DOI: https://doi.org/10.24297/jap.v18i.8831

There are two solutions to the equations of Feynman's Quantum Electrodynamics (QED): the newly discovered solution is free of quantum weirdness

Jeffrey H. Boyd*

*Retired. 57 Woods Road, Bethany, CT, 06524-3103 USA

Jeffrey.Boyd@alumni.harvard.edu

Abstract:

No one previously noticed there is a second solution to the equations of Richard Feynman's Quantum Electrodynamics (QED). It makes identical predictions in the lab. The new solution (Reverse-QED) is closer to nature: it is free of quantum weirdness. For example, it eliminates Schrödinger's cat. This article is the first time the equations of R-QED have been published. The R-QED amplitude is the negative of Feynman's amplitude. Because of the Born rule, both amplitude and negative amplitude, when squared, produce the same probability to be tested against empirical data. If you were to measure the distance from Los Angeles to New York City with R-QED's accuracy, it would be exact to the breadth of a human hair. If reality corresponds to the newly discovered R-QED equations, but scientists use the old QED equations, the result would be predictions for the lab that are precisely accurate, but scientists would be unable to construct a coherent picture of the quantum world. R-QED is based on a different picture of how the quantum world is organized. Experiments, including a neutron interferometer experiment we review, show that particles follow waves backward. R-QED integrates in the same direction that the waves travel.

Subject Classification: Mathematics Subject Classification 81Q30: Feynman integrals and graphs. Library of Congress Classification sh85109459: quantum electrodynamics

Keywords: Reverse Quantum Electrodynamics (R-QED), symmetry, Theory of Elementary Waves (TEW), wave-particle duality, quantum weirdness, Lewis E. Little.

1. Introduction

Although Richard Feynman's QED (Quantum Electrodynamics) is the most accurate science ever, its equations can be understood in two divergent ways, as we will show. No one has previously noted the second solution. Each approach corresponds to a picture of reality. The first is mundane, the second uncharted. Only the second approach leads to a science free of quantum weirdness. But it is unfamiliar, involving as it does, a paradigm shift. (1,3,7-28,31-33)

1.1 Comparing the two approaches

The two solutions to the path integral equations of QED differ in terms of the direction of integration. Garden variety QED moves from particle source to detector and computes an amplitude (K) that works for half our needs. It works for predicting lab results but leaves the quantum world opaque.

Reverse QED (R-QED) integrates in the opposite direction. The R-QED amplitude (K_R) is the negative of the QED amplitude ($K_R = -K$). To predict lab results we use the Born rule ($P = |K_R|^2 = |-K|^2$), yielding identical predictions. With R-QED the quantum world is transparent. (6)

The two solutions cannot both be true. They contradict one another.

With R-QED path integration start at the detector and initiates action earlier than the emission of the particle. During Phase 1 of our scheme, equations work their way across all pathways from **b** to **a**, where they offer the particle an array of choices. The particle selects one at random. We call that, "wave function collapse," a term defined below. In Phase 2 the particle follows only that one path from **a** to **b** with a probability of one. That path was already blazed in Phase 1. In Phase 2 the Euler-Lagrange equation is no longer relevant since there is only one path. Time always goes forwards: $t_3 > t_2 > t_1$ (**Fig. 1**).

In Phase 1 there are equations but no particle. In Phase 2 there is a particle with no interesting equations. When we time the flight of the particle going from **a** to **b**, we are timing Phase 2 ($t_3 - t_2$ in Fig. 1), and the time is identical to that of ordinary QED.

The R-QED scheme is analogous to how everyday life works. In phase one you might flirt with and date many people. Then you marry one. That is analogous to wave function collapse. The phrase "wave function collapse" means a decision has been made. In phase two you are constrained by your previous choice. The open field of options is no longer available.

Our model is controversial because the path integration starts before a particle is emitted, moving in what most people consider to be the "wrong direction." It is a different concept of what reality is.

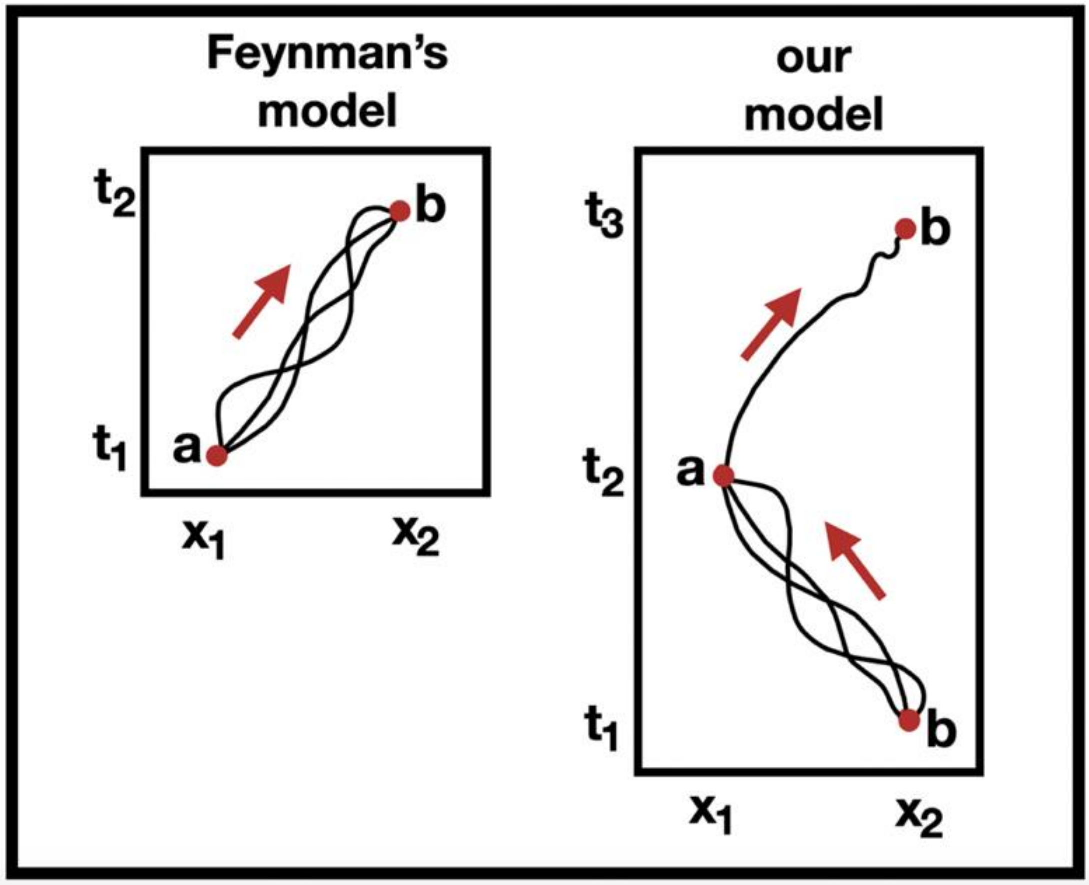

Fig. 1. Both graphs show exactly the same probability for a particle from point **a** arriving at point **b** in a certain time **t**.

Our approach has nothing in common with theories of time reversal, such as those of Wheeler & Feynman, nor the pilot wave theory of Louis de Broglie and David Bohm, nor the transactional interpretation of John Cramer, nor Hugh Everett's many worlds theory, nor wave function collapse theories such as those of Angelo Bassi. Ours is not an "interpretation" of quantum mechanics (QM). It is an alternative to QM, a new mathematics. If the equations of QED are correct then our equations are wrong, and vice versa. (2,4,5,29,30,40)

1.2 Comparing QED and R-QED

QED equations involve a propagator, which measures the amplitude for a particle to travel from point **a** to **b** in time **t** on any path. QED is so accurate that if the distance from Los Angeles to New York were measured with this degree of accuracy, the error would be less than the width of a human hair. QED also carries baggage: nonsensical ideas that are tolerated as part of quantum weirdness. For example, Feynman said that every single particle always takes ALL the infinite paths from **a** to **b**, for all points **a** and **b**. That is an idea required by his mathematics, because he needs to add together all the amplitudes, and cannot imagine how to do so unless the particle traverses all paths.

When we reverse the direction of integration, we can add together all the amplitudes without requiring the particle to take all paths. To test our approach in the lab, we use probabilities, and as we said, the probabilities from both schemes are identical. R-QED is so accurate that if the distance from Los Angeles to New York were measured with this degree of accuracy, the error would be less than the width of a human hair. R-QED makes the quantum world intelligible. But it means that reality is not what we previously thought. It's a paradigm shift. Paradigm shifts usually sound like unintelligible gibberish to the experts.

The propagator and R-propagator are incompatible. You must choose to integrate your equations from **a** to **b**, or **b** to **a**. You cannot do both.

1.3 Defining wave function collapse

The term "wave function collapse" means that something decisive has happened. In QM it originally meant that many eigenstates collapsed into one, when a measurement was made, which was why measurement theory was central. Feynman doesn't speak of eigenstates nor of measurement theory. In this article we will change the meaning of that phrase. We will use the term "wave function collapse" to mean only that the particle departs the source (heading for **b**) on just one of the paths. What collapses is the number of paths: from infinity to one. Every path is bidirectional.

Wave function collapse occurs earlier and at a different location than previously thought: at the particle source (**a**) rather than at the detector (**b**). After wave function collapse it becomes a deterministic experiment. The particle follows only one trajectory $\mathbf{x_n}$ with a probability of one and strikes point **b** in the upper right (**Fig. 1**).

1.4 Defining an R-propagator

We define an R-propagator to be a function that specifies the probability amplitude of a particle going from point **a** to **b** in a certain amount of time **t**. It differs from Feynman's propagator in three ways:

1. The R-propagator integrates across all paths, moving centripetally toward the particle source before the particle is emitted, and
2. For that reason, the amplitude K_R is the negative value of the amplitude K from QED. By definition, if you swap the bounds of integration, you get the negative of the original integral:

$$\int_b^a f(x)dx = -\int_a^b f(x)dx \qquad \forall f \tag{1}$$

3. In Phase 2, the particle travels on one path $\mathbf{x_n}$ from point **a** to **b** with a probability of one. That trail was already blazed in Phase 1, but not visible because it was bundled with all the other paths. Even in Phase 2 that trail is not visible. We have no way of knowing which path it is. In Phase 2 there is only the one path. So, asking whether it is the path of least action is, in Phase 2, a meaningless question, because there is no other path to compare it to.

1.5 Boundary conditions

The book by F&H (Feynman and Hibbs) has two different viewpoints vis-à-vis boundary conditions. First they define their kernel (propagator) function K(b,a) in Eq. (2.25) without boundary conditions. That is the version of QED used in this article. (33)

But then on pp. 81 and 124, Eq. (4.28 and 6.14) F&H introduce a boundary condition {$K(b, a) = 0$ for $t_b < t_a$}. Why they do that is a technical issue discussed in the Supplementary Materials (below, after the Bibliography). They do it so that they can write less text. The boundary condition is not mathematically necessary to their model. If you eliminate that boundary condition from QED, nothing fundamental changes. We ignore that boundary condition in this article.

1.6. An example of quantum weirdness

Here is a fun example of what the term "quantum weirdness" means.

1.6.1. Accuracy of QED in lab studies

The accuracy of QED can be studied by focusing on the electromagnetic fine structure constant α. This gives the strength of electromagnetic interactions and is one of the fundamental constants in physics. The electron **g** value is a measure of the magnetic moment in terms of the Bohr magneton and is a fundamental property of the simplest elementary particles. QED provides a precise relationship between α and **g**. (34)

Gerald Gabrielse at Harvard University led a research team investigating this. They used a single electron caught for months in a cylindrical Penning trap in a cyclotron, as one of the sources of empirical data. The QED data were based on studies of Feynman diagrams with complicated branch points. The probability amplitudes were generated by many supercomputers all over the world working collaboratively for more than a decade.

Fig. 2 illustrates what two of the simplest Feynman diagrams look like. Each diagram symbolizes an equation. The more branch points in a Feynman diagram, the more difficult the math. By "difficult" we mean that each equation mushrooms in size, and the number of such equations increase exponentially. The amplitude from each Feynman diagram is added together to arrive at the total amplitude.

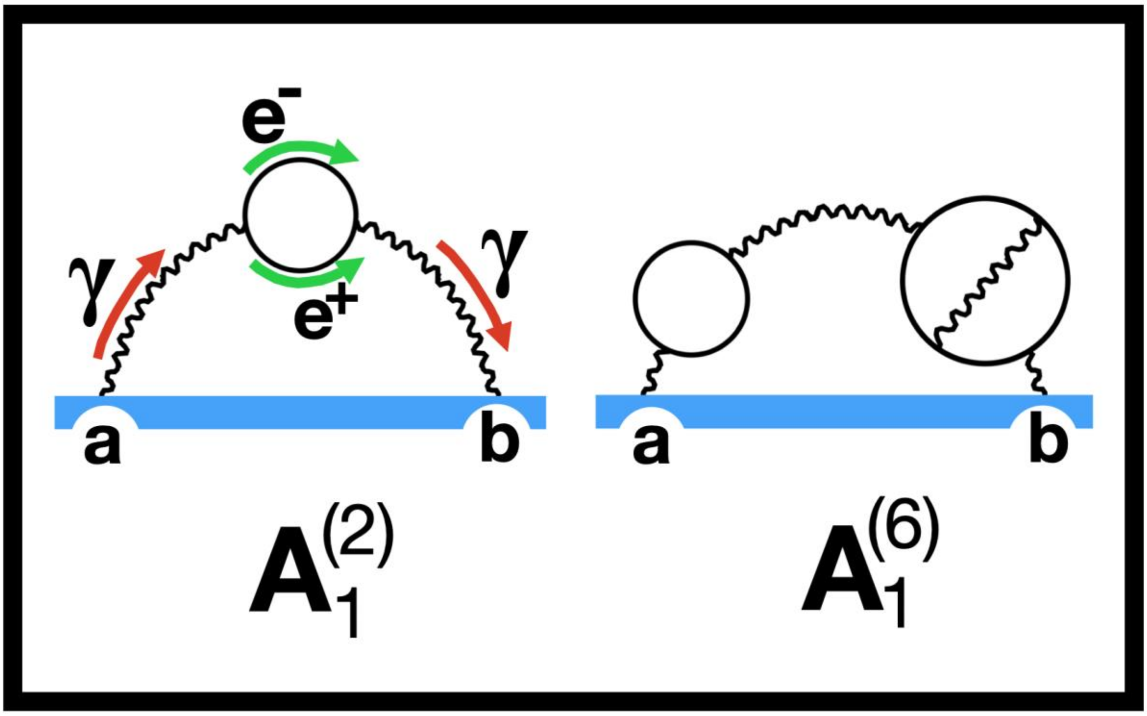

Fig. 2. These are two of the Feynman diagrams used in the Gabrielse study, in which solid and wiggly curves represent electrons (**e**) and photons (γ), respectively. On the left a photon leaves point a, moving up an arc. Before it gets to the top of the curve, it splits into an electron-positron pair. They zip around the small circle, then collide and annihilate each other. A photon emerges on the right to arc down to point b. So, there are two branch points in the left diagram (photon to electron-positron, and electron-positron to photon) which makes it a second order Feynman diagram, which is denoted $A_1^{(2)}$. The right-hand diagram has six branch points: $A_1^{(6)}$.

Gabrielse's group report on 891 eighth-order Feynman diagrams, which allows them to calculate α with a precision of 0.70 parts per billion. Alpha is α = 137.035,999,710. This means that QED is very, very accurate.

Even in the Gabrielse study there is quantum weirdness. It is assumed that every single photon crosses every Feynman diagram, and there are an infinite number of those diagrams.

1.6.2. The direction of integration creates or eliminates weirdness

As we said, the direction of integration is a toggle switch that controls whether quantum weirdness is present or absent.

Feynman always assumed the toggle switch was "ON", i.e. that integration moves in the same direction as the particle. In order to explain the astonishing accuracy of QED, he needed to add together the amplitudes from all the infinite number of Feynman diagrams. Since the switch was "ON" that Feynman was forced to embrace the illogical claim that every particle traversed ALL Feynman diagrams simultaneously. That made no sense to his students.

Common sense tells us that one particle only takes one path. If we toggle the switch to "OFF" then it is the mathematical engine that traverses an infinite number of Feynman diagrams before a particle gets involved. We can account for the accuracy of QED, yet one particle traverses only one Feynman diagram.

The reason the direction of integration is a toggle switch is because our mathematics mirrors the direction of waves in nature. Below we discuss a neutron interferometer experiment in which neutrons follow waves backwards. That is how reality works. Therefore, it is congruent with nature if our integration moves in the same direction as the waves, and discordant with nature if we integrate in the same direction as the movement of the particle. Feynman's approach is discordant with our view of nature. Feynman did not share our view of nature.

2. Materials and Methods

We swap the bounds of integration in equations from Feynman and Hibbs [1965, pages 26 to 35; Eqs. (2.1) to (2.25)]. Therefore, all our equations are the negative of the corresponding equations from F&H. The subscript "R" will denote functionals in our domain ("R" meaning "Reverse"), in contrast with F&H's domain which will have no subscript.

2.1. The principle of least action

For a trajectory x(t) we define the action S_R as follows:

$$S_R = \int_b^a \mathcal{L}_R(\dot{x}, x, t)\, dt \tag{2}$$

where L_R is the lagrangian for the system. For a particle of mass m subject to a potential energy V(x,t), the lagrangian is:

$$\mathcal{L}_R = \frac{m}{2}\,\dot{x}^2 - V(x,t) \tag{3}$$

We call the trajectory $\overline{x}(t)$ that goes from b to a with the minimum action S_R in classical mechanics. If we keep the end points fixed, but otherwise displace the path away from $\overline{x}(t)$ by an increment of $\delta x(t)$,

$$\delta x(b) = \delta x(a) = 0 \tag{4}$$

This use of the variable $\delta x(t)$ is not the Dirac delta function. The fact that $\overline{x}(t)$ is the path of least action implies that, to the first order in $\delta x(t)$

$$\delta S_R = S_R[\overline{x} + \delta x] - S_R[\overline{x}] = 0 \tag{5}$$

Using Eq. (2) we can say:

$$S_R[x + \delta x] = \int_b^a \mathcal{L}_R(\dot{x} + \delta\dot{x}, x + \delta x, t)dt \tag{6}$$

$$= \int_b^a \left[\mathcal{L}_R(\dot{x}, x, t) + \delta\dot{x}\frac{\partial \mathcal{L}_R}{\partial \dot{x}} + \delta x\frac{\partial \mathcal{L}_R}{\partial x}\right]dt \tag{7}$$

$$= S_R[x] + \int_b^a \left[\delta\dot{x}\frac{\partial \mathcal{L}_R}{\partial \dot{x}} + \delta x\frac{\partial \mathcal{L}_R}{\partial x}\right]dt \tag{8}$$

Upon integration by parts the variation in S becomes (this is straight from F&H, p. 27, Eq. (2.6))

$$\delta S_R = \left[\delta x \frac{\partial \mathcal{L}_R}{\partial \dot{x}}\right]_b^a - \int_b^a \delta x \left[\frac{d}{dt}\left(\frac{\partial \mathcal{L}_R}{\partial \dot{x}}\right) - \frac{\partial \mathcal{L}_R}{\partial x}\right] dt \qquad (9)$$

The first term after the equal sign is zero because we defined the end points **b** and **a** to be fixed. Elsewhere on the curve δ x(t) can vary without restraint.

The **path of least action** $\overline{x}(t)$ always satisfies the following condition:

$$\frac{d}{dt}\left(\frac{\partial \mathcal{L}_R}{\partial \dot{x}}\right) - \frac{\partial \mathcal{L}_R}{\partial x} = 0 \qquad (10)$$

which is the Euler-Lagrange equation

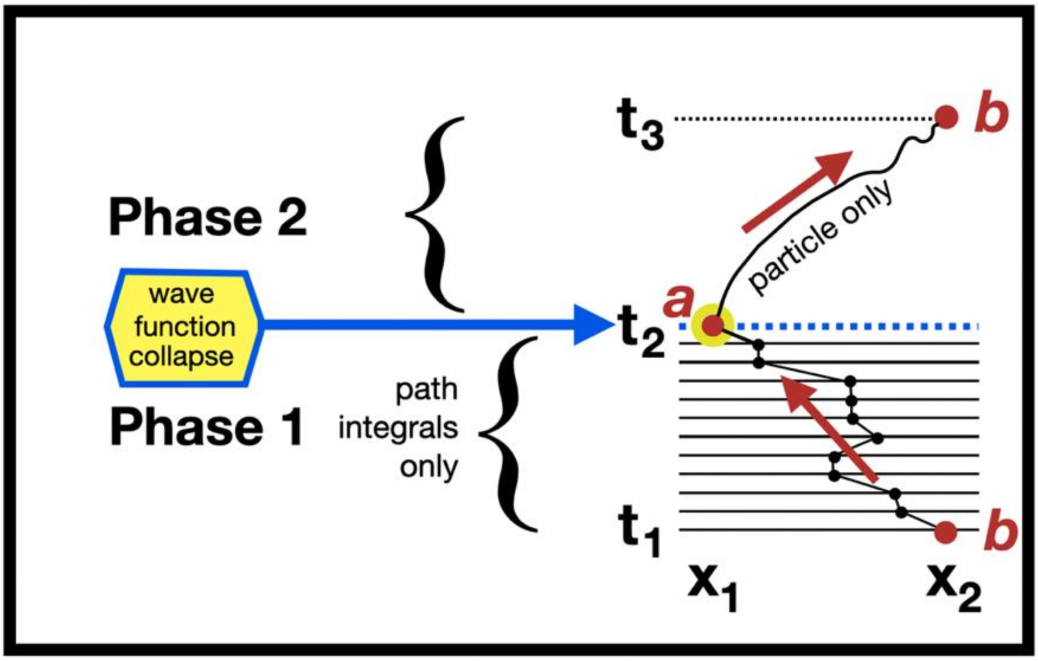

Fig. 3. Our model for how to calculate an R-propagator. We will start in the center and move to the upper right: at point **a** (the particle source) wave function collapse occurs. Phase 2 occupies the upper half of the figure, and consists of the particle following one and only one path with a probability of one up to the detector at point **b**. Point **b** appears twice: top and bottom right. It is always present, but those are the times when it is interesting. The lower half of the diagram is Phase 1. During that, Eq. (17) integrates across an infinity of paths from point **b** to **a**. Only one path (named "x_n") is diagrammed here. It is choppy, consisting of dots connected by short straight lines crossing a stack of time slices, each with a duration ε. As ε diminishes towards zero, this choppy path approaches a smooth path x_n.

2.2 Definition of the R-propagator

If we sum across all the paths from **b** to **a**, we arrive at a first approximation of the R-propagator:

$$K_R(b,a) = \sum_{\text{All paths from } b \text{ to } a} \phi_R[x(t)] \qquad (11)$$

This is not the amplitude of any one path. Rather, all the paths contribute to the total amplitude K_R. This is from F&H p. 29, Eq. (2.14).

The phase of each path is the action S_R in units of the reduced Planck's constant (the quantum of action). Each path has a phase proportional to the action S_R which is defined in Eqs. (2 and 16).

$$\phi_R[x(t)] = \text{constant } e^{(i/\hbar)S_R[x(t)]} \qquad (12)$$

We need a constant that will normalize Eq. (12). F&H proposes A^{-N} for that purpose (on p. 33, Eq. 2.21), where:

$$\mathcal{A} = \left(\frac{2\pi i\hbar\epsilon}{m}\right)^{1/2} \tag{13}$$

We adopt it:

$$\mathcal{A}_R = \left(\frac{2\pi i\hbar\epsilon}{m}\right)^{1/2} \tag{14}$$

where the variable ε is the duration of a slice of time (**Fig. 3**). If we sum across all the paths as ε goes to zero, we end up integrating across everything everywhere:

$$K_R(a,b) = \lim(\epsilon \to 0)\ \frac{1}{\mathcal{A}_R}\int \dots \iint e^{(i/\hbar)S_R(a,b)}\frac{dx_1}{\mathcal{A}_R}\frac{dx_2}{\mathcal{A}_R}\dots\frac{dx_{N-1}}{\mathcal{A}_R} \tag{15}$$

where the action (we repeat Eq. 2)

$$S_R(a,b) = \int_b^a \mathcal{L}_R(\dot{x},x,t)\ dt \tag{16}$$

is a line integral taken over the trajectory passing through the points of x_n (**Fig. 3**). We define the R-propagator

$$\text{R-propagator} \equiv K_R(a,b) \equiv \int_b^a e^{(i/\hbar)S_R(a,b)}\mathcal{D}[x(t)] \tag{17}$$

where the script D is a reference to Eq. 15, integrating across all the paths. At every step we developed our equations in parallel with F&H, but we always swapped the bounds of integration. Therefore, our R-propagator is negative Feynman's propagator:

$$\text{Feynman's propagator} \equiv K(b,a) \equiv \int_a^b e^{(i/\hbar)S(b,a)}\mathcal{D}[x(t)] \tag{18}$$

$$\text{Our R-propagator} \equiv K_R(a,b)\ =\ -K(b,a) \equiv \text{kernel or propagator of QED}$$

2.3 Quantum Field Theory

So far, we have been discussing non-relativistic QED. In F&H's 1965 version of quantum field theory the general formulation of QED is:

$$K = \int e^{(i/\hbar)S_3[\mathbf{A},\phi]}T[\mathbf{A},\phi]\ \mathcal{D}\mathbf{A}\ \mathcal{D}\phi \qquad \text{where} \tag{19}$$

$$T[\mathbf{A},\phi] \equiv \int \exp\left\{\frac{i}{\hbar}\Big(S_1[x] + S_2[x,\mathbf{A},\phi]\Big)\right\}\mathcal{D}x \tag{20}$$

where S_1 is the action for matter alone, S_2 is the interaction of matter and the field, S_3 is the action of the field alone, **A** and φ describe the field, T is defined by Eq. (20), and x stands for the coordinates for matter. These are Eqs. (9.104 and 9.103) from F&H. We define the quantum field theory R-QED propagator, K_R, to equal the negative of Feynman's QED propagator K in Eq. (19). K_R gives the negative amplitude that the particle goes through a certain motion *and* the field undergoes a certain transition. (F&H, p. 263)

The F&H equations for quantum field theory are 55 years out of date. It is beyond the scope of this article to update Eqs. (19 & 20) to the Landau-Ginzburg sophistication of our time. (41) The scope of this article focuses on F&H's 1965 book, and showing how the QED equations in that book need to be revised to fit the R-QED approach.

2.4 Phase 2 in non-relativistic R-QED

In Phase 2 the particle travels on the nth path from point **a** to **b** with a probability of one:

$$\int_a^b x_n(t)\,dt \;=\; \mathbf{1} \qquad (21)$$

No need to worry about δx(t) in Phase 2. The path doesn't wiggle around. It just retraces the steps following backwards one of the trails that was already blazed and defined in Phase 1.

Feynman often has an image in mind when he builds an equation. The Supplementary Material (below, after the Bibliography) analyzes some, and thereby we get inside Feynman's head so we can picture what he was thinking and modify it by toggling the switch: reversing the direction of integration in a Feynman diagram.

3. Results

What constitutes a "Results section" when you develop new mathematics? We present Schrödinger's cat alive as the "result" of our work! As we said, Propagators and R-propagators differ in the timing and location of wave function collapse. With R-propagators wave function collapse occurs at point **a**, when the particle is emitted, not at point **b** when the particle is measured.

The Schrödinger's cat paradox vanishes! The paradox had assumed that there was wave function collapse (i.e. the cat materialized out of a superposition) when we opened the box and observed it, which would correspond to point **b**. Our perspective is that the superposition was already collapsed before anyone opened the lid. The cat was either dead or alive but not both, before it was observed. "Wave function collapse" means that something decisive happened, like when a hammer smashed a vial of cyanide and the cyanide caused brain death in the cat.

4. Discussion

If you find a cluster of paths in the backcountry that allow travel from point **a** to **b**, the paths do not determine which of the two directions you choose to travel. One person might hike from **b** to **a**, another from **a** to **b**. The energy comes from the particle. The path doesn't push or pull the particle. It does no work. A path in the backcountry suggest a direction to the hiker, but the energy comes from the hiker, not from the path.

4.1 The integration follows the direction of waves

It would make sense to integrate in the "wrong direction" if waves were going in that direction, and particles were following the waves backwards. There is abundant empirical evidence that this is true. (7-28) Most physicists have never heard of this. We will cite an example.

Helmut Kaiser and his team published a neutron interferometer experiment, that could not be explained by quantum mechanics. (35) They built the apparatus shown in **Fig 4**. Neutrons from a nuclear reactor, came down into a neutron interferometer. A silicon blade split them into two streams (ψ_1 and ψ_2). At that bifurcation there was an oscillating aluminum plate that induced a phase difference in ψ_1 versus ψ_2. When the two streams were re-combined in the last silicon blade on the right, there was therefore wave interference, which was seen by the detector (lower right **Fig 4**) as a sinusoidal wave. The height of the sine wave corresponded to the amount of interference inside the interferometer.

Bismuth is a metal (the 83rd element) which slows down neutrons and neutron waves. When a sample of bismuth 20 mm thick was inserted in the upper stream (ψ_2), the upper wave packet was slowed relative to the lower wave packet (ψ_1), to such an extent that the upper wave packet (ψ_2) missed the boat. The lower wave packet (ψ_1) had already left the interferometer before the upper wave packet (ψ_2) arrived at the reunion point in the right-hand silicon blade. Therefore, all interference was obliterated (i.e. no sinusoidal wave in the output stream). A neutron wave packet has a width of ΔX = 86.2 Angstroms. A sample of 20 mm of Bismuth delays the wave packet by 435 Angstroms.

This neutron interferometer experiment is explained in a lively, 6 minute YouTube video: https://www.youtube.com/watch?v=jPNOUevkuHk&feature=youtu.be

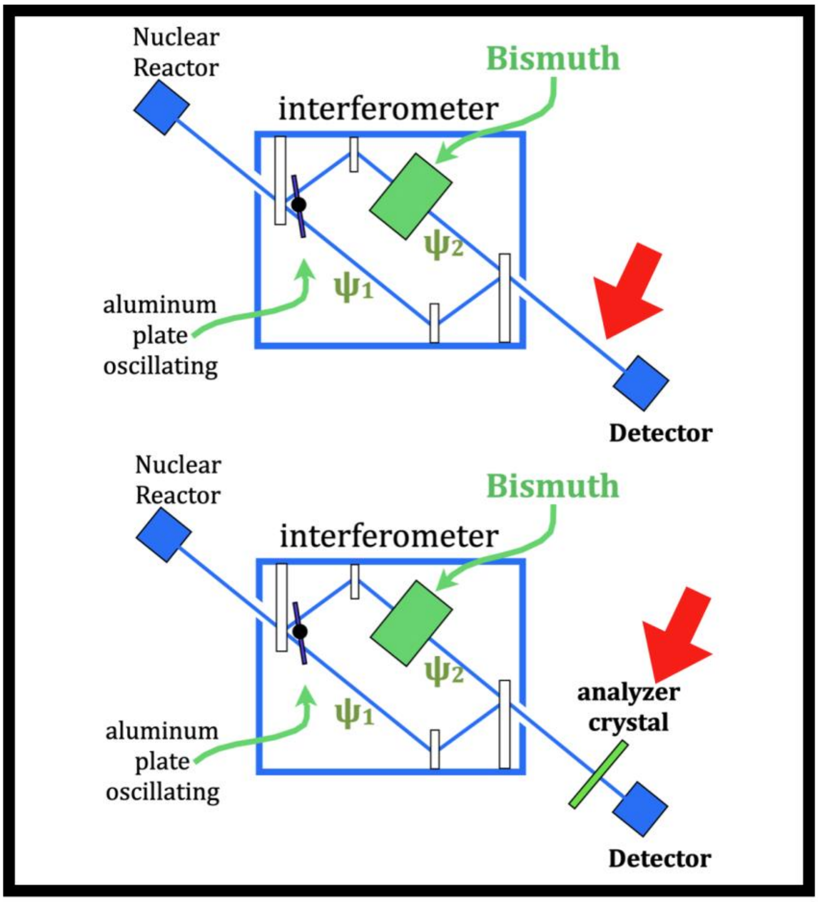

Fig. 4. Kaiser's neutron interferometer equipment, without and with a silicon analyzer crystal inserted at the red arrow.

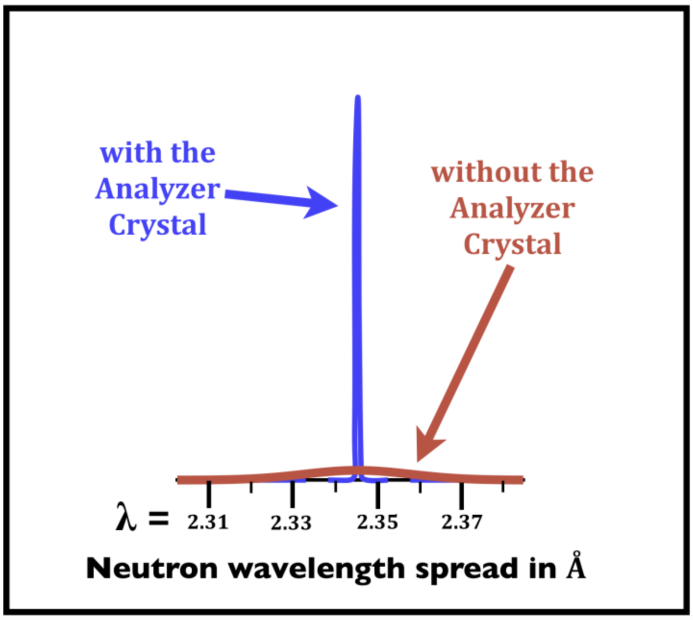

Fig. 5. Impact of the analyzer crystal on the spread of neutron wavelengths: it narrows the Gaussian and focuses it so it should penetrate better. If waves move in the same direction as neutrons, this analyzer crystal should not affect the interference that had occurred earlier, upstream, inside the interferometer.

The researchers then inserted a nearly perfect pressed silicon analyzer crystal as shown (**Fig. 4**, right lower corner), outside and downstream from the interferometer. The analyzer crystal focuses the beam so it should penetrate better (**Fig. 5**). That crystal increases the coherence length of a neutron wave packet from 86.2 to 3450 Angstroms. If QM were correct then the insertion of the analyzer crystal would have no effect on the interference that had already occurred upstream, inside the interferometer. The researchers were astounded with and could not explain the results: **Fig. 6.**

The data (**Fig. 6**) show that the presence or absence of an analyzer crystal in the lower right corner of **Fig. 4** determines the presence or absence of interference inside the interferometer (**Fig. 6**, bottom row). It is as if the bismuth were transparent! The only possible explanation of this experiment is that waves and neutrons travel in opposite directions. Elementary waves start at the detector, move northwest through the interferometer, then enter the nuclear reactor and recruit neutrons to follow the waves southeast through the interferometer and into the detector. The detector "clicks" when a neutron strikes it, because neutrons carry mass and energy, but waves carry neither. The elementary waves convey probability amplitudes, but no energy. From the viewpoint of the detector, elementary waves are invisible, and their presence is known only when a neutron makes the detector "click."

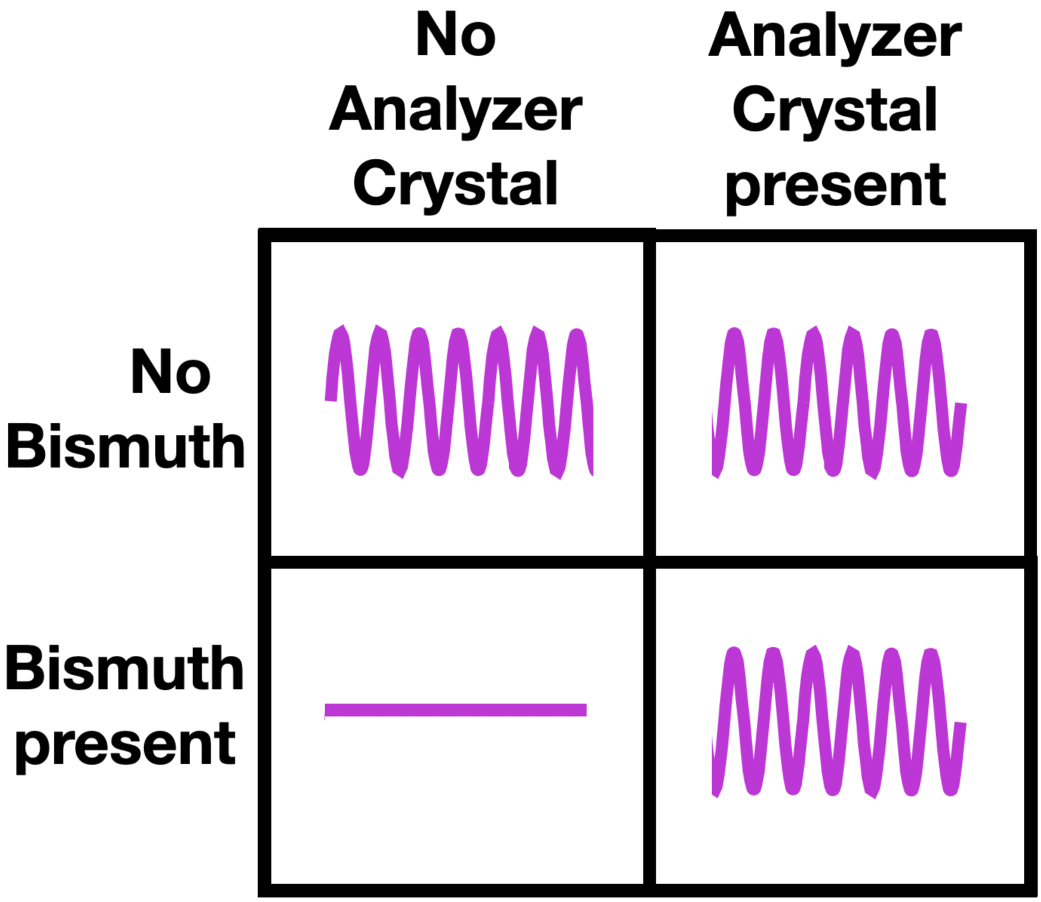

Fig. 6. Final data from the Kaiser interferometer experiment. With no analyzer crystal (left column) insertion of a 20 mm sample of bismuth obliterates all wave interference. When an analyzer crystal is inserted outside, and downstream from the interferometer (right column), full wave interference is restored inside the interferometer. So, if the presence or absence of an analyzer crystal controls the presence or absence of wave interference (bottom row), then the analyzer crystal must be upstream from the interference. This can only happen if waves are traveling from the detector, backwards through the interferometer, then up to the nuclear reactor, and neutrons are following the waves southeast through the interferometer and to the detector.

Here is a detailed account of how the neutron interferometer works from our viewpoint. Zero energy waves travel from the detector, northwest to the nuclear reactor. All wave interference is located in the upper left corner of **Fig. 6**, between the oscillating aluminum plate, and the reactor. Interference means there is a sinusoidal variation in intensity of the waves entering the reactor, and therefore a sinusoidal variation in the number of neutrons per second that travel southeast and strike the detector. If a thick sample of bismuth is inserted in the upper stream (ψ_2), it delays the ψ_2 contribution to the interference near the oscillating aluminum plate, therefore there is no sinusoidal wave entering the reactor. If an analyzer crystal is then inserted, it increases the coherence length of a neutron wave packet from 86.2 to 3450 Angstroms, so that the bismuth becomes transparent. Waves easily penetrate through the bismuth sample, and interference is restored in the northwest corner of the experiment.

4.2 Ramifications

When we change our picture of reality so that quantum particles follow waves backwards, some of the central tenets of QM lose their foundations. In other publications we show that **this changes the meaning of data**, so the quantum world looks astonishingly similar to the classical world. (7-28) We show that:

- Data cannot be erased backwards in time in the quantum world;
- There is a simple model that explains double slit experiments;
- A particle can only be in one location simultaneously;
- There is a non-Einstein, non-QM explanation of the Bell test experiments;
- Our model is compatible with quantum computers.

Although QED and R-QED predict identical results in almost all experiments, we published three experimental designs that have a moving part, so that QED and R-QED predict divergent outcomes. Those experiments have never been conducted. (9,17,21,23)

4.3 History

Lewis E. Little, with a PhD in physics, was troubled by quantum weirdness. He thought there must be an error in the starting assumptions of QM. He spent thirty years isolated, talking to no one, seeking a solution. That is four time as much time as Andrew Wiles spent sequestered, working on Fermat's last theorem. In 1993 Little came up with the odd idea that quantum particles and waves travel in opposite directions. He called it the Theory of Elementary Waves (TEW). It was published in *Physics Essays*, and he spoke at the Jet Propulsion Labs. (36-39)

In 2011 this author complained that TEW needed a mathematics. We are cousins. Little replied, "OK, it is your task to build it, since you have a degree in mathematics." The author, a medical doctor, thought that was impossible. His undergraduate math brain had rusted from years of disuse. They don't teach quantum physics in medical school, nor in continuing medical education.

The author joined the American Physical Society and gave 18 scholarly presentations in a decade, explaining TEW, thereby learning how physicists respond to it. As the sole author he wrote 21 scholarly articles on TEW that were published in peer reviewed journals of physics and mathematics. In the process he discovered a mountain of empirical evidence supporting TEW. To his astonishment, his math brain came back to life. (7-28)

Nine years after being given the assignment, he wrote this article. In the history of mathematics, the decisive step in unknotting insoluble problems was finding the right plan of attack based on a counterintuitive idea. Little provided a counterintuitive idea. The author persevered, motivated by how important the project was in the history of science.

This article is a treatise on the calculus of variations. It is well known that swapping the bounds of integration produces the negative of the original integral (Eq. 1). No one else has applied that to idea to the equations of QED.

Summary

Two solutions of the equations of QED are mutually incompatible. The bounds of integration cannot be both (**a** to **b** in Eq. (18)) and (**b** to **a** in Eq. (17)). It is either or. We expect that R-QED will lead to a blossoming of science and technology because now we can lift the veil and see what is hiding behind quantum weirdness.

Scientists think from particle source to detector and arrive at an amplitude: K. Nature thinks from detector to particle source and arrives at a negative amplitude: -K. Nature offers each particle many possibilities to choose from. The Born rule hides from view the difference between K and -K.

The direction in which you integrate equations is determined by your idea of reality. Feynman thought that waves and particles went from point **a** to **b**, and he integrated in that direction. Based on a mountain of empirical data, such as the Kaiser neutron interferometer experiment, we think the waves travel in the opposite direction and particles follow the waves backwards. Therefore, we integrate from **b** to **a**. This is a paradigm shift that requires that we rethink everything.

Acknowledgement

The author thanks Lewis E. Little.

Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this article.

Author Biography

Fig. 7. Jeffrey H. Boyd in July 2020 sequestered during the COVID19 pandemic. The author was raised in the family of a factory worker in New Jersey, USA. He helped his father dig out the basement of a house with a pick, shovel and wheelbarrow. In elementary school he and his family discovered that he had a talent in mathematics. His cousin, Lewis E. Little had a profound, positive impact on his life. It was Little that urged Boyd to go to Brown University to study mathematics, and later assigned Boyd the task of building a mathematics to accompany TEW. Boyd is the first member of his immediate family to graduate from college. He subsequently graduated

with advanced degrees from Brown (mathematics), Harvard (world religions), Yale (epidemiology) and Case Western Reserve (medicine) Universities and spent a decade on the research faculty of the National Institutes of Health in Bethesda, Maryland, USA. He served as Chairman of Behavioral Health and Chairman of Medical Ethics at Waterbury Hospital in Connecticut, USA. He is now retired. Boyd was previously embarrassed that in high school he excavated a basement by hand, in the age of power equipment. Eventually he realized it was from that experience that he learned that, with perseverance, anything could be accomplished: if you just keep at it. There were a multitude of rocks and oak tree stumps concealed in the ground where that basement was excavated. Digging a basement by hand was where the author learned the meaning of determination and grit, which was the key to everything that followed, including this article. The author's website is ElementaryWaves.com.

References

1. J. Baggott, *The Quantum Story: a history in 40 moments*, Oxford University Press, 2011. ISBN:978–0-19-956684-6
2. A. Bassi, K. Lochan, S. Satin, T.P. Singh and H. Ulbricht, "Models of wave function collapse," *Reviews of Modern Physics*, 85. 471. DOI: 10.1103/RevModPhys.85.471
3. A. Becker, *What Is Real?* Basic Books, 2018. ISBN:978–0-19-956684-6
4. D. Bohm "Interpretation of quantum theory in terms of 'hidden' variables, I", *Phys. Rev., 85*, 166-179 (1952). DOI: 10.1103/PhysRev.85.166
5. D. Bohm "Interpretation of quantum theory in terms of 'hidden' variables, II," *Phys. Rev., 85*, 180-193 (1952). DOI: 10.1103/PhysRev.85.180
6. M. Born, "Zur Quantenmechanik der Stoßvorgänge [On the quantum mechanics of collisions]. *Zeitschrift für Physik, 37*," pp. 863-867, 1926. In J. A. Wheeler and W. H. Zurek (eds.), *Quantum Theory and Measurement*, Princeton, pp. 50-55, 1983. ISBN 978-0-691-08316-2. DOI: 10.1007/BF01397477
7. J. H. Boyd, "If the propagator of QED were reversed, the mathematics of Nature would be much simpler," *Journal of Advances in Mathematics*, vol. 18, pp. 129-153, 2020. DOI: 10.24297/jam.v18i.8746
8. J. H. Boyd, "A tiny, counterintuitive change to the mathematics of the Schrödinger wave packet and Quantum ElectroDynamics could vastly simplify how we view Nature," *Journal of Advances in Physics*, vol. 17, pp. 169-203, 2020. DOI: 10.24297/jap.v17i.8696
9. J. H. Boyd, "New Schrödinger wave mathematics changes experiments from saying there is, to denying there is quantum weirdness," *Journal of Advances in Mathematics*, vol. 18, pp. 82-117, 2020. DOI: 10.24297/jap.v17i.8696
10. J. H. Boyd, "Decrypting the central mystery of quantum mathematics: Part 1. The double slit experiment," *Journal of Advances in Mathematics*, 2 vol. 17, pp. 255-282, 2019. DOI: 10.24297/jam.v17i0.8475
11. J. H. Boyd, "Decrypting the Central Mystery of Quantum Mathematics: Part 2. A mountain of empirical data supports TEW," *Journal of Advances in Mathematics*, vol. 17, pp. 283-314, 2019. DOI: 10.24297/jam.v17i0.8489
12. J. H. Boyd, "Decrypting the central mystery of quantum mathematics: Part 3. A non-Einstein, non-QM view of Bell test experiments," *Journal of Advances in Mathematics*, vol. 17, pp. 315-331, 2019. DOI: 10.24297/jam.v17i0.8490
13. J. H. Boyd, "Decrypting the central mystery of quantum mathematics: Part 4. In what medium do Elementary Waves travel?" *Journal of Advances in Mathematics*, vol. 17, pp. 332-351, 2019. DOI: 10.24297/jam.v17i0.8491
14. J. H. Boyd, "The quantum world is astonishingly similar to our world," *Journal of Advances in Physics*, vol. 14, pp. 5598-5610, 2018. DOI: 10.24297/jap.v14i2.7555

15. J. H. Boyd, "The von Neumann and double slit paradoxes lead to a new Schrödinger wave mathematics," *Journal of Advances in Physics*, vol.14, pp. 5812-5834, 2018. doi.org/10.24297/jap.v14i3.7820

16. J. H. Boyd, "The Boyd Conjecture," *Journal of Advances in Physics*, vol. 13, pp. 4830-4837, 2017. DOI: 10.24297/jap.v13i4.6038

17. J. H. Boyd, "A symmetry hidden at the center of quantum mathematics causes a disconnect between quantum math and quantum mechanics," *Journal of Advances in Mathematics*, vol. 13, pp. 7379-7386, 2017. DOI: 10.24297/jam.v13i4.6413

18. J. H. Boyd, "Paul Dirac's view of the Theory of Elementary Waves," *Journal of Advances in Physics*, vol. 13, pp. 4731-4734, 2017. DOI: 10.24297/jap.v13i3.5921

19. J. H. Boyd, "A paradigm shift in mathematical physics, Part 1: The Theory of Elementary Waves (TEW)," *Journal of Advances in Mathematics*, vol. 10, pp. 3828-3839, 2015. DOI: 10.24297/jam.v10i9.1908

20. J. H. Boyd, "A paradigm shift in mathematical physics, Part 2: A new local realism explains Bell test & other experiments," *Journal of Advances in Mathematics*, vol. 10, pp. 3828-3839, 2015. DOI: 10.24297/jam.v10i9.1884

21. J. H. Boyd, "A paradigm shift in mathematical physics, Part 3: A mirror image of Feynman's quantum electrodynamics (QED)," *Journal of Advances in Mathematics*, vol. 11, pp. 3977-3991, 2015. DOI: 10.24297/jam.v11i2.1283

22. J. H. Boyd, "A paradigm shift in mathematical physics, Part 4: Quantum computers and the local realism of all 4 Bell states," *Journal of Advances in Mathematics*, vol. 11, pp. 5476-5493, 2015. DOI: 10.24297/jam.v11i7.1224

23. J. H. Boyd, "The Theory of Elementary Waves eliminates Wave Particle Duality," *Journal of Advances in Physics*, vol. 7, pp. 1916-1922, 2015. DOI: 10.24297/jap.v7i3.1576

24. J. H. Boyd, "A new variety of local realism explains a Bell test experiment," *Journal of Advances in Physics*, vol. 8, pp. 2051-2058, 2015. DOI: 10.24297/jap.v8i1.1541

25. J. H. Boyd, "A proposed physical analog of a quantum amplitude," *Journal of Advances in Physics*, vol. 10, pp. 2774-2783, 2015. DOI: 10.24297/jap.v10i3.1324

26. J. H. Boyd, "Re-thinking a delayed choice quantum eraser experiment: a simple baseball model," *Physics Essays*, vol. 26, pp. 100-109, 2013. DOI: 10.4006/0836-1398-26.1.100

27. J. H. Boyd, "Re-thinking Alain Aspect's 1982 Bell test experiment with delayed choice," *Physics Essays*, vol. 26, pp. 582-591, 2013. DOI: 10.4006/0836-1398-26.1.100 10.4006/0836-1398-26.4.582

28. J. H. Boyd, "Rethinking a Wheeler delayed choice gedanken experiment," *Physics Essays*, vol. 25, pp. 390-396, 2012. DOI: 10.4006/0836-1398-25.3.390

29. J. G. Cramer, "An overview of the transactional interpretation," *International Journal of Theoretical Physics*, vol.27 pp. 227-236, 1988. DOI: 10.1007/BF00670751

30. H. Everett, J. A. Wheeler, B.S. DeWitt, L.N.Cooper, D. Van Vechten, and N. Graham, "Theory of the Universal Wave-Function," pp. 1-150, in DeWitt, B.S., and N. Graham, editors, *The Many Worlds Interpretation of Quantum Mechanics*, Princeton University Press (1973). ISBN: 0-691-88131-X

31. R. P. Feynman, *QED: The Strange Theory of Light and Matter*, Princeton University Press, 1985. ISBN 978-0-691- 12575-6

32. R. P. Feynman, *Feynman Lectures on Physics, vol. 2.* New York: Basic Books, c1964. ISBN-13: 978-0-4650294-0

33. R. P. Feynman and A. R. Hibbs, *Quantum Mechanics and Path Integrals*, Mineola, NY: Dover Publications, c1965. ISBN-13 978-0-468-47722-0.

34. G. Gabrielse, D. Hanneke, T. Kinoshita, M. Nio, and B. Odom, "New determination of the fine structure constant from the electron g value and QED," *Phys. Rev. Lett. 97*, 030802 (2006). DOI: 10.1007/BF00670751

35. H. Kaiser, R. Clothier, S. Werner, et. al., "Coherence and spectral filtering in neutron interferometry," *Physical Review A*, vol. 45, pp. 31-42, 1992. DOI: 10.1103/PhysRevA.45.31

36. L. E. Little, "Theory of Elementary Waves," *Physics Essays*, vol. 9, pp. 100-134, 1996. DOI: 10.4006/1.3029212

37. L. E. Little, "Theory of Elementary Waves @ JPL, Feb 2000," https://www.youtube.com/watch?v=3_9LB0RzgWg

38. L. E. Little "Introduction to Elementary Waves," 2016. https://www.youtube.com/watch?v=xx5V03iCbAo&t=16s

39. L. E. Little, "We have seen these waves," 2016. https://www.youtube.com/watch?v=xWMiNsD_xdM&t=5s

40. J. A. Wheeler and R. P. Feynman, "Interaction with the absorber as the mechanism of radiation," *Reviews of Physics*, vol 17, pp.157-181, 1945. DOI: 10.1103/RevModPhys.17.157

41. A. Zee, *Quantum Field Theory in a Nutshell*, Princeton University Press, 2010. ISBN: 978-0-691-14034-6

Supplementary Materials

Feynman sketches and diagrams

Visual intuition was a strong suit in Feynman's thinking. We can only understand and revise Feynman's equations if we understand and revise pictures that were in his mind as he wrote equations. They are two sides of the same coin. If we can draw like him then we can reverse his drawings as we reverse his equations. His drawings were about QED. We need to redraw them, so they become pictures R-QED.

We will first examine a picture from Feynman's 1985 book *QED*, (31).

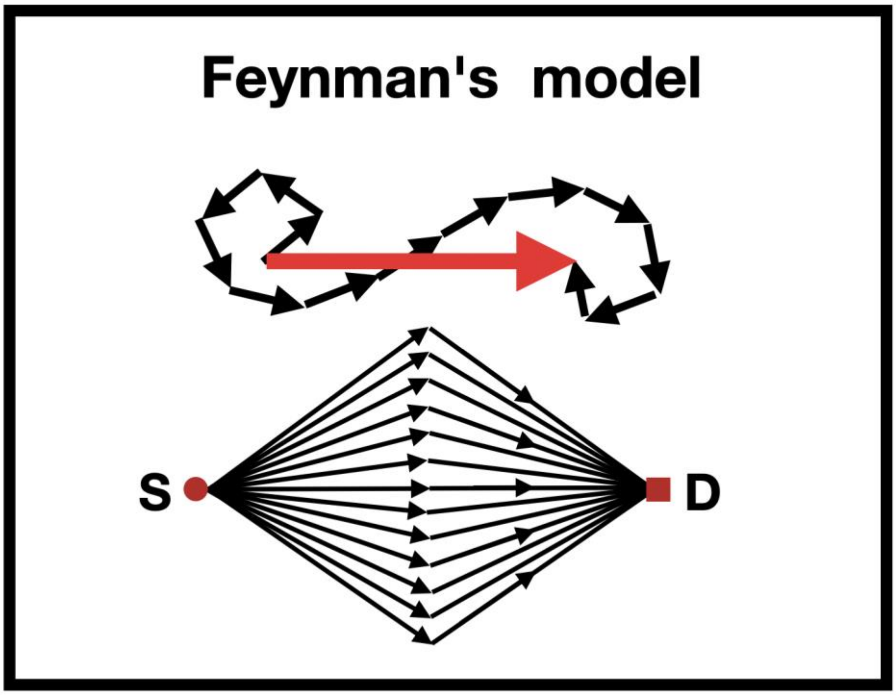

Fig. S1.

This is Figure 35 from Feynman's book *QED*, p. 57. At the top of this figure there is a choppy "figure 8" lying horizontally. In the "figure 8" each of a dozen black amplitude vectors is added to the previous one, tail to head. The sum of all the short vectors in the "figure 8" produce the long red arrow, which represents the propagator K, named "K" after Feynman's **K**ernel. In the bottom are a dozen arrows going by crooked paths from the photon

Source to a **D**etector. Each of these long skinny pathways is a route taken by a photon traveling from **S** to **D**. Each path has a corresponding amplitude vector in the top (part of the "figure 8").

One problem with this drawing is that Feynman collapses both time and distance into the "X" axis (the abscissa). Since our theory says that things can go backwards in space (distance), but not backwards in time, we will need to separate time and distance. So, in the next figure we will plot distance on the abscissa and time on the "Y" axis (ordinate). That makes the next figure is more complicated.

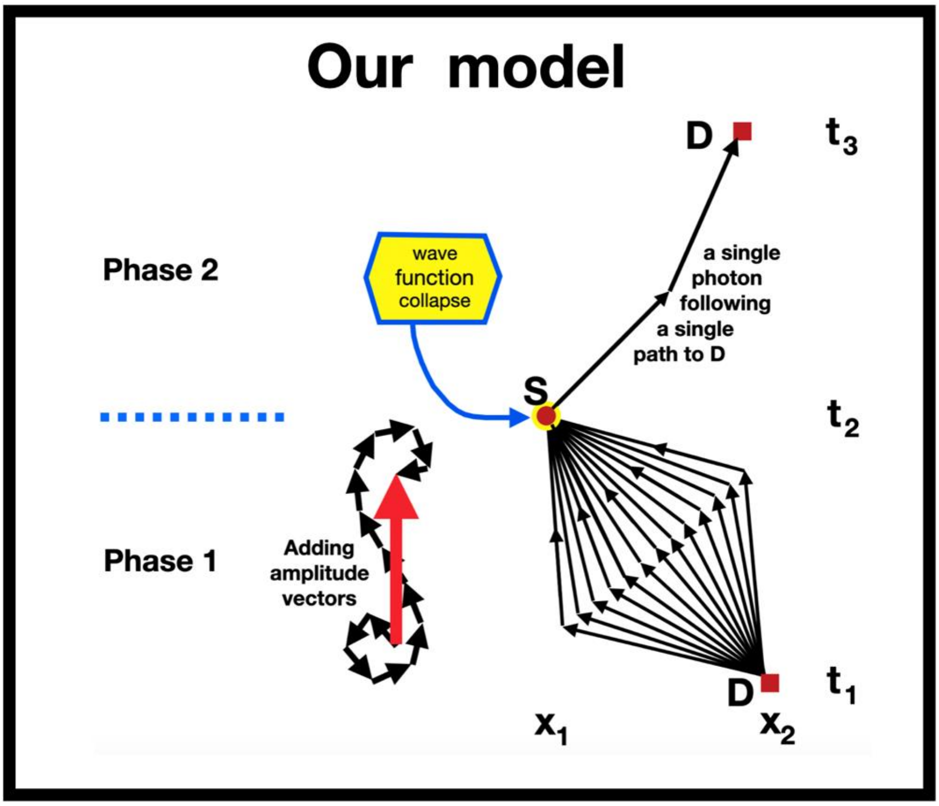

Fig. S2.

This is our model corresponding to **Fig. S1.** In the lower right quadrant is the same diamond full of crooked paths, but the entire diamond is tilted, and the **S**ource "**S**" has been swapped with the **D**etector "**D**." In Phase 1 (lower half of the diagram) no photon is involved. The long skinny arrows in the diamond represent the R-propagator equations integrating across all the pathways, from **D** to **S**. All the paths converge on the photon **S**ource "**S**" in the center. One of those paths is selected at random by the photon to follow backwards to the detector **D** (in the upper right). We just said, "follow backwards." What does that mean? Time always moves forwards in our system: t3 > t2 > t1, so what does the word "backwards" mean? The paths are bidirectional, similar to the paths you find in the backcountry when you are hiking. The photon never goes backwards in time. The photon moves from **S** at (x1, t2) in the center, following its one path, up to **D** at (x2, t3) in the upper right corner. The Detector "**D**" appears twice in this drawing (at times t3 and t1). It's always present. The amplitude for the photon to travel from **S** to **D** in time **t** is given by the length of the red vector (R-propagator K_R). Our red vector is the mirror image of Feynman's in **Fig. S1**. The reason Feynman's red arrow is horizontal in **Fig. S1.**, but ours is vertical in **Fig. S2.,** is because time is graphed horizontally (on the abscissa) in **Fig. S1** but on the vertical axis (the ordinate) in **Fig. S2.**

Although we emphasized the orthogonality of distance and time in **Fig. S2.,** it would be wise to forget that when examining the Feynman diagrams that come next (Figs. **S3** to **S5**). The Feynman diagrams that follow are not primarily a map of a system of paths. Primarily they are a symbolic catalog of complicated equations. By writing down a Feynman diagram you can avoid a briar patch of tangled equations, as you will see.

A Feynman diagram

Feynman diagrams are used extensively in particle physics. The following figures explain the relationship between Feynman diagrams and a scalar Propagator inside the QED way of thinking. **Fig. S5** shows how to transform this into the R-QED way of thinking.

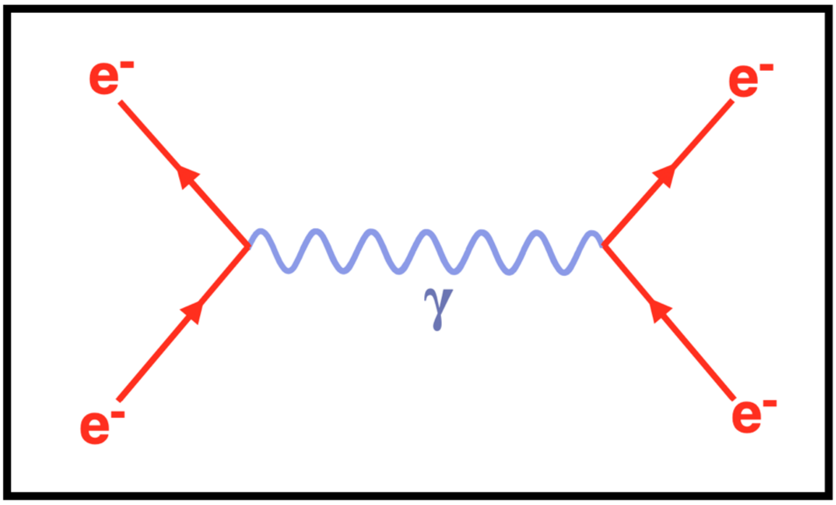

Fig. S3. Feynman diagram with two vertices. On the lower left an electron comes in, emits a photon γ and a lower energy electron leaves to the upper left. The photon γ is then absorbed on the right by another electron, and a higher energy electron exits in the upper right.

Feynman diagrams are an elegant way of dealing with the monster equations of particle physics. In **Fig. S3** two electrons go in toward the center, and two electrons come out. There is an exchange of energy between the electrons. **Fig. S3** shows one of the ways in which that could happen. The photon γ in the center of this diagram is called a "virtual particle" which has questionable existence. We never see it and cannot measure it. The only parts of this diagram which are visible to our detectors are the periphery: two electrons going in and two electrons coming out with a changed energy. What happens in the middle is shrouded in mystery. Feynman's approach is to speculate about what happens in the center, and his speculation takes the form of an infinite number of Feynman diagrams.

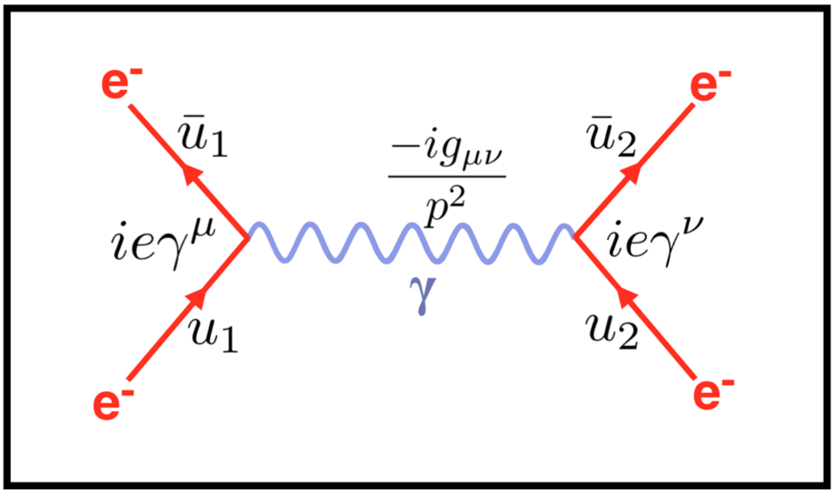

Fig. S4. This Feynman diagram is actually a shorthand for organizing complicated equations. In this case the equation corresponding to this entire diagram is:

$$\textbf{Propagator} = \left\{ \bar{u}_1 \, ie\gamma^\mu \, u_1 \left[\frac{(-ig_{\mu\nu})}{(p^2)} \right] \bar{u}_2 \, ie\gamma^\nu \, u_2 \right\}$$

Because this Feynman diagram has only two vertices, this is one of the simplest equations in particle physics.

In the next figure we will show how such a Feynman diagram can be moved from QED to R-QED.

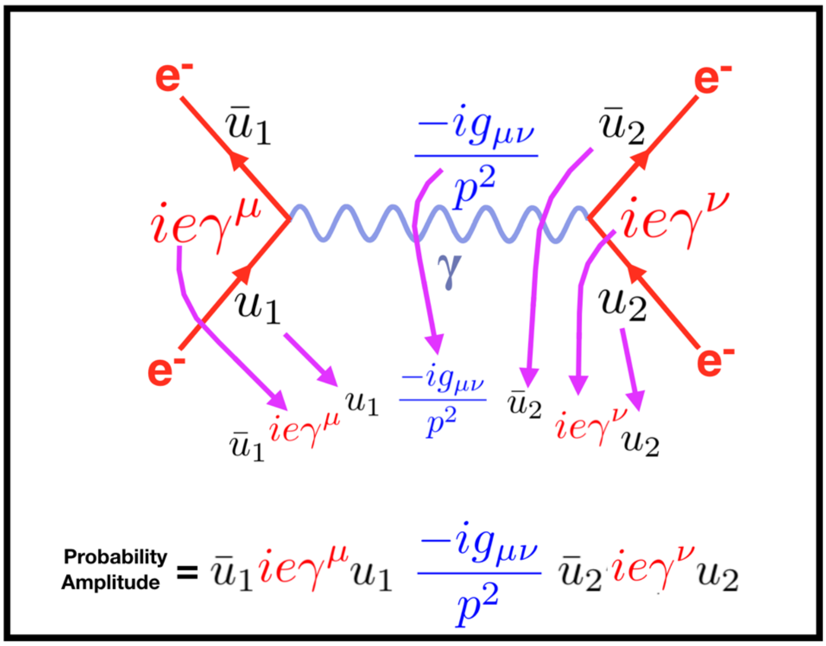

Fig. S5. When we switch from QED to R-QED we place **a minus sign** in front of the equation:

$$\textbf{R-Propagator} \equiv \mathbf{K}_R = -\left\{\bar{u}_1\ ie\gamma^\mu\ u_1 \left[\frac{(-ig_{\mu\nu})}{(p^2)}\right] \bar{u}_2\ ie\gamma^\nu\ u_2\right\}$$

Feynman's sketch of a particle scattering in a potential V

As we noted, the Feynman and Hibbs book, Quantum Mechanics and Path Integrals, has two approaches to the question of boundary conditions for their propagator (which they call a kernel). For our purposes these two approaches are contradictory, because the first is compatible with our program whereas the second one obstructs our program of reverse integration. Primarily they define their kernel function K(b, a) in Eq. (2.25) without boundary conditions, which is what we use in our article. But later in the same book they introduce a boundary condition, {K(b, a) = 0 for tb < ta}, which they refer to as their "convention" i.e. their way of doing things. We claim this boundary condition is not necessary from a mathematical point of view. Their mathematical system works the same without it.

We need to know why the F&H boundary condition is imposed, and how important it is in QED. It turns out to be a trivial reason: to simplify the amount of text they have to write in order to explain a scattering diagram and scattering equations.

They first mention the boundary condition on pp. 81 and 124, Eq. (4.28 and 6.14). The first time they explain in detail why they impose this boundary, is in the discussion of the figure that we call (**Fig. S6.**).

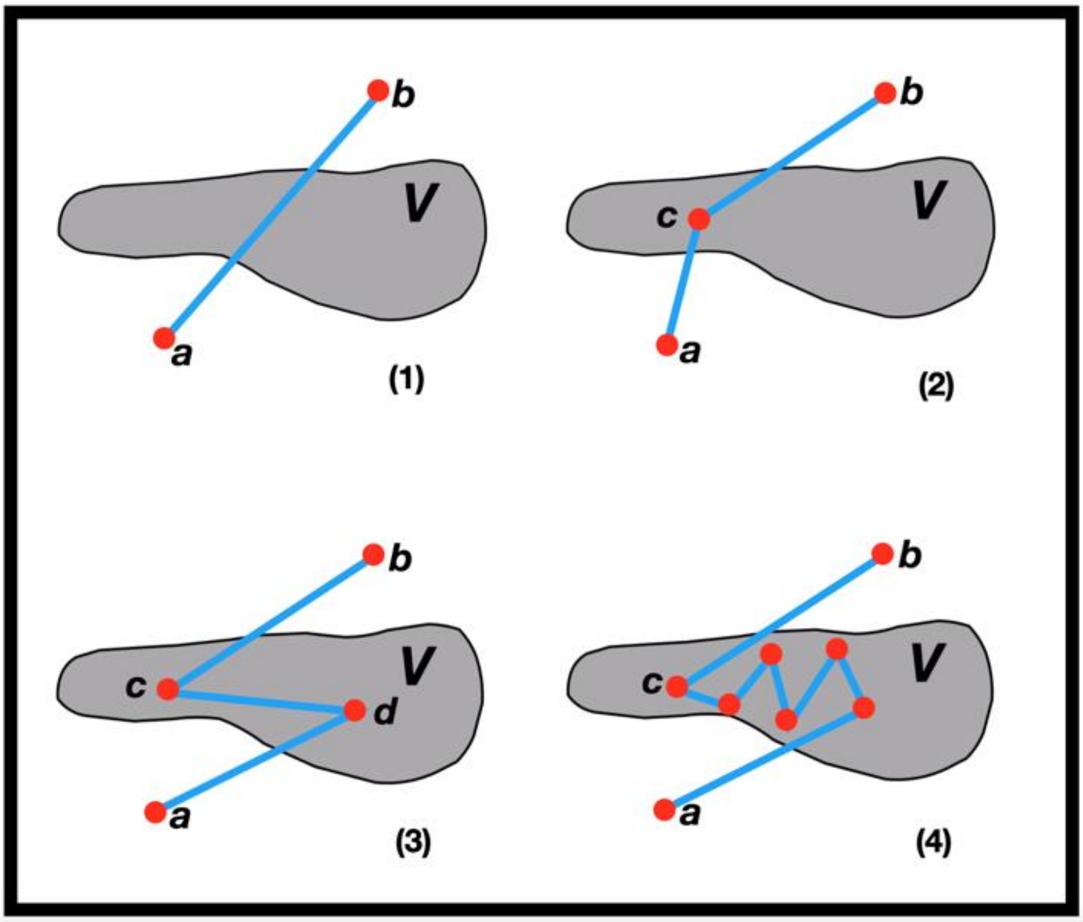

Fig. S6. This Fig. 6-2, from F&H, p. 123. It shows a particle moving from point **a** to **b**, through the potential **V**. In (1) the particle moves from **a** to **b** without scattering, and the amplitude for that is K_0(b,a). In (2) it scatters once and the amplitude is K(1)(b,a). In (3) it scatters twice and the amplitude is K(2)(b,a). In (4) it scatters "n" times, and the amplitude is K(n)(b,a). The total amplitude for the particle to move from a to b with any number of scatterings is K0 + K(1) + K(2) + . . . + K(n) + ...

In the **Fig. S6** the gray region in the lower left has two dots inside, named "c" and "d" respectively. The entire boundary condition that is imposed by S&H is for the purpose of declaring that the dot named "c" is on the left and "d" is on the right. This is important in order to keep the following integral straight (their Eq. (6.13)), where at the right-hand end it says "dτc dτd" which means that first you integrate with dτd and then with dτc:

$$K^{(2)}(b,a) = \left(-\frac{i}{\hbar}\right)^2 \iint K_0(b,c)V(c)K_0(c,d)V(d)K_0(d,a)d\tau_c d\tau_d$$

They say, "We have tacitly assumed that $t_c > t_d$," which means the dot named "c" is to the left of the dot named "d" inside **Fig. S6.** They continue, "In order to avoid the complication of having to introduce this assumption explicitly in each such example we shall" impose a uniform boundary condition {K(b, a) = 0 for $t_b < t_a$}, throughout the later chapters.

To summarize, F&H introduce the boundary condition {K(b, a) = 0 for $t_b < t_a$}, so they don't have to use so many words when they explain scattering equations. That boundary condition could be omitted if they said something like, "first d, then c" in their discussion of scattering equations. We assert that the boundary condition is mathematically unnecessary in their system of QED. Furthermore, it prevents us from studying what happens when the bounds of integration are swapped.