# A relativity of information theory explains quantum criticality and matter-wave duality

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## Abstract

The present article proposes an epistemic approach to relativity, termed *information relativity theory*, and utilizes it to infer about two quantum phenomena: quantum phase-transition and matter-wave duality. We propose a theoretical model of physical systems in which two an observer in the "rest" reference-frame receives information on measurements taken in another frame moving with constant velocity *v* relative to the observer's "rest" frame. We avoid questions pertaining to the *true* state of Nature. We only ask how physical measurements taken in the "moving" frame are transformed when they are received in the observer's "rest" frame. We constrain the analysis to simple one-dimensional, one-body inertial systems, in which information in communicated between the reference frames using an information carrier with known velocity $v_c$ ($v_c > v$). We make no other assumptions, thus our approach is *completely epistemic*. For systems of the above described type we derive the relativistic time, distance, mass, and energy transformations, relating measurements transmitted by the information sender, to the corresponding information registered by the receiver. The resulting terms are simple and beautiful with Golden Ratio symmetries. For $\beta = \frac{v}{v_c} << 1$, all the derived transformations reduce to Galileo-Newton terms. For bodies approaching the observer, the theory predicts time and length contraction, and increase in mass density, while for bodies distancing from the observer, it predicts time and length extension, and decrease in mass density. Strikingly, the relativistic kinetic energy density of a distancing body as a function of velocity $\beta$ displays a non-monotonic pattern, with a unique maximum at a normalized velocity $\beta = \Phi$, where $\Phi$ is the golden ratio (≈ 0.618). For $v_c = c$, where $c$ is the velocity of light, we show that the theory could not be forbidden by Bell's Inequality and demonstrate its power in predicting and explaining two key quantum phenomena: quantum phase-transition, and matter-wave duality. We conclude by summarizing the theory's main features and alluding to its applications in various fields of physics, including cosmology.

**Keywords**: Information; Inertial systems; Special relativity; Time dilation effects; Distance contraction, Michelson-Morley experiment; Neutrino velocity experiments.

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## 1. Introduction

The present article aspires to make a contribution to important ongoing efforts to construct a unitary theory of physics, which is capable of predicting and explaining the dynamics of moving bodies at all scales, form quantum to cosmic scales. We do not pursue the superior goal of constructing an *ontic* theory of reality like in Special Relativity [1] or Doubly Special relativity [2-4] and its various formalisms (see [5]). Instead we pursue a modest goal of constructing an *epistemic* view of reality. We do not ask what the real nature of the physical world is, but how such reality is reflected in our observations and measurement. We deal only with observable or measurable physical variables. We analyze the simple yet general case of a physical system in which two observers move with constant linear velocity ($v$) with respect to each other, while communicating information about physical observables, such as time durations of events and lengths of objects. We assume that one observer's measurements are communicated to the second observer by an information carrier with a constant velocity $v_c$ with respect to the information transmitter's rest-frame. For rendering the situation practical, we assume $v_c > v$. We make no additional assumptions. We are interested in the following *epistemic* question: How would observations taken in "moving" reference frame vary upon its receipt by an observer stationed in the "rest-frame"? Although we do not speculate about the true state of Nature, the above question is of great importance to empirical investigation of the physical reality, since it speaks in it language. Moreover, we shall demonstrate that our approach is powerful in providing new insights and making good predictions regarding two key quantum phenomena: quantum phase transition and matter-wave duality. Other explanations and predictions of the theory in other fields of physics, including cosmology, will be alluded to briefly in the concluding section.

We start in in the following section by presenting a detailed derivation of the theory's transformations and discuss their main properties. In section 3 we present the theory's prediction and explanations of quantum criticalness and quantum phase transition. In section 4 present the theory's predictions and explanation of matter-wave duality. In section 5 we summarize, allude to other applications of the theory in various fields of physics and draw some general conclusions.

## 2. Theory of information relativity

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. Aside from the preparation describes above throughout our entire analysis no further assumptions are made. Moreover, we do not undertake any logical step or mathematical calculation, unless the variables involved in such steps or calculation are experimentally measurable.

### *2.1 Relativity of time*

We ask: what is the event duration time to be concluded by each observer, based on his or her own measurements? Formally, we consider two observers in two reference frames $F$ and $F'$ distancing from each other with constant velocity *v*. 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, such that $t_1$ = $t_1{}'$ =0, and that at time zero the points of origin of $F$ and $F'$ were coincided (*i.e*., $x_1$=$x_1{}'$ = 0). Suppose that at time zero in the two frames, an experiment started in $F'$at the point of origin, terminating exactly $\Delta\mathrm{t}'$ seconds according to the clock stationed in $F'$, and that promptly with the termination of the experiment, a signal is sent by the observer in $F'$ to the observer in $F$. The "experiment" can be any event at the origin with duration of $\Delta\mathrm{t}'$ (as measured in $F'$).

After $\Delta\mathrm{t}'$ 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:

$x_2 = v\,\Delta t'$ ……. (1)

Notably, in eq. 1 the left side includes a measurement of distance taken in *F*, while the right side includes a measurement of time duration taken in $F'$. The validity of equation could be verified by an experimentally feasible method. As example, if the observer in *F* conducts an identical experiment, to the experiment conducted in $F'$. Because the laws of physics are the same everywhere, he or she will conclude that when the event at $F'$ has terminated, $F'$ was at a distance of $x_2 = v\,\Delta t'$ away as measure in *F*.

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

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

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

$$V_F = V_0 - v \quad \text{…… (3)}$$

Where $V_0$ denotes the information carrier's velocity in the light-source rest frame ($F'$). Substituting the value of $V_F$ from eq. 3 in eq. 2, we obtain:

$$t_d = \frac{v\,\Delta t'}{V_0 - v} = \frac{1}{\frac{V_0}{v} - 1}\,\Delta t' \quad \text{…… (4)}$$

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

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

$= \left( \frac{1}{1-\frac{v}{V_0}} \right) \Delta t'$ …(5)

Denoting $\frac{v}{V_0} = \beta$ eq. 5 becomes:

$$\frac{\Delta t}{\Delta t'} = \frac{1}{1-\beta} \qquad \ldots (6)$$

For $\beta$ << ($v$ << $V_0$) eq. 6 reduces to the classical Newtonian equation $\Delta t = \Delta t',$ while for $\beta \rightarrow 1$ ($v \rightarrow V_0$), $\Delta t \rightarrow \infty$ 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 is larger than the velocity of the relative motion, i. e. $\beta < 1$.

It is especially important to note further that the above derived transformation applies to *all* carriers of information, including *acoustic*, *optic*, etc. For the case in which information is carried by light or by electromagnetic waves with equal velocity, we have $\beta = \frac{v}{c}$, where $c$ is the velocity of light in the light-source rest frame. Without loss of generality, because the present paper treats only systems involving transmission of information by light or other electromagnetic waves, in what follows we shall set $V_0 = c$.

Note that eq. 6, derived for the time travel of moving bodies with constant velocity, is quite similar to the Doppler Effect formula, derived for the wave-length (frequency) of waves emitted from traveling bodies. In both cases *the direction of motion matters*. In the Doppler Effect [6, 7] 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. Interestingly, while eq. 6 predicts that the time dilation for distancing bodies approaches infinity when β→ 1, it puts a theoretical limit on the time contraction to for approaching bodies, since for β→ -1, it predicts a time contraction of exactly $\frac{1}{2}$.

## 2.2 Relativity of distance

To derive the distance transformation, consider the two reference-frames $F$ and $F'$ discussed above. Without loss of generality assume as before that when $F$ and $F'$ start distancing from each other $t_1$ = $t_1{}'$ =0, and $x_1$=$x_1{}'$ = 0. Assume further that $F'$ has onboard a rod placed along its $x'$ axis between the points $x' = 0$ and $x'$ = $x_2'$ (see Figure 1) and that the observer in $F'$ uses his clock to measure the length of the rod (in its rest frame) and communicates his measurement to the observer in $F$. As before, assume that the information carrier from frame $F'$ to frame $F$ is light or another electromagnetic wave with velocity $c$ (as measured in the light source rest frame). To perform the measurement of the rod's length, at $t_1{}'$ = $t_1$ =0 a light signal is sent from the rare end of the rod, i.e., from $x'$ = $x_2'$ to the observer at the point of origin $x' = 0$.

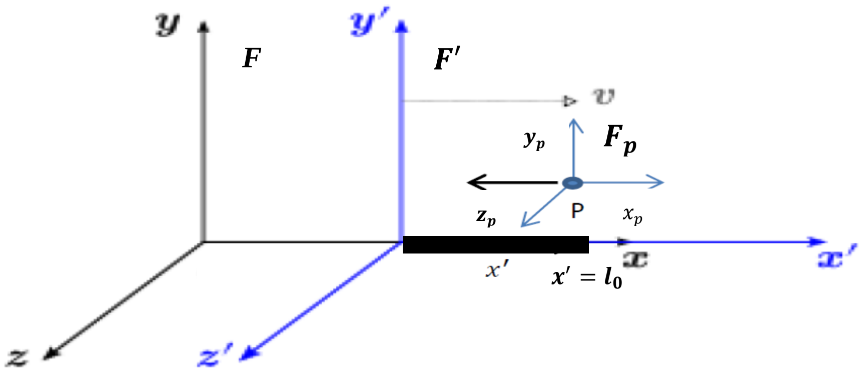


**Figure 1**: Two observers in two reference frames, moving with velocity *v* with respect to each other.

Denote the reference frame of the first light photon by $F_p$ (see Fig 1) and the time duration in $F_p$ for the light photon to arrive the observer in $F'$ by $\Delta t_p$. If the signal arrives to the observer in $F'$ at time $t' = t_2'$, then he or she can calculate the length of the rod as being

$$l_0 = x_2' = c\, t_2' \qquad \text{...... (7)}$$

Using eq. 6 $t_2'$ as a function of $\Delta t_p$ can be expressed as:

$$t_2' = \frac{1}{1-\frac{-v}{c}}\,\Delta t_p = \frac{1}{1+\frac{v}{c}}\,\Delta t_p \qquad \text{...... (8)}$$

Which could be rewritten as:

$$\Delta t_p = (1+\frac{v}{c})\, t_2' \qquad \text{...... (9)}$$

Because $F'$ is departing $F$ with velocity $v$, the light signal reach and observer in $F$ at time $t_2$ equaling:

$$t_2 = \Delta t_p + \frac{v t_2}{c} = \Delta t_p + \frac{v}{c}\, t_2 \qquad \text{...... (10)}$$

Substituting the value of $\Delta t_p$ from eq. 9 in eq. 10 yields:

$$t_2 = (1+\frac{v}{c})\, t_2' + \frac{v}{c}\, t_2, \qquad \text{..... (11)}$$

Which could be rewritten as:

$$t_2 = \frac{(1+\frac{v}{c})}{(1-\frac{v}{c})}\, t_2' \qquad \text{...... (12)}$$

Substituting the value of $t_2'$ from eq. 7 we get:

$$t_2 = \frac{(1+\frac{v}{c})}{(1-\frac{v}{c})}\,\frac{l_0}{c} \qquad \text{..... (13)}$$

Thus, the observer in *F* will conclude that the length of the rod is equal to:

$$l = \mathrm{c}\ t_2 \ = \frac{(1+\frac{v}{c})}{(1-\frac{v}{c})}\, l_0 \qquad \text{….. (14)}$$

Or:

$$\frac{l}{l_0} = \ \frac{1+\beta}{1-\beta} \qquad \text{….. (15)}$$

Where $\beta = \frac{v}{c}$.

The above derived relativistic distance equation predicts *distance contraction only when the two reference-frames approach each other*. On the other hand, it predicts *distance extension when the reference-frames distance from each other*. Thus, for particles distanced from another particle with high velocity β, the eq. 15 predicts that its spatial dimension along the travel axis will incur a relativistic "stretch". This means that at sufficiently high $\beta$, two particles, although distanced from each other, could remain spatially connected. This is a crucial feature of information relativity distinguishing it from all current theories, which presuppose that two particles which are distancing from each other become spatially disconnected.

The relationship between relativistic distance and time could be easily derived from equation 6 and 15 yielding:

$$\frac{l}{l_0} = 2\,\frac{\Delta t}{\Delta t_0} - 1 \qquad \text{…. (16)}$$

Which means that the relativistic distance $\frac{l}{l_0}$ is a simple linear function of the relativistic time $\frac{\Delta t}{\Delta t_0}$, with slop =2. Figure 2 depicts the relativistic time and distance as a function of $\beta$. As examples, for $\beta = \frac{1}{4}, \frac{1}{3}, \frac{1}{2}, \frac{2}{3}, \frac{3}{4}$, for $\frac{\Delta t}{\Delta t_0}$ and $\frac{l}{l_0}$ we get ($\frac{4}{3}$, $\frac{3}{2}$, 2, , 3, 4), and ($\frac{5}{3}$, 2, 3, 5, 7), respectively.

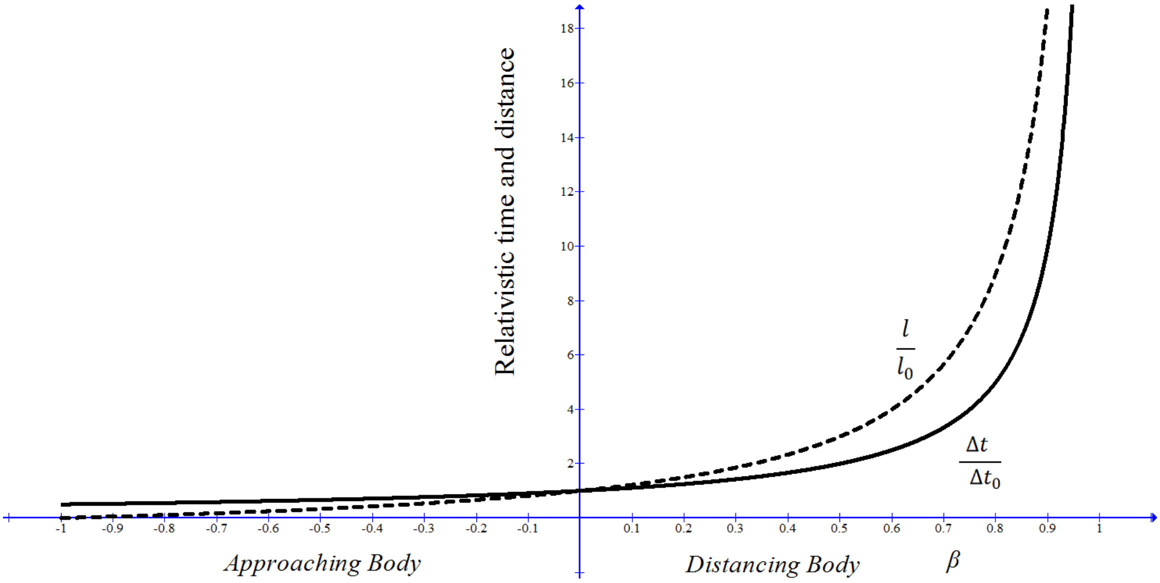


**Figure2**: Relativistic time and distance as a function of $\beta$

### 2.3 Relativity of mass and kinetic energy

Let us assume that that the rod has a total rest-mass $m_0$ distributed uniformly along the *x* axis.

According to eq. 15 an approaching rod will contract causing the mass density along the x axis to increase. On the other hand, a distancing rod will extend causing its mass density along the x axis to dilute. Denote the body's density in its rest-frame by $\rho'$, then its mass density distribution will be given by $\rho' = \frac{m_0}{A\, l_0}$, where *A* is the area of the body's cross section, perpendicular to the direction of movement. In *F* the density is given by: $\rho = \frac{m_0}{Al}$, where *l* is the object's length in *F*. Using the distance transformation (eq. 15) we can write:

$$\rho = \frac{m_0}{Al} = \frac{m_0}{A\ l_0\ (\frac{1+\beta}{1-\beta})} = \rho_0\ (\frac{1-\beta}{1+\beta}) \qquad \text{``} \qquad \ldots. (17)$$

Or,

$$\frac{\rho}{\rho_0} = \frac{1}{l/l_0} = \frac{1+\beta}{1-\beta} \qquad \ldots (18)$$

As could be seen from eq. 18 the relativistic mass density is inversely proportional to the distance transformation. It is predicted to increase for approaching bodies and a decrease for distancing bodies. The relativistic kinetic energy density is given by:

$$e_k = \frac{1}{2}\rho\ v^2 = \frac{1}{2}\rho_0\, c^2\ \frac{(1-\beta)}{(1+\beta)}\,\beta^2 = e_0\,\frac{(1-\beta)}{(1+\beta)}\,\beta^2 \qquad \ldots. (19)$$

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

For $\beta \to 0$ (or $v << c$) eq. 18 reduces to $\rho = \rho_0$ and eq. 19 reduces to $e = \frac{1}{2}\rho_0\, v^2$, which are the classical Newtonian expressions.

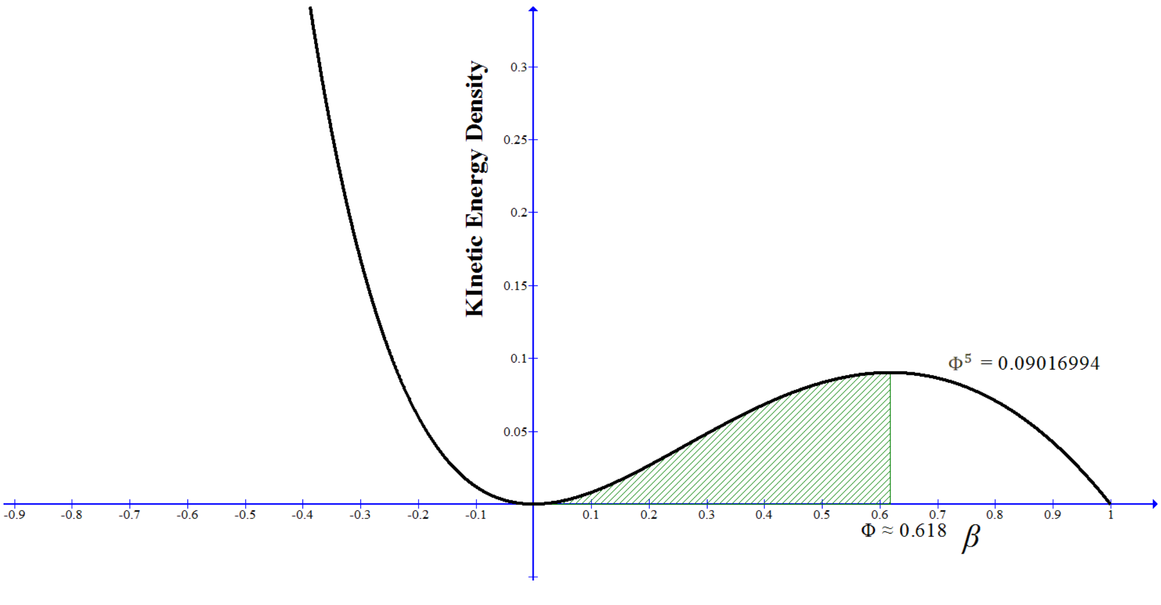


**Figure 3.** Kinetic energy density as a function of velocity

As shown by Figure3 the relativistic kinetic energy density for *approaching* bodies is predicted to increase with $\beta$, up to infinitely high density 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 $\beta_{cr}$ is obtained by deriving eq. 25 with respect to β and equating the result to zero, yielding:

$$\beta^2 + \beta - 1 = 0 \qquad \dots (20)$$

Which solves for:

$$\beta_{cr} = \frac{\sqrt{5}-1}{2} = \Phi \approx 0.618 \qquad \dots (21)$$

Where Φ is the famous Golden Ratio [8, 9]. Substituting $\beta_{cr}$ in the energy expression (eq. 19) yields:

$$(e_k)_{max} = e_0 \quad \Phi^2 \frac{1-\Phi}{1+\Phi} \qquad \dots. (22)$$

From eq. 20 we can write: $\Phi^2 + \Phi - 1 = 0$, which implies $1 - \Phi = \Phi^2$ and $1 + \Phi = \frac{1}{\Phi}$.

Substitution in eq. 22 gives:

$$(e_k)_{max} = \Phi^5 e_0 \approx 0.09016994 \; e_0 \qquad \dots. (23)$$

Table 1 depicts the four derived transformations. In the table, the variables $\Delta t_0$, $\Delta x_0$, and $\rho_0$ denote measurements of time duration, distance, and the body's mass density in the rest frame, respectively, $\beta = \frac{v}{c}$, and $e_0 = \frac{1}{2}\rho_0 \; c^2$.

**Table 1**

Information Relativity Transformations

| Physical Term | Relativistic Expression |
|---|---|
| Time | $\frac{\Delta t}{\Delta t_0} = \frac{1}{1-\beta}$ .... (I) |
| Distance | $\frac{l}{l_0} = \frac{1+\beta}{1-\beta}$ …. (II) |
| Mass | $\frac{\rho}{\rho_0} = \frac{1-\beta}{1+\beta}$ .... (III) |
| Kinetic energy | $\frac{e_k}{e_0} = \frac{1-\beta}{1+\beta}\beta^2$ ... (IV) |

The transformations in the table have nice and important properties: (1) they are beautiful, with astonishing Golden Ratio symmetries. (2) They are very simple. (3) They are *scale independent with respect to the size of the investigated physical system*, and thus apply to the dynamics of very small and very large bodies (4) they depend only on the ratio between the relative velocity *v* and the velocity of the information carried (5) for low velocities ($\beta$ << 1), all the transformations reduce to the classical Newtonian formulas.

**2.4 Symmetries**

Before we apply the theory to quantum phenomena, we like to make a brief note about the aesthetic golden ratio of the derived transformations. This type of symmetry, is found in abundance in nature and in technology and the arts, including in the structure of plants [10-12], physics [13-15], structure of the human brain [16], music [17-18], aesthetics [8, 9, 19], and more. The Golden Ratio symmetry manifest in the kinetic energy function is also manifest, albeit in a more subtle way, in the transformations of time, distance and mass density. As examples, it could be verified that:

$\frac{\Delta t}{\Delta t_0}(\beta = \Phi) = \Phi + 2 \approx 2.618$ ....(24)

$\frac{l}{l_0}(\beta = \Phi) = \frac{1}{2\Phi - 1} \approx 4.236$ .... (25)

$\frac{\rho}{\rho_0}(\beta = \Phi) = 2\,\Phi - 1 \approx 0.236$ ... (26)

Notably $\frac{\Delta t}{\Delta t_0}(\beta = \Phi)$ - $\frac{l}{l_0}(\beta = \Phi) = \frac{1}{2\Phi - 1} - (\Phi + 2) = \Phi + 1 \approx 1.618$. Other simple symmetries are also revealed. For example, it is easy to show that the derivatives with respect to $\beta$ of the relative time: $\tau \triangleq \frac{\Delta t}{\Delta t'} = \frac{1}{1-\beta}$ satisfies the simple recursion:

$$\begin{cases} \tau^{(n)} = a_n\, \tau^{(n-1)} \\ a_n = n\, a_{n-1} \end{cases} \quad (n = 1, 2, 3, \ldots;\ a_0 \triangleq 1) \qquad \ldots (27)$$

Where $\tau^{(n)}$ denotes the $n^{th}$ derivative of $\tau$ with respect to $\beta$; which could be simplified to yield:

$$\tau^{(n)} = n!\ \tau^{n+1} \quad (n = 1, 2, 3, 4). \qquad \ldots\ldots (28)$$

For the first five derivatives we get: $\tau^{(1)} = \tau^2$; $\tau^{(2)} = 2\,\tau^3$; $\tau^{(3)} = 6\ \tau^4$; $\tau^{(4)} = 24\ \tau^5$; $\tau^{(5)} = 120\ \tau^6$; ($\tau = \frac{1}{1-\beta}$). The distance transformation has also some nice symmetries. Denoting $\frac{l}{l_0}(\beta)$ by $\delta(\beta)$, we can write:

$\delta(\beta)\,\delta(-\beta) = 1$ .... (29)

Using relationship in eq. 15 we can also write:

$\delta(\beta) = \frac{1+\beta}{1-\beta} = \frac{\frac{1}{1-\beta}}{\frac{1}{1+\beta}} = \frac{\tau(\beta)}{\tau(-\beta)}$ .... (30)

Moreover, calculating the $n^{th}$ derivative of $\delta(\beta)$ with respect to $\beta$ yields:

$$\delta^{(n)} = 2n!\ \tau^{n+1} \quad (n = 1, 2, 3, \ \ldots). \qquad \ldots\ldots (31)$$

Which by using eq. 28 yields:

$$\delta^{(n)} = 2\tau^{(n)} \ (\mathrm{n} = 1, 2, 3, \ \ldots) \qquad \ldots. (32)$$

## 3. Application to quantum physics

Ostensibly theories of local realism are forbidden by Bell's inequality from being candidates for reproducing the confirmed predictions of quantum mechanics [20, 21]. However, information relativity uncovers a novel type of locality not accounted for by Bell's Theorem and its many tests [22-26]. As remarked in section 2 and shown in detail in [27], at sufficiently high velocities the predicted relativistic extension or "stretch" can produce spatial locality even when the temporal locality, forbidden by Bell's theorem, is impossible. To substantiate our claim we shall demonstrate hereafter that information relativity can predict and explain quantum phenomena. The two phenomena discussed hereafter were chosen as examples because their explanation lends itself by direct interpretation of the derived energy density term. The prediction and explanation of quantum entanglement are more elaborate and are given elsewhere [27].

### 3.1 Quantum criticalness and quantum phase transition

Investigation of the theory's prediction of quantum criticalness and quantum phase transition could be inferred directly by looking at Fig. 3. As could be seen in the figure for the range ($-1 < \beta < \Phi$) the relationship between the relativistic kinetic energy density and velocity is semi-classical, in the sense that higher velocities of approaching bodies are associated with higher kinetic energies density. At a critical $\beta = \Phi$, the positive monotonicity breaks down and higher velocities are associated with lower kinetic energy density. This reversal in the dependence of kinetic energy density is a product of the relative effects of velocity and matter density on the energy density of a distancing body ($\beta > 0$), up to with the first dominating up to β = Φ the velocity's positive effect (proportional to $\beta^2$) dominates the negative effect caused by the relativistic dilution of matter density (see eq. III). For β = Φ the two opposing effects become equal and for β > Φ the effect of matter density dilution dominates the effect of increase in velocity, causing matter to behave in non-classical manner. The seeming contradiction between the explanation above and the law of energy conservation will be clarified in the following section. The critical velocity β = Φ is characterized by several fascination symmetries, in the transformation of time, distance, matter density and energy, which we shall say more about in the concluding section.

Strikingly the above prediction of quantum criticalness at the Golden Ratio confirms with a recent experimental result by Coldea *et al*. [14] 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. Moreover, the obtained value of the normalized kinetic energy density $(e_k)_{max}/e_0 = \Phi^5 \approx 0.09016994$ is precisely equal to Hardy's maximum probability of obtaining an event which contradicts local realism [28]. These findings which lend strong confirmation to the above analysis suggests that in theory matter in inertial movement like the one discussed here any matter will undergo a quantum phase transition at point characterized by Golden Ration symmetries in its physical structure and matter-energy.

### 3.2 Matter-wave duality

The concept of matter-wave duality is central to quantum theory, ever since 1924, when Louis de Broglie introduced the notion in his doctoral dissertation [29, 30]. This feature of quantum dynamics has been demonstrated in many double-slit experiments on photons, electrons, atoms, and molecules [31-34]. The quantum mechanical model of De Broglie, although insightful and successful in accounting for the experimental evidence, remains largely hypothetical. In particular, de Bruglie's assumption for the existence of matter's wave is a mere conjecture, and so is his assumption regarding the coexistence at any given time of both the wave and matter components.

Here we show that information relativity theory sheds a new light on matter-wave duality by demonstrating how it evolves quite naturally from relativistic considerations. For this purpose consider a particle of rest mass $m_0$ which travels along the positive $x$ axis, with constant velocity $v$ away from an observer. We define the wave energy density $e_w$ as the difference between the Newtonian classical kinetic energy density term and its relativistic term. That is:

$$e_w \triangleq e_0 - e_k = \frac{1}{2}\rho_0 v_c{}^2 \beta^2 - \frac{1}{2}\rho_0 v_c{}^2 \frac{1-\beta}{1+\beta}\beta^2$$

$$= (\frac{1}{2}\rho_0 v_c{}^2)\frac{2\beta^3}{1+\beta} = \frac{2\beta^3}{1+\beta} e_0 \qquad .. (33)$$

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

The accompanying wave energy density alongside with the matter kinetic energy density is depicted in Fig.4.

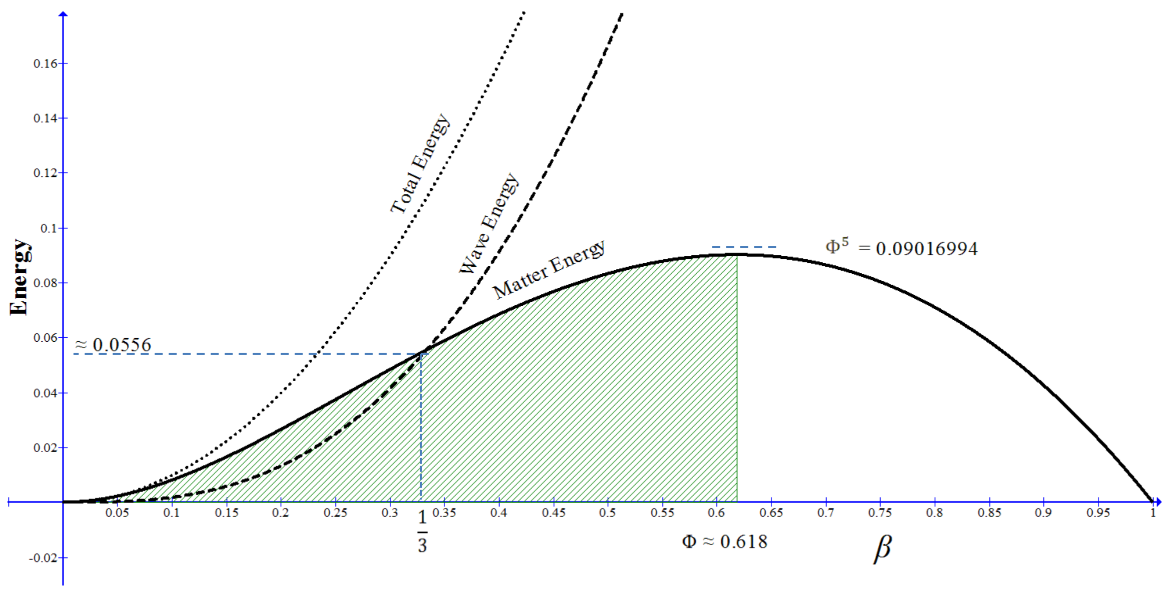


**Figure 4.** Matter energy and wave energy as functions of velocity

As conjectured by de Broglie, for bodies moving with fixed velocity β the matter and wave energies are in a state of equilibrium. As figure 4 shows, the predicted wave-energy component of the total energy carried by a moving body is rapidly increasing with velocity (see Fig. 4). At relatively low velocities, the bulk of the particle's energy is carried by its matter while at high enough velocities the particle's energy is carried by its accompanying wave. The energy carried by matter and the energy carried by the wave are predicted to be equal precisely at $\beta = \frac{1}{3}$, after which the matter becomes very diluted and the accompanying wave becomes the primary carrier of the total energy.

While our relativistic approach to matter-wave duality is completely different from the one taken by de Broglie, the two models show much similarity. However, our relativistic approach has two important advantages: 1. it is not based on conjectures or assumptions. 2. It gives a complete and testable description of the dynamic interplay between a body's matter and its accompanying wave, as carriers of the body's total energy.

## Summary and general remarks

We considered an inertial physical system in which signals about physical measurements of time and other physical variables conducted in one reference frame are transmitted to a receiver moving with relative constant velocity $v$, by an information carrier with a constant velocity $v_c$ with respect to the transmitter's rest frame ($v_c > v$). Without making any further theoretical assumptions or putting constraints on the systems variables, we derived relativistic time, distance, mass, and energy expressions, relating measurements transmitted by an information sender, to the corresponding information registered at the receiver. The derived relativistic distance expression violates the Lorentz principle for distancing bodies, by predicting length extension instead of contraction, but this feature is the one which renders the theory applicable to quantum phenomena, enabling it to reproduce quantum results pertaining to quantum criticality and matter-wave duality. In another paper [27] we demonstrated that the proposed model leads to the prediction that at sufficiently high velocities, distancing bodies can maintain spatial locality, interacting with each other proximally and not at a distance, indicating that at in a typical EPR preparation particles distancing from each other at sufficiently high velocities can become physically entangled, thus resolving the issue of "spooky action at a distance" [34] in favor of Einstein's local realistic view of physical reality.

We mention briefly that the same set of transformations in Table, without alteration or addition of other variables or free parameters yields excellent predictions of several phenomena and experimental findings concerning the dynamics of small particles, including the Michelson-Morley's "null" result, the relativistic lifetime of decaying muons, Sagnac effect, and neutrino velocities reported by OPERA and other collaborations [35, 36].

For application of the model to cosmology detailed elsewhere, we expressed the set of transformations in Table 1 in terms of redshift instead of velocity. In the constructed cosmological model $\beta$ is interpreted as the recession velocity of some cosmological structure, such as a galaxy receding from Earth, while emitting light or other electromagnetic waves that are received by an observer on Earth. Using Doppler's formula we found that the recession velocity β in terms of redshift z could be written as: $\beta = \frac{z}{1+z}$ [37]. The resulting transformation in terms of z for time, distance and matter density are the simple functions $z$+1, 2$z$ +1, and $\frac{1}{2z+1}$, respectively. The kinetic and wave energy in terms of redshift are plotted on a logarithmic scale in Figure 5. What is of interest in the present paper is the similarity between the dynamics described here for the quantum sector and the dynamics revealed at the cosmic scale. The simplicity and golden ration beauty of the theory's cosmological model could not be ignored. The cosmological model in Fig.5 predicts that the density of normal energy reaches a maximum at redshift and wave energy (which we refer to in the model's cosmology as the "unobserved" or "dark" energy" are predicted to be equal at redshift $z = \frac{1}{2}$, which corresponds to a recession velocity of $\beta = \frac{1}{3}$ .

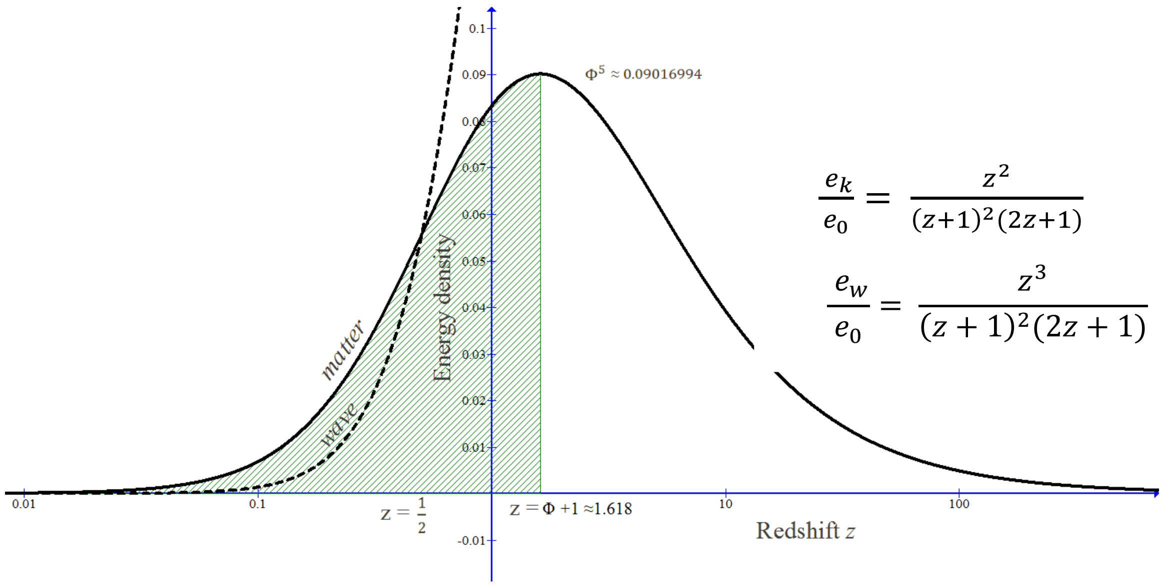


**Figure 5:** Densities of matter kinetic energy and wave energy as functions of redshift z

In other papers [37, 38] we show that the above summarized model is successful in accounting for several important cosmological findings, including the pattern of recession velocity predicted by inflationary theories, the amounts of matter and dark energy in various segments of redshift, reported in recent ΛCDM cosmologies, the GZK energy suppression phenomenon. The main point to be stressed here is that the proposed model of information relativity, just like Newton-Galileo physics does not "discriminate" between physical systems depending on their scale or magnitude. Put succinctly, we argue that the laws of physics, agreed to be the same everywhere, are also the same for everything (i.e., for all bodies of mass regardless of their size and rest mass).

We conclude by underscoring the simplicity and beauty of the derived expression. Isaac Newton, Albert Einstein, Paul Dirac, Robert Penrose, and others, have 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. Such emphasis seems needed today given the intolerable complexity and ugliness of most current theories and the apathy of physicists to increasing mathematical complexity. We believe the appearance of Golden Ratio and other beautiful symmetries in numerous phenomena in physics and in life forms might be associated with some optimal self-organization processes common to all dynamical systems in equilibrium.

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