Some Advantages of a Local Realist, 3D Wave Soliton Approach to EPR

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Not only are the foundation theories mutually compatible, they are also compatible with local realism once this concept is properly formulated (without presuming atomism in addition to locality). Relativity Theory is reconstructed in the context of a preferred frame, but so as to secure the Relativity Principle in every experiment except the measurement of the preferred frame, defined by a null result for the dipole component of the Microwave Background Radiation (MBR). The 3D soliton approach to physical modelling is found to be consistent with both Special Relativity and Quantum Mechanical Nonlocality, exemplified by the EPR paradox.

Keywords: nonlocality, nonseparability, preferred frame, wave solitons.

1 Introduction

Quantum Mechanics makes the fundamental assertion that we can obtain the best possible predictions concerning the outcome of a given physical situation by adopting certain mathematical procedures (consistent with its axioms) in order to: a) encode information known about the system into a "wavefunction"; b) chart the evolution of this representation between preparation and measurement; and *c*) extract predictions by re-expressing it as a linear superposition of the eigenfunctions of simultaneously measurable observables, and then applying the projection postulate. Whilst there remain physical situations for which the appropriate mathematical formalism remains the subject of debate (*e.g.,* continuous measurements; relativistic state reduction), and whilst the future may prove different, there is a complete absence of any evidence based challenge to this remarkable, information theoretic approach. All the evidence shows that we can succeed in any practical goal by restricting ourselves to a consideration of in-principle accessible information alone.

On the other hand, it so happens that quantum mechanical predictions conflict with some deeply held metaphysical beliefs concerning the nature of interaction, which are also frequently associated with, but actually predate, the Special Theory. Specifically, and quite independent of Relativity, they conflict with the commonly assumed paradigm of retarded interaction, wherein interaction is mediated by the motion of some element of the ontology ("Interaction Mediating Particles"—IMPs) between primary, point particle participants. The problem has now been clarified, refined and subjected to experimental investigation by virtue of several famous contributions especially those due to EPR [1], which clearly exposed the basic conflict by showing that quantum mechanics predicts influences between space-like separated events, and Bell [2], which both made the matter testable, and showed that it could not be resolved by recourse to any Local Hidden Variables (LHV) method. Although there are a couple of outstanding loopholes [3], [4], all the experimental evidence [5], [6], [7] firmly supports the quantum mechanical predictions, leaving the physics community with a new, and qualitatively different kind of challenge to all those it has dealt with in the past. The current debate is dominated not by its quantitative aspects, which we may take to be as given by Ordinary Quantum Mechanics (OQM), but rather by the need of the community to understand how such facts could be physically possible. In short, the problem with EPR is unique in that it lies not so much in the field of Physics, but rather in that of Metaphysics.

An analysis by Percival [8] has exposed an essential feature of the EPR paradox [1]. Percival considers sets of two (or more) EPR experiments in relative motion with respect to each other, and so organised that the "inputs" (choices of the measurement axis in a given arm) of one apparatus are determined by the "outputs" (measurement outcomes along the chosen axis) of the other. Assuming only relativity of simultaneity and the relevant quantum predictions, he shows that it is possible, with a judicious choice of the reference frame pertaining to each experiment, to generate paradoxical temporal loops (such that an input is equal to the opposite of itself)—a manifest and in-principle testable contradiction that questions the notion of "peaceful coexistence."

Since these two assumptions lead to a contradiction, at least one of them must be false, and since the quantum predictions just describe the experimental outcomes, we have to look closely at the concept of relativity of simultaneity. Is it a completely general "metaphysical truth" (as Physics presently has it), or merely an artefact of observation, a matter of perspective? The introduction of a preferred frame would go a long way to address the problem, but this is an option seldom considered in any detail because a preferred frame (or so it seems) must disrupt the mathematical symmetries at the heart of all modern physics.

This article shows that there is at least one way to introduce a suitable, experimentally observable, preferred frame so as to open the door to EPR, whilst preserving these valuable symmetries and retaining the 4-vector calculus. We cannot progress towards a physical understanding of EPR without introducing some physical content, so let us identify a single, radically simplifying, ontological constraint to take the place of the usual epistemic[1] postulates underlying the Special Theory, and from which these will be derived.

Radiation propagates at the characteristic velocity, c, whilst, for matter, only speeds below the characteristic velocity can be observed. The logical necessity of an energy equivalence between these distinct classes of phenomena is already reflected in the Theory, but this does raise a perplexing question about photon absorption processes: How can the inherently propagative be transformed into the inherently non-propagative? A simple, but highly productive, resolution of this is to deny the possibility, and instead raise the matter-radiation energy "equivalence" to the level of an identity by asserting that the energy constituting a photon cannot be fundamentally different from that constituting a massive body. In this case, the fact that the photon has a characteristic velocity mandates that energy has a characteristic velocity in all contexts, matter as well as radiation. This will be our central assumption: energy propagates at c.

We shall show that subluminal phenomena in a universe in which all the "elements of reality" [1] are dynamically constrained to constant speed motion behave relativistically, whilst the converse, that a universe that behaves relativistically has little choice but to be constructed from elements constrained to constant speed, seems to be strongly implied. After first identifying the Microwave Background Radiation (MBR) as the only plausible candidate preferred frame, and then discussing its essential properties, a second motivation behind this assumption is found in Section 2—it binds the only suitable

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[1] *i.e.,* both postulates relate to the facts of observation

candidate preferred frame tightly to Relativity Theory and therefore makes it highly relevant to the ordinary practice of Physics.

As far as particle models are concerned, the dynamical constraint places us in the domain of 3-dimensional, local realist wave soliton models—particle models constructed from definitively "physical" wave elements. Several consequences of this general approach are considered in Section 3, where the analysis is based on the necessary conclusion that, when we consider physical, momentum carrying entities (such as waves), then Conservation of Momentum (CoM) can only mean that the momentum of a superposition is given by a sum over its components' momenta. The usual form of wave packet analysis (using a dispersion relation in the context of infinitely extensive wave components constrained to propagate in the same direction as the motion of the particle) will be found to be non-physical. This direct approach to CoM in 3D soliton wavepackets leads immediately to: a) the invariance of the 4-momentum; b) an internal "clock" concept and the value of its time dilation parameter; and *c*) the elliptical transformation of the fields of a moving charged particle (a surrogate for the Lorentz-Fitzgerald contraction).

The result is that we have the usual relativistic symmetries, embedded in a preferred frame. The final task (Section 4) is to reconsider our understanding of the EPR paradox from this new perspective. We shall find a significant loophole in EPR's sufficiency condition for an "element of reality." In the physical wave soliton context, where the localised image of a "point-particle" results from a Fourier superposition of inherently distributed components, it is wrong to assume that elements of reality must be co-located with the observations to which they correspond. From this it is argued that EPR does not conflict with local realism (the combination of proximate causation with a "no superluminal movements" constraint), only with point or point-like local realist models (*i.e.,* LHV models), and that the inherently extended nature of wave phenomena is logically sufficient to explain all the known experimental evidence without invoking instantaneous action at a distance or indeed any phenomenon that moves faster than light.

2 The Preferred Frame

2.1 Specification

If we are to include this controversial idea amongst the foundations upon which physical theory is built, then the preferred frame must be unequivocally experimentally observable. In addition, any solution relying on observations over large (galactic) distances is fraught with difficulties from the outset since we cannot assume the homogeneity over such great distances of any underlying reference system. So, let us limit the range of acceptable proposals to those that can be determined exclusively by local measurements. Only one preferred frame has been proposed that conforms to this criterion. It is the frame of reference defined by a null result of a measurement of the dipole component of the Microwave Background Radiation (MBR) [9], [10].

2.2 Key Properties of the Preferred Frame

Consider an observer remote from all massive objects and equipped with a suitable directional detector for the MBR temperature. He first finds that the temperature distribution is in general anisotropic, but that it can be expressed as the sum of an almost perfectly isotropic distribution and a dipole component (which is of order one part per thousand for the earth, corresponding to a speed of approximately 350 Km/Sec) [11], [12]. Varying his own condition of motion in a controlled manner and repeating the experiment several times, he finds that the strength and direction of the dipole component depends upon his condition of motion, and that there exists a particular condition of motion for which there is no dipole component. He can achieve this condition of motion by accelerating towards the minimum of the MBR temperature distribution in 3-space.

Since, prima facie, the MBR radiation is expected to be isotropic, he infers that the dipole component of the MBR temperature is just the Doppler shift induced by his own motion. When no dipole component can be observed, the Doppler shift from his own motion is equal in all directions, and therefore equal to zero. He recognises that the same must be true, not only for MBR photons, but for all photons in his local space, emitted as well as absorbed. Amongst all observers, his measurements of all photon momenta in general are privileged in not being influenced by his own motion, so anything that propagates at *c* is referenced to the MBR preferred frame[2].

In order to extend the applicability of the MBR preferred frame to cover massive bodies in addition to the radiation, he reasons that this can follow if, and only if, his measurements of all momenta (massive particles as well as radiation) are similarly privileged, which in turn follows immediately if the massive particles are formed as superpositions of generalised photonic waves. Since the components of such superpositions are referenced to the preferred frame, the superposition as a whole is automatically similarly referenced provided only that momentum is conserved. The mathematical forms of such waves are irrelevant because logic requires only that momentum propagates at the characteristic velocity and is conserved.

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[2] Including EPR experiments with photons.

2.3 Implications for Modelling Massive Particles

Massive bodies are usually well-localised, whereas propagative phenomena are usually well-distributed, so we invoke the Fourier principle to explain the localised appearance as an interference phenomenon amongst multiple, distinct, extensive, interpenetrating waves.

Photonic waves all propagate at the same speed, whilst the material body has variable speed. Therefore the direction of propagation of a given wave component must vary in time and so cannot be fixed in the direction of motion of the particle (as is common in the usual form of wave packet analysis). For example, a rest particle might be represented by two physical wave components of equal momentum, which always propagate in opposite directions[3] (or in a variety of other ways).

Material bodies persist in a self-similar condition throughout extended periods of time, whereas a superposition of real, physical, photonic waves would immediately dissipate. It follows from this that there must be interaction between the wave components such that they execute bounded motion and so remain associated as a group[4]. This seems to be, but is in fact not, a new assumption. If we contemplate only photonic elements, and recall that we observe interactions amongst the massive particles, then interaction amongst the constituent waves of different particles is absolutely implied, and so, therefore, is interaction between the different constituent waves of the same particle.

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[3] Which is to say they are spinning about each other.

[4] Typically introduced into soliton analyses by virtue of a non-linearity in the medium.

This basic concept of distributed wave-wave (or field-field) interaction is a complete departure from the usual metaphysical framework where the problem is stated in terms of separated point particles, which can affect each other across a large distance only by the exchange of (retarded) IMPs. In the distributed case, no point-to-point relationships need to be calculated because every object is present at every point, at least in principle. The interaction occurring at some place and time depends upon those parts of the various objects (*e.g.,* their respective field variables) that are co-located at that place and time, and the total interaction is an integral over all space of the local interactions. There is no need for action at a distance, retarded or instantaneous.

3 Lorentz Invariance of Photonic Systems

Given that the several, standard relativistic wave equations (including especially the Helmholz and Dirac equations) all feature the same characteristic velocity, the suggestion that systems of photonic waves exhibit Lorentz Invariance is no great surprise. In this section, we derive the usual relativistic invariances directly, without invoking any wave equation (which would limit the scope of the results to the particular equation(s) at hand), by showing that any field of 3-momentum subject to CoM and the dynamical constraint obeys the Special Theory. Wave momentum behaves differently from the linear momentum concept assumed by Galileo and Newton—it behaves like relativistic momentum.

The critical assumption upon which this relies is that, having once asserted that the superposed wave objects are physically real, we must allow that the wave momentum carried by each component is equally real, so the particle momentum must be a (vector) sum over components' wave momenta. This requires some explanation because it is not usually valid in a wave packet analysis, but let us first emphasise that this has nothing to do with quantum mechanics, where the components are not even considered to be physical, and where CoM between wave components and the particle turns on the probability weights Ordinary Quantum Mechanics (OQM) attaches to each of its wave components in the momentum basis. OQM provides good quality predictions, period. Although wave packet analyses originated in physical situations, the wave components introduced by Fourier analysis are typically constrained to propagate in the same direction as the particle. This produces a 1-dimensional rather than a 3-dimensional image, dispersion is mandatory, and the wave components must be thought of as infinitely extended in the direction of motion, so that the representation of the original, finite object is itself infinite and therefore non-physical. Since the components continuously slide past the localised image, CoM between such abstract components and the superposition can only be explicated using an appropriate wave equation. By contrast with this, with bounded motion under the dynamical constraint introduced above, the momentum that forms a given wave component constantly changes direction (due to interaction with the other wave components), so that its time average velocity is equal to the particle's group velocity, under which conditions CoM should be applied directly.

3.1 Invariance of the 4-Momentum

Consider the following general, multi-component form for a wave packet

$$\Psi(\mathbf{r},t)=\begin{bmatrix} y_{1}(\mathbf{r},t) \\ \vdots \\ y_{i}(\mathbf{r},t) \\ \vdots \\ y_{N}(\mathbf{r},t) \end{bmatrix} \tag{1}$$

where each y_i describes a momentum carrying wave component in 3-space + time (and so includes its direction of propagation, the unit vector $\hat{\mathbf{q}}_i$). Throughout this article we shall use lowercase symbols to refer to wave components, and uppercase to refer to superpositions as a whole. Let the momentum carried by the i^{th} component be $\mathbf{p}_i$. Suppressing the functional forms of the various components, we can, by our CoM assumption, always write for the particle momentum:

$$\mathbf{P}=\sum_{i=1}^{N}\mathbf{p}_i=\sum\mathbf{p}_i=\sum p_i\hat{\mathbf{q}}_i \tag{2}$$

where:

$\mathbf{P}$ = Group (or particle) momentum
$\mathbf{p}_\mathrm{i}$ = momentum carried by the i^{th} component
$p_i=\|\mathbf{p}_i\|$
N = number of components in the particle representation. Since the summation range is always from 1 to N, it will be omitted from here on.

Now let us also put $c = 1$, again by choice of units, so that the energy, $e_i=\hbar w_i$, of the i^{th} component is equal to the scalar value of the momentum carried, $e_i=c\|\mathbf{p}_i\|=p_i$, and so the total energy of the superposition is given by:

$$E = \sum e_i = \sum p_i \tag{3}$$

Noting that component velocities, $(\mathbf{v}_i = \mathbf{p}_i / p_i)$, all have unit modulus but variable orientations, the group velocity (consistent with our CoM assumption) is a momentum weighted average:

$$\mathbf{V} = \frac{\sum p_i \mathbf{v}_i}{\sum p_i} \tag{4}$$

where $\mathbf{V}$ = Group velocity. The modulus of group velocity, V, is a real number in the range [0, 1] (this is ***b*** in most texts). Define the effective mass from the usual relation between momentum and velocity:

$$\mathbf{P} = m_e \mathbf{V} \tag{5}$$

So, from equations 2, 3, 4, and 5:

$$m_e = \frac{1}{c} \sum \|\mathbf{p}_i\| = \sum p_i = E \tag{6}$$

The rest mass, m_0, is just the effective mass at zero group velocity. The above definitions will turn out to be good for all observers, but to make it clear that we are in no way assuming the result, let us begin by restricting the analysis to an observer at rest in the MBR frame. As the momentum, $\mathbf{P}$, of a typical superposition varies in response to an interaction, the question arises how changes in the group momentum become distributed amongst the components. As far as these individual $\dot{\mathbf{p}}_i$ are concerned the following conditions are required if the superposition of momenta is to be linear as CoM mandates:

a) $\dot{\mathbf{p}}_i \propto \mathbf{p}_\mathbf{i}$ (In order to preserve superposition of components).

b) $\dot{\mathbf{p}}_i \propto \dot{\mathbf{P}}$ (In order to preserve superposition of interactions)[5]

c) $\dot{\mathbf{p}}_i \propto 1/m_e$ Interactions are usually calculated on the basis of an invariant "interaction" property (*cf*.: "electric charge" is the interaction property of the Electromagnetic interaction.) Since the sum of scalar momenta (the energy of the superposition) varies under interaction, we also require that $\dot{\mathbf{p}}_i \propto 1/m_e$ in order to retain the invariance of the interaction property.

d) $\dot{\mathbf{p}}_i \neq f\left(\mathbf{p}_i/p_i\right)$ ($\mathbf{p}_i/p_i$ is a unit vector, $\hat{\mathbf{q}}_i$ in the direction of propagation). Since the various $\dot{\mathbf{p}}_i$ are parallel, all the components of a superposition rotate towards the same direction under interaction. Therefore $\dot{\mathbf{p}}_i$ must be independent of $\hat{\mathbf{q}}_i$ to preserve the interaction property.

Summarising, the distribution of changes to the group momentum amongst components is governed by:

$$\dot{\mathbf{p}}_i \propto \dot{\mathbf{P}}\left(\frac{p_i}{m_e}\right) \Rightarrow \dot{\mathbf{p}}_i = \dot{\mathbf{P}}\left(\frac{p_i}{m_e}\right) \tag{7}$$

The effect of Equation 7 is just to apportion the interaction property amongst the components of the group whilst conserving it for the group as a whole. In principle, one cannot rule out other kinds of dependency (especially upon the phases of components). However the equality must apply to an average over a time interval sufficient to measure the group momentum and/or its rate of change.

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[5] This condition can (and probably should) be relaxed without affecting the analysis by replacing the LHS with its time average or an expectation. The main point is that, by definition, any components of the $\dot{\mathbf{p}}_i$ that are transverse to $\dot{\mathbf{P}}$ sum to zero, so we need deal only with the parallel components.

In contrast to the classical idea, where a force causes a change in the condition of motion of an otherwise unchanged particle, an increase in the momentum carried by a wave propagating at constant velocity implies a substantive change to the wave itself (a change in amplitude or frequency, for example)[6], as opposed to a mere change in its condition of motion. Now, consider a superposition for which $\mathbf{P} = 0$, in the MBR frame. From Equations 2, 6, and 7 above, we have:

$$\mathbf{P} = \sum \mathbf{p}_i = \int \dot{\mathbf{P}}\, dt = \int \sum \dot{\mathbf{p}}_i\, dt;$$

$$\dot{\mathbf{p}}_i = \dot{\mathbf{P}}\left(\frac{p_i}{m_e}\right)$$

and

$$m_e = \sum p_i \Rightarrow \dot{m}_e = \sum \dot{p}_i$$

where $\dot{p}_i$ is the component of $\dot{\mathbf{p}}_i$ parallel to $\mathbf{p}_i$. One readily finds that $m_e \dot{m}_e = \mathbf{P} \bullet \dot{\mathbf{P}}$. Integrating, we get:

$$m_e^2 = P^2 + m_0^2 \tag{8}$$

which is equivalent to stating that the norm of the energy-momentum 4-vector of a particle is invariant for observers in the MBR. Substituting equation 5 in this gives:

$$\mathbf{P} = \frac{m_0 \mathbf{V}}{\sqrt{1 - V^2}} = g\, m_0 \mathbf{V} \tag{9}$$

Since $c = 1$ by choice of units. Although this determines mechanics within the selected frame, momentum involves both length

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[6] It will become clear later that the change is, in this case, a change in frequency

and time, so reconstructing the Lorentz Transformation between frames requires that we now identify at least one of these by itself. The following subsections develop both time and length transformations separately, however the analysis of length contraction (Subsection 3.3) necessarily touches on Electromagnetics, so we take time dilation first.

3.2 Time dilation

As is evident from Equation 4, spatial correlation amongst the directions of propagation, $\hat{\mathbf{q}}_i$, of the components of a superposition is necessary if it is to have a non-zero group velocity (again, let us establish the result in the MBR frame first). Higher degrees of correlation correspond to greater relative velocities. As the group velocity approaches the speed of light, the components approach the parallel:

$$\text{As } V \to 1, \quad \hat{\mathbf{q}}_i \to \hat{\mathbf{V}} \text{ for all } i.$$

But, if all the components of a group were exactly parallel to each other, no changes would arise in the spatial configuration of the group as it moved through our observer's frame of reference. Considering such a situation he must conclude that nothing ever happens in the inertial frame of the group. So, just as correlations amongst the $\hat{\mathbf{q}}_i$ are necessary for movement of the group, decorrelations are necessary for it to evolve internally. As the velocity of a group increases, its rate of internal evolution reduces. Changes in the spatial configuration of components with respect to each other (internal evolution) are thus associable with the passage of time, so the internal movements form a velocity dependent clock.

Each component contributes to the evolution of the group spatial configuration by virtue of its motion relative to the group (its “internal” motion). So, if we write, for the i^{th} component: $\mathbf{v}_i = c\hat{\mathbf{q}}_i \left(=\mathbf{p}_i / p_i\right)$ then the corresponding internal motion is given by:

$$\mathbf{v}_{zi} = c\hat{\mathbf{q}}_i - \mathbf{V} = \hat{\mathbf{q}}_i - \mathbf{V} \tag{10}$$

There is a meaningful comparison between this simple expression and the motion of the electron as described by the Dirac Equation [13], for which the velocity operator, $\vec{a}$, has constant modulus, c [14]. Although the instantaneous speed of the electron is constant in the theory, this is usually thought of in two parts, the group velocity $\mathbf{P}/H$, and a high frequency $(\sim 2H/h)$, small amplitude $(\sim \hbar/2mc)$, internal oscillatory motion, commonly known as the *zitterbewegung* [15], [16]. Equation 10 describes the internal motion of a component of a generalised photonic superposition, and in this sense corresponds to the *zitterbewegung*. Both the *zitterbewegung* and the $\mathbf{v}_{zi}$ scale with the group velocity according to the usual time dilation parameter, g.

With respect to the *zitterbewegung*, the result follows from the equation for the time dependence of the velocity operator in the Heisenberg representation of the Dirac theory [17]:

$$\vec{a}(t) = \left[\vec{a}(0) - \frac{\mathbf{p}}{H}\right] e^{-2iHt} + \frac{\mathbf{p}}{H} \tag{11}$$

in which $\mathbf{p}$ and H are both constants, so $\mathbf{p}/H = \mathbf{V}_g = \text{constant}$. The quantum mechanical expectation of the *zitterbewegung*, the first term on the RHS, is then $\dfrac{\langle y | \vec{a}(0) - \mathbf{V}_g | y \rangle}{\langle y | y \rangle}$ which varies with the group velocity, V$_g$, as $\sqrt{1 - V_g^2}$, since $\vec{a}$ has real eigenvalues.

To establish the same result for the $\mathbf{v}_{zi}$, note that the term "internal motion" has no meaning except in the context of a superposition. We must ensure that two representations which are identical in all respects except that, in the direction $\hat{\mathbf{q}}_i$, one has, say, p_i components of strength unity, whilst the other has a single component of strength p_i, are treated equivalently. So the necessary measure to connect these zero mean components of the internal movement with the evolution of the pattern formed by the whole superposition is a momentum weighted standard deviation. Let us define:

$$V_z = \sqrt{\frac{\sum p_i \mathbf{v}_{zi}^2}{m_e}} \tag{12}$$

It is readily shown (expand the square as the dot product of $\hat{\mathbf{q}}_i - \mathbf{V}$ with itself) that:

$$V_z = \sqrt{1 - V^2} \tag{13}$$

is the time dilation factor for superpositions of propagating waves.

The argument from internal atomic processes to real world clocks has long been established [18], and has been the subject of exhaustive empirical review [19], [20], [21], so we find:

$$\frac{\mathbf{D}t'}{\mathbf{D}t} = \frac{1}{g} = V_z \tag{14}$$

where $\Delta t'$ is the interval observed to pass on a moving clock corresponding to Δt, the interval observed to pass on a stationary clock.

This reduction in the rate of internal evolution, or time dilation, is a direct consequence of the constraint to constant velocity propagation:- To whatever extent the motion of a given wave component

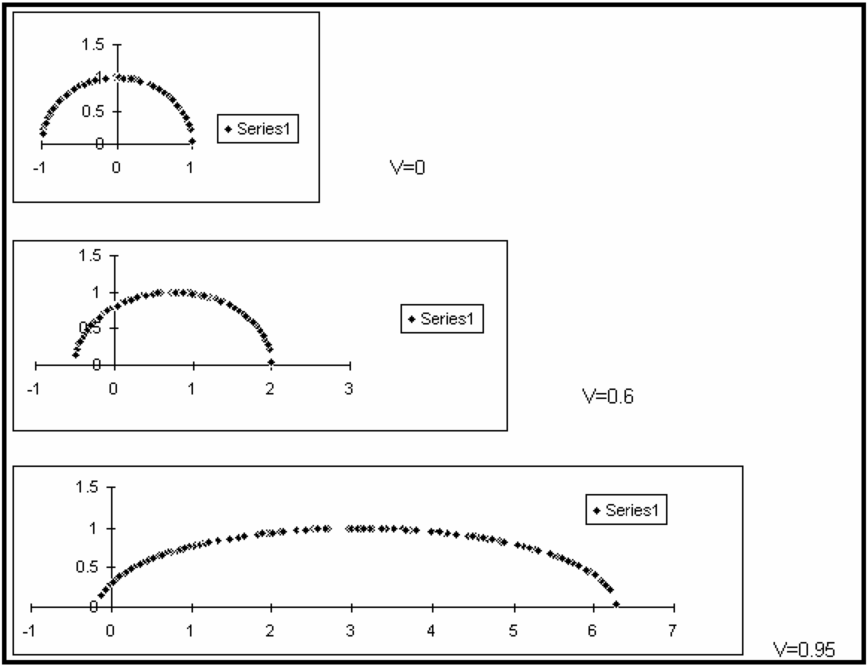

Figure 1: Momentum Flux Distributions at various particle velocities. Each plot is an ellipsoid of revolution about the *X*-axis, which lies in the direction of motion. Eccentricity increases with the group velocity, and the geometric centre of any given ellipsoid corresponds to the particle momentum.

contributes towards transporting the superposition through space, it is unavailable to contribute towards its (temporal) evolution *in situ* and *vice versa*.

3.3 The Electromagnetic Fields of a Moving Particle

The preceding sections have shown how analysis of spatial correlations amongst the components of a photonic superposition leads to characteristic relativistic behaviour. Here, we consider how the correlations develop as a superposition is Lorentz boosted. The result is a relation connecting the group velocity of a superposition with the shape of its momentum flux distribution in 3-space.

This relation echoes the transform that connects the Electromagnetic fields of a moving particle to those of a stationary particle. Of course it is well known that this transform describes a compression of the Electromagnetic fields of a charged particle in the direction of its motion, which equates to a Lorentz contraction of dimensions in the same direction [18].

3.3.1 Numerical Analysis

We take the case of a rest particle with an isotropic distribution of the momentum flux, and consider how it appears to other Lorentz observers. This distribution is defined by the condition that the expected value of the momentum flux density in one direction is equal to that in any other direction (which obviously gives us $\mathbf{P} = 0$). In order to illustrate the (elliptical) distortion of this distribution when considered from various reference frames, the equations of Subsection 3.1 have been analysed numerically. The result, shown in Figure 1, is a series of ellipsoids of revolution whose long axes lie in the direction of motion, and whose eccentricity increases with the group velocity.

3.3.2 Calculation of the Momentum Flux Distribution

This can be analysed directly if we replace the spherically symmetric distribution by a superposition of balanced pairs of waves (waves of equal but opposite momentum). If we put $N = 2$ in the analysis of Sub-Section 3.1, it can be seen that a balanced pair of waves contributes to the rest mass, but not to the particle momentum of a larger superposition. However it may be oriented, such a pair transforms (under interaction or, equivalently, a change of referential) such that its contribution to the total energy of a moving superposition

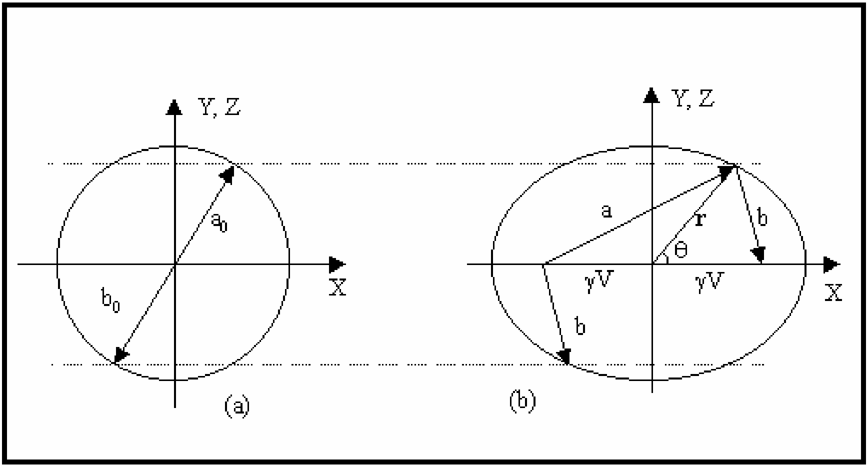

Figure 2: Transformation of the momentum flux distribution. Waves a_0, b_0 map to waves a, b respectively. a) rest particle; b) group velocity = V_x **i**.

is always in proportion to its contribution to the rest mass energy, so a balanced pair transforms independently of the rest of a superposition.

Consider such a pair of waves arbitrarily oriented with respect to the velocity separating two inertial frames. Figure 2, in which the *X*-axis is selected to lie along the direction of the velocity separation, depicts the situation. Fig. 2(a) shows a pair of waves, (a_0, b_0) the sum of whose momenta is zero, whilst fig. 2(b) shows the same pair from an inertial frame in which the group velocity of the superposition is $\mathbf{V} = V_x \hat{\mathbf{i}}$.

Since we are concerned only with the ratios, let $a_0 = b_0 = 1$ (in momentum units). Then:

$$a + b = 2\gamma \ ; \mathbf{a} + \mathbf{b} = 2\gamma V_x \hat{\mathbf{i}}$$

$$a^2 = r^2 + (\gamma V)^2 + 2\gamma Vr \cos\theta$$

$$b^2 = r^2 + (g V)^2 - 2g\, Vr \cos q$$

Upon eliminating *a* and *b* from this, it is found that:

$$r = \frac{1}{\sqrt{1 - \mathrm{V}^2 \cos^2 q}} \tag{15}$$

This transform connects the expected value of the momentum instantaneously propagating in a given direction with the group velocity for superpositions of generalised photonic wave components.

3.3.3 Compression of the $1/r^2$ fields

Now, let us bring the Electromagnetic field into the discussion by positing that attributable to each photonic wave component is an associated Electromagnetic field[7], and that it is the superposition of these that appears to us as the fields of the particle, described by the interaction property, "charge," *Q*. Allocating this property to wave components in accordance with Equation 7 gives: $Q(V) = Q(0) \Rightarrow q_i = Qp_i/m_e = Qp_i/g\, m_0$. Following this through introduces an extra factor of g in the denominator of the RHS of equation 15, upon which it becomes the result usually calculated to transform the Electromagnetic fields of a rest particle into those of a moving particle [22], except that Cos$q$ has replaced Sin$q$. Poynting's Theorem [23] has it that the Energy flux density vector **S**, is parallel to the momentum carried by the Electromagnetic field, and in the direction of the cross-product **E** ´ **H**, so **E** and **H** are both transverse to **p**, and we should expect Cos$q$ to replace Sin$q$ in a transform expressed in terms of wave momenta.

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[7] *i.e.,* the EM fields are a property of the waves, to which we have granted prior status. We need not suggest that the EM field is the total reality.

Finally, forming this connection to Electromagnetics has ensured that the physical wave elements, whilst unbounded, are indeed finite.

3.4 The Relativity Principle

Given Equations 9 and 14, the observer in the MBR can use standard methods to reconstruct the perspective encountered by any other inertial observer. In doing so, he will deduce the Lorentz Transform, the Relativity Principle and the constant observed velocity of radiation without any heuristic redefinition of momentum, and without needing the Ives-Stillwell experiment [21] to confirm the separation of time dilation from length contraction. The Relativity Principle states that all experiments work the same for all observers. Since the experimental fact is that different observers do not get the same result when measuring the MBR temperature distribution, the wave soliton approach includes new facts, which cannot be accounted for within the usual interpretation. Doesn't this exception undermine the Relativity Principle?

On the contrary, measurements on the MBR are the exception that proves the rule: Photonic motion both defines the preferred frame and forms the basis for inherently relativistic particle models. Consequently there is no reason to reject the Relativity Principle in any other context. As far as the empirical Physics goes, Einstein's original argument, although it was formulated within a particle theoretic framework, did not depend upon it. Now, it is widely presumed that this argument precludes the preferred frame concept, but this is simply not the case—the fact that the Special Theory does not *require* one neither proves nor disproves the existence of a preferred frame, so Relativity Theory is silent [24]. Philosophy (Machian positivism), not Physics, provided what has long been the decisive argument—that all the elements of a theory ought to be observable, at least in principle. Although this remains sound, the positivist error lay in assuming that what was then unimaginable would remain forever impossible—a century ago it was impossible to predict the discovery of the MBR. Since we do have an observable preferred frame, the philosophical argument that excluded the preferred frame concept on the basis of its vaunted unobservability should be inverted—we require a theory that includes all the observables. The present interpretation categorically fails to achieve this goal.

The Relativity Principle was originally postulated on essentially aesthetic grounds. Now, it has been deduced from one of the surest observations in all of Physics—there are phenomena that propagate at the characteristic velocity. Rather than introducing new concepts, we removed the concept of inherently subluminal motion, then re-synthesised it from superposed photonic movements. Perhaps to deny the existence of matter qua material substance is a drastic step, but modern physics has taught us to think of material particles as dynamic systems, and has eradicated the notion of substance as well as any concept of persistence of identity [25], so what real evidence is there for a non-propagative energy? Where is the conceptual economy in a Physics with two distinct forms of the same thing? How should something which moves by its nature be transformed into something not inherently motional? The only support for the complications introduced by the idea of matter as distinct from radiation lies in the notoriously unreliable "common experience."

Before returning to the EPR paradox, it is worth noting two recent papers by H.Y. Cui [26], [27] in which a series of key results, from the structure of Electromagnetics to the Klein-Gordon and Dirac equations, as well as the Schwarzchild metric tensor, have been deduced from the constancy of the 4-velocity. We have shown that the invariance of the 4-velocity is implied by the invariance of the 3-

velocity, and from this it follows that this significant body of knowledge can be inferred from a single observation.

4 Understanding EPR

Percival's temporal loop paradox is resolved—relativity of simultaneity is in the eye of the beholder, and there is a physically meaningful sense in which quantum mechanics relies upon the distinction between what is immediately presented to observers and what actually is. "Wave function collapse" is in the MBR frame. Although constructing Relativity Theory around a preferred frame opens the door to EPR, there remain, amongst the many different lines of argument in the discussion of EPR, two available paths in logic capable of explaining these experiments physically.

These are superluminality and nonseparability arguments, as epitomised by those of Redhead [28]. Whilst superluminality seems readily intelligible, the somewhat subtler nonseparability arguments are all too commonly dismissed as obscure, philosophical, even non-physical. It is the intention in the balance of this article to clarify the reasoning involved by placing it in a specific physical context, namely local realist wave theories. We shall expand upon Redhead's central philosophical conclusion, note some experimental instances, and finally describe a typical EPR experiment from the wave perspective.

First however, let us assess the relative merits of these two proposals.

4.1 Superluminality or a Local Realist Wave Theory?

Within the context of the wave mechanical interpretation of Relativity Theory provided above, the particles of matter are thought of as 3-

dimensional wave solitons. Superluminality is then the proposition that, in addition to this primary wave ontology, there is a second ontological form (such as the superluminal shock wave, *e.g.,* [29]) that mediates long range interactions.

Refining the timing windows in EPR experiments can never eliminate the possibility of superluminal interaction mediation, so this proposition isn't falsifiable. On the other hand, it would undermine the nonseparability case if such a refinement ever led to a failure of the quantum predictions. Physics (at least to date) has always been essentially epistemological, and quantum mechanics' central assertion is that this is good enough for all practical purposes. Superluminality substantially undermines both this assertion and the structure of Relativity Theory. To the extent that there is an alternative, should one seriously entertain an unobserved, brand new class of phenomenon that denies the validity of an extensively tested, theoretical centerpiece combining elegance with unprecedented predictive power, to which there is no hint of any practical exception, and whose only downside is the fact that it is difficult to understand why it is so?

It will of course be observed that this article, based on an assumption about physical reality, crosses the boundary at least into the metaphysical sub-category of ontology. However, human beings (physicists included) *do* seek to understand the world, and will continue to demand that it have rationally comprehensible mechanisms. The information theoretic approach to physics can never, in principle, assist us in that area. With EPR, we already have a working theory, but just can't decide whether or not it is philosophically acceptable. Apart from the deduction that wave function collapse can be evaluated in the MBR frame, this article makes no new physics as such, but its central purpose is not to replace either of the foundation theories, merely to point out that they are compatible with at least one self-consistent, realist framework. Epistemological physics has advanced to the point where it actually sheds light on genuine metaphysical problems, and there can be useful feedback, but these distinct philosophical categories should still remain separate.

Finally, superluminality retains the retarded interaction paradigm which, though initially attractive, raises too many problems. When it has been faithfully implemented it becomes unintelligible and analytically disastrous (as in the case of the pre-acceleration induced by the Abraham-Lorentz self-force [30])—a central problem being: When the (virtual) IMP (or worse still, field, as in Classical Electrodynamics) has transferred its momentum to the target, how and when is (or was?) the reaction communicated back to the source? Anyone who doubts the severity of this problem should study the history of the failure to solve the two body problem in Classical Electrodynamics.

4.2 Philosophical Review of the Nonseparability Argument

Redhead's central conclusion [28] is that Ontological Locality (OLOC) does not of necessity imply Epistemological Locality (ELOC). An alternate statement of this is that local realism (a philosophical construct which maintains that no part of the ontology moves faster than light) does not imply the Principle of Locality (which erroneously insists that events at one place cannot influence those at another, remote location within the light time).

We can begin to make sense of this initially bizarre conclusion by considering the specific experimental situation discussed in the EPR paper [1], in which a particle pair, having become entangled in position-momentum, subsequently became well separated. Measuring the position of one member of the pair enables quantum mechanically a prediction with certainty concerning the position of the other, which is to say the result that would be obtained should the second particle's position be observed. Noting that the "position of the particle" (an observation) is not the same as "the particle" (a "thing in itself") we are entitled to question the inadvertent and almost universal assumption that the elements of reality that "correspond" [1] to an observation are necessarily co-located with it. A trivial example demonstrates the alternative.

In a typical small tornado the most readily observed phenomenon is a well-localised tower of dust in the distance. But it is well understood that this is caused by the distributed system of winds in the wider vicinity of the tornado. The winds suck the dust into the air. The distributed gives rise to the local. To suggest that the dust causes the wind would be absurd, but this is the position we have adopted with respect to sub-atomic particles.

Once we combine this error in logic with the condition of proximate causation (which remains vital), all long range interactions must be retarded relative to the "body" of the particle. On the other hand, if we recognise that localisation is more reasonably seen as an effect caused by distributed field "elements," the whole question of retardation becomes moot. In the context of wave soliton models, the retarded "attached field" [30] assumption makes no sense at all. The essence of the soliton approach is that interference amongst distributed components gives rise to a well localised "image," so the more reasonable assumption would seem to be an "attached particle."

This error of presuming the causal relationship between a particle's "body" and its distant "fields" is closely related to another difficulty common in the Physics literature, namely the tendency to equate "realism" with "atomism." Again, an example (from the recent literature) illustrates the point:

> *"... the realist philosophy, which claims that the reason why we see macroscopic objects as having definite forms and definite localisations in space is that they really exist as such, quite independently of us, that is, of our sensorial and intellectual equipment. We see them at definite places because they are at definite places." —B. d'Espagnat [31]*

Now, whilst this is one realist formulation, it is far from the only possible formulation of the fundamental realist proposition. We are led to formulate an alternative that is more compatible with a wave theoretical approach to realism, *viz*:

> *The reason why we see macroscopic objects as having definite forms and definite localisations in space is that there exists, quite independently of our sensorial and intellectual equipment, a unique, objective physical reality underlying, and causative of, our sense experience.*

This formulation, whilst still realist (as opposed to idealist, instrumentalist, positivist and so on) conforms with d'Espagnat's later statement that:

> *"Most contemporary philosophers take it as more reasonable to consider that "the fact that we perceive such "things" as macroscopic objects lying at distinct places is due, partly at least, to the structure of our sensory and intellectual equipment." [31]*

And so:

> *"We should not therefore take it as being part of the body of sure knowledge that we have to take into account for defining a quantum state." [31]*

With which, noting that the word "it" in this quote includes the association between the location property and the "thing in itself," we have no issue. Indeed, it is central to the nonseparability argument that we reject such an association, and instead assume that the reality underlying the observation of an (unextended) location property is itself inherently extended. This is the converse of atomism, whose central idea is that the reality actually subsists where we identify it to be, a position which contradicts either locality or quantum mechanics or both. Since the observation of point-like phenomena is an effect of the assumed distributed reality rather than its cause, any talk about interactions between primary point-like phenomena is misplaced. It is more meaningful to speak of distributed interactions between inherently extended elements of reality as having kinematic consequences for the corresponding image locations.

4.3 Examples of Nonlocality in Local Realist Wave Theories

4.3.1 Apparent Superluminal Light Propagation

Culminating a series of similar results, a widely publicised experiment by Wang *et al.* [32] featured a light pulse that "transits" a chamber containing excited Caesium gas at an effective speed of some 300 *c*. The author's analysis, using local realist wave theory, clearly illustrates the distinction between ELOC and OLOC.

A pulse enters the chamber, and a pulse leaves the chamber, but the pulse leaving is not the "same," in the sense of having a persistent identity, as the one that entered. Instead, the result is explained by phase disturbances amongst the wave components of the input pulse induced by the dispersive medium, leading to a reconstructed pulse at the output that appears ahead of the light time through the apparatus. There is no contention that any ontological element actually moved faster than light. Rather, re-phasing of already distributed wave components causes the observed non-locality. Although the physical scale of EPR experiments is larger, the energies involved are relatively trivial, so this mechanism can apply equally well to EPR, as discussed in subsection 4.4.

One important implication to note is that the distributed (wave components) seem to have a better claim to the description "real" than does the localised (image of the pulse).

4.3.2 Tunnelling

A variety of theoretical and experimental investigations have shown the independence of tunnelling time with respect to the dimensions of the barrier. A more dramatic example however, is provided in the case of a single particle tunnelling through two successive barriers [33], wherein it is shown that the traversal time depends neither upon the barrier widths, nor upon the distance separating them. Moreover, this paper emphasises the formal analogy between the Helmholtz and Schroedinger equations, which enables the substitution of waveguide experiments (and the associated local realist wave theoretical analysis) for particle experiments. Again, re-phasing of already extended components explains the nonlocality, and there is no persistence of identity.

4.4 A Wave Theoretical Account of EPR

For context, let us consider an EPRB experiment involving two electrons entangled in the angular momentum. The entire experiment comprises: the two particles, A and B; measurement apparatus in each arm of the experiment, M_a and M_b; and the environment, W. Let each of these subsystems be represented by a suitable set of distributed wave components, designated as $\{A\}$, $\{B\}$ and so on, all of which are assumed to extend in space significantly farther than the distance separating the two arms of the apparatus.

Now, under normal (unentangled) conditions, we find that interactions are range dependent, so let us assume that, immediately prior to any measurement having been performed, the following sets of possible wave-wave interactions are insignificant:

$$\{A\} \leftrightarrow \{M_b\} \sim 0$$

$$\{B\} \leftrightarrow \{M_a\} \sim 0$$

$$\{M_a\} \leftrightarrow \{M_b\} \sim 0$$

where the symbol $\leftrightarrow$ means "exchanges of momentum between."

Ordinarily we would also expect $\{A\} \leftrightarrow \{B\} \sim 0$, however, the particles having been created at a common origin with zero nett angular momentum, their respective sets of wave components are intimately correlated which provides a legitimate physical basis upon which to anticipate a continuing interaction sufficient, under carefully controlled experimental conditions, to maintain the entanglement in spite of some modest, decohering interactions with the environment, $\{W\} \leftrightarrow \{A\}$ and $\{W\} \leftrightarrow \{B\}$.

The close range measurement interaction, $\{A\} \leftrightarrow \{M_a\}$ or $\{B\} \leftrightarrow \{M_b\}$, whichever happens first (in the MBR frame), predominates over the $\{A\} \leftrightarrow \{B\}$ interaction, disrupting the interparticle correlations and therefore terminating any future possibility of a significant interaction between the two particles. Note that the wave components $\{M_a\}$ are widely distributed, as are the wave components $\{A\}$, so there is no paradox in the proposition that this disruption happens instantaneously at large distances from the location of the particle / measurement equipment, as recently pointed out:

> *"Of course, if we make some excitation for field at the point O, then a propagation of this excitation from this point will have a finite speed. But in the scope of the unified field model we do not be able to make this excitation or modify arbitrarily the world solution. Any excitations of the field at the point O belong to the world solution which is a single whole" (sic)—A.A. Chernitski [34]*

In a wave theory local realism means that changes propagate away from their causes at (or below) the speed of light, but there are no point sources, only distributed excitations.

Prior to any measurement interaction, then, the two particles co-evolve. Each one might[8] be said to have at any instant a certain angular momentum, in balance with the other member of the pair, and the projection of this onto the selected measurement axis determines the distribution of outcomes for the measured particle. Angular momentum conservation then requires that the unmeasured particle is left in the corresponding eigenstate[9].

There is no "spooky action at a distance" involved, and the essential feature of the experiment is the distributed cessation of a distributed interaction that had been ongoing prior to the first measurement, all of which provides a physical sense to the quantum mechanical concept of wave function collapse.

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[8] Or might not, if we think about the $\{A\} \leftrightarrow \{B\}$ interaction as a slight resonance, storing energy neither in one particle nor the other, but in the combined distributed system. In either case, the realist sense is maintained.

[9] Applicable (non-local) hidden variables models exist, however, as repeatedly stressed, there is no motivation to depart from the restriction to observables—our arguments are only intended to show that local realism is conceptually compatible with Quantum Mechanical nonlocality.

Conclusions

Recent EPR experiments provide increasingly secure experimental evidence that there are indeed influences between space like separated events. Further evidence to the same effect has been found in the context of gravity [35], where astronomical observations establish a minimum bound of $\sim 10^{10}c$ for the velocity of any putative gravitational IMP.

Now, since it is customary to seek to replace a successful physical theory when, and only when, it is found to be empirically deficient, the fundamental challenge presented by EPR is not to improve upon quantum mechanics, but to identify and develop a worldview commensurate with it. There are two principal impediments to such a development.

The first of these, introduced no less than two and a half millennia ago, is the atomist metaphysic, which has it that the world ultimately consists of a multitude of distinct elementary particles. Whilst this approach is appealing to the extent that it mimics our ordinary experience of a world apparently divided into spatially distinct objects, it fails to provide an adequate account of interaction between remote particles. Retarded interaction has long been thought to overcome the indisputable logical necessity that interaction must be predicated upon co-location. However, this metaphysical Band-Aid addresses neither the question of how the source particle "knows" which Virtual IMPs have actually been absorbed (in order to account for the momentum transferred to the target), nor the fact that the co-location constraint is never satisfied by a point model (because, if we treat them both as point particles, no matter how close the mediating particle may be to the target, it remains separated from it by an infinite number of points). Therefore, the elements of any ontological proposition competent to represent interaction processes must be inherently extensive. Concerning the degree of extension, there are two possibilities: ontological elements may be effectively bounded (*e.g.,* within a radius of $\sim 10^{-15}$m for an electron) or effectively unbounded, as in this article.

In the bounded case, retardation is still a requirement, so EPR mandates that we need to invoke not just IMPs, but superluminal ones at that. Such an approach seems quite unrelated to the foundation theories. Why should mechanics be non-linear? Why should massive particles projected onto a slit system display interference patterns? How can the source particle know when, or if, a given virtual IMP is absorbed? The conceptual gap between the foundations remains unbridged. Finally, the pseudo-point particle approach to ontology is profligate: we have propagating and non-propagating, inherently subluminal, inherently photonic and inherently superluminal classes of phenomena, with no means to comprehend transitions amongst these classes.

Contrasting with this, we have considered the unbounded case with ontological elements constrained to propagate at the characteristic velocity. The restriction to extensive elements immediately poses the question of how it is that phenomena appear to be well-localised, which points directly to Fourier superposition methods in general, and wave solitons in particular. There is only one ontological class, so there is no question of unexplained inter-class transitions. Under the assumed dynamical constraint, a wave theoretical approach to particle mechanics reproduces the Special Theory and all its valuable symmetries, with the one essential exception that the theory is automatically embedded in the only suitable candidate preferred frame that has been identified experimentally—a critical fact in the light of EPR's instantaneous correlations, but one that cannot be explained within the usual interpretation of Relativity Theory. Taking our locally realistic wave elements to be widely distributed allows the model to embrace apparently instantaneous interaction at a distance, just as has been found with the classical local realist wave theory. Qualitatively, this approach is clearly compatible with quantum mechanics. Quantitatively, the invariance of the 3-velocity in a physical wave model implies the invariance of the 4-velocity for particles, which in turn has been shown to imply most of the physics presently in use, including quantum mechanics' most important founding equations.

Is this not the simplest resolution of the EPR paradox imaginable?

The second impediment to the development of a worldview commensurate with the state of the art in Physics lies somewhere in the no man's land between Physics and Metaphysics. The single most vital practical principle underlying the successful development of Physics to date has been the restriction to observables. This is what allows experiments to be the ultimate arbiters of our models. However, as helpful as it is for Physics, it can be equally unhelpful to Metaphysics, because we can never, in-principle, observe reality sui generis, only properties. The very process of observation is necessarily a matter of abstracting from the reality. Therefore one should not proceed too confidently from Physics to Metaphysics, from the truth value of an empirical model to truths about the ultimate nature of physical reality.

Unfortunately, it must be said that this is precisely what has occurred with Relativity Theory: an empirically valid fact (that observers will not necessarily agree about the temporal ordering of spatially separated events), has combined with the presumption of atomism to evolve into an incontrovertible metatruth (that there is no fact of the matter concerning such temporal orderings). We have moved, with no positive proof, from an empirical model with the attraction that it does not rely upon the preferred frame to the certain metaphysical position that there cannot be one.

Can relativity of simultaneity, having been discovered by pure reason rather than by any mundane experiment, be so absolute as to transcend multiple forms of empirical evidence (EPR, gravity, and an experimental preferred frame)? Should Physics disavow all metaphysical pretensions yet take its own deductions to be metaphysically axiomatic? And if we must continue to cling to a philosophical position against the evidence, mounting for more than thirty years now, what became of the restriction to observables?

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