A TRIADIC THEORY OF ELEMENTARY PARTICLE INTERACTIONS AND QUANTUM COMPUTATION

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To Reinhardt Lane, visionary and friend

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Preface

This monograph summarizes an attempt to demonstrate that there are direct applications of Peirce's Logic of Relations, in particular, the Sign Relations, to the theory of elementary particles and their interactions. Further, the Peircean logic leads to new ideas on the construction of computers which function at the quantum level.

This application of Peircean logic is not surprising when one considers that Peirce was by profession an experimental and mathematical physicist over most of his productive years. It is reasonable that his work in logic might be applicable to physics. We do not speculate on why this application has not previously occurred. We also do not speculate how the direction of the currents of Twentieth Century physics might have been altered if Peircean logic had been understood and used. However, it is our hope that a reading of this monograph might inspire such speculation on the part of the reader.

Specifically, we show here that there is a direct correspondence between a bonding scheme of Peirce's triadic sign diagrams and a representation of interactions between elementary particles. Thus, a complete history of a set of interacting particles can be modeled by a set of interconnected triadic diagrams.

Also, we find that there are fortuitous physical parallels with Peirce's principles of Tychism (chance) and Synechism (continuity).

The resulting model is facilitated by some alternative concepts in elementary particle physics, including Einstein's needle radiation, advanced fields, Brittingham waves, and a wave function which can be interpreted as the amplitude of single particle fields rather than a probability distribution. This leads, incidently, to the possible resolution of several ancient conundrums in quantum theory including hidden variables, spooky action at a distance, and collapse of the wave function.

We mentioned that a significant contribution of this description of elementary particle interactions is to provide a new rationale for the design of quantum computers. This application has led far enough to produce a United States patent (Beil and Ketner (2004)). This is appropriate indeed since Peirce himself designed an electrical computing machine (Ketner (1984,1988)).

This monograph is written so as to require a background level not far beyond that of the "intelligent layperson," either in logic or physics. For example, there are no displayed equations. More detailed and technical versions of the material have been published or are in preparation (Beil and Ketner (2003,2004), Beil (2004)).

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I. Introduction

Charles Sanders Peirce (1839-1914) was a physicist employed (1860-1892) by the United States Coast and Geodetic Survey as Geodecist and expert in the Logic of Science (on Peirce's life, see Fisch (1986), Eisele (1979), Samway (1995), Ketner (1998)). In 1877 he was elected to the National Academy of Sciences on the basis of his work in scientific logic (Quine, 1999). Peirce was one of the developers of mathematical logic in use today in applications such as computing (Putnam (1982), Ketner (1984, 1988), Dipert (1995), Quine (1995), Houser, et al. (1997)). Throughout his career he worked to develop a new logic of relations, which by 1897 burst forth as a completely functional diagrammatic approach to the subject, based within a graphical or topological method (Roberts (1973), Ketner (1986), Burch (1991)).

Peirce's ideas, though recognized as profoundly innovative, were not widely used in the physics of the 20th century. A notable exception is the work of David Finkelstein (1988, 1994, 1996) (Finkelstein and Galiautdinov (2001)) who has explored several avenues where Peirce's concepts might be illuminating, ranging from quantum theory to cosmology. Others who have pointed out possible applications are Christiansen (1993), Fernandez (1993), and Schmeikal (2000).

None of these proposed applications has been refined to the point of constituting a specific model which is an appliction of the principles of physics. We undertake this task in the present work.

The main feature of our model is the use of Peirce's relational logic. We employ a new method of diagrammatization with triadic sign relations which directly extends Peirce's insights into particle physics. The method also specifically relates to Peirce's principles of tychism and synechism (Peirce (1898, 1891-3)) as will be seen.

This work will proceed as follows:

In Chapter II we give a brief introduction to Peirce's Logic of Relations. A graphical representation of this logic is shown to give not only a very useful way of visualizing how the logical elements fit together (valency and bonding), but also a means for understanding fundamental principles of the logic. The basic nature of the triadic relation becomes more obvious. The type of triadic relation emphasized here, the sign relation, is introduced. Other relevant principles of Peirce, tychism and synechism, are discussed.

In Chapter III, three suggestive ideas—time-symmetric wave functions, advanced waves, and Einstein's needle radiation—are scrutinized. These ideas, separately and in combination, introduce an alternate way of looking at elementary particles. We are led to advocate a picture of elementary particles as individual wave bundles comprised of both advanced and retarded waves. These particles travel along (and are concentrated near) timelike or null paths which can point either forward or backward in time.

Chapter IV contains further physical preliminaries which justify certain features of the model, namely, that the theory refers to single particles or wave bundles which interact as quanta, not as fields. The particle interactions are visualized to occur in regions limited in extension in space and time. A correspondence with quantum theory is indicated along with a rationale for the application of triadic graphs.

In Chapter V the diagrammatic model itself is presented. Part A introduces the diagrams (called Peirce/Beil/Ketner (**PBK**) diagrams), Part B gives the correspondence of these diagrams with quantum theory, Part C focuses on a description of the internal structure of elementary particles, and Part D is a study of particle interactions which leads to issues concerning continuity.

Chapter VI presents an outline for the application of the **PBK** method to the design of quantum computers and also shows how the one-particle state picture relates to the conventional multiparticle state viewpoint.

Chapter VII is a concluding discussion of how our model can be applied to a resolution of several interpretational problems in quantum theory.

II. Peirce's Logic of Relations

Peirce distinguished three fundamental relational types, using a classification technique based on external relational structure. He described a relation as "a fact about a number of things." A dyadic relation, for example, is a fact about two things. Sentences in everyday language can be used to describe relations: for instance, "John is a friend of Howard." Here there is a fact about two things, John and Howard. If we generalize, it will be possible to think of "____ is a friend of ____" as a description of the dyadic relation of friendship. "The stove is black" is a fact about one thing, a property in other words. "Susan sold her car to Ike" is a triadic relation, a fact about three things. Table 1 summarizes these examples.

The above forms, which Peirce labeled **Rhemata**, are acquired by generalizing on the subject (or noun-like) elements in each relation. If we add a second generalization on the predicate (or verb-like) elements in the above examples, the forms of Figure 1 are realized.

Notice that Peirce's relational types in their final form are completely general and are in effect classifications on the basis of the external structure of each type, a feature Peirce labeled **Valency** . Thus, a monadic relation is any relation which, when fully generalized in both its subject and predicate aspects, has the external graphical form of a monad in Figure 1. Similar remarks can be made about dyadic relations, triadic relations, and so forth.

This valency aspect is important, because it provides a basis for discussing how relations can combine, or bond, to form more complex relations. Peirce referred to the noun lines in the above fully generalized relational forms by the name **loose ends**. If the loose end of one relation becomes identical with some loose end in another relation, those loose ends become one line, and are said to be **bonded**. What were two separate noun-like items in a previous state of information, because of new information (the new information that these two items are now identical) are now one item as the graphs show quite clearly. After bonding, their other relational properties stay intact. Each such bond, in this system, always involves two loose ends. The valency of a relational graph is the number of loose ends the graph possesses in a given state of information. From these considerations, the statements of Table 2 easily follow.

By as early as 1867, Peirce discovered some important properties of such completely generalized relational forms and their bonding patterns. His results are listed in Table 3.

Monadic relation	___________ is black
"Something is black"	
Dyadic relation	__________ is a friend of _________
"Someone is a friend of someone"	
Triadic relation	________ sold ______ to _______
"Someone sold something to someone"	
Tetradic relation	______ sold _____ to ______ for _______
"Someone sold something to someone for some amount"	

Table 1: Peirce's generalization of the subject aspect of relations

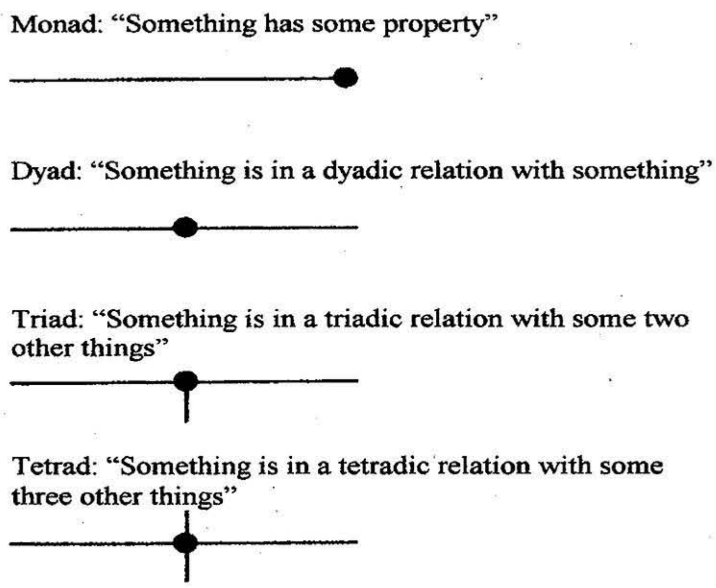
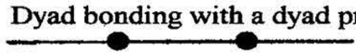


Figure 1: Peirce's graphical representations of elementary relational forms generalized on both subject and predicate aspects

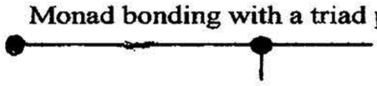
Monad bonding with a monad produces a medad (zero valent)

Monad bonding with a dyad produces a monad

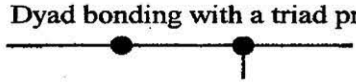
Dyad bonding with a dyad produces a dyad



Monad bonding with a triad produces a dyad



Dyad bonding with a triad produces a triad



Triad bonding with a triad produces a tetrad

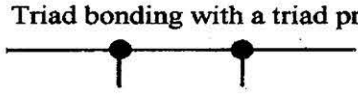


Table 2: Elementary bonding patterns in Peirce's graphical relational logic

REDUCTION PRINCIPLE:

No genuine triadic relation can be reduced to collections composed only of dyadic relations.

(Conversely: There is no collection of dyadic relations which will suffice to construct a genuine triadic relation.

COMPLETENESS PRINCIPLE:

All genuine relations of complexity greater than three (tetrads and above) can be constructed from triadic relations only.

Table 3: Peirce's Relational Principles

Peirce argued for the truth of these principles throughout his career, but subsequent researchers thought his demonstrations to be inadequate within contemporary levels of increased rigor in proof. However, due to work by Herzberger (1981), Ketner (1986), and Burch (1991), Peirce's hypotheses about relations have been established at the highest level of rigor. Thus, these ideas deserve to be labeled as *Principles*, for they have been successfully established.

Among relations that possess the triadic external form, perhaps the most important type was described as **Sign Relations** (or just **Signs**) by Peirce. A sign is a triadic relation involving an **Object**, a **Representamen**, and an **Interpretant**. Some obvious examples of **Signs** occur in communication. For instance, consider that in a classroom, a student suddenly raises her hand. This raised hand could be considered a reresentation (**Representamen**) of an idea (the **Object**) she has and wishes to express, this **Representamen** being understood by the instructor as "student wishing to participate in class discussion" which would serve to function to interpret the raised hand (such interpreting function being known as the **Interpretant**). The general sign relation is depicted in Figure 2 (where **S** is the triadic sign relation proper).

To summarize, an **Object** is that which the triadic sign relation "is about." A **Representamen** is a representation of the **Object**. The **Interpretant** functions: to ascertain what the **Representamen** (**R**) means, or to make **R** less indefinite, or to interpret **R**. Remarkably, it will be shown that there is a direct correspondence between the parts of a Peirce Sign Relation and the quantum mechanical description of a particle.

An important tool for routine work with Peirce's Logic of Relations is his crucial distinction between items that are real and items that exist. The basic condition for something being **Real** is that it have properties which are independent of any one person's hope, wish, desire, belief, command (one could make a long list here) about it. Alternatively one could say that reality is not brought into being by an ego's wish, desire (etcetera). Something that is real is the opposite of being arbitrary. This notion is closely associated with the contemporary idea that each scientific investigator should be disinterested (one's ego should not be involved as a determiner of the outcome of a scientific investigation).

Items which **Exist** comprise a subset of reals. In particular, existents are object-like in the everyday sense, and typically involve brute or unintelligent reactions. Examples of existing things are cars, rocks, trees, buildings.

In some ways of approaching the basic ideas of science, existents are considered as fully exhausting the stock of world realities. Peirce argued for a different route (Peirce, 1931-1958): namely, that in addition to existents, there is another subset of reals which one could identify as items that are real but do not exist. Relations are fine examples of this subset of **Nonexisting Reals**.

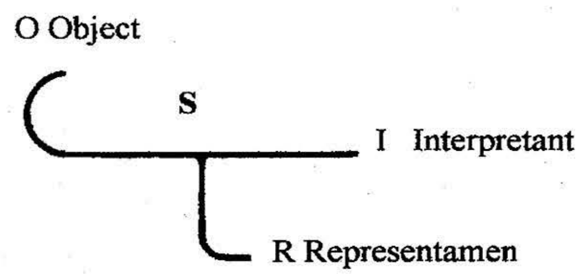


Figure 2. Peirce's general sign relation expressed in his graphical logic of relations

Consider a simple relation such as "The coffee is in my cup." This is a fact about these two things that comprises more than the coffee and the cup alone, and if true, being a fact, the nature of the relation is independent of any one person's hope or wish about the situation. One could have spilled one's coffee, and wished that the accident had not happened. But it is a fact that it did spill. Such relational facts are realities, but the presence of a relation is not an existent: relations have no weight, no color, no metric properties as relation. However, relations are factual and real, and are found very commonly in our daily lives, perhaps so commonly so that they are easily overlooked as one establishes the basic tools of science.

Because existents as well as other phenomena can be described in terms of Peirce's logic of relations, Peirce came to the conclusion that all of reality is composed fully of relations.

Sometimes physicists have sought to avoid the question of the reality status of the phenomena they study, and in some cases reply to questions along that line with comments such as, "We don't raise that question about reality–we just run the equations." Since mathematical equations are expressions of relations, we regard this remark to be equivalent in practice to Peirce's conclusion that reality as a whole is indeed composed of relations.

In addition to the logic of relations, two other fundamental aspects of Peirce's analysis will be employed, tychism and synechism.

Tychism is the principle that there is an element of chance in physical processes. Significantly, Peirce advanced this principle several decades before the formulation of quantum theory.

Synechism is the principle that there is a basic continuity in physical reality. This goes beyond the continuity of space-time (Riemannian spaces) to a statement that there are potentials which merge or superpose to become a unified whole. Finkelstein (1996) relates this to quantum condensation. Here, in another quantum approach, we will develop the idea of a continuity of interaction.

III. Time Symmetry, Advanced Potentials, and Needle Radiation

In this section we concentrate on physics and bring up three interrelated concepts which will be of considerable use in developing the application of the above Logic. First, our triadic scheme has some ideas in common with quantum theories which are time-symmetric. Mainly, we incorporate wave functions which propagate backward in time. Second, we use advanced waves both as components of particle wave functions and as total wave packets. Third, the existence of these wave bundles, both advanced and retarded, allows a specific mathematical realization of Einstein's needle radiation.

Time-symmetric quantum theories have been advocated by Aharonov, Bergmann, and Lebowitz (1964), Csonka (1969), Costa de Beauregard (1979), Sutherland (1983), Cramer (1986, 1988), Rayski (1988), Davies and Twamley (1993), Price (1996), and Vaidman (1998). It is quite easy to see that this type of theory can solve the well-known problems related to nonlocality or "spooky action-at-a-distance." If one accepts the main assumption of time-reversed states, then there is a plausible resolution of some traditional Copenhagen dilemmas. The book by Price (1996) argues this in detail.

The role of advanced potentials in fundamental physics was explored by Wheeler and Feynman (1945) who considered spherical waves. Subsequent discussion of advanced fields in cosmology was given by Hoyle and Narlikar (1974).

Following the remarkable discovery by Brittingham (1982) of localized, dispersionless wave packet solutions of homogeneous wave equations, it was shown by Besieris, Shaarawi, and Ziolkowski (1989) that these solutions are bidirectional in time, that is, they are superpositions of advanced and retarded waves. Heyman (1989) pointed out the noncausal nature of these solutions. Hillion (1992a) showed that these wave packets can satisfy the Dirac equation and also (Hillion, 1992b) that it might be possible to construct a model of the photon. Beil (1993) proposed a model of the electron using the Brittingham solutions and also (Beil, 1997, 2002) an actual wave-particle model of the photon.

To understand the argument for needle radiation, imagine a spherical electromagnetic wave going backward in time from an infinite number of distant sources and coherently converging at a point. This is the assumption of Wheeler and Feynman. Now imagine a single advanced photon traveling backward in time along a particular path and arriving at the point. Which is more likely?

The idea of radiation being ultimately reducible to single photons propagating along null lines goes all the way back to Einstein (1917) who convincingly advocated Nadelstrahlung, "needle" or unidirectional radiation, over Kugelstrahlung, spherical (including plane wave) radiation. Einstein proved, in several papers in 1916-1917, that only the needle-like radiation of single photons along null paths could satisfy the requirements of relativistic covariance.

This work of Einstein has been largely forgotten, but was effectively recalled by Cormier-Delanoue (1989) who gives complete references. The needle-like radiation composed of single photons is a direct continuation of the epoch-making 1905 discovery of radiation quantization. There is now extensive experimental confirmation of the primary role of needle radiation, for example, in measurements of the recoil of emitting atoms (see Cormier-Delanoue, 1989). The impossibility of spherical wave radiation from atoms is also discussed by Milonni (1997).

It has been thought that needle radiation was somehow not compatible with Maxwell's classical electrodynamics. However, the discovery of the Brittingham wave packets has led to the proof that single photons on null paths are derivable in the Maxwell context (Beil, 1997). The theory includes advanced as well as retarded photons (Beil, 2002).

IV. Physical Preliminaries

In this chapter other physical ideas are explored which contribute to the picture of quantum theory as a theory which can refer to single particles.

The model to be outlined applies to the particles presently understood to be "elementary." We consider, however, at first only the stable particles such as electrons, photons, and protons. Primarily, we are trying to develop parallels with Quantum Electrodynamics and will leave more difficult symmetries for future study.

Another basic assumption here is that the only contact an elementary particle (EP) has with the external world is through interactions with other EPs. All we know about the physical parameters of a particle are the values conveyed to measuring instruments by other EPs acting as observers.

This means that we take field quantization quite seriously in that all interactions are mediated by exchanges of virtual particles. For example, the electromagnetic field influences a charged particle only through "scattering" of its virtual photons. Thus, the electromagnetic field as it produces a Lorentz force on an electron is an average of many two-particle interactions between photons and the electron.

The point is that a large part of physics is contained in the study of two-particle interactions. This is reminiscent of the S-matrix approach or the use of Feynman diagrams. These are both related to the present model.

A further point to be emphasized is that quantum mechanics must be a theory of individual particles and not a theory of probabilities. The Copenhagen Interpretation is just no longer viable. This has not yet been fully assimilated by many physicists, but it has been overwhelmingly demonstrated by experiments ranging from the work by Dehmelt with single electrons to the results by Aspect and followers with single or few photons. Also, many measurements have been made of individual atoms. New results with small numbers of particles appear every month. A recent list of experiments relating to the photon as "soliton" has been given by Hunter (1997). In every case the results agree with formal quantum predictions. The only reasonable conclusion is that the wave function applies to a single particle and therefore must refer to something real which is not a probability. Clearly, a new interpretation is needed.

Also, these experimental results, as well as the most ancient of quantum measurements such as the Compton and photoelectric effects, clearly show that particles have a finite extension, that is, a characteristic length. With massive particles this is of the order of the de Broglie wavelength and with photons this is about the ordinary wavelength. So EPs are not really plane waves, but wave bundles with limited extension in space and time. On the other hand, EPs are extended and not points. The lower limits of extension would be compatible with the formal Uncertainty Principle interpreted as applying to a single particle and no longer probabilistic.

Many physicists at this juncture will recall textbook discussions of dispersion and spreading of wave packets. We respond that with the discovery of Brittingham solutions these discussions have been superceded, since dispersionless, stable wave packets of finite extension are now proven to exist. Specific models of both electrons and photons have been given (Beil; 1993, 1997, 2002).

The general mathematical form for these finite wave bundles can be expressed as a wave function. This form will be discussed presently. It contains particle parameters such as energy and momentum in the same way as conventional quantum theory such that there is an uncertainty in their values. The parameter values are estimated only by interaction with another EP.

The interactions themselves have limited extension of the order of the characteristic wavelengths of the two EP's. Of course, interaction is used here as a generic term for physical processes such as scattering, particle-antiparticle annihilation, pair production, or photon emission.

The path of an EP is a straight line from one interaction to the next. At an interaction with another particle the parameters of the particle are "measured" and the EP proceeds with a new set of parameters.

This picture of EP interactions meshes quite nicely with Peirce's logic of relations, in particular, with the triadic sign relation. The correspondence will not only be graphical, but will also lead to new interpretative insights into the fundamental understanding of quantum mechanics.

V. Triadic Relations and Elementary Particles

A. The Diagrammatic System

In the triadic scheme, an EP corresponds to a succession of signs (triadic sign relations as in Figure 2) in space-time. These signs are connected or "bonded" to represent a history of the particle. Each triad has exactly three valency places or "legs" with the canonical aspects (one each) of Object (**O**), Representamen (**R**), and Interpretant (**I**). The internal bonding which constitutes the history of the particle is always **O** to **R**. The external bonding which produces an interaction with another particle is always **I** to **I**.

We describe the internal bonding first. In this, the Object leg of one triad is bonded to the Representamen leg of an adjoining triad of the same EP. For a particle with mass, the space-time interval from one triad to the next is always timelike. The timelike property is preserved from one relativistic reference frame to another.

For a normal particle (as opposed to antiparticle) the internal bonding is such that the **R** leg of any triad is bonded to the **O** leg of the next triad in time. Figure 3 shows this history.

For an antiparticle the bonding is in the opposite sense (Figure 4) such that the **O** leg of a triad is bonded to the **R** leg of the next triad.

Then a particle-antiparticle annihilation would be diagrammed as in Figure 5. with the particle on the left.

For massless particles the space-time intervals from one particle triad to the next are null (on a light cone). The null property is preserved from one reference frame to another.

What does this **O** - **R** bonding actually signify? A specific meaning in familiar physical terms will be given later, but for the time being we can understand that the Object aspect means that the EP has an independent physical existence in each interval between interactions. The Representamen aspect means that the EP can be described mathematically in a given interval by a certain formal expression which is an element of some algebra. The **O** - **R** bonding then means that there is a mathematical expression or wave function which represents the physical nature of the EP even though the EP has no contact between interactions with the external world. In particular, certain properties such as charge, mass, and spin can be computed from this wave function (Beil, 1993).

Continuing with the triad scheme we specify that the Interpretant or **I** leg of each triad is bonded to an **I** leg of a neighboring triad which belongs to the history of a second EP. This external bond depicts the interaction of the two particles. The interaction takes place, as stated above, in a limited region of space-time. This is

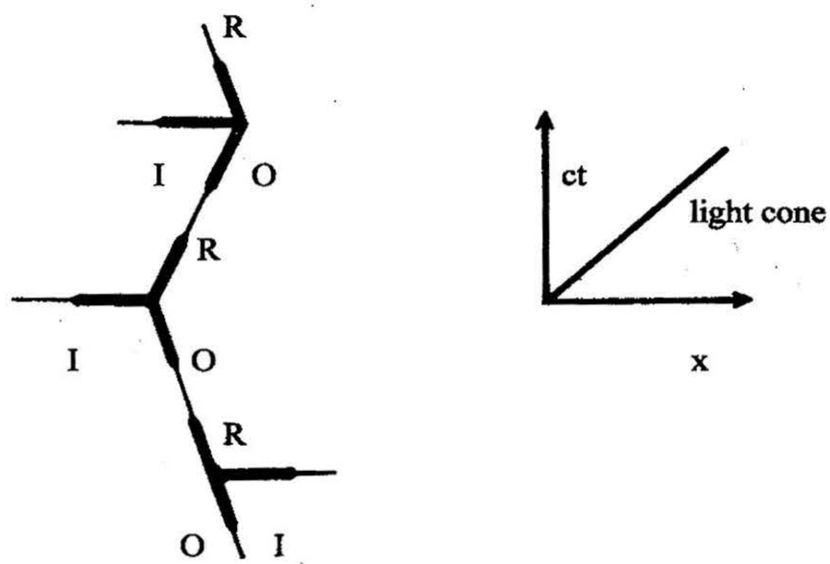


Figure 3. Triadic history of a particle

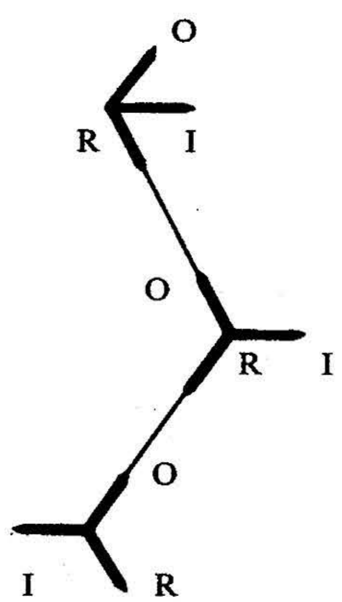


Figure 4. Triadic history of an antiparticle

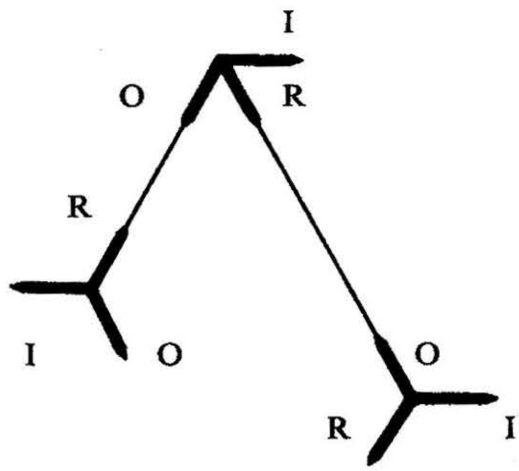


Figure 5. Triadic history of particle-antiparticle annihilation

basically a scattering or contact interaction. Particles interact only when they are in each other's neighborhood. Further, the details of the interaction are determined by the impact parameter. Evidence for an extension in space and time of quantum interactions or jumps has been given by Greenstein and Zajonc (1995).

The significance of the external or **I** - **I** bonding in terms of Peirce's relational logic is that it is between Interpretants or, in more physical terms, between observers. Each particle observes or makes a measurement of the other. Each alters the state of the other and carries away an interpretation of the interaction.

So we assert that in its **O** - **R** aspect a particle exists (in the sense of Peirce) and therefore is real by way of that existence. In its **I** aspect, as it interacts with other particles, it is a nonexisting real. The reality of the sign relation is expressed in the nonexistent reality of the interaction, even though the particle loses its independent existence.

A diagrammatic representation of the interaction of two particles, say, an electron (EP-A) and a photon (EP-B) is given in Figure 6.

We call this general type of diagram a Peirce/Beil/Ketner (**PBK**) diagram. For this particular case a physical process corresponding to the diagram would be Compton scattering.

If one considers the interaction itself (A2-B2) in this diagram it is recognizable as a tetrad rather than a triad. It is not hard to see that any **PBK** diagram could be drawn with tetrads as the basic elements. This would emphasize the role of interactions in the realm of elementary particles. We choose, however, to recall Peirce's Completeness Principle which states that a tetrad is constructable from two triads. In our case all **I** - **I** bonds accomplish this. So we emphasize here the triad components in our diagrams. The reason for this choice will be made clear in the following discussion of quantum correspondence.

Note that Peirce's Reduction Principle forbids the construction of triads from dyads. All interactions are triadic and cannot be separated into dyadic components.

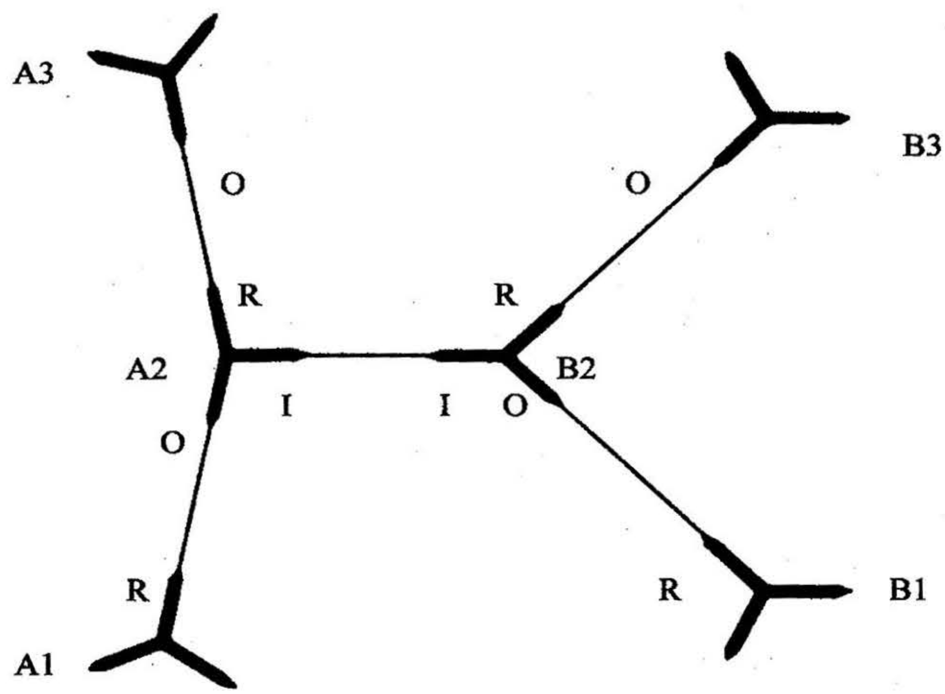


Figure 6. **PBK** diagram for interaction of an electron (EP-A) and photon (EP-B)

B. The Quantum Correspondence

There is a direct correspondence of the Peirce relational logic (as given in **PBK** diagrams) to quantum mechanics.

The internal intervals, represented by the **O-R** bonds, correspond to wave functions. These wave functions are solutions of an appropriate wave equation, for example, the Dirac equation for electrons or the Maxwell wave equation for photons. These wave functions can be written in standard Dirac notation as bras $<|$ or kets $|>$. For example, in Figure 6 the wave function for the interval A1 to A2 can be written as the ket $|A1, A2>$ or the associated adjoint or bra $< A1, A2|$. The mathematical form of these wave functions can be the same as in standard quantum theory, however, we assert that they can also refer to single particle states. For an argument supporting this view see Hegerfeldt (1998).

The expectation value is the usual $< A1, A2|A1, A2 >$. This is not interpreted as a probability, but as an amplitude of a single-particle field density. In either case, though, there is a formal correspondence between the **O-R** bond, as it refers to a mathematical representation of the EP as it exists in the interval between triads, and the wave function.

We note that a time-symmetric view of quantum mechanics could enter here since the bra states might be interpreted as propagating backward in time (Cramer, 1988; Vaidman, 1998). We do not adopt this view here, however. A main reason being that the mathematical form of the adjoint or bra state for a massive particle involves the same argument as the ket function. This bra wave also propagates forward in time. A new, nonstandard definition of the adjoint wave function would be necessary for any time-symmetric theory of this type.

Our theory uses advanced waves as components of the wave function, but the function itself and its adjoint both move forward in time. We do adopt the view, common in interpretations of quantum electrodynamics, that antiparticles propagate backward in time.

The **I** leg of each tetrad corresponds to a matrix operator involving the quantum states which are connected through the triad. For example, in Figure 6 at triad A2 the operator is $|A2, A3 >< A1, A2|$.

This operator produces the transition $|A2, A3 >< A1, A2||A1, A2 >= |A2, A3 >$ from one ket state $|A1, A2 >$ to the next, $|A2, A3 >$.

The same operator would take a bra state $< A2, A3|$ to a "previous" bra state $< A1, A2|$, that is, $< A2, A3||A2, A3 >< A1, A2| =< A1, A2|$.

The wave functions are assumed to be normalized. This implies that all expressions are integrated over appropriate spaces according to the usual practice.

The history of an EP (for example, EP-A in Figure 6) has the quantum representation as shown in Figure 7.

The **I-I** bond in an interaction of two EP's then corresponds to the operator equivalence $|B2, B3 >< B1, B2| = E|A2, A3 >< A1, A2|$ where E is a constant. This meshes nicely with the quantum concept of operators as observables.

So the action of EP-B on EP-A is $|B2, B3 >< B1, B2||A1, A2 >= E|A2, A3 >$. This is a general type of expression for the action of a quantum operator on a wave function. The operator $|B2, B3 >< B1, B2|$ functions as a sort of S-matrix. The outgoing states $|A2, A3 >$, however, are not the usual spherical waves, but are wave bundles propagating along the physical path of a single particle.

There is an analogy here of **PBK** diagrams to Feynman digrams. For example, Figure 6 looks like a lowest order Feynman diagram for Compton scattering (see Weinberg, 1995, p. 362) as shown in Figure 8.

The labels for the vertices in Figure 8 compare with those in Figure 6. However, Figure 6 represents a sum of all orders of Feynman diagrams applicable to this interaction and not just the process depicted in Figure 8. Note that the sum used to obtain the **PBK** diagram is a sum over component Brittingham waves and not the perturbation theory sum applied to Feynman diagrams.

We exhibit **PBK** diagrams for other electron-photon interactions. Figure 9 shows electron-positron annihilation.

The electron A1-A2 and its antiparticle A3-A2 produce photons B2-B1 and B2-B3. The time-reversed version of this diagram describes the production of an electron-positron pair. One of the photons is the incoming gamma particle, the second is the necessary photon from a nearby nucleus.

A diagram for the repulsive Coulomb or electromagnetic interaction between two electrons is shown in Figure 10.

This is also called Møller scattering. The photon EP-B is the mediating particle for the interaction between electrons A and C. The A,B part of the diagram is identical with Figure 6. Here, the process would be iterated so that the photon "bounces" or is exchanged between A and C until it is radiated. Each interaction or bounce transfers momentum to one of the electrons.

Radiation occurs when a quantum of the repulsion energy escapes as a photon. At a given time there could be a large number of photons being exchanged and radiated. The spectrum of these photons is obviously continuous and we speculate that it has a Gaussian sort of distribution, as opposed to the flat distribution assigned to Bremsstrahlung. Such a distribution could be related to the dimensions of the structure of the electron. The existence of such a distribution centered, say, in the optical range, could provide a solution to problems with both infrared and ultraviolet divergences.

A diagram for an attractive Coulomb interaction is shown in Figure 11. The photon EP-B is the mediating particle between an electron EP-A and a proton EP-C. The photon bounces between A and C in a stable configuration forming a bound state

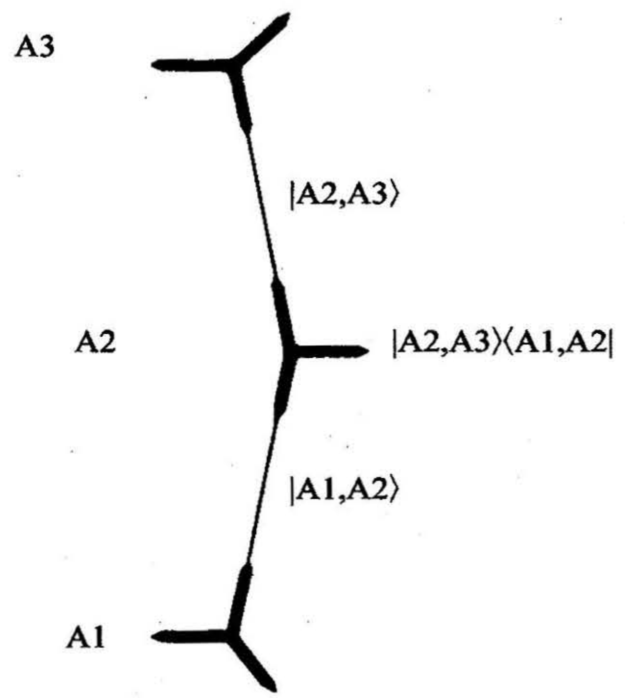


Figure 7. Quantum representation of an EP history

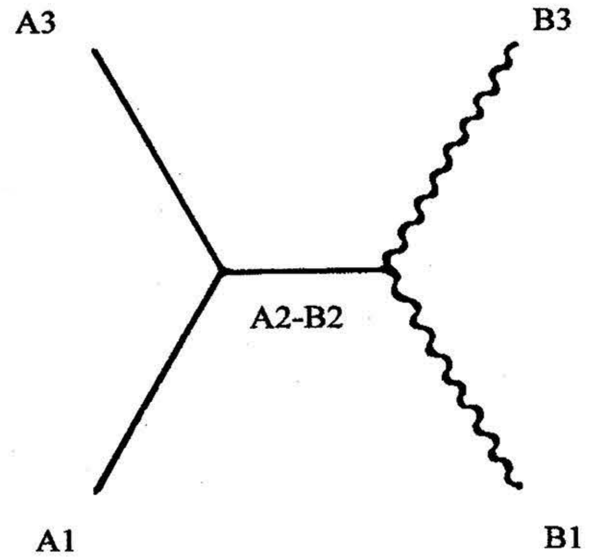


Figure 8. Feynman diagram of lowest order for Compton scattering

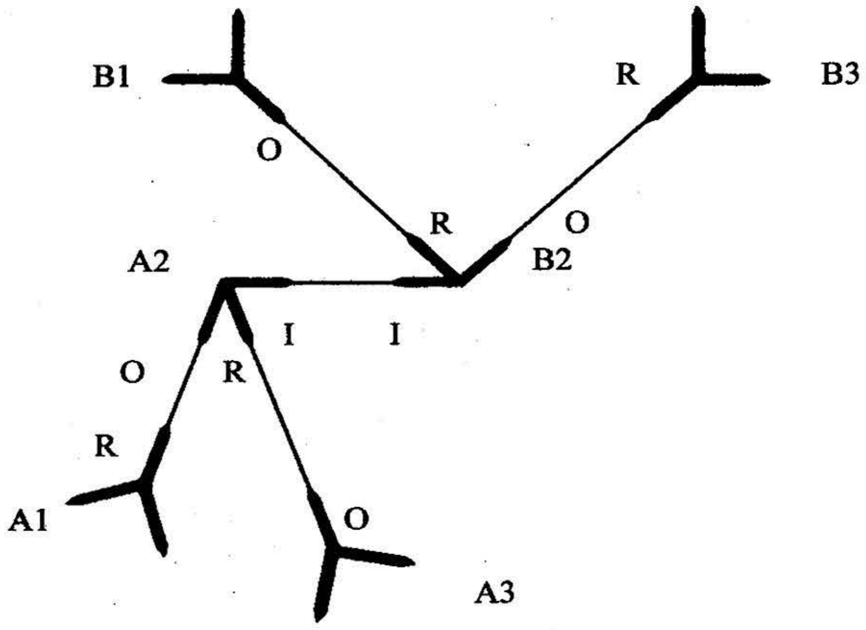


Figure 9. **PBK diagram for annihilation of an electron and a positron**

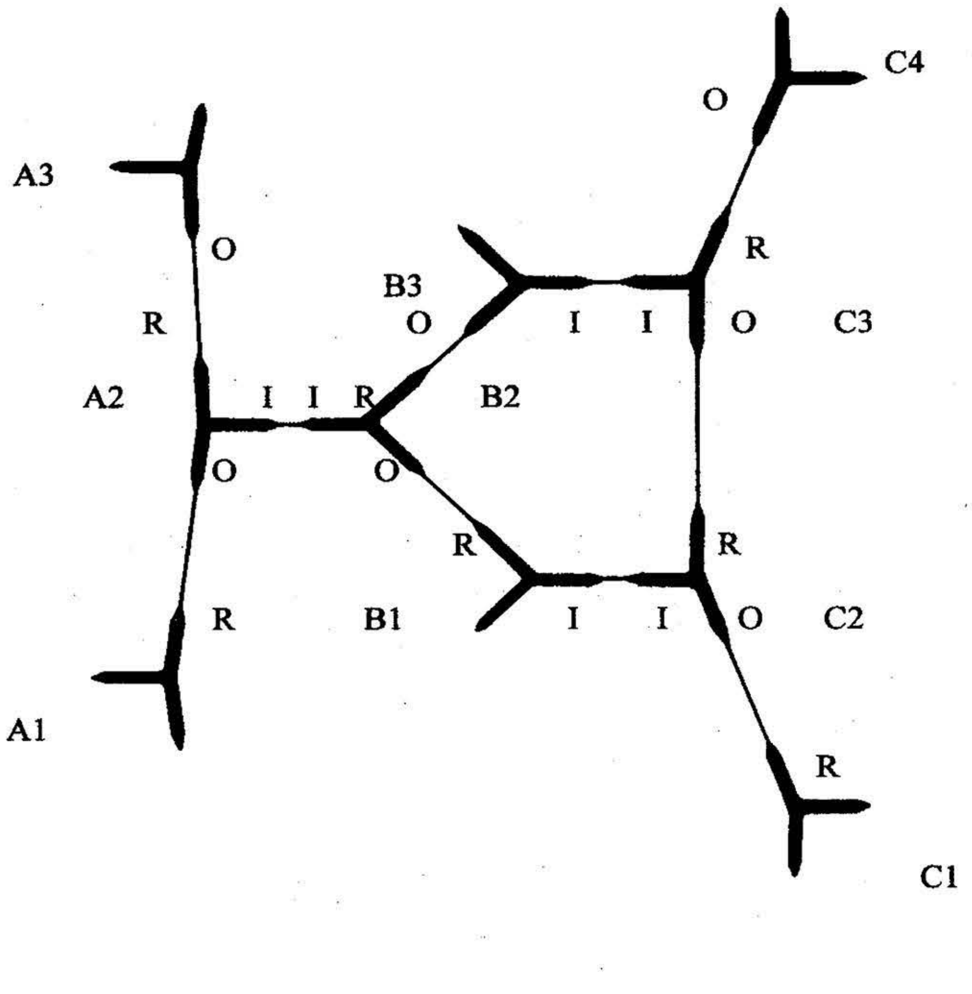


Figure 10. **PBK** diagram for the repulsive Coulomb interaction (Møller scattering)

of the hydrogen atom. EP-B is a virtual photon confined to the atomic system.

An operator of the photon as interpretant can be identified as a Hamiltonian $H = |B3, B2 >< B1, B2|$. Since the electron states are stable, $|A2, A3 >= |A1, A2 >$ so that $H|A1, A2 >= E|A1, A2 >$ which is a typical quantum eigenstate equation with E as the eigenvalue or energy. The spectrum of these eigenvalues is discrete.

A diagram for the emission of radiation from a hydrogen atom is shown in Figure 12.

A virtual photon EP-B escapes to the external world. The state of the electron changes from $|A1, A2 >$ with energy E1 to state $|A2, A3 >$ with energy E2. The photon energy is E2-E1 corresponding to the difference in energy levels.

The diagrams in Figure 11 and Figure 12 will be discussed again in Part D of this chapter.

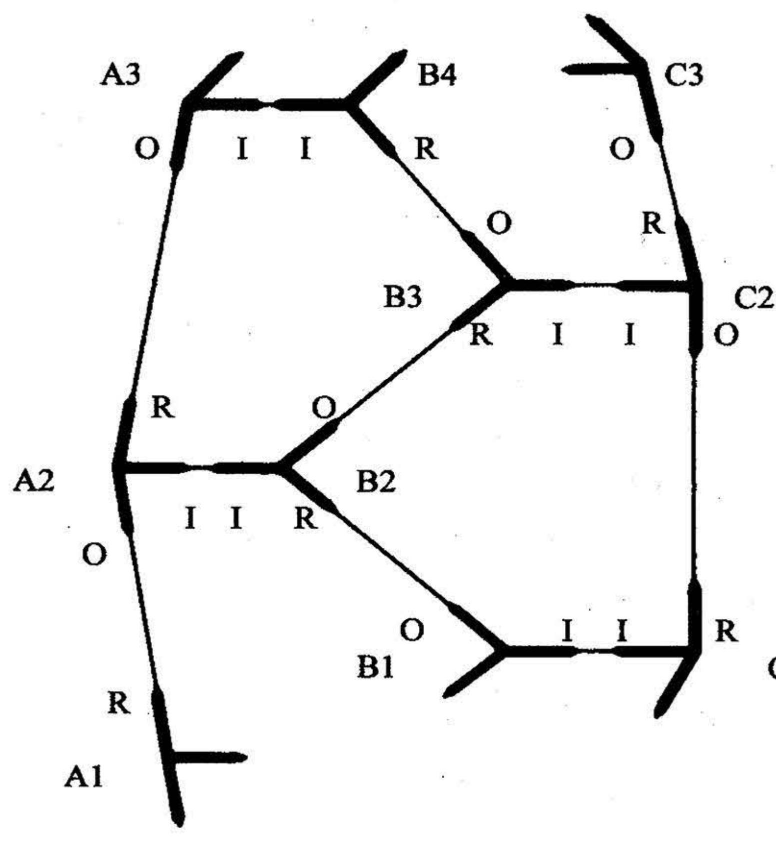


Figure 11. **PBK diagram for the attractive Coulomb interaction (hydrogen atom)**

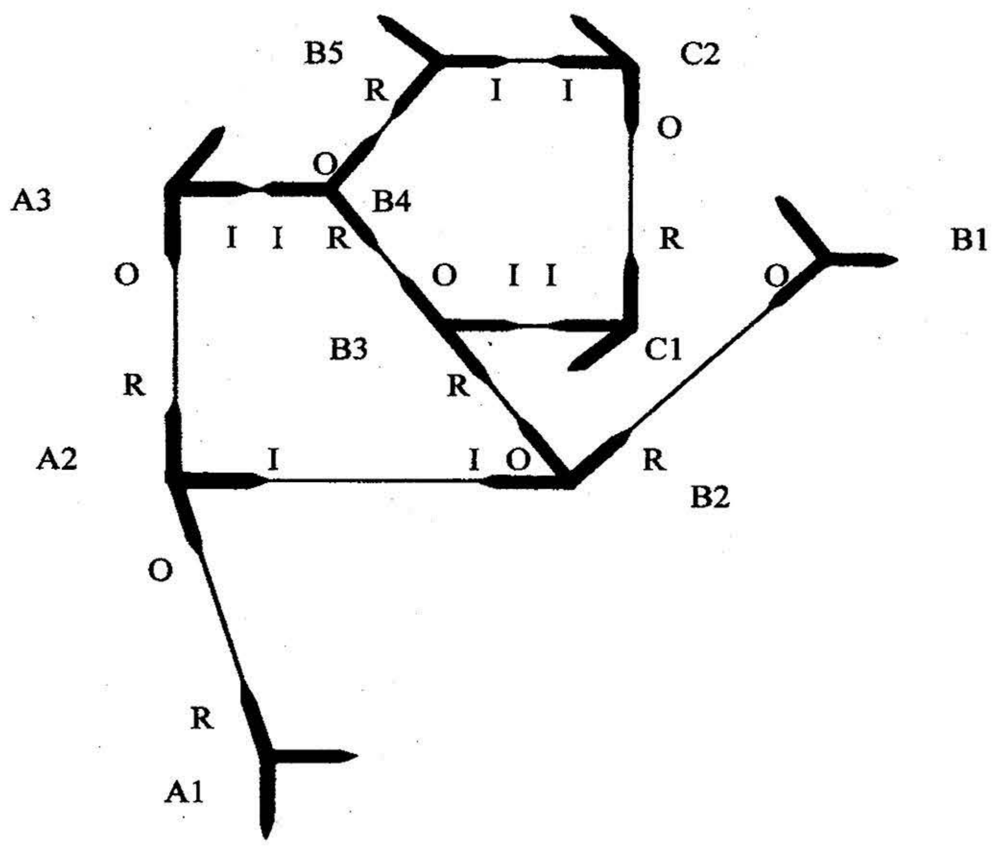


Figure 12. **PBK diagram** for emission of radiation from a hydrogen atom

C. Internal Structure of Elementary Particles

Decades ago, when it became clear that quantum field theory could say nothing sensible about the origin of the principal properties (for example, charge, mass, spin) of elementary particles, a collective fabrication developed to the effect that if the theory does not explain this internal structure, then the structure must be unexplainable. The peculiar attitude is that the blame for an inadequate explanation must be placed on nature rather than on the current theory. It is well documented that this "know-nothing" development was unappealing to such luminaries as Einstein, Dirac, Schrödinger, de Broglie, and even Feynman. But when no satisfactory alternative theory was forthcoming, the fabrication became so ingrained that new students are now advised not to even think about trying to understand these properties.

We modestly propose that it is time to reopen the book on these ancient mysteries and to see if there are not, indeed, some developments which might shed light on the internal structure of EPs. We must confess that we have actually already done so. What we have discovered is that the even more ancient wisdom of Charles Sanders Peirce is the light source which allows us to bring these long-hidden areas into view.

For example, the Peirce logic suggests to us that the **O** - **R** bonding in the interval of an EP between triads has a definite mathematical form which corresponds to a wave function. Further, that wave function refers to a single particle that propagates along a straight path in space-time.

Quantum field theory also assigns a wave function to an EP. For example, for the electron the wave function is a solution of the Dirac equation. This solution, however, is taken to be basically a plane wave which contains no information about the internal structure of the electron. This is a bare framework which can give some of the measurable properties quite accurately, but has no hope of explaining the principal properties. The principal properties are just inserted *ex machina* into the formalism.

There are some obvious problems with plane waves. They imply infinite extension of each particle. That is, particles, unless confined artificially to boxes, cover the entire universe. Each particle also has infinite energy. These built-in divergences have to be dealt with by various unsavory recipes.

The probabilistic interpretation is dogmatically embraced in spite of contrary experimental evidence. The fundamental question as to what the wave function is a wave *of* remains unanswered.

So what do we offer as an alternative?

First, for electrons we postulate that the wave functions are still spinor solutions of the Dirac equation, but are no longer just plane waves. The necessary modification is not complicated: A form factor which multiplies the plane wave is inserted in the wave function. This form factor is related to an electromagnetic potential which is a solution of a Maxwell wave equation. Thus the structure of the electron is given by this classical electromagnetic potential. The nature of this potential has previously been given (Beil, 1989, 1993). It is an extended, dispersionless wave bundle of the Brittingham type with extension defined on a light cone. The form factor has a Gaussian shape which limits the extension of the particle to the order of the classical electron radius. The charge shape allows an exact computation of the electron mass using Maxwell techniques.

The mathematical expression of the wave function can be given in the context of a unified approach to Dirac solutions. These solutions are Clifford matrices rather than spinors. The electromagnetic potentials and fields are also expressed in a Clifford algebra matrix representation so that a single formalism encompasses both Maxwell and Dirac (Beil (2004)).

A key property of the form factor potential is that it is a superposition of both retarded and advanced waves. The particle's internal structure is determined by waves (advanced) propagating backward in time from its final triad as well as waves (retarded) propagating forward in time from its initial triad. Thus, some properties of an EP may not be determined until interaction with an observing final triad has taken place.

We can distinguish between permanent properties (charge, mass, spin magnitude, and magnetic moment) and transient properties (position, momentum, and spin direction). The permanent properties can be computed from the form factor. The possible values of transient properties are contained in the entire wave function. These are actually specified by **I** - **I** measurement of eigenvalues by other particles.

As we asserted above, the interaction aspect of a particle is a nonexistent real, showing how an object gives up its existence but continues its reality through an interaction.

The kinematics of the electron is obtained by assuming the particle resides on a moving frame which propagates according to a subgroup of the 10-parameter Poincaré group. A detailed classification of this group applied to frames is given in Beil (1995). The classification is similar to that of Wigner. The particular set of group parameters chosen for the electron produces timelike transport with a Zitterbewegung. The wavelength of the Zitterbewegung is the de Broglie wavelength. This gives a computed value for the electron spin equal to the measured value. The electron is thus a charge distribution of a size comparable to the classical electron radius which is moving in a helical path with the de Broglie wavelength. The internal structure is a wave bundle contained in a waveguide-like tubular volume similar to the model of Jennison (1989). The model gives a value for the gyromagnetic ratio including the anomalous part.

So the Dirac wave function with electromagnetic form factor permits a calculation of mass, spin, and magnetic moment. The form factor involves a certain propagating charge distribution. The integration of this charge distribution produces a value equal to the electron charge (Beil, 1989). The electromagnetic potential is a Brittingham solution with a field which satisfies the Maxwell equations.

The expectation value of the Dirac wave function including form factor is equal to the magnitude of the electromagnetic field density. Thus, the quantum expectation is directly related to a single particle quantity and is no longer constrained to be a probability. The particle solutions have certain eigenvalues for properties such as energy, spin, and polarization. The wave function can be characterized by all or part of these sets of eigenvalues. Every particle can be described by a complete set of commuting matrices which correspond to observable quantities.

Another feature of the new theory is that the negative energy or antimatter solutions are decoupled from the particle solutions so there is no problem dealing with "holes." The antiparticle solutions clearly propagate backward in time and are independent of positive energy solutions. There is no necessity for multiparticle states; the theory can refer only to single particles. There is time symmetry in the sense that the time reversed (positron) states are predicted, but the theory recognizes the fundamental predominance of matter in the universe.

The electron wave functions used in this theory also explicitly obey the Pauli exclusion principle. The product of one of these Clifford wave function matrices with itself is zero.

The internal structure of the photon can be described by a theory which has some characteristics in common with the above electron outline, but also differs in important ways.

The photon wave functions are simply electromagnetic potentials which are Brittingham solutions of the wave equation (Beil, 1997). Essentially, the wave functions are just the form factors. These potentials and their associated field densities can be written as matrices in the Clifford algebra representation so that a unified formalism applies to all EPs (Beil and Ketner (2003), Beil (2004)).

The Brittingham photon solutions are also superpositions of advanced and retarded waves. Solutions have been derived (Beil, 1997) from which the predicted values for four-momentum and spin magnitude can be computed.

Photons, like electrons, are considered to reside on moving frames which propagate according to a Poincaré group. The group parameters in this case produce transport along a null path with a rotation of the frame on an axis parallel to the direction of propagation (Beil, 1995). This is a demonstration of the existence of photons as examples of needle radiation.

Over and above the advanced and retarded component waves of these photons it is not hard to see that the photons (wave bundles) themselves can propagate in either advanced or retarded directions. So we actually have "antiphotons" moving backward in time. The implications of this are discussed in Part D of this chapter.

One can consider that the actual solution for a particle is not complete until the "final" and "initial" interactions. These interactions may be chosen according to the boundaries which have physical significance.

D. Interactions and Continuity

As we have pointed out, **O-R** bonding refers to the internal structure of an EP and **I-I** bonding relates to particle interactions. An **I-I** bond equates the matrix operators of two particles in the space-time region where the interaction takes place.

The actual mathematics of an interaction involves products of wave functions of the two particles as discussed in Part B above. Cross sections and other results such as the Klein-Nishina formula can be obtained. These calculations will be given in future work.

One aspect of our theory which is a significant innovation is the application of photons ("antiphotons") moving backward in time (see Beil (2002)). These particles have negative momentum. This means that, while the interaction with an electron of a photon going forward in time results in a transfer of positive momentum to the electron (the electron is repulsed), the interaction of a photon going backward in time results in a negative transfer of momentum (the electron is attracted). So the repulsive Coulomb force is mediated by virtual photons and the attractive Coulomb force is mediated by virtual antiphotons.

This fits nicely with the fact that the atomic Coulomb potential well has a negative energy.

We can now reexamine Figures 11 and 12 in this light. Recall that Figure 11 is the **PBK** diagram for the hydrogen atom with the electron, EP-A in a stable state. The mediating photon EP-B can now be identified as propagating backward in time. This was already implied by the nature of the **O-R** bonding (see Figure 4). The negative momentum transferred by each electron-photon interaction keeps the electron in "orbit." The energies of the successive electron states remain constant as long as the orbit is stable. Each momentum transfer is inward toward the nucleus so that the electron moves in a zig-zag path. An average of these paths would approximate motion in an inverse square Coulomb field.

Figure 12 shows the hydrogen atom emitting at triad B2 a photon $|B2, B1>$ which propagates forward in time. The antiphoton $|B2, B3>$ and sequential states mediate the Coulomb attraction. The electron state $|A2, A3>$ has more negative energy than $|A1, A2>$ so there is a change in electron energy at triad A2. The energy difference is radiated as photon $|B2, B1>$. There is no quantum "jump" as such, only the change in energy produced by the interaction A2-B2.

It is easy to recognize that our theory has a built-in nonlocality which can explain all of the current difficulties relating to causality and action at a distance. Since the wave function is composed of both advanced and retarded waves, the particle state is not revealed until the final interaction which closes the parenthesis on that interval. Only when the interaction with an observing particle has taken place does the external world know the results of that observation. So the states of two different particles which proceed out of the same initial interaction can be correlated even though the two final interactions may have a spacelike separation. The two sets of advanced waves proceeding backward to the original common interaction transmit the correlation.

A picture which is developing here is of a network of triads continuously bonding in space and time. Each particle exists as a series of intervals defined by an **O-R** bond between successive triads. The interactions are defined by **I-I** bonds with other particles. The network of bonds forms as time moves forward. Essentially, time does move forward because there is much more matter than antimatter in the universe. There are always "loose ends" since some isolated particles may not experience their next interaction until far in the future. But a web has been formed which encompasses the whole universe.

Actually, one can speak of at least three types of continuity in the universe:

The underlying continuity is that of the universal background electromagnetic medium. This is a continuum from which the potentials or form factors are constructed. Waves in this medium cover the entire electromagnetic spectrum. These waves satisfy the homogeneous Maxwell wave equation. This medium is somewhat like the venerable ether, but differs from the ether in that it is fundamentally relativistic. Also, the objects composed of these waves are real and have measurable properties. The medium space has the mathematical properties of a Riemann space of general relativity.

A second type of continuity is the web of bonded triads just discussed. This network imposes a nonlocal structure on the universe which goes beyond the metric properties of Riemann space. This nonlocality resides in the internal structure of a particle which is not "complete" until a subsequent triad. The particle's internal structure forms a noncausal link between two causally (timelike or null) separated triads. This is a new application of Peirce's Synechism expressing a total connectedness of the universe from beginning to end.

The third type of continuity is a superposition of Representamen or wave functions. The wave functions of any number of EPs can be combined to produce a wave function of a multiparticle state. Any interconnected set of particles can be described as an n-particle state. One can, in principle, write a wave function for any set of interacting EPs. A wave function of the universe (see Hartle and Hawking (1983)) is conceivable.

In practical terms, wave functions for objects, say, in increasing order of size, are supplanted by Representamens which are less mathematical but more useful such as "carbon atom," "DNA molecule," "blood cell," "George," or the like. That is, the objects become those of ordinary experience and the Representamens are the words of everyday language. There is still, on the macroscopic scale, a system of **O-R** bonding where names are given to objects and also **I-I** bonding where objects interact by observing or measuring each other.

The three types of continuity, taken together, might be proposed as an example of Peirce's synechism. That is, together they produce a "supercontinuity" in the universe which goes beyond that of ordinary physical spaces.

The theory also gives a coherent vision of the four "forces" commonly invoked in attempts to create a unified explanation of physics. We say here that the electromagnetic field is fundamental and that the other three forces are derivable from it. The gravitational field is the result of integration of the energy momentum density tensor (extended on the particle's light cone). This produces a finite mass (Beil (1989)).

The "weak" field is the electromagnetic field of the Poincaré motion of the charge distribution. This is computed in the laboratory frame. For example, the electron moves in a spiral with a radius of the order of the Compton length.

The "strong" field is a composite of single-particle fields. It is a multiparticle state which consists of bound states of electromagnetic fields. The so-called quarks cannot exist independently.

VI. A Triadic Quantum Computer

In this chapter the **PBK** method is extended to apply to quantum logic and quantum computing. A specific model is proposed for implementation of computer logic on the quantum or elementary particle scale. It is emphasized, however, that by "quantum" the reference is not to probabilistic models such as the Feynman computer, but to the single particle model developed above.

The interacting particles here are taken to be electrons and photons. These are in a sense more fundamental, especially in the context of Quantum Electrodynamics. However, implementation using other particles or atoms is certainly possible and may be more favorable for experimental reasons.

One can think of a network of EP interactions as a "circuit" analogous to a conventional circuit with wires and circuit elements such as transistors. In the EP case the "wires" are EPs themselves moving along paths in spacetime and "transistors" are other EPs which change their quantum state as they interact with the wire EPs.

The basic circuit using, say, electron-photon interactions can be represented by the **PBK** diagram of Figure 13.

The diagram has been somewhat simplified from the previous example of Figure 6. The photon changes from state A to state B while the electron changes from state C to state D. Depending on how this circuit is "connected" externally, either the photon or the electron could play the role of wire while the other assumes the function of the switching device or transistor. So either the electron measures the change of state of the photon or vice-versa.

The physical property which determines the particular EP state could be, for example, polarization, spin direction, or energy level. The state values could be binary, but could also have more than two values. Multiple values could be the energy levels of an electron in an atom.

The universal circuit element shown in Figure 13 is given the name **trisistor**. It depicts the triadic interaction of two particles. Again, although electrons and photons are used here, any type of EP or even atoms or molecules could be used.

In addition to Figure 13 there are three other configurations of the trisistor. Figure 14 shows the annihilation of photons A and B. This is simply the absorption of radiation from two sources with a measurement by the electron C-D of the relative states of A and B. Alternatively, the photon A-B measures the change of state of the electron from C to D.

Figure 15 shows the creation of a photon-antiphoton pair. This is the emission of a correlated or "entangled" pair of photons. Specifically, the states of the emitted photons could be the same. The relative values of the states are measured by the electron system. Alternatively, the photon could measure the relative states of the electron.

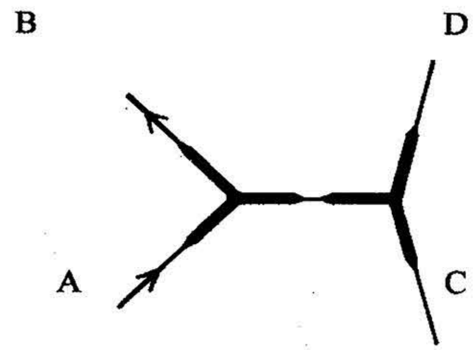


Figure 13. Simplified **PBK** diagram for electron-photon interaction. First transistor configuration.

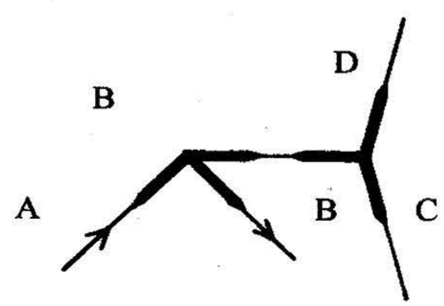


Figure 14. **PBK** diagram for photon annihilation. Second transistor configuration

Figure 16 is a configuration which involves the change of state of an antiphoton. Again, either particle could be the one which makes the measurement. For example, most recent experiments which examine quantum information or quantum entanglement of particles use polarization states of photons as input-output and use electrons (or devices which apply electron-photon interactions) as registers of storage. The "quantum teleportation" experiments are an example (Dehlinger and Mitchell (2002)). The experimental techniques for such devices are well developed and could be applied almost "off the shelf."

On the other hand, devices which use electron energy levels as input-output and photons as storage will perhaps be more useful in the long run. A larger number of distinguishable states is available and the input or output (photons of particular frequency and spin) easier to handle. The experimental techniques are open for refinement.

It should be understood that "storage" functions somewhat differently in quantum circuits than it does in conventional circuits. In classical logic the circuit element (for example, a transistor) is in a definite setting (say, on or off). This setting takes definite input states and converts them to definite output states.

In quantum circuits the settings of the circuit elements are not known. What is known is the change of state which is produced by the element. Thus the quantum element performs one of the following operations: It produces a pair of particles with known relative polarization. Or, it measures the relative polarization of a pair of particles. Or, it changes the polarization of a particle by a certain amount. These are just the operations depicted in Figures 13 - 16. This type of measurement is sometimes called a Bell state measurement.

So quantum circuits determine the changes of states, not the value of the states themselves. A classical circuit element says to an input signal, "I will put you in a definite state." A quantum circuit element says, "I will change your state by a definite amount."

This is why the Peircean triadic approach is so suitable for quantum analysis. It focuses on the interaction of particle or the change produced by one on the other particle. And, since it is a theory of single particles in interaction, it avoids the conceptual problems of the conventional probabilistic theory.

An example of a general logic circuit which uses the above principles is now given. It uses electron states as input-output and photon states as internal storage. The circuit is shown in Figure 17.

The triads X, Y, Z, and W represent electrons or electron systems interacting with the photon states A, B, and C. The photons A and B are going forward in time and the photon C can be thought of as going backward in time.

The sequence of events is

1. System X emits an entangled pair of photons A and C. A has a known polar-

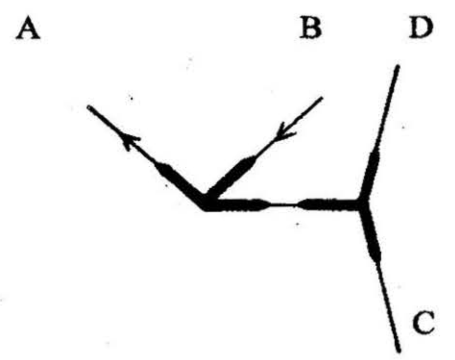


Figure 15. **PBK** diagram for creation of entangled photon pair. Third trisistor configuration

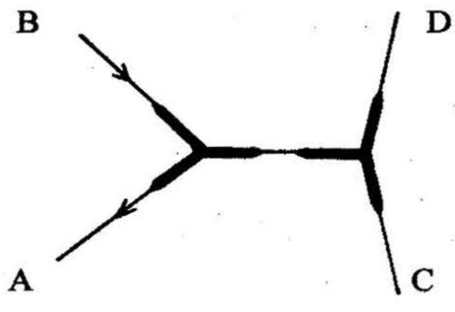


Figure 16. **PBK** diagram for electron-antiphoton interaction. Fourth trisistor configuration

ization (a certain angle) relative to C. This is the input value due to X.

2. System Y interacts with A and changes it to B which has a known polarization relative to A. This is the input value due to Y.

3. Meanwhile, the direction of photon C has been changed by system W without changing the polarization of C.

4. System Z measures the relative polarization of B and C. The resulting state of Z is the output of the circuit.

The direction change of C is necessary so that C can appear at Z at the same space-time event as the arrival of B at Z.

A parenthetical note on terminology: If C is actually an antiphoton going backward in time then the pair creation or "emission" of A and C at X is actually the emission of A and the absorption of C. Similarly, the pair annihilation or "absorption" of B and C at Z is the absorption of B and the emission of C. This is consistent with terminology used for advanced radiation by, for example, Wheeler and Feynman.

If only two polarization states are used, the possible input and output state differences can only be two-valued, say, s (same) and d (different). The "truth table" in this case is given in Table 4.

The output of the circuit is automatically determined by the two inputs and does not require additional processing of the output as do the currently popular circuits which demonstrate "entanglement" or "teleportation."

For three possible polarization state differences, labeled now 1, 2, and 3, the table is given in Table 5.

Table 5 is a 3-element modular sum. It is clear that addition with higher numbers of possible state differencess is possible. The 3-element table can easily be adapted to function as either a binary adder or as one of the standard logic gates.

We wish to emphasize now that the single particle interaction viewpoint described above is actually equivalent to the two-particle or multiparticle approach commonly used. That is, referring to Figure 17, in a theory using two-particle states, the interaction X would produce an entangled state consisting of particles A and C. This could be a two-particle Bell state. On the other hand, in the one-particle picture, the particle C travels backward in time, interacts with the system X and becomes particle A going forward in time. Mathematically, the operator X acting on the one-particle orthonormal pure state $|C>$ gives a similar state $|A>$. This is equivalent to the preparation of a two-particle state $|A, C>$ which could be a Bell state.

In either case, for two possible state values a single "qubit" of quantum information is contained in the system. In the two-particle picture the qubit is in the two-particle wave function and is "read" when the state of either A or C is measured. In the one-particle picture the qubit is in the system X and is determined by the preparation of A relative to C.

Even though the single-particle and multiparticle viewpoints are equivalent, they

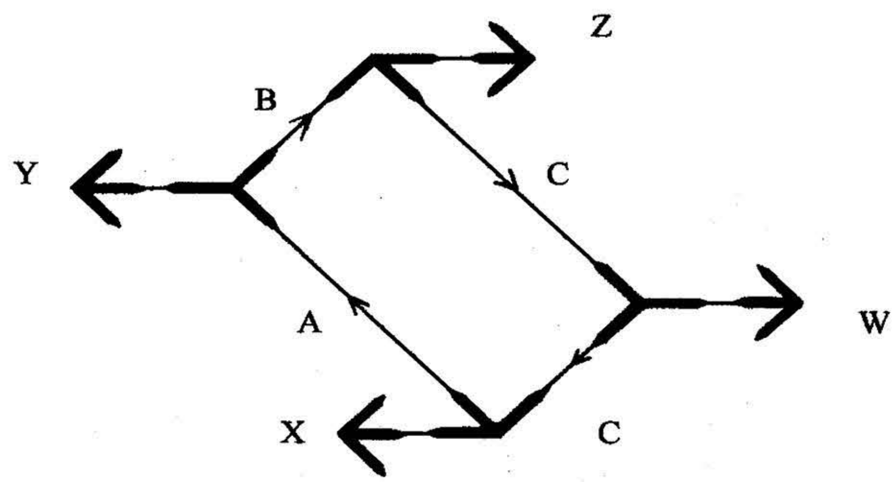


Figure 17. Elementary logic circuit using trisistors

X	Y	s	d
s		s	d
d		d	s

Table 4: "Truth table" for logic circuit of Figure 17. Two polarization state differences.

X	Y	0	1	2
0		0	1	2
1		1	2	0
2		2	0	1

Table 5: "Truth table" for logic circuit of Figure 17. Three polarization state differences.

lead to rather different rationales for computer design. The multiparticle designs involve massively parallel processing while the single particle designs involve sequential processing with successive particle interactions.

VII. Concluding Remarks

A. Summary

This work has been based on several concepts: Primary has been the application of the relational logic of Charles S. Peirce in the form of triadic diagrams of the **PBK** type. These diagrams have provided a useful framework for the discussion of the structure and interactions of elementary particles.

Other concepts which were used included the notion of wave bundles of limited extension propagating both backward and forward in time along paths determined by the Poincaré group. Advanced and retarded waves and needle radiation were essential to this picture.

These bundles were assumed to correspond to single particle quantum states. The quantum correspondence carried through to interactions comparing with operators and wave bundle exchanges comparing with the mediating virtual particles of quantum field theories.

The internal or **O-R** bonding developed into new types of wave functions which include form factors constructed of advanced and retarded waves propagating on moving frames. For these wave functions the expectation values are the field densities. These wave functions permit explicit computation of principal EP properties such as charge, mass, and spin. The external or **I-I** bonding developed into a description of particle interactions related to Feynman diagrams and S-matrices. This involved single particle mediation with virtual particles propagating backward and forward in time, depending on whether the interaction is attractive or repulsive. In the light of the above picture we now comment on some of the larger scale issues of quantum mechanics.

B. Determinism Versus Chance

The form factor part of our wave function is known and gives definite values for charge, mass, and spin. The plane wave part is not determined for states in the continuous spectrum. The eigenvalues depend on interaction with an observing particle. The Heisenberg principle predicts the uncertainty of measured values which can be obtained, just as in conventional theory. This uncertainty, however, is not a probabilistic effect but is due to the actual size of the single particle wave bundle. The chance element is due to the impact parameter when this bundle encounters the observing particle. This sort of random element was anticipated by Peirce's tychism at least 40 years before quantum theory.

C. Hidden Variables

The hidden variables of an EP are contained in the expression of the form factor. This form factor is the same for all particles of a given type (for example, an electron). Since the form factor is nonlocal, Bell's analysis does not apply. The nonlocality is a result of the composition of the form factor from advanced and retarded waves originating at both extremes (triads) of the particle interval.

D. Action at a Distance

Due to the fact that advanced waves from the next interaction contribute to the structure of an EP, there are noncausal phenomena in each interval of an EP. This gives the possibility for a correlation between the measurements of two particles which proceed from a common interaction. That is, the advanced waves from one of the particles interact with the retarded waves from the other particle. This explains the current experimental results where correlation is observed in measurements made at spacelike separations.

E. Quantum Jumps and Collapse of the Wave Function

There is a continuous transition from one state of an EP to the next. This occurs in the region of interaction where the matrix operator of the observer acts on the wave function of the observed particle. Mathematically, this interaction is an integrated product of wave functions which gives a new wave function for the particle after the interaction. The new wave function is mathematically similar to the one preceding, except that it has different transient values. There is no "collapse" as such, just a selection of eigenvalues. This applies to both continuum and bound states. The resulting eigenvalues are not knowable beforehand, but are revealed after the interaction is complete. The outcome of any experiment is determined in that way, but unknowable until the experiment is performed. Even then, there is uncertainty (except for bound states) since the observing particles themselves have to be measured.

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