Information Relativity Theory Surpasses Bell's Inequality and Reproduces Quantum Theoretic Predictions

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Abstract

Bell's Theorem prescribes that no theory of nature that obeys locality and realism can reproduce all the predictions of quantum theory. However the theorem presupposes that distanced physical systems become spatially disconnected. This presupposition, although in agreement with our intuition, has never been confirmed experimentally. As a result Bell's Theorem prohibits only *temporal* locality, but not *spatial locality* between distanced particles. Here, I show that any local-deterministic relativity theory that violates Lorentz's contraction for distancing bodies cannot be forbidden by Bell's inequality. I further show that the predictions of a recently proposed local and deterministic Information Relativity Theory, are consistent with quantum theory and quantum thermodynamics, and reproduce the same results for key quantum phenomena, including matter-wave duality, quantum criticality and phase transition, formation of Bose-Einstein condensate, and quantum entanglement.

The theory assumes that observers who are in inertial motion with respect to each other with relative velocity v, communicate information about physical observables using an information carrier with known velocity (v_c) which satisfies $v_c > v$. No other presumptions are made. For velocities satisfying $v \ll v_c$ all the theory transformations reduce to Galileo-Newton laws. The theory is simple and is also beautiful due to its Golden Ratio symmetries. More importantly, the theory is *scale independent* with respect to the investigated physical systems' dimensions and the velocity of the information carrier, which renders it applicable to the dynamics of moving bodies in all inertial physical systems.

Keywords: Relativity, Information, Bell's Theorem, Locality, EPR, Matter-Wave, Phase Transition, quantum criticality, Bose-Einstein Condensate, quantum entanglement. .

"If you can't explain it simply, you don't understand it well enough".

Albert Einstein

"The research worker, in his efforts to express the fundamental laws of Nature in mathematical form, should strive mainly for mathematical beauty. He should still take simplicity into consideration in a subordinate way to beauty".

Paul Dirac, "the relation between mathematics and physics".

1. Introduction

Quantum phenomena are empirically proven properties of nature with tremendous potential for future technologies. In particular, quantum entanglement has nowadays applications in emerging technologies of quantum computing and quantum cryptography, and quantum teleportation experimentally. A short list of exciting developments includes Ekert's pioneering invention of a secure cryptographic key [1-2], quantum communication dense coding [3-4], and teleportation experiments, starting from pioneering experiments (e.g., [5-6]), to more recent experiments on teleportation in different scenarios (see, e.g., [7-8]).

For many decades Quantum Theory has been gaining much success in predicting quantum entanglement and other quantum phenomena. The common view of current physics adopts the assertion of Bell's Theorem that no theory of nature that obeys locality and realism can reproduce the predictions of quantum theory [9-11]. The most serious objection to the nonlocality of quantum theory was formalized by Einstein, Podolsky, and Rosen in their famous EPR paper [12]. In essence, the paper argue that the *nonlocality* prescribed by quantum theory implies that the theory is incomplete, such that its elements are not in one-to-one correspondence with physical reality. EPR concluded that the wave function does not provide a complete description of the physical reality, and that the open question left is whether or not a complete description of physical reality exists? EPR concluded their paper by stating: "We believe, however, that such a theory is possible" (see in [12], p. 780).

John Bell formalized the EPR deterministic world idea in terms of a local *hidden variable*s model (LHVM). The LHVM assumes that: (1) measurement results are determined by properties the particles carry prior to, and independent of, the measurement (“realism”), (2) results obtained at one location are independent of any actions performed at space-like separation (“locality”), and (3) the setting of local apparatus are independent of the hidden variables that determine the local results (“free will”) [13]. Bell proved that the above assumptions impose constraints on statistical correlations in experiments involving bipartite systems, in the form of the famous Bell Inequality. He then showed the probabilities for the outcomes obtained when suitably measuring some entangled quantum states violate Bell’s inequality. From this he concluded that entanglement is that feature of quantum formalism that makes simulating the quantum correlations within any classical formalism impossible.

It is now commonly accepted that the correlations predicted by quantum mechanics and observed in experiments reject the principle of local realism, and with it the possibility of "hidden variables" as mediator of information about one system state to a distanced system.

Notably, while the main reason behind Einstein's "spookiness" was the "action at a distance", i.e., the *spatial nonlocality* between distanced systems, Bell’s primary concern was the temporal aspect *of non-locality*, which in his views created the essential contradiction between quantum theory and Special Relativity, which prohibits faster than light causation [9]. In Bell's words "We have an apparent incompatibility, at the deepest level, between the two fundamental pillars of contemporary theory” (Bell, 1984, p. 172, quoted in [13]).

Our main concern here is not with the above mentioned difference in perspectives, but with the fact that Bell's Theorem has completely neglected the aspect of spatial dimension of non-locality, and that this neglect constitutes a serious shortcoming of the theorem. As a result, all the experimental tests of

Bell's theorem (e.g., [14-18] were designed to close the temporal locality loophole, with nothing done to close a probable spatial locality loophole. It is possible that the possibility of spatial locality between distanced particles was never thought off because our intuition and commonsense tell us that particles that are distanced from each other become spatially disconnected. This intuition, however, has never been tested experimentally.

Given the above, we believe that it is justifiable to interpret Bell's Theorem as a theorem that prohibits only theory of nature that obeys *temporal* locality and realism from being a candidate for reproduce the predictions of quantum theory. However, Bell's Theorem cannot forbid realistic theories which predict spatial locality from being legitimate candidates for reproducing the predictions of quantum mechanics. The questions that remain are: (1) what conceivable theories, if any would predict the existence of spatial locality between distanced particles? And (2) would any of these theories, supposing they exist, reproduce the prediction of quantum mechanics? We address each question in turn in the following two sections.

2. Can a theory that obeys realism predict spatial locality?

We answer the above stated question by demonstrate that under appropriate conditions, any local-deterministic relativity theory that violate Lorentz's contraction for distancing bodies can secure spatial locality between distancing particles. For this purpose consider a system in which two particles A and B are distanced from each other along the x axis with normalized constant velocity β ($0 \leq \beta \leq 1$). Denote the radius of particle B in its rest frame by Δx^0.

For an inertial system as the one described above, the relativistic distance transformation is given by:

$$\Delta x = \Lambda_x(\beta)\, \Delta x^0, \qquad \ldots (1)$$

where Δx is the length of particle B along the x-axis in the reference frame of particle A and $\Lambda_x(\beta)$ is a distance transformation factor. Now consider the set of all continuous and well-behaved local and deterministic relativity theories in which $\Lambda_x(\beta)$ satisfies the following conditions:

$\Lambda_x(0) = 1$ …. (2)

$\frac{\partial \Lambda_x(\beta)}{\partial \beta} \geq 0$, for $\beta \geq 0$, and $\frac{\partial \Lambda_x(\beta)}{\partial \beta} < 0$, for $\beta < 0$ …. (3)

$\Lambda_x(1) = \infty$. .... (4)

The condition in (2) ensures the invariance of Δx^0 if the two particles are stationary with respect to each other. The conditions in (3) and (4) contrary to the Lorentz contraction prescribe that the spatial dimension Δx^0 of particle B, along its movement relative to particle A, will continually "stretch" with β, approaching ∞ as β approaches 1. Because the Lorentz invariance contradicts quantum theory itself [19-20], objecting to its violation by conditions (3) and (4) (for distancing bodies) is hard to justify.

In theories of the above defined type, local entanglement becomes feasible even when temporal locality has been eliminated. Note that for any distance *d* between A and B, conditions (2)-(4) guarantee the existence of a critical velocity $\beta^*(d)$ above which the *relativistic stretch* of particle B in particle A's rest frame is larger than *d*.

3. Can a local and deterministic theory reproduce the predictions of quantum theory?

The positive answer to the above question is given here constructively. For this purpose we utilize a simple relativity theory, termed "Information Relativity," (IR) [21-24] and show that despite being deterministic and local, it reproduces several key results of quantum theory and quantum thermodynamics. First, we give a brief account of Information Relativity Theory (IR). Following we apply the theory to motion of a body of mass and show that it yields predictions consistent with De Broglie's model of wave-matter duality and reproduces the critical De Broglie's wave length for the formation of the Bose-Einstein condensate [25-26]. We further show that IR accounts successfully for experimental results concerning the point of quantum criticality [27]. Following we analyze a simple EPR bipartite system, and explain the phenomenon of entanglement while providing the same result derived by derived by L. Hardy [28-29] for the maximum probability of obtaining an event which contradicts local realism (p = 0.090169994). We end with summary and conclusions.

4. Information Relativity (IR) – A Brief Account

Information Relativity Theory takes a completely different view of relativity than the ontic view of Einstein's Relativity. Rather than treating relativity as a true state of nature, the theory argues that relativity accounts for information differences (i.e., differences in knowledge about nature) between observers who are in motion with relative velocity v with respect to each other. Within this new framework of relativity we ask, what information will be received by an observer in a "stationary" reference frame, concerning some physical measurement taken by a second observer in the "moving frame, knowing that the information carrier transmitted by the observer in the "moving frame" to his/her frame travels with constant velocity (v_c > v).

Notice that the above described set up is universal. It supposes two reference frames moving with respect to each other while communicating information about observables measured in one reference frame to the other. Except for the specific measurements taken by an observer in his or her rest frame, and the two velocities, v and v_c, no additional information is known to us. We also do not make any pre-assumption.

We ask: what will be the value inferred by an observer in reference frame 1 based on the information he or she receives from an observer in reference frame 2 regarding a physical measurement conducted reference frame 2.

For the case of two frames of reference moving in constant velocity v with respect to each other, Table 1 depicts the theory's resulting transformations (for complete derivations, see supporting information). In the table, the variables Δt_0, Δx_0, and ρ_0 denote measurements of time duration, distance, and body's mass density in the rest frame, respectively, $\beta = \frac{v}{v_c}$, and $e_0 = \frac{1}{2}\rho_0 \ {v_c}^2$.

Table 1

Information Relativity Theory's Transformations

Physical Term	Relativistic Expression	
Time	$\frac{\Delta t}{\Delta t_0} = \frac{1}{1-\beta}$	.... (5)
Distance	$\frac{\Delta x}{\Delta x_0} = \frac{1+\beta}{1-\beta}$	…. (6)
Mass density	$\frac{\rho}{\rho_0} = \frac{1-\beta}{1+\beta}$	.... (7)
Kinetic energy	$\frac{e_k}{e_0} = \frac{1-\beta}{1+\beta}\beta^2$	... (8)

As eq. 5 shows, IR disobeys the Lorentz Invariance principle. It predicts time dilation with respect to distancing bodies, and time *contraction* with respect to approaching bodies. Note the eq. 5 resembles the Doppler formula for wave travel [30-31] which predicts red-shift or blue-shift, depending on whether the wave-source is distancing from or approaching the observer. The relativistic distance term (eq. 6) prescribes length contraction for approaching bodies, and length *extension* for distancing bodies, causing the mass density along the travel axis to increase or decrease, respectively. It is important to note that the predicted length extension is the feature that grants the theory an exempt from Bell's Inequality test.

Information Relativity Theory has some nice properties: First, is very simple. Second, for low velocities β << 1 the transformations in Table 1 reduce to the classical Newtonian formulas. Third, the theory satisfies the EPR necessary condition for theory *completeness*, in the sense that every element of the physical reality must have a counterpart in the physical theory [1]. In fact, all the variables in the theory are observable by human senses or are directly measurable by human-made devices. Fourth the theory is scale independent with respect to the size of the investigated physical system. It applies to the dynamics of very small and very large bodies, suggesting the dynamics of the too small and too large bodies abide the same laws of physics. This property which follows from that fact that the theory puts no limits on the physical dimensions of the moving bodies, has been validated successfully in applications of the above transformations, without additions of constants or free parameters, to predicting the dynamics of small particles [22, 32-33] as well as the galactic universe [23, 34]. Fifth, and more importantly, the theory is also scale independent with respect to the information carrier's velocity v_c, (provided that $v_c > v$), suggesting that it could also be applied to the dynamics of moving bodies in classical physical system (e.g., acoustic, thermal, seismic, etc.).

5. Prediction of Quantum Phenomena

For application of the theory to high energy particle physics and to cosmology we assume that $v_c = c$, where c is the velocity of light in the observers' internal frame.

5.1. Prediction of Matter-Wave Duality

The concept of matter-wave duality is central to quantum theory, ever since 1924, when Louis de Broglie introduced the notion [35-36]. Nonetheless, it remains a strange and unexplained phenomenon. Here I show that IR sheds a new light on this issue by demonstrating that it is a natural consequence of relativity. To show this I use a setup involving a simple closed system in inertial linear motion. Specifically, I consider a particle of rest mass m_0 which travels along the positive *x* axis, with constant velocity *v* away from the rest frame *F* of another particle. Denote the "traveling" particle's rest frame by F'. The kinetic energy of the particle, as function of the relative velocity β = v/v_c (see eq. 8), is depicted by the continuous line in Fig.1. The dotted line in the figure corresponds to the classical Newtonian term. At very low velocities relative to the information carrier velocity, the bulk of the particle's energy is carried by its matter while at high enough velocities, relative to the carrier velocity, the particle's energy is carried by the particle's wave (see fig. 1). Thus, although completely different in its approach, IR's description of the matter-wave is akin to de Broglie's matter-wave model.

The difference, shown by the dashed line, corresponds to the energy carried by the body's wave.

Formally we define the body's wave energy at a given velocity as the difference between the matter's Newtonian energy term e_0 and its relativistic energy term e_k, or:

$$e_w = e_0 - e_k = \frac{1}{2}\rho_0 v_c^2 \beta^2 - \frac{1}{2}\rho_0 v_c^2 \frac{1-\beta}{1+\beta}\beta^2 = (\frac{1}{2}\rho_0 v_c^2) \frac{2\beta^3}{1+\beta} = \frac{2\beta^3}{1+\beta} e_0 \quad ..(9)$$

Where $e_0 = \frac{1}{2}\rho_0 v_c^2$.

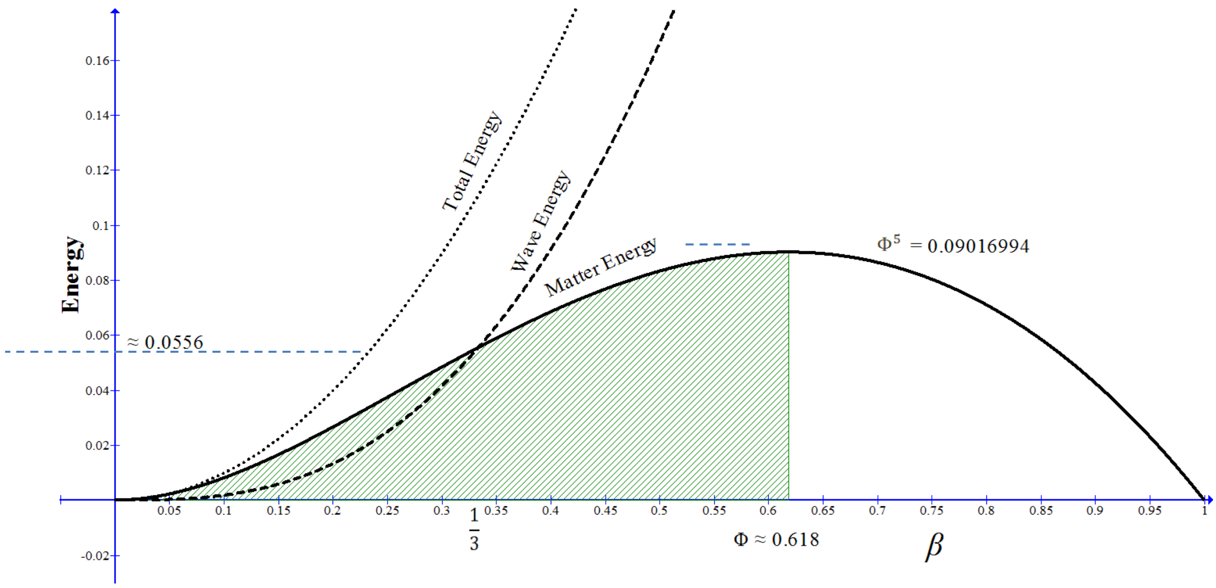

Figure1. Matter energy and wave energy as functions of velocity

5.2 Matter Phase Transition

Figure 1 reveals that the predicted particle's wave energy increases quite sharply with β. In contrast; the matter energy function is non-monotonic with β. It increases up to a maximum and then decreases to zero at $\beta = 1$.

The critical velocity β_{cr} at which the matter energy achieves its maximum value can be obtained by deriving e_k in eq. 8 with respect to β and equating the derivative to zero, which yields (see section c in SI):

$$\beta^2 + \beta - 1 = 0 \quad \dots (10)$$

Which for $\beta \neq 0$ solves for:

$\beta_{cr} = \frac{\sqrt{5}-1}{2} = \Phi \approx 0.618$ … (11)

Where Φ is the famous Golden Ratio [37-38] . Substituting β_{cr} in the eq. 8 yields:

$$\frac{(e_k)_{max}}{e_0} = \Phi^2 \, \frac{1-\Phi}{1+\Phi} \qquad …. (12)$$

From eq. 10 we can write: $\Phi^2 + \Phi - 1 = 0$, which implies $1 - \Phi = \Phi^2$ and $1+\Phi = \frac{1}{\Phi}$.

Substitution in eq. 12 gives:

$$\frac{(e_k)_{max}}{e_0} = \Phi^5 \approx 0.09016994 \qquad …. (13)$$

The above result is precisely equal to Hardy's maximum probability of obtaining an event which contradicts local realism. More importantly, the point of maximum marks a point of matter phase transition, at which matter becomes critically quantum. Up to this point ($0 < \beta < \Phi$) the relationship between energy and velocity is semi-classical, in the sense that higher velocities are associated with higher matter energies, while for ($\Phi < \beta < 1$), higher velocities are associated with lower matter energies. This result confirms with a recent experimental result by Coldea *et al*. [27] who demonstrated that applying a magnetic field at right angles to an aligned chain of cobalt niobate atoms, makes the cobalt enter a quantum critical state, in which the ratio between the frequencies of the first two notes of the resonance equals the Golden Ratio.

The critical point of matter phase transition could be described in terms of the relativistic extension, or "stretch" $\hat{l}$, defined as l/l_0. From eq. 6 we can write:

$$\beta = \frac{\hat{l}-1}{\hat{l}+1} \qquad …. (14)$$

Substituting the value of β from eq. 14 in the eq. 8 yields:

$$\frac{e_k}{e_0} = \frac{1}{\hat{l}} \cdot \frac{(\hat{l}-1)^2}{(\hat{l}+1)^2} . \qquad ….. (15)$$

The point of maximum energy is obtained by deriving the above expression with regard to $\hat{l}$ and equating the result to zero, which yields:

$$\frac{\partial \frac{e_k}{e_0}}{\partial \hat{l}} = \frac{(\hat{l}-1)(\hat{l}^2-4\hat{l}-1)}{\hat{l}^2(\hat{l}+1)^3} = 0 \,, \qquad \text{..... (16)}$$

Which for $\hat{l} \neq 0$ solves for

$$\hat{l}_{cr} = 2 + \sqrt{5} \approx 4.2361 \qquad \text{..... (17)}$$

$\hat{l}_{cr}$ could be expressed in terms of the Golden Ratio as:

$$\hat{l}_{cr} = 2 + \sqrt{5} = \frac{1+\Phi}{1-\Phi} = (1+\Phi)^3 \qquad \text{.... (18)}$$

Notably, the resulting critical "stretch" is the "silver mean" [39-40], a number related to topologies of the Hausdorff dimension [41].

Before we turn to the analysis of the relativistic wave energy, it is appropriate to underscore the astonishing Golden Ratio symmetries depicted in equations 11, 13 and 18, particularly given the key role played by the Golden Ratio and the related Fibonacci numbers as ordering and symmetry numbers in esthetics and arts [46-48], biology [49], brain sciences [50-51], the social sciences [52-54], and more. We believe that the emergence of these numbers in many systems in the physical and social world might be associated with some optimal self-organization processes. However, the validity of our conjecture, and the nature of the systems' observables that are ostensibly optimized, remain to be investigated.

5.3 Wave Phase Transition and Bose-Einstein Condensate

The body's wave energy as a function of the relative stretch is obtained substituting the value of β from eq.14 in eq. 9, yielding:

$$\frac{e_w}{e_0} = \frac{2\left(\frac{\hat{l}-1}{\hat{l}+1}\right)^3}{1+\left(\frac{\hat{l}-1}{\hat{l}+1}\right)} = \frac{\left(\hat{l}-1\right)^3}{\hat{l}\left(\hat{l}-1\right)^2} \qquad \ldots.\ (19)$$

The matter and wave energies as functions of the relative stretch $\hat{l}$ are depicted in Figure 2.

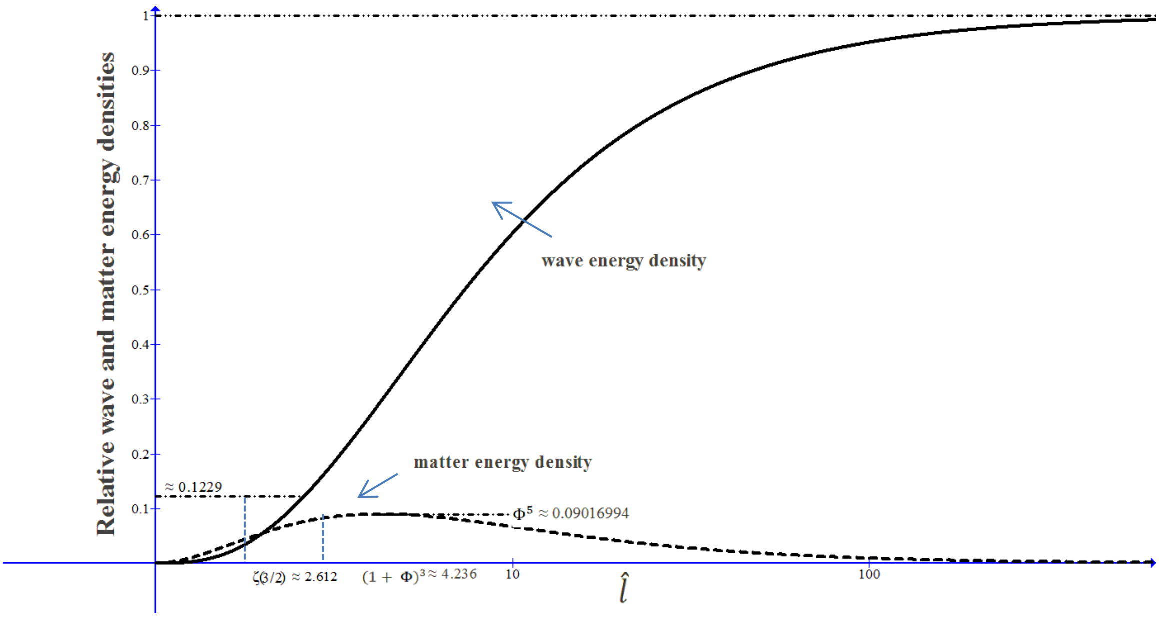

Figure 2: e_m and e_w as functions of stretch $\hat{l}$

The figure reveals that the normalized wave energy $\frac{e_w}{e_0}$ increases rather sharply with the stretch $\hat{l}$, and then levels relatively slowly, approaching 1 as $\hat{l} \longrightarrow \infty$.

The turning point of the function's slope could be found by deriving e_w in eq. 19 with respect to $\hat{l}$ twice, and equating the result to zero, yielding:

$$\frac{\partial^2 e_w}{\partial \hat{l}^2} = \frac{2\left(5\,\hat{l}^4-16\,\hat{l}^3+6\,\hat{l}^2+4\hat{l}+1\right)^3}{\hat{l}^3\left(\hat{l}+1\right)^4}\ e_0 = 0 \qquad \ldots.\ (20)$$

For $\hat{l} > 1$ we get:

$$5\,\hat{l}^4 - 16\,\hat{l}^3 + 6\,\hat{l}^2 + 4\hat{l} + 1 = 0, \qquad \text{.... (21)}$$

Which solves for:

$$\hat{l}_{cr} = \frac{1}{15}\left(11 + \sqrt[3]{2906 - 90\sqrt{113}} + \sqrt[3]{2906 + 90\sqrt{113}}\right) \approx 2.612139 \approx \zeta(\tfrac{3}{2}) \qquad \text{.. (22)}$$

Where ζ is the Riemann zeta function [42-43].

Thus, the critical stretch at which the wave energy density undergoes a "second order" phase transition is predicted to occur at stretch $\hat{l}_{cr} \approx 2.612375 \approx \zeta(\frac{3}{2})$. Strikingly, this result is identical to the critical de Broglie wave-length in connection with the critical temperature *Tc* for the formation of a Bose-Einstein condensate [25-26]. As it is well known, in the framework of de Broglie's wave-particle model, the statistical quantum mechanical analysis yields a critical de Broglie wave-length given by:

$$\lambda_{dB} = \left(\frac{2\pi\hbar^2}{mT_cK_B}\right)^{\frac{1}{2}} = \zeta(\frac{3}{2}) \qquad \text{.... (23)}$$

Where m is the particle's atomic mass *m*, *Tc* is the critical temperature, K_B is Boltzmann Constant, and ħ is the reduced Planck's constant. From equations 22 and 23 we can write:

$$e_{w_{cr}} = \frac{\left(\hat{l}_{cr} - 1\right)^3}{\hat{l}_{cr}\left(\hat{l}_{cr} - 1\right)^2}\; e_0 \approx 0.1229\; e_0 \qquad \text{.... (24)}$$

5.4 Quantum Entanglement

According to quantum theory, entanglement between observables in two separate systems implies the existence of global states of composite systems that cannot be written as a product of the states of individual subsystems [11, 44-45]. For example, one can prepare two particles in a single quantum state such that when one is observed to be spin-up, the other one will always be observed to be spindown and vice versa. As a result, measurements performed on one system seem to be instantaneously influencing other systems entangled with it, even when the systems are at large distances from each other.

In the following I show entanglement could be accounted for by the causality of spatial locality. For demonstration I treat here a simple EPR bipartite system comprised of two identical particles moving away from each other with constant linear velocity. Suppose that at $t = t_0 = 0$ the two particles are distanced from each other, such that particle A moves leftward (in -*x* direction) toward Alice's box, while the particle B is moving rightward (in +*x* direction) toward Bob's box (see Figure 3).

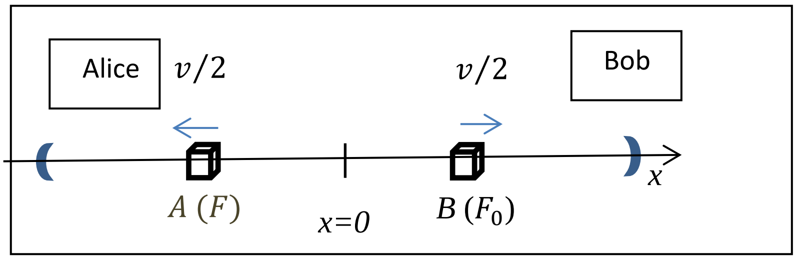

Figure 3: Illustration of an EPR-type experiment

For a relative distancing velocity $\beta = \frac{v}{v_c}$, the relative length "stretch" of particle B in the frame of reference of particle A is given by eq. 6, that is: $l/l_0 = \frac{1+\beta}{1-\beta}$, and its relative mass density from eq. 7 is given by: $\rho/\rho_0 = \frac{1+\beta}{1-\beta}$. These relationships are depicted in Figure 4.

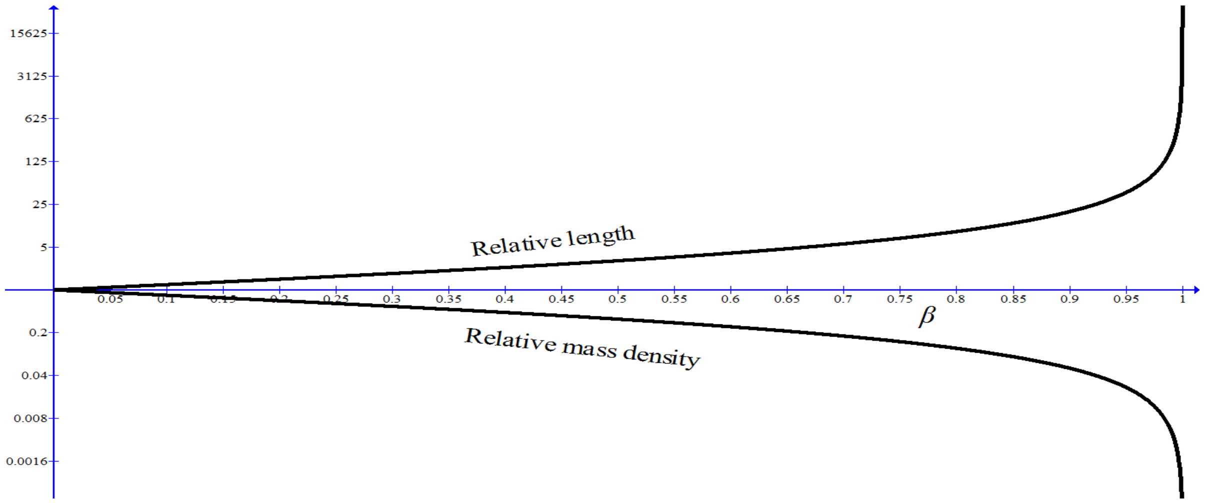

Figure 4. Relative length and mass density as functions of velocity

The above results could be summarized as follows: when a particle is distanced from another particle with velocity v, it will incur a relativistic "stretch" in the rest frame of the other particle, and the amount of stretch will depend on the relative velocity as described by eq. 6 (see Figure 4). Concurrently, the particle's total rest mass m_0 will be distributed along the stretched length and its mass density along the travel path will be diminished (see eq. 7 and Figure 4). The rates of stretching in distance and decrease in density will always balance, such that the total rest mass of the body remains unchanged. Note that the state of affairs described above is consistent with de Broglie's wave-particle model. In general, at high-enough velocities, $\beta,$ a distancing particle with respect to a rest frame of reference will gradually abandon its matter properties and behave more like a wave packet. Similarly, wave quanta that are forced to decelerate will eventually reach a point of phase transition, after which it will behave more like a particle than a wave. Put simply, in the framework of Information Relativity, waves could be considered extremely stretched matter, whereas matter could be viewed as extremely crunched waves.

The cross correlation between the two energy densities of particles A and B for a given relative velocity β, over the dimension of motion, could be calculated as

$$r(\hat{l}) = e_k * e_0 = \int_{\hat{l}\geq 1} e_k(\xi)\, e_0\big(\xi + \hat{l}\big)\, d\hat{l} = \ln\left(\frac{\hat{l}+1}{\hat{l}}\right) - \frac{4}{(\hat{l}+1)(\hat{l}+2)} \; . \qquad \text{.... (25)}$$

Maximum correlation is obtained at $\hat{l}$ satisfying $\frac{\partial(\, e_k * \, e_0)}{\partial \hat{l}} = 0$, which yields:

$$-\hat{l}^3 + 3\,\hat{l}^2 + 4\,\hat{l} - 4 = 0\,, \qquad \text{.... (26)}$$

Which for $\hat{l} \geq 1$, solves at $\hat{l} \approx 3.7785$.

Substitution in eq. 26 gives $r_{max} \approx 0.08994$.

6. Summary and Conclusions

We described a local and deterministic relativity theory termed Information Relativity Theory. We showed that the theory cannot be disqualified by Bell's Theorem. We also showed that the theory accounts successfully for several key quantum phenomena, including matter-wave duality, quantum phase transition, quantum criticality, formation of Bose-Einstein condensate, and quantum entanglement in a bipartite EPR experiment. Our main conclusions could be summarized as follows:

(1) Bell's Theorem is not a universal theorem, since it neglects the possibility of a spatial locality between distanced particles. As a result, all its tests, including the most stringent ones (e.g., [18]) were blind to this aspect of locality.

(2) Information Relativity theory violates the Lorentz contraction for distancing bodies, and thus cannot be prohibited by Bell's inequality.

(3) The theory accounts successfully for a several key quantum phenomena, while reproducing the same results obtained by quantum theory.

(4) The theory is *scale independent* with respect to the size of the investigated system. In fact, the same set of transformations without addition free parameters or arbitrary constants, have proven successful in accounting for several important findings concerning high energy particle physics (e.g., photon, neutrino) [22, 32-33] and cosmology [23, 34].

(4) The theory is *scale independent with respect to the velocity of the information carrier*. In application to quantum mechanics, as well as in applications to high energy particles and cosmology the information carrier v_c equals the velocity of light as measured at the observer's reference frame. However many other applications of the theory are possible, including thermodynamic, acoustic, and seismic systems provided the velocity of the information carrier is specified, and that the relative velocities involved cannot exceed the velocity of the information carrier.

Although our main objective was to demonstrate that Information Relativity Theory can account successfully to quantum phenomena, the theory's scale independence with respect to the size of the investigated system and the information velocity, allows us to conclude that the laws of physics, which are acknowledged to be the same in all inertial frames of reference, are also scale independent.

We are puzzled by the fact that a relativity theory of information which attends only the observables: time duration, distance, masses and energy etc. is successful in reproducing the result of quantum theory and quantum thermodynamic. We believe that the striking consistency between vastly different approaches, suggests that the dynamics of physical systems, as captured by macro-level observables, are consistent with the micro-level dynamics of the elementary particles and atoms comprising the physical systems.

We cannot conclude without underscoring the simplicity of the proposed theory, which would have probably impressed Albert Einstein, Paul Dirac and other fathers of modern physics, who emphasized the importance of the mathematical simplicity and beauty in theorizing about the physics of the world, which they believed to be harmonious and simple.

What I think is at hand is a simple and beautiful universal relativity theory for inertial systems. The question that remains: How much the physics community is ready to sacrifice for the sake of testing it?

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Supplementary Information

Derivation of Information Theory's Transformations

A. Derivation of the Time Transformation

We consider a simple preparation in which the time duration of an event, as measured by an observer A who is stationary with respect to the point of occurrence of the event in space, is transmitted by an information carrier which has a constant and known velocity v_c, to an observer B who is moving with constant velocity v with respect to observer A. We make no assumptions about nature of the information carrier, which can be either a wave of some form or a small or big body of mass. Aside of the preparation describes above and the measurements taken by each observer, throughout the entire analysis to follow, no further assumptions are made. This also means that we do not undertake any logical steps or mathematical calculations unless measurements of the variables involved in such steps or calculations are experimentally measurable.

We ask: what is the event duration time to be concluded by each observer, based on his or her own measurements of time? And what could be said about the relationship between the two concluded durations?

In a more formal presentation, we consider two observers in two reference frames F and F'. For the sake of simplicity, but without loss of generality, assume that the observers in F and F' synchronizes their clocks, just when they start distancing from each other with constant velocity v, such that t_1 = $t_1{}'$ =0, and that at time zero in the two frames, origin points of were F and F' were coincided (i.e., x_1=$x_1{}'$ = 0).

Suppose that at time zero in the two frames, an event started occurring in F'at the point of origin, lasting for exactly $\Delta\mathrm{t}'$ seconds according to the clock stationed in F', and that promptly with the termination of the event, a signal is sent by the observer in F' to the observer in F.

After $\Delta t'$ seconds, the point at which the event took place stays stationary with respect F' (i.e., $x_2{}'$ $=x_1{}'= 0$), while relative to frame F this point would have departed by x_2 equaling:

$$x_2 = v\,\Delta t' \qquad \text{……. (1a)}$$

The validity of eq. 1a could be checked and verified by more than one operational, i.e., experimentally feasible methods: For example, if the two observers meet any time after the event has terminated, then the observer in F will be able to read the time of the event as registered by the clock stationed in F' and learned what the duration of the event in F', for which the event was stationary. Another operational way by which the observer in F can infer about the actual time of travel until the event terminated and the signal was sent is by mimicking the even in F by having an identical event with the same duration (in its inertial frame), start promptly with the even in F'. It is important to note that the above two operational suggestions presume the rule stating that the laws of nature are the same in the two frames. In the first example, the above restriction leaves no possibility for the observer in F to suspect that the reading of the clock stationed F' in e time duration of the event in reading of the clock at F' (in the first example), or to suspect that a time registered by a clock at his/her own frame F will differ by the time that will be registered for an identical event, by an identical clock placed in F'.

If the information carrier sent from the observer in F' to the observer in F travel with constant velocity V_F relative to F, then it will be received by the observer in F after a delay of:

$$t_d = \frac{x_2}{V_F} = \frac{v\,\Delta t'}{V_F} = \frac{v}{V_F}\,\Delta t' \qquad \text{……. (2a)}$$

Since F' is distancing from F with velocity v, we can write:

$$V_F = V_0 - v \qquad \text{…… (3a)}$$

Where V_0 denotes the information carrier's velocity with respect to the event's inertial frame F'. Substituting the value of V_F from eq. 3a in eq. 2a, we obtain:

$$t_d = \frac{v\,\Delta t'}{V_0 - v} = \frac{1}{\frac{V_0}{v} - 1}\,\Delta t' \qquad \text{...... (4a)}$$

Due to the information time delay, the event's time duration ***Δt*** that will be registered by the observer in F is given by:

$$\Delta t = \Delta t' + t_d = \Delta t' + \frac{1}{\frac{V_0}{v} - 1}\,\Delta t' = \left(1 + \frac{1}{\frac{V_0}{v} - 1}\right)\Delta t' = \left(\frac{\frac{V_0}{v}}{\frac{V_0}{v} - 1}\right) = \left(\frac{1}{1 - \frac{v}{V_0}}\right)\Delta t' \quad \text{...(5a)}$$

Or:

$$\frac{\Delta t}{\Delta t'} = \frac{1}{1 - \frac{v}{V_0}} \qquad \text{... (6a)}$$

For $v << V_0$ eq. 6 reduces to the classical Newtonian equation $\Delta t = \Delta t'$, while for $v \rightarrow V_0$, $\Delta t \rightarrow \infty$ for all positive $\Delta t'$.

For a communication medium to be fit for transmitting information between frames in relative motion, a justifiable condition is to require that the velocity of the carrier be larger than the velocity of the relative motion, i. e., $v < V_0$.

Quite interestingly, eq. (6a), derived for the time travel of moving bodies with constant velocity is quite similar to the Doppler's Formula derived for the frequency modulation of waves emitted from traveling bodies. Importantly, in both cases **the direction of motion matters**. In the Doppler Effect a wave emitted from a distancing body will be red-shifted (longer wavelength), whereas a wave emitted from an approaching body with be blues-shifted (shorter wavelength). In both cases the degree of red or blue shift will be positively correlated with the body's velocity.

The same applies to the time duration of an event occurring at a stationary point of a moving frame. If the frame is distancing from the observer, time will be dilated, whereas if the frame is approaching the observer will contract.

It is especially important to note further that the above derived transformation applies to *all* carriers of information, including the commonly employed *acoustic* and *optical* communication media. For the case in which information is carried by light or by electromagnetic waves with equal velocity, equation (6a) becomes:

$$\frac{\Delta t}{\Delta t'} = \frac{1}{1-\frac{v}{c}} \qquad \text{..... (7a)}$$

Since an objection might be raised for the cases of information translation by means of light or other waves with equal velocity, such objection could be avoided by restricting the theoretical model derived above to wave propagation in mediums that are not a vacuum, which in fact the case in almost all physical situations of interest.

B. Derivation of the Distance Transformation

To derive the distance transformation, consider the two frames of reference F and F'shown in Figure 1b. Assume the two frames are moving away from each other at a constant velocity *v.* Assume further that at time t_1 in F (and t_1' in F'), a body starts moving in the +*x* direction from point x_1 (x_1' in F') to point x_2 (x_2' in F'), and that its arrival is signaled by a light pulse that emits exactly when the body arrives at its destination. Denote the internal framework of the emitted light by F_0. Without loss of generality, assume $t_1 = t_1'$ = 0, $x_1 = x_1'$ = 0. Also denote $t_2 = t$, $t_2' = t'$, $x_2 = x$, and $x_2' = x'$.

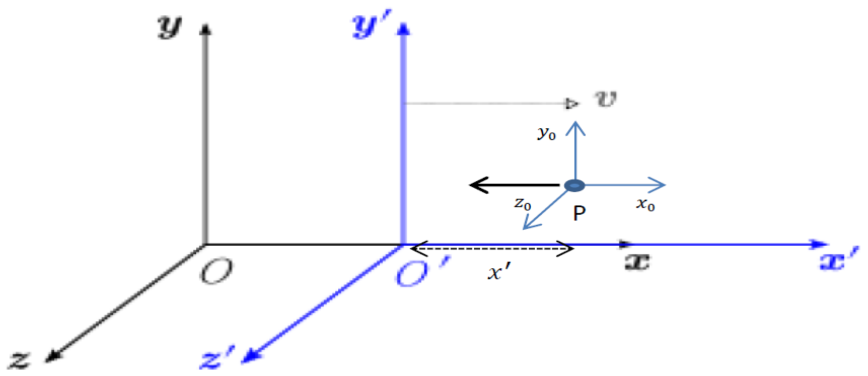

Figure 1b: Two observers in two reference frames, moving with velocity v with respect to each other.

From eq. 7a, the time duration in F that takes the light signal to reach an observer in F' equals:

$$\Delta t_p = (1 - \left(-\frac{v}{c}\right)\ )\ \Delta t' \quad \text{..... (1b)}$$

Where $\Delta t'$ is the corresponding time duration in F', and c is the velocity of light in frame F. Because F' is moving away from F with velocity v, the time that takes the light signal to reach and observer in F is equal to:

$$\Delta t = \Delta t_p + \frac{v\Delta t}{c} = \Delta t_p + \frac{v}{c}\ \Delta t \quad \text{...... (2b)}$$

Substituting Δt_p from eq. 1b in eq. 2b yields:

$$\Delta t = (1 + \frac{v}{c})\ \Delta t' + \frac{v}{c}\ \Delta t, \quad \text{..... (3b)}$$

or:

$$\frac{\Delta t}{\Delta t'} = \frac{(1+\frac{v}{c})}{(1-\frac{v}{c})}\ . \quad \text{...... (4b)}$$

But $\Delta x = c.\Delta t$ and $\Delta x' = c.\Delta t'$. Thus, we can write:

$$\frac{\Delta x}{\Delta x\prime} = \frac{(1+\frac{v}{c})}{(1-\frac{v}{c})} \qquad \text{……. (5b)}$$

C. Derivation of the Mass and Energy Transformations

Consider the two frames of reference F and $\boldsymbol{F'}$shown in Figure 3a. Suppose that the two frames are moving relative to each other at a constant velocity v. Consider a uniform cylindrical body of mass $\boldsymbol{m_0}$ and length of $\boldsymbol{l_0}$ placed in $\boldsymbol{F'}$ along its travel direction. Suppose that at time $\boldsymbol{t_1}$ the body leaves point $\boldsymbol{x_1}$ ($\boldsymbol{x_1}'$ in $\boldsymbol{F'}$) and moves with constant velocity v in the +x direction, until it reaches point $\boldsymbol{x_2}$ ($\boldsymbol{x_2}'$ in $\boldsymbol{F'}$) in time $\boldsymbol{t_1}$ ($\boldsymbol{x_2}'$ in $\boldsymbol{F'}$). The body's density in the internal frame $\boldsymbol{F'}$ is given by: $\boldsymbol{\rho'} = \frac{\boldsymbol{m_0}}{\boldsymbol{A\, l_0}}$, where A is the area of the body's cross section, perpendicular to the direction of movement. In F the density is given by: $\rho = \frac{\boldsymbol{m_0}}{\boldsymbol{Al}}$, where l is the object's length in F. Using the distance transformation (eq. 8a) l could be written as:

$$l = \frac{1+\beta}{1-\beta}\ l_0 \qquad \text{…… (1c)}$$

Thus, we can write: $\rho = \frac{m_0}{Al} = \frac{m_0}{A\ l_0\,(\frac{1+\beta}{1-\beta})} = \rho_0\ (\frac{1-\beta}{1+\beta})$ …. (2c)

Or,

$$\frac{\rho}{\rho_0} = \frac{1+\beta}{1-\beta} \qquad \text{…. (3c)}$$

The kinetic energy of a *unit of volume* is: given by:

$$e_k = \frac{1}{2}\rho\ v^2 = \frac{1}{2}\rho_0\, c^2\ \frac{(1-\beta)}{(1+\beta)}\,\beta^2 = e_0\,\frac{(1-\beta)}{(1+\beta)}\,\beta^2 \qquad \text{…. (4c)}$$

Where $e_0 = \frac{1}{2}\rho_0 c^2$.

For β →0 (or $v << c$) eq. 3c reduces $\rho = \rho_0$, and the kinetic energy expression (eq. 4c) reduces to Newton's expression $e = \frac{1}{2}\rho_0 v^2$. Figures 1c depict the relativistic energy as functions of β.

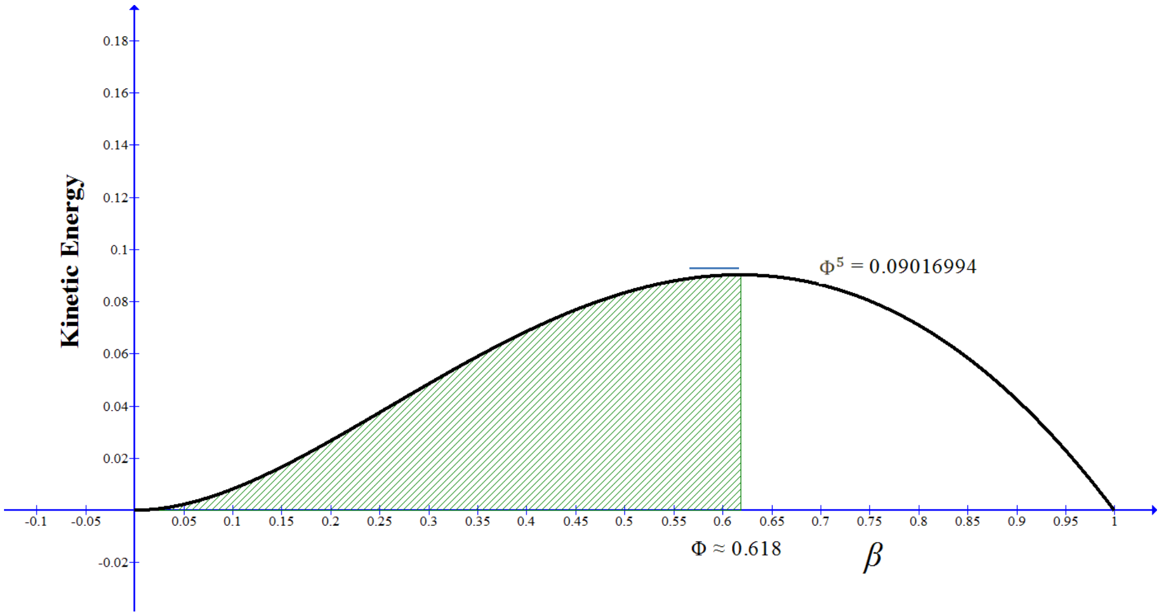

Figure 1c. Kinetic energy as a function of velocity

As shown by the figure the relativistic kinetic energy of *distancing* bodies relative to an observer in *F* is predicted to *decrease* with β, approaching zero as $\beta \to 1$, while the density in F for *approaching* bodies is predicted to increase with β, up to extremely high values as $\beta \to -1$. Strikingly, for distancing bodies the kinetic energy displays a non-monotonic behavior. It increases with β up to a maximum at velocity $\beta = \beta_{cr}$, and then decreases to zero at β = 1. Calculating β_{cr} is obtained by deriving eq. 4c with respect to β and equating the result to zero, yielding:

$$\frac{d}{d\beta}\left(\beta^2\frac{(1-\beta)}{(1+\beta)}\right) = 2\,\beta\frac{(1-\beta)}{(1+\beta)} + \beta^2\frac{[(1+\beta)(-1)-(1-\beta)(1)]}{(1+\beta)^2} = 2\,\beta\frac{(1-\beta^2-\beta)}{(1+\beta)^2} = 0 \quad \dots (5c)$$

For $\beta \neq 0$ and we get:

$$\beta^2 + \beta - 1 = 0 \qquad \ldots (6c)$$

Which solves for:

$$\beta_{cr} = \frac{\sqrt{5}-1}{2} = \Phi \approx 0.618 \qquad \ldots (7c)$$

Where Φ is the Golden Ratio. Substituting β_{cr} in the energy expression (eq. 4c) yields:

$$(e_k)_{max} = e_0 \quad \Phi^2 \frac{1-\Phi}{1+\Phi} \qquad \ldots. (8c)$$

From eq. 6c we can write: $\Phi^2 + \Phi - 1 = 0$, which implies $1 - \Phi = \Phi^2$ and $1+\Phi = \frac{1}{\Phi}$.

Substitution in eq. 8c gives:

$$(e_k)_{max} = \Phi^5 e_0 \approx 0.09016994 \ e_0 \qquad \ldots. (9c)$$