains accepted.

It seems that the Nobel Committee was not convinced of the Relativity Theory for a long time, but recently it also has been converted. Only two Nobel Prizes have been given directly to work in the Relativity Theory, those to Weiss, Thorne and Barish for finding graviational waves (spin 2 gravitons that do not exist) in 2017 and to Penrose, Genzel and Ghez for their work in Einsteinian black holes (which do not exist) in 2020.

Instead, many Nobel Prizes have been given for work in quantum physics, including to Einstein for an article introducing wave-particle dualism (which is incorrect), to Bohr (but not to Sommerfeld) for his work, while this work led to quantum mechanics that has several serious paradoxes. Born got a Nobel Prize for his interpretation of the wavefunction (which I find incorrect), Bethe got a Nobel Prize for renormalization (which I find an incorrect way to solve the divergence issue). Feynman and Schwinger got a Nobel Prize from QED (there are many errors in that theory and it is not verified by measurements of anonymous magnetic moment of an electron).

No-one was given a Nobel Prize for the Stern-Gerlich experiment, but Stern did get a Nobel later, Gerlich did not. Wu did not get a Nobel Prize, Lederman did.

There is some inbalance in the number of Nobel Prizes between countries, universities and populations. This is natural, some universities are better than some other, some people are better than some other. But what is strange is that so many results are wrong in this field. It is not that better results get acknowledged. It is more like that some false results get accepted while some other results do not even get reviewed. An interesting situation.

9. References

[1] Jormakka, J., "Why the Schwarzschild metric is not a metric and reviews from General Relativity and Gravitation", ResearchGate, 2025.

[2] Wiki has the references to the distribution and closing one slit.

[3] Jormakka, J., "On quantization of a scalar gravity field with Feynman's path integral quantization method", ResearchGate, 2025.

[4] Jormakka, J., *Reconsidering Einstein, Lambert, 2020.*

[5] Sillitto, R.M., Wykes, C., "An interference experiment with light beams modulated in anti-phase by an electro-optic shutter", Phys. Lett. A 39 (4), 333-334, 1972.

[6] Bach, R., Pope, D., Liou, S-H., Batelaan, H., "Controlled double-slit electron diffraction", New J. of Physics, 15(3) 033018. IOP Publishing, 2013.

[7] Fan, X., Myers, T.G., Sukra, B.A.D., Gabrielse, G., "Measurement of the Electron Magnetic Moment", Physical Review Letters, 130 (7) 071801, 2023.

[8] Morel, L., Yao, Z., Cladé, P., Guellah-Khélifa, S., "Determination of the fine-structure constant", *Nature*, 588 (7836), pp. 61-65, 2020.

[9] Aoyama, T., Hayakawa, M, Kinoshita, T., Nio, M., "Tenth-order QED contribution to the electron g-2 and an improved value to the fine structure constant", Phys. Rev. Lett., 109(11) 111807, originally 2012. arxiv 1205.5368, date Nov. 27, 2024.

[10] Bailin D. and Love A., *Introduction to Gauge Field Theory.* Adam Hilger, Bristol and Boston, 1986.

[11] Bertozzi, W., "Speed and Kinetic Energy of Relativistic Electrons". *American Journal of Physics,* 32(7):551-555 (1964)

[12] Jormakka, J., "Longitudinal apparent mass in Compton scattering", ResearchGate, 2025.