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Rethinking Alain Aspect's 1982 Bell test experiment with delayed choice

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Abstract: The Theory of Elementary Waves (TEW) is under development as a possible alternative to quantum mechanics. A minimum requirement for any such theory would be that it must be able to explain the delayed choice experiments of quantum mechanics (QM), and explain a vast amount of quantum mathematics. This is the third in a series of articles proposing that TEW can explain delayed choice experiments. Whether or not TEW provides substantial insight into quantum math is beyond the scope of this article. This article focuses on an elementary wave explanation of the Bell test experiment, published in 1982 by Aspect *et al*., We propose that elementary bi-waves are able to explain the experiment, without the concept of nonlocality. TEW is not a local hidden variable theory. Our model does not sneak through some loophole in Bell's Theorem, but lies outside the jurisdiction of Bell's Theorem. Although there are experiments for which TEW and QM predict different outcomes, the Bell test experiments cannot make that distinction. The model presented in this article is the ONLY model that claims to explain Aspect's experiment in such a way as to preserve the concept of there being a local physical reality independent of the observer, at the quantum level. TEW comes in two varieties: the original version, and a more advanced form. According to the original TEW, waves (or rays) normally come from the detectors, and a particle follows them backwards. How could rays come from the detectors? Everywhere in nature there are said to be rays of all wavelengths and polarizations, traveling in all directions at the speed of light, and time goes forwards only. This is not the Wheeler–Feynman time-symmetric theory, nor "backwards in time waves," nor "pilot waves." The rays have properties: direction, wavelength, polarization, and amplitude. The wavelength of a ray corresponds to the momentum of a particle that will follow it, according to deBroglie's formula $\lambda = h/p$. A more advanced version of TEW says that a ray (i.e., flux) traveling in one direction, can pair up with a coaxial ray traveling in the opposite direction, to form an object called a bi-ray or bi-flux. Particles can follow such a bi-ray as a pathway. The rays do no work: they neither push nor pull particles. They provide a possible trajectory. Particles are physically real, not in a superposition of states, not wave packets. TEW contradicts the idea of wave particle duality, an issue that will be addressed at the end of this article, when we rethink the Davisson Germer experiment. Why would anyone want a replacement for QM, which is so successful that our civilization would collapse without quantum technology? Leading QM proponents (such as James J. Binney of Oxford University) say there is something wrong with QM. It is such observations by QM experts that motivate an effort to "rethink everything." For example, there is no consensus about how to understand wave function collapse. TEW offers solutions to such questions. © *2013 Physics Essays Publication*. [http://dx.doi.org/10.4006/0836-1398-26.4.582]

Résumé: La Théorie des ondes élémentaires pourrait bien devenir une alternative à la mécanique quantique. Pour être considérée comme telle, cette théorie doit pouvoir expliquer les expériences à choix retardé en mécanique quantique et appuyer ou expliquer un vaste nombre de théories mathématiques dans ce domaine. Cet article est le troisième d'une série qui soutient le fait que la théorie des ondes élémentaires permettrait de comprendre les expériences à choix retardé. La question de la contribution de cette théorie aux mathématiques quantiques n'y est pas traitée. L'auteur de cet article s'attache principalement à démontrer, à l'aide des ondes élémentaires, l'expérience basée sur les Inégalités de Bell et publiée en 1982 par Aspect, Dalibard et Roger. Il part du principe que les ondes doubles élémentaires permettent d'expliquer cette expérience sans avoir recours au concept de choix retardé. La Théorie des ondes élémentaires n'est pas une théorie à variables cachées locales. Ce modèle dépasse le cadre du Théorème de Bell sans chercher à en exploiter d'éventuelles notions ambiguës. Bien qu'il existe des expériences pour lesquelles la Théorie des ondes élémentaires envisage des résultats différents de ceux prédits en mécanique

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quantique, cette distinction n'existe pas avec les tests sur les Inégalités de Bell. Le modèle présenté dans cet article est le SEUL qui explique l'expérience d'Aspect d'un point de vue quantique en affirmant qu'il existe une réalité physique locale qui ne dépend pas de l'observateur. Il existe une version d'origine et une version plus approfondie de la Théorie des ondes élémentaires. Selon la théorie d'origine, les ondes (ou rayons) proviennent normalement des détecteurs et sont suivies par une particule qui se déplace à rebours. Qu'est-ce qui prouve que ces rayons proviennent des détecteurs? Dans la Nature, les rayons possèdent toute sorte de longueurs d'onde et de polarisations et se déplacent dans toutes les directions à la vitesse de la lumière tandis que temps se déplace uniquement vers l'avant. Il ne s'agit pas ici de la Théorie de l'absorbeur de Wheeler et Feynman ni de "propagation à rebours des ondes" ou d'"ondes pilotes". Les rayons sont caractérisés par une direction, une longueur d'onde, une polarisation et une amplitude. Dans sa formule $\lambda = h/p$, De Broglie définit la longueur d'onde d'un rayon comme la quantité de mouvement d'une particule qui le suit. Dans sa version plus approfondie la Théorie des ondes élémentaires déclare qu'un rayon (ou flux) qui se déplace dans une direction peut s'associer à un rayon coaxial qui se déplace dans le sens opposé pour former un objet bi-rayon ou bi-flux. Les particules peuvent se déplacer sur cet objet comme sur une trajectoire. Les particules ne sont pas poussées ni tirées par les rayons. Ceux-ci n'interagissent pas avec les particules. Ils leurs fournissent uniquement un chemin sur lequel se déplacer. Les particules sont des objets physiques réels qui ne découlent pas de la superposition d'états ni de paquets d'ondes. La Théorie des ondes élémentaires conteste l'idée de dualité onde-particule. Ce point est traité à la fin de l'article dans le cadre d'une nouvelle étude sur l'expérience de Davisson Germer. Personne ne veut remplacer la mécanique quantique et mettre en péril un monde essentiellement bâti sur la technologie quantique. Pourtant, les plus grands théoriciens en mécanique quantique (James J. Binney de l'Université d'Oxford, par exemple) disent que certains postulats ne fonctionnent pas. Face à de telles déclarations, il est important de "tout repenser". Et si les experts en mécanique quantique ne parviennent pas à se mettre d'accord sur l'interprétation de la réduction du paquet d'onde, par exemple, la Théorie des ondes élémentaires, elle, y apporte des réponses.

Key words: Theory of Elementary Waves; TEW; Lewis E. Little; Biwaves Bi-Waves; Biflux Bi-Flux; Wave Particle Duality; Aspect; Nonlocality; Local Hidden Variable Theory; Bell's Theorem; Davisson Germer Experiment.

I. INTRODUCTION

A minimum requirement for a theory proposed as an alternative to quantum mechanics (QM) would be that it must be able to explain the delayed choice experiments, and explain a substantial amount of quantum mathematics. The Theory of Elementary Waves (TEWs) has been proposed as such an alternative to QM. Whether TEW can explain a substantial amount of quantum mathematics is not the focus of this article. Recent publications in *Physics Essays* in 2012–2013 show that TEW is able to explain some of the famous delayed choice experiments of QM.[1]

1. Jacques *et al.*, "Experimental realization of Wheeler's delayed choice gedanken experiment," was reported in Science in 2007.[2] Rethinking that experiment, TEW proposes that it can be understood from a TEW perspective, and there is no need for the concept of nonlocality to explain it.
2. The experiment of Kim *et al.*, "A delayed choice quantum eraser experiment," published in 2000,[3] when re-interpreted by TEW, can be understood without use of any of the following concepts: nonlocality, quantum eraser, nor complementarity.

The purpose of this article is to explore whether TEW might also be able to explain the delayed choice Bell test experiment published in 1982, by Aspect *et al.*[4] Such an explanation would need to account for the experimental data, including the delayed choice. "Delayed choice" in the Aspect experiment means that when two photons are emitted, the angle of the polarizers at which they will be tested has not yet been selected.

Lewis E. Little discovered TEW. Starting in 1996, he proposed novel ways that waves and particles might interact.[5] His original idea, published in *Physics Essays*, was that waves travel in one direction and particles follow them backwards. He called these "elementary waves." Rays (or flux) would come from the detectors in a typical experiment, and travel backwards through the equipment (but forwards through time). Wave interference is located at the particle source, and occurs prior to and during particle emission. The probability of particle emission in response to such incident rays would be proportional to the intensity of the impinging ray, which is determined by wave interference at the particle source.

Once a particle is emitted, all interference relevant to the trajectory of that particle ends. If a particle were emitted in response to one such ray, it would follow that ray backwards with a probability of one, and strike the detector from which that ray originated. This would explain why so many experiments discover that the final arrangement of the detectors appears to send a signal to the incoming particle, alerting it about how to interact harmoniously with that detector.

In TEW a particle would have a trajectory, and would not be in a superposition of states, nor would it be a wave packet. Because each particle has a trajectory, there would be no need for the concept of wave function collapse, therefore no call for a "many worlds theory." The probability densities of QM would be replaced by ordinary probabilities located at the particle source, based on wave interference at that location, prior to and at the time of particle emission. Particles such as photons are not polarized; it is the waves they follow that are capable of being polarized.

How could an elementary ray come from a detector, when the detector is emitting no energy to speak of? The implication is that everywhere in nature there must be rays of all wavelengths, traveling in all directions at the speed of light. Only when a particle follows such a ray backwards, can we gain information about the ray. Particles carry all the energy and momentum. Previous publications show there is empirical evidence that particles and waves travel in opposite directions,[6] and empirical evidence that zero energy waves occur in nature,[7] as Franco Selleri observed.[8]

If elementary rays travel in all directions, then each such ray would have a coaxial partner, traveling in precisely the opposite direction. Little proposed a second, more complicated version of TEW, in which particles would follow bi-rays, meaning a pair of coaxial rays traveling in countervailing directions. To the best of our knowledge, Little has not yet published a second version of his theory. This article is based upon my interpretation of his theory as of 2012 conversations Dr. Little and I had. The hypothesis is that an elementary ray in one direction would have an amplitude, as would its coaxial partner traveling in the opposite direction. The probability of a particle following such a bi-ray would be the amplitude of one ray times the amplitude of its partner. Amplitudes are not squared to get probabilities. This model could explain one of the mysteries of QM: why probabilities are derived by squaring amplitudes. The answer is: that is a shorthand way of multiplying the amplitudes of two countervailing rays of equal amplitude.

Elementary rays are understood to be real physical objects. Although they can be studied mathematically, they are not primarily mathematical in nature. In this regard they differ from quantum waves. QM sometimes assumes that all you can know is what your measuring devices measure ("observables"). TEW assumes there is a "real" physical reality at the quantum level, and that reality has intrinsic characteristics that are independent of the observer. In that specific respect, TEW is similar to the assumptions of Einstein. However, TEW conceptualizes the nature of that local physical reality in a different way than did Einstein. We will show that if TEW is correct, Einstein, Podolsky, and Rosen (EPR) are wrong.

A pivotal difference between TEW and QM is that TEW proposes that the quantum world is "picture-able," whereas QM says it is not.[9]

II. WHY SEEK AN ALTERNATIVE TO QM?

Why would anyone seek an alternative to QM? The success of QM is legendary. Our civilization would collapse were it not for quantum technology. Why the hostility toward QM? This author is not hostile toward QM. It is a mixture of curiosity and respect for QM that motivates this author. QM experts, such as James J. Binney of Oxford University, say there is something wrong with the theory.[10] QM does not inspire the level of comfort that relativity theory inspires. This discomfort with QM among physicists is partly because of riddles and brainteasers, collectively called "quantum weirdness."

If an error had been made at the founding of a theory, a mistake in its starting assumptions, then that theory would be expected to unfold with an endless succession of "weirdnesses." This author proposes that there was such an error. None of the founders of QM (Einstein, Bohr, Schödinger, Heisenberg, Dirac, de Broglie, Feynman, etc) ever asked the question, "In which direction do the waves travel?" Without any discussion, without any empirical evidence, without ever acknowledging that they were making an assumption, they all assumed that it was "obvious" that waves and particles travel in the same direction. The history of science has been one of proving erroneous that which appeared to be "obvious." This in itself does not prove there was an error. It shows that if there were such an error, it would not have been noticed.

The undeniable power of quantum mathematics at solving practical problems led to a trade-off: out of respect for the success of QM, we more-or-less agree not to be too troubled by the weirdness. "Metaphysics" is a wastebasket into which quantum weirdness is discarded. Because of its pragmatic power, QM will never be replaced or supplanted, even if TEW were successful at establishing a toehold in science.

III. THE EXPERIMENT OF ASPECT *ET AL.*

John Bell said[11] that an experiment proposed by EPR[12] would produce slightly different results if QM were true, than if local realism were true. Both EPR and Bell were originally focusing on spin $1/2$ particles. Photons detected at polarizers would be easier for experimenters to work with. Clauser, Horne, Shimony, and Holt (CHSH)[13] designed such an experiment:

> "Consider an ensemble of correlated pairs of particles moving so that one enters apparatus I_a and the other apparatus I_b, where a and b are adjustable parameters. In each apparatus a particle must select one of the two channels labeled $+1$ and -1. Let the results of these selections be represented by $A(a)$ and $B(b)$ each of which equals ± 1 according as the first or second channel is selected."

What do those sentences mean? Aspect *et al.* interpreted those three sentences and built an apparatus based on their interpretation, shown in Fig. 1. A pair of photons, emitted at the source (the yellow circle in the center) travel in opposite directions and enter a contraption on the left, called "Alice," or on the right, called "Bob." Alice and Bob independently rotate their polarizers during the flight of the photons. In Fig. 1, "Alice" is synonymous with a blue switch C_1, and

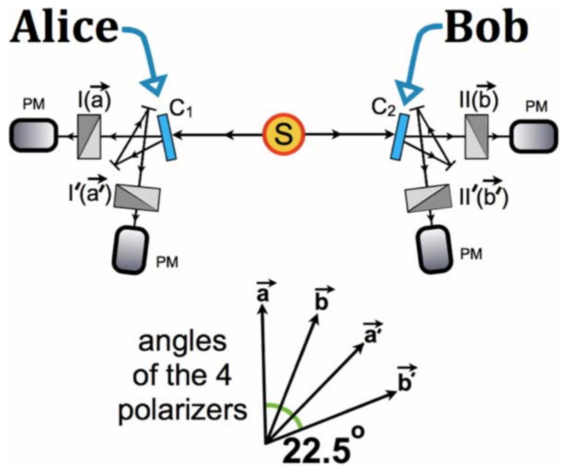

FIG. 1. (Color online) This is the experiment that CHSH designed and Aspect's team built. A pair of photons produced by calcium cascade is emitted from the source "S," traveling in opposite directions. C_1 and C_2 are optical switches that we may call "Alice" and "Bob." Alice's switch systematically allow each photon on the left to travel straight to polarizer $I(\vec{a})$ oriented at the angle of vector $\vec{a}=90°$, or to be deflected toward a different polarizer $I'(\vec{a}')$ with angle of vector $\vec{a}'$ being 45°. Similarly, Bob's switch systematically allows his photon on the right to travel straight to a polarizer $II(\vec{b})$ at the angle $\vec{b}=67.5°$, or to be deflected toward a different polarizer $II'(\vec{b}')$ with the angle of $\vec{b}'=22.5°$. Each switch changes position every 10 ns, whereas each photon takes 40 ns to travel from the source to the switch. The term PM refers to a photo multiplier, which we are calling a "detector."

"Bob" is synonymous with the blue switch C_2. Alice assigns her photon to be tested at polarizer angle $\theta_1=90°$ (which is called $\vec{a}$ in the diagram), or at polarizer angle $\theta_1=45°$ (which is called $\vec{a}'$ in Fig. 1). Bob assigns his photon to be tested at polarizer angle $\theta_2=67.5°$ (which is called $\vec{b}$ in the diagram), or at polarizer angle $\theta_2=22.5°$ (which is called $\vec{b}'$ in the diagram).

Figure 2 is a conceptual interpretation of the Aspect 1982 experiment. Here, the polarizers are rotated during the flight of the photons (i.e., "delayed choice") to angles θ_1 and θ_2. The Aspect experiment did not use a full range of polarizer angles. In that experiment, Alice made a binary selection $\theta_1=90°$ versus $\theta_1=45°$ every 10 ns, and Bob made an independent binary selection $\theta_2=67.5°$ versus $\theta_2=22.5°$. At the time of photon emission the angles were not yet determined, and when the angles were selected (during the flight of the photons), Alice and Bob made their decisions independent of one another. The results were consistent with a correlation rate of $\cos(\theta_2-\theta_1)$. The probability of two photons being detected simultaneously would be the square of that.

A different kind of 2-photon source used in subsequent Bell test experiments with delayed choice might find the correlation rate consistent with $\sin(\theta_2-\theta_1)$. Whether the correlation data are consistent with $\cos(\theta_2-\theta_1)$ or $\sin(\theta_2-\theta_1)$ depends on the internal architecture of the 2-photon source, as we will discuss later.

Bell inequalities provide bounds on the maximum values of certain variables in a local hidden variable theory such as that proposed by EPR. By showing that those variables sometimes exceed that bound, an experiment can show that

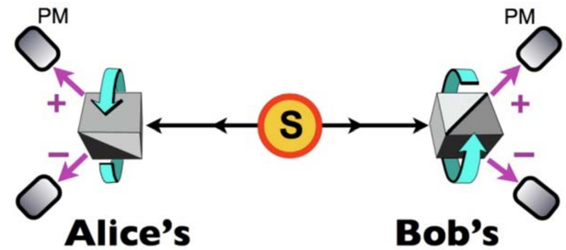

FIG. 2. (Color online) This is a conceptual diagram of a Bell test experiment with delayed choice, testing a pair of photons at polarizers. During the photons flight from the 2-photon source S, Alice and Bob rotate their polarizers to random angles θ_1 and θ_2. Only data from the "+" side of each polarizer are used.

such a local realistic theory cannot explain the data. The Bell inequalities for the Aspect experiment can be stated,[14]

$$-\beta \le (C(\vec{a},\vec{b})+C(\vec{a},\vec{b}')+C(\vec{a}',\vec{b})-C(\vec{a}',\vec{b}')) \le \beta, \quad (1)$$

where $\vec{a}$, $\vec{b}$, $\vec{a}'$, and $\vec{b}'$ are from Fig. 1, "C" refers to a correlation rate, and β is a real number. Cirel'son proved that the maximum value of β is 2 for local realism, but $2\sqrt{2}$ for QM.[15] The hypothesis which Aspect *et al*. rejected in this experiment was that $\beta\le 2$.

Our goal is to rethink the Aspect 1982 experiment starting with a different set of assumptions. Different starting assumptions will lead to different conclusions. The model we propose will continue to reject the hypothesis that $\beta\le 2$, and therefore any local realistic theory of hidden variables will still be rejected.

When the Bell test experiments were designed, there were only two competing pictures of the quantum world: QM versus EPR. Now there is a third competitor (TEW), and the Bell test experiments were never designed to distinguish between QM and TEW.

IV. AN ELEMENTARY WAVE INTERPRETATION OF ASPECT'S EXPERIMENT

The elementary wave hypothesis is that everywhere in nature there are rays of all wavelengths and all polarizations, traveling in all directions, at the speed of light. The top diagram in Fig. 3 shows two such rays approaching the photon source, coaxial, traveling in opposite directions. The bottom half of Fig. 3 shows that these two rays have passed through

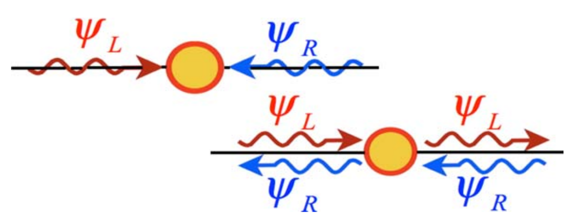

FIG. 3. (Color online) Elementary rays traveling in opposite directions through the photon source. In the top half of this diagram, an elementary ray from the left ψ_L and a similar ray ψ_R from the right, approach a 2-photon source (yellow circle in the middle). These rays do not come from Alice and Bob's polarizers. They are examples of the rays of all polarizations that exist in nature all the time. We are immersed in an invisible ocean of such countervailing bi-rays. The bottom half of Fig. 3 shows that the two rays have passed through the source and form a coaxial partnership.

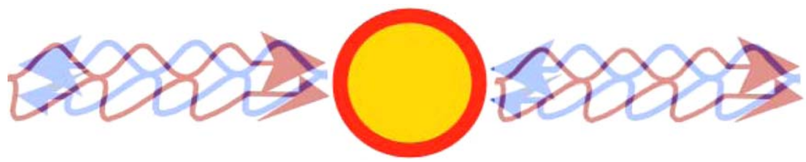

FIG. 4. (Color online) For each ray we define orthogonal eigenstates, all of which are coaxial. These eigenstates are shown in a different format in Fig. 5.

the source, to form a bi-flux or bi-ray, which we will refer to using the symbol: $\psi_L \rightleftarrows \psi_R$. Particles (in this case photons) follow this $\psi_L \rightleftarrows \psi_R$ contraption. The details are unknown. It is unknown how such a bi-ray would stimulate the emission of a pair of photons. It is unknown why or how a photon would follow such a bi-ray. According to this model, the photons would carry all the energy and momentum, the bi-rays none. On the other hand photons are never polarized, as we said earlier. They simply follow polarized bi-rays.

The rule is that the probability of a single particle following a $\psi_L \rightleftarrows \psi_R$ bi-flux is proportional to the amplitude of one ray (ψ_L) times the amplitude of its partner (ψ_R). This is a key mathematical difference between the theory of bi-flux and quantum math, in terms of how probabilities are calculated. Although our theory does not square amplitudes to get probabilities, we arrive at the same results.

The research question concerns the probability of a pair of photons being simultaneously detected by Alice and Bob. A rule of probability is that Pr(Alice and Bob) = Pr(Alice)•Pr(Bob). The probability of two photons following a $\psi_L \rightleftarrows \psi_R$ bi-flux is proportional to the amplitude of (ψ_L) on Alice's side of the experiment times the amplitude of (ψ_R) on Alice's side of the experiment, times the amplitude of (ψ_L) on Bob's side of the experiment times the amplitude of (ψ_R) on Bob's side. That last sentence is tricky, but is the key to understanding subsequent trigonometry.

Let us start with Alice and Bob holding their respective polarizers at fixed position θ_1 and θ_2. There is not yet any delayed choice. Alice's polarizer sends an elementary ray $\psi_{\rm ALICE}$ toward the photon source, of amplitude one, polarized at θ_1. Alice's polarizer is not the source of that elementary ray. Rather elementary rays are everywhere in nature, and one of them acquires a θ_1 polarization as it travels centripetally through Alice's polarizer toward the 2-photon source. The black dotted lines on the left side of Fig. 6 symbolize the mapping $\psi_{\rm ALICE}$ onto the four EIGENSTATES described in Fig. 5. The word EIGENSTATES (in capital letters), and how it differs in this article from eigenstates (in small letters) is defined in Fig. 5. When $\psi_{\rm ALICE}$ maps onto each of the four EIGENSTATES (A, B, C, and D in Fig. 6), the amplitudes can be calculated using cosines. The initial amplitude of $\psi_{\rm ALICE}$ is defined as one.

At this point, Alice and Bob are holding their respective polarizers at fixed positions θ_1 and θ_2 For row "A" (the top row of Fig. 6), the probability of Alice observing a photon will be $\cos(\theta_1 - V)\cos(\theta_1 - V)$. Likewise, the probability of Bob observing a photon will be $\cos(\theta_2 - V)\cos(\theta_2 - V)$. Combining these, the probability of Alice and Bob simultaneously detecting a photon will be $\cos(\theta_1 - V)\cos(\theta_1 - V)\cos(\theta_2 - V)\cos(\theta_2 - V)$. That is for the top row of Fig. 6, i.e., for one of the four EIGENSTATES.

Another rule of probability is that if something can happen in any one of four ways, then Pr(A or B or C or D) = Pr(A) + Pr(B) + Pr(C) + Pr(D). Therefore, we add together the four EIGENSTATES (i.e., the four rows A, B, C, and D) in Fig. 6. When we work out the cosines for each of

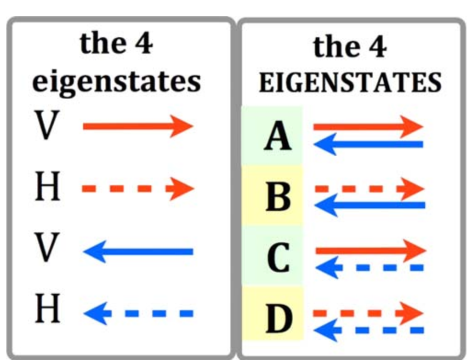

FIG. 5. (Color online) On the left are red and blue arrows that symbolize the four eigenstates mentioned in Fig. 4: two of them vertical (V) and two horizontal (H). The red arrows are the vertical and horizontal eigenstates of ψ_L and the blue arrows are the eigenstates of ψ_R. Now, we will discuss the right side of the diagram. We will use the same word "EIGENSTATE" to mean something different when it is spelled with capital letters. Each EIGENSTATE ("A," "B," etc.) consists of a combination of the two arrows from the left. The EIGENSTATES on the right are four orthogonal states of the entire bi-flux $\psi_L \rightleftarrows \psi_R$.

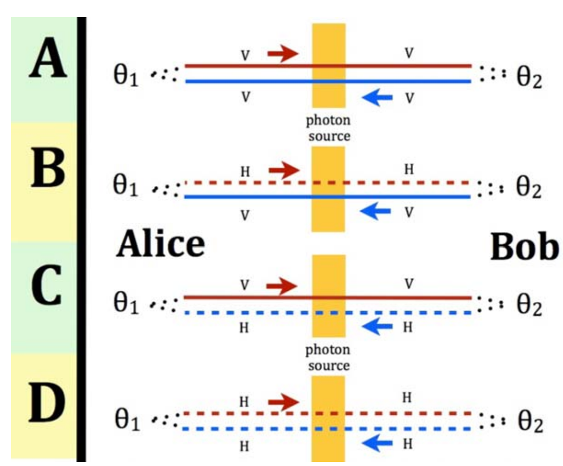

FIG. 6. (Color online) From this diagram our trigonometry will arise. This diagram concerns the orientation of the eigenstates (shown in red and blue), and how the polarized rays $\psi_{\rm ALICE}$ and $\psi_{\rm BOB}$ map onto the $\psi_L \rightleftarrows \psi_R$ bi-rays. That mapping is represented as black dots. $\psi_{\rm ALICE}$ is polarized at θ_1 (on the left). We use the symbol θ_1 to refer to $\psi_{\rm ALICE}$, and we use the symbol θ_2 to refer to $\psi_{\rm BOB}$.

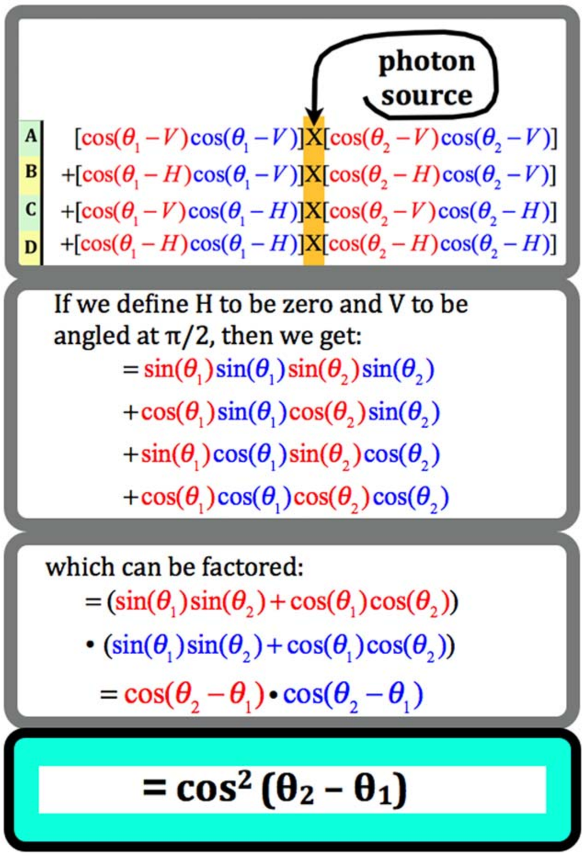

FIG. 7. (Color online) Here four boxes are stacked vertically. The color red always refers some amplitude of ψ_L (meaning part of the elementary ray travelling left to right), and the color blue refers to an amplitude of ψ_R. The top box comes directly from Fig. 6, and shows the probability of both Alice and Bob seeing a photon simultaneously. The next box is a simplification of the previous formula, based on us defining the angle of polarization of H to be zero, and V to be $\pi/2$. Simple trigonometry leads to the bottom two boxes. The bottom box shows that the probability of both Alice and Bob seeing a photon simultaneously is $\cos^2(\theta_2 - \theta_1)$. This is the same result as Aspect 1982 found.

the rows, and add the rows together, we get the equation shown in the top box of Fig. 7. Figure 7 shows how that equation can be simplified. The probability of Alice and Bob seeing a simultaneously (Fig. 7, bottom box) is $\cos^2(\theta_2 - \theta_1)$. Thus TEW comes up with the same results as did the Aspect 1982 experiment.

Aspect *et al*. used a calcium cascade source that had an internal architecture such that the correlation of Alice and Bob's data was proportional to $\cos(\theta_2 - \theta_1)$. We presume that their 2-photon source was arranged HH–VV. If another Bell test experiment were conducted with a 2-photon source with a different internal architecture (such as HV–VH), then elementary rays would rotate by $\pi/2$ as they traveled left to right through the source, and $-\pi/2$ as they traveled right to left, as shown in Fig. 8. When you work out the trigonometry for Fig. 8, the probability of Alice and Bob simultaneously seeing a photon would be proportional to $\sin^2(\theta_2 - \theta_1)$. The correlation rate would be the square root of that.

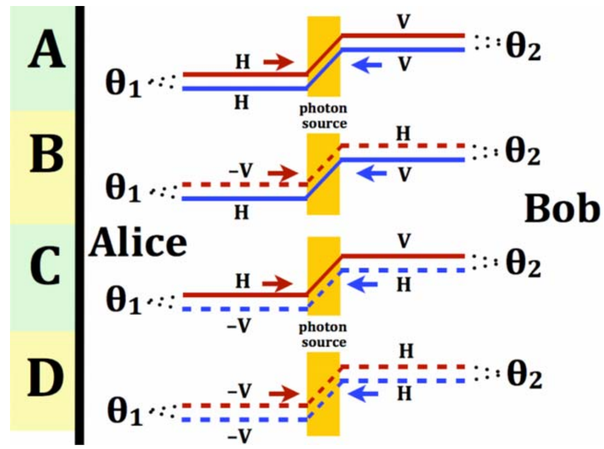

FIG. 8. (Color online) This diagram assumes a different photon source than Fig. 6. Here, the internal architecture is assumed to be HV–VH (Figure 6 assumed HH–VV). Now elementary rays rotate by $\pm\pi/2$ as they travel through the source. This rotation is symbolized by the kink in the red and blue lines as they pass across the yellow rectangles in the center. When you work out the trigonometry, this would lead to a probability of $\sin^2(\theta_2 - \theta_1)$ that Alice and Bob will simultaneously detect a photon.

V. INTERNAL STRUCTURE OF THE $\psi_L \rightleftarrows \psi_R$ BI-FLUX

We will now explore the structure of this bi-flux. Let us say that Alice and Bob have cousins named Ann and Bill. These cousins borrow the apparatus that Alice and Bob used. Ann and Bill conduct a series of "N" experiments. We are looking at the limit of those experimental results as N increases towards infinity.

Throughout each experiment, Ann and Bill hold their polarizers at fixed angles ξ_1 and ξ_2, respectively: i.e., no delayed choice. In a series of N experiments, they systematically explore every possible angle ξ_1 and every possible angle ξ_2. They use the graph paper shown in Fig. 9, as a place to chart every possible (ξ_1, ξ_2).

Ann and Bill discover that for every point (ξ_1, ξ_2) on the graph the probability that they will simultaneously see a pair of photons is $\cos^2(\xi_2 - \xi_1)$. This is consistent with what Alice and Bob previously discovered.

This shows us the internal structure of the $\psi_L \rightleftarrows \psi_R$ bi-flux. The entire experiment, including the photon source, is bathed in this bi-flux from before the experiment began. Furthermore according to TEW, when photons are born and emitted, it is in response to this impinging bi-flux. The internal structure of the bi-flux is shown in Fig. 10.

Consider the photons located 1 Å on either side of the source. The photons act as if they were "entangled," but the cause of that apparent entanglement is that they are both

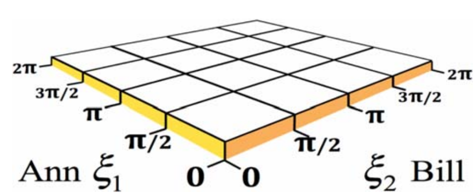

FIG. 9. (Color online) Every possible relationship between angles ξ_1 and ξ_2. Since the range of each of these variables is 0 to 2π, and both are continuous, therefore it is possible to chart all (ξ_1, ξ_2).

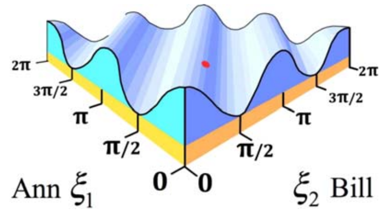

FIG 10. (Color online) This diagram shows the internal structure of the $\psi_L \rightleftarrows \psi_R$ bi-flux, as discovered by Ann and Bill's experiments. Both photons are emitted in response to this bi-flux, and follow it throughout their flight. If we test the two photons by means of polarizers set at angles ξ_1' and ξ_2', respectively, then the probability (Z or vertical axis) of simultaneously seeing a pair of photons is $z = \cos^2(\xi_2' - \xi_1')$, as shown in this diagram. The red dot will be explained later.

attached to the same bi-ray. The internal structure of that bi-ray is shown in Fig. 10. Neither photon is polarized (i.e., neither is following a polarized bi-ray). If we were to test the photon on the left by means of a polarizer angled at ξ_1' and test the right photon by means of a polarizer angled at ξ_2' and plot that probability on the "Z" axis, then we would find the probability of that pair of photons being seen at the "+" channel of those two polarizers to be $z = \cos^2(\xi_2' - \xi_1')$, as shown in Fig. 10, which looks as if it were ocean waves.

QM observes this same phenomenon and says that the apparent "entanglement" is because the two photons are part of one wave function. According to our theory, the controlling factor in this experiment is the bi-flux, not the photons, and not the wave equation. The wave equation is a way of modeling the bi-flux.

The photons continue throughout their flight to be attached to this same bi-ray. It does not matter if we test them 1 Å or 1 km from the source, the results will always be the same as that predicted by Fig. 10.

VI. COMPARISON WITH "LOCAL HIDDEN VARIABLES"

We can think of the photons as subjected to external contingencies: "if x then y." Specifically, the contingencies are: "If the left photon (Fig. 10) is visible to Alice at a polarizer angled at ξ_1', then the probability of the right photon being seen by Bob at ξ_2' will be

$$\Pr(\text{Bob}) = \frac{\Pr(\text{Alice and Bob})}{\Pr(\text{Alice})} = \frac{\cos^2(\xi_2' - \xi_1')}{\Pr(\text{Alice})}.$$

Since a photon IS seen by Alice at ξ_1', therefore $\Pr(\text{Alice}) = 100\%$ or 1, which means

$$\Pr(\text{Bob}) = \cos^2(\xi_2' - \xi_1')."$$

These contingencies are embedded in the bi-flux, and determine (in a probabilistic way) the outcome of Alice and Bob's tests 1 km later. It is important to emphasize the location of these contingencies: they are not variables internal to each photon. They are part of the photon's environment.

Is not this a "local hidden variable" model. No! Why? Because the CHSH inequalities do not apply to our model.

In order to be subject to the CHSH inequalities, you have to fit the starting assumptions within which the CHSH inequalities were developed. Here are those assumptions:

> Suppose now that a statistical correlation of $A(a)$ and $B(b)$ is due to *information carried by and localized within each particle*, and that at some time in the past the particles constituting one pair were in contact and communication regarding this information. The information, which emphatically is not quantum mechanical, is part of the content of a set of hidden variables, denoted collectively by λ. The results of the two selections are then to be deterministic functions $A(a, \lambda)$ and $B(b, \lambda)$. *Locality reasonably requires $A(a, \lambda)$ to be independent of b and $B(b, \lambda)$ to be likewise independent of a*, since the two selections may occur at an arbitrarily great distance from each other. Finally, since the pair of particles is generally *emitted by a source physically independent of the adjustable parameters a and b*, we assume that the normalized probability distribution $\rho(\lambda)$ characterizing the ensemble *is independent of a and b*. (Emphases added)

Our bi-flux model does not fit this paragraph. Therefore, the CHSH inequalities do not apply to our model. This is a key issue. It is pivotal. It is why we say that our model exists outside the jurisdiction of the CHSH inequalities. There is another theory that does not fit within the starting assumptions of the CHSH inequalities. That other theory is called QM.

Our model does not sneak through some loophole in Bell's theorem. Our model exists in a foreign country where Bell's inequalities have no jurisdiction. Bell's theorem comes from an era when there were only two theories being debated: Einstein's view of separate objects versus QM's nonlocal view of interconnected objects. That is ancient history. Now there is a third contender. Although TEW is a local causal model of reality, it simulates nonlocal phenomena. It could be imagined to be like a world in which everything is connected to everything else by ineffable cobwebs, but every element of such cobwebs is local. There are experiments that will produce different outcomes if TEW is correct than if QM is correct, but the Bell test experiments cannot make that distinction.

VII. DELAYED CHOICE EXPERIMENTS BY ALICE AND BOB

Let us review where we are: Ann and Bill had systematically explored the relationship between every possible angle ξ_1 of Ann's polarizer, and every possible angle ξ_2 of Bob's polarizer. Figure 9 was a plot of every possible point (ξ_1, ξ_2). For each such point, it was found that the probability of Ann and Bill's equipment simultaneously seeing a pair of photons is $\cos^2(\xi_2 - \xi_1)$.

Now Ann and Bill depart. Alice and Bob take their equipment and conduct a different series experiments. While the photons are in flight, Alice and Bob rotate their polarizers independently of each other. In the last nanosecond before a

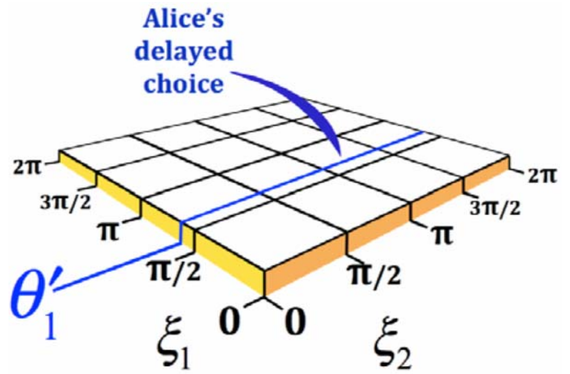

FIG. 11. (Color online) When Alice makes a delayed choice of angle θ_1', we can plot that on the graph as a blue line. Since $0 \le \theta_1' < 2\pi$ and $0 \le \xi_1 < 2\pi$, and both are continuous variables, there must be some value of the variable ξ_1 for which $\theta_1' = \xi_1$. Since we know that everywhere on this graph $\Pr(\xi_1, \xi_2) = \cos^2(\xi_2 - \xi_1)$. Therefore, we know that everywhere on Alice's blue line the probability will be $\Pr(\theta_1', \xi_2) = \cos^2(\xi_2 - \theta_1')$.

photon is detected, each of them fixes her or his polarizer at a random angle, which we will call θ_1' and θ_2'. This is delayed choice.

No matter what angle θ_1' Alice chooses, there is always some value of the variable ξ_1 which will be identical, so that $\theta_1' = \xi_1$. They are both continuous variables with a range of 0 to 2π. We can plot Alice's choice on the graph (Fig. 11).

Meanwhile, 2 km away, Bob is rotating his polarizer in a delayed manner to a random angle θ_2'. The value of θ_2' cannot be known in Alice's neighborhood for another 6.6 μs (assuming nothing travels faster than light). Since $0 \le \theta_2' < 2\pi$ and $0 \le \xi_2 < 2\pi$, there is some value of the variable ξ_2 for which $\theta_2' = \xi_2$. We represent that on the graph as a green line (Fig. 12).

To reiterate: It was previously established by Ann and Bill, for all values of (ξ_1, ξ_2) that $\Pr(\xi_1, \xi_2) = \cos^2(\xi_2 - \xi_1)$. There is some value of the variable ξ_1 for which $\theta_1' = \xi_1$ and some value of the variable ξ_2 for which $\theta_2' = \xi_2$. So we can substitute variables and find the probability (of Alice and Bob simultaneously seeing a photon) at the red dot is $\Pr(\theta_1', \theta_2') = \cos^2(\theta_2' - \theta_1')$.

This is the same result as was found by Aspect.

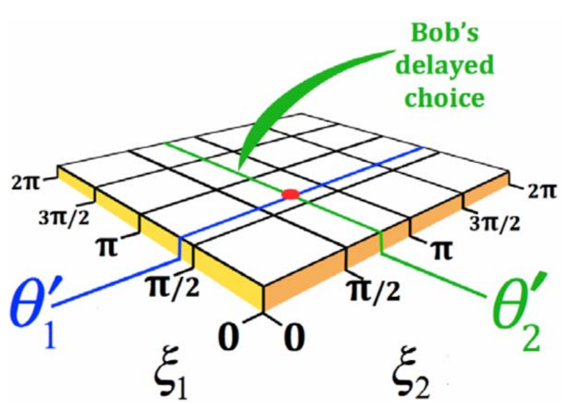

FIG. 12. (Color online) When Bob makes a delayed choice of angle θ_2', we can plot his choice as a green line, on the same graph. We place a red dot wherever Bob's line at θ_2' happens to intersect Alice's line θ_1'. No matter where that red dot is located, we know that the probability of Alice and Bob simultaneously seeing a photon will be $\cos^2(\theta_2' - \theta_1')$.

Therefore, we have shown that which we set about to show. We have shown that our bi-flux model finds the same probabilities as did Aspect *et al*. We have shown that it does not matter how far away from the photon source this test is made. Delayed choice does not affect the results in any way.

VIII. CRITICISM OF OUR MODEL

One critic said of this article that it presented a "nonlocal theory, and we know that nonlocal theories are able to reproduce the results of QM. TEW is a particularly obtuse nonlocal theory. Given nonlocality, why bother with the complexity of TEW?"

This same critic also said that the bi-flux described in this article is "static," a kind of invisible property that is always present. Both these statements misrepresent the article.

The distinction between "nonlocal" and "local" was developed to distinguish between QM and Einstein's ideas, but does not apply to TEW. Ours is a local model of reality that appears to be nonlocal, i.e., the bi-flux simulate nonlocal phenomena. It is local because it consists of waves (or biwaves) traveling at the speed of light. An event at one time and place interacts with that bi-flux locally, which conveys the signal to the adjoining bit of bi-flux, etc. The advantage of this theory over theories that are nonlocal is that ours is a local causal model to explain the phenomena of the Alain Aspect experiment, and this model is independent of the observer. Ours is the only theory to make this claim. The other local causal model, the EPR model, was disproved by Aspect's experiment. Now, there is a new local causal model that is different than EPR.

Einstein was a champion of local physical reality. His discredited EPR model is not the only way that local realism can be portrayed. If there is such a thing as physical reality independent of the observer, then local cause-and-effect phenomena must exist in order to explain those QM phenomena that appear to be "nonlocal."

The bi-flux model proposed in this article fits those criteria. Why bother with our so-called "obtuse model"? Our model rescues local realism from the trash heap of discarded concepts in quantum physics. If you are fond of the idea that local physical nature exists and is independent of the observer, then there are no competitor models to choose from. Ours is the only game in town.

The other criticism is that the bi-flux is "static." This is a misunderstanding. Our model is "static" the way an automobile is static when sits in a parking lot. It does not move until someone gets in, starts the engine, and drives it off. Then it becomes dynamic.

During the Aspect experiment, nothing was done to change the bi-flux. It is like a car sitting in a parking lot. If you want a dynamic experiment, it would require a different experimental design. Let us imagine a different experiment in which the engine of the car starts up and it drives off. Supposing we were to change the architecture of the 2-photon source during the experiment: imagine that the 2-photon source could be changed in 1 ns from an HH–VV architecture to a different source with an HV–VH architecture. The

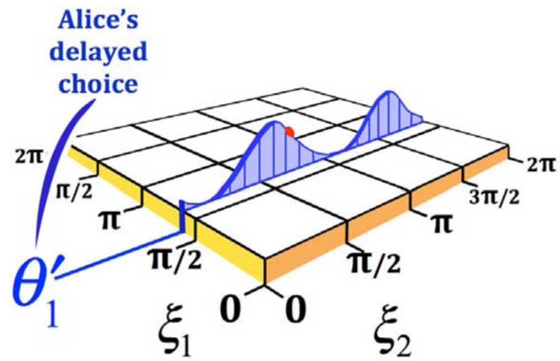

FIG. 13. (Color online) When Alice makes a delayed choice of her polarizer angle (θ_1'), Bob's selection of his angle cannot be known in Alice's neighborhood for another 6.6 μs (because of the speed of light). The blue curve in this diagram shows a wide range of possible correlation rates (shown as vertical blue lines) that would be consistent with Alice's choice of θ_1', depending on different possible choices by Bob. Alice has no idea which is the correct one. Therefore, according to our critic, if we choose one specific correlation rate (the red dot), then we imply that information from Bob's polarizer was acquired by Alice instantaneously.

bi-flux would instantly change. The next pair of photons emitted would travel out from the source at the speed of light. Prior to that change arriving at the detectors, Alice and Bob would find that the probability seeing a photon simultaneously is $\cos^2(\theta_2 - \theta_1)$. After that change, it would be $\sin^2(\theta_2 - \theta_1)$.

That same critic said we present no empirical data to show that our bi-flux theory is correct. He overlooks the fact that the Alain Aspect experiment provides exactly the evidence that supports our theory.

That same critic said something that we will quote at length because it is so important: "It is emphasized by Boyd that the bi-ray has this information 'built-in,' so that there is no need for information to propagate, thus making the notion of delayed choice irrelevant. However, this is nothing more than smuggling in the assumption of information propagating at infinite velocity ('spooky actions at a distance'), since there is no way to locate the photon pair on the surface of [the red dot on the curve shown in Fig. 10] without both angles being known at the current location of both photons. While the 'holistic' nature of TEW is emphasized, this feature is not materially different than David Bohm's gloriously nonlocal quantum potential theory."

This is important: Fig. 13 portrays the concept of the instantaneous transmission of information from Bob to Alice, but does not correspond to the actual experiment conducted by Aspect *et al*. Aspect did not calculate the correlation rate at the instant when Alice made her choice. It was calculated more than 6.6 μs later. Perhaps it was calculated the next day. What actually happened is that the experimenters knew the data from both Alice and Bob. Then they calculated the correlation rate. Therefore, Fig. 13 is not supported by the data from the Aspect experiment. The concept of the instantaneous transmission of information from Bob to Alice is an interesting idea, but it is not an idea that is supported by the Aspect experiment.

A different critic said, "This paper explores some of the implications of the theory of elementary waves (TEW). I do not personally buy this alternative, but the need for some kind of improvement of quantum mechanics is quite clear, and every candidate deserves its day in court."

The fact that our model looks weird and bizarre is, paradoxically, an advantage. Why? Think about it: for a century hundreds of the greatest geniuses of all time including dozens of Nobel laureates spent their lifetimes trying to figure

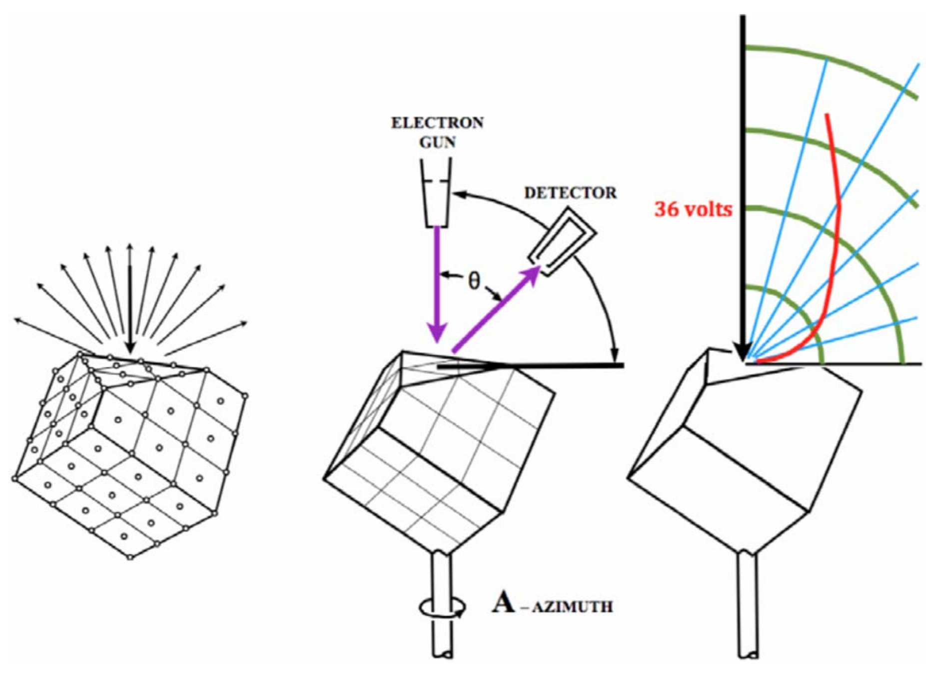

FIG. 14. (Color online) These diagrams, from Davisson,[17] show a cut nickel crystal lattice (left), from which electrons are scattered when they are shot straight down from above (center). There are two variables controlled by the experimenters. The voltage of the electron gun can be adjusted, which determines the velocity of the electrons. The angle θ of the detector can be changed. On the right is a graph of data when the electron gun is set at 36 V.

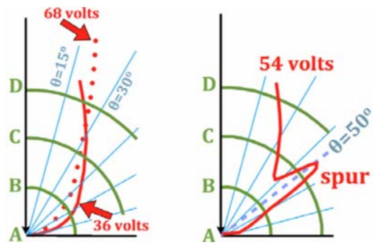

FIG. 15. (Color online) These 2 diagrams show data from Davisson.[17] On the left, the graphs for electrons fired at 36 and 68 V are shown as a solid line and a dotted line, respectively. The green circular arcs (B, C, and D) represent different amounts of current measured at a galvanometer, when an electron is detected. The diagram on the right shows the graph for electrons fired at 54 V. Here, an unusual spur appears at $\theta = 50°$. This "spur" is the central focus of all claims about "wave particle duality."

out how quantum mathematics could relate to any picture of the real world. Every plausible concept was examined and discarded. If there is such a thing as a picture of the physical world that corresponds to quantum math, then it must be some implausible idea. Since our idea is implausible, therefore it is a perfect candidate.

IX. CONCLUSIONS

This article proposes that elementary bi-waves can explain the results of Aspect *et al*. delayed choice experiment, published in 1982. With this explanation, there is no need for the concept of information transmitted instantaneously. The idea of entanglement is unnecessary. Nor is there any need for the concept of nonlocal.

Thus elementary waves appear to meet some of the minimum requirements for a QM alternative. TEW has not yet proved that it can explain a substantial amount of quantum mathematics. That issue is outside the scope of this article.

ACKNOWLEDGMENTS

This article is based on my interpretation of Lewis E. Little's TEW theory as of 2012 conversations he and I had.

APPENDIX: WAVE PARTICLE DUALITY

Although this article is about a reinterpretation of the Aspect experiment, many readers are hesitant to accept the starting assumptions of TEW, because those assumptions imply a rejection of wave particle duality, a cornerstone of QM that allegedly rests on considerable empirical evidence. We will briefly address that issue. We propose that one's starting assumptions shape how data are interpreted. We will briefly review the experiment by Davisson and Germer,[16] shown in Figs. 14 and 15.[17]

When the electron gun is set at voltage 36 or 68 V, the electrons scatter like particles bouncing off the surface of the crystal, which means that there are smooth lines of data in Fig. 15(a) (left diagram). But when the voltage of the electron gun is set at 54 V, there is a spur in the data (see Fig. 14(b), right diagram), at $\theta = 50°$. This spur can only be explained if there are waves of wavelength $\lambda = 1.67\,Å$ refracting through the crystal.

Every textbook of physics says that Davisson and Germer "proved" wave particle duality. But that is an overstatement. A more cautious statement would be: that Davisson and Germer proved that there are electrons and waves present in their experiment, and that they interact.

There are at least two other ways that waves and electrons could interact. One is the introductory level of TEW, according to which waves of 1.67 Å would come out of the detector, refract through the nickel crystal, and then electrons of 54 V would follow the waves backwards. Another is the bi-wave theory discussed in this article, according to which bi-flux of 1.67 Å would refract through the crystal and then, subsequently, an electron of 54 V would follow that bi-flux. Textbooks of physics should state things more cautiously, as follows: "Davisson and Germer proved that wave particle duality is *one* of the ways in which electrons and waves could interact."

In conclusion, the Davisson and Germer data are consistent with TEW.

[1] J. H. Boyd, Phys. Essays **25**, 390, (2012); *ibid*. **26**, 100 (2013).
[2] V. Jacques, E. Wu, F. Grosshans, F. Treussart, P. Grangier, A. Aspect, and J. R. Roch, Science **315**, 966 (2007).
[3] Y. H. Kim, R. Yu, S. P. Kulik, Y. H. Shih, and M. O. Scully, Phys. Rev. Lett. **84**, 1 (2000).
[4] A. Aspect, J. Dalibard, and G. Roger, Phys, Rev. Lett. **49**, 1804 (1982); A. Aspect, P. Grangier, and G. Roger, Phys, Rev. Lett. **47**, 460 (1981); *ibid*. **49**, 91 (1982).
[5] L. E. Little, Phys. Essays **9**, 100 (1996); *Theory of Elementary Waves* (New Classics Library, New York, 2009); URL=http://www.youtube.com/user/tewlipdotcom (access date January 19, 2013).
[6] J. H. Boyd, http://elwave.org/1501-2/physics_essays_b/ (access date 5/4/2013).
[7] J. H. Boyd, http://elwave.org/1501-2/physics_essays_a/ (access date 5/4/2013).
[8] F. Selleri, Found. Phys. **12**, 1087 (1982).
[9] C. A. Fuchs A. Peres, Phys. Today **53**, 70 (2000).
[10] J. J. Binney, http://www.youtube.com/playlist?list=PLE73AA240E8655D16 (access date May 26, 2013).
[11] J. S. Bell, Physics **1**, 195 (1964).
[12] A. Einstein, B. Podolsky, and N. Rosen, Phys. Rev. **47**, 777 (1935).
[13] J. F. Clauser, M. A. Horne, A. Shimony, and R. A. Holt, Phys. Rev. Lett. **23**, 880 (1969).
[14] S. L. Braunstein, A. Mann, and M. Revzen, Phys. Rev. Lett. **68**, 3259 (1992).
[15] B. F. Cirel'son, Lett. Math. Phys. **4**, 93 (1980).
[16] C. J. Davisson and L. Germer, Nature **119**, 558 (1927).
[17] C. J. Davisson, Bell Syst. Tech. J. **7**, 90 (1928).