# God Does Not Play Dice

## Matter-Wave Duality, Quantum Phase Transition and Bose-Einstein Condensate as Deterministic and local Phenomena

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**Ramzi Suleiman**

**University of Haifa & Al Quds University**

Please address all correspondence to Dr. Ramzi Suleiman, University of Haifa, Haifa 31509, Israel. Email: suleiman@psy.haifa.ac.il, Mobile: 972-(0)50-5474- 215.

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### Abstract

The non-locality of quantum mechanics continues to be an unexplainable phenomenon. In a previous paper [1] I utilized a recently proposed relativity theory, termed Information Relativity (IR) to account, both qualitatively and quantitatively to the entanglement in an EPR type experiment. IR rests on two well accepted propositions: The relativity axiom, plus an axiom specifying the information carrier and its velocity. The theory is deterministic and local. It is also complete, in the sense that each element in the theory is in a one-to-one correspondence with reality. Contrary to special relativity which predicts that an object's length will always contract along the direction of its relative motion with respect to an observer, IR predicts length contraction for approaching bodies and length stretching for departing bodies. In the present paper I demonstrate that IR is also successful in explaining and predicting de Broglie's matter-wave duality, quantum phase transition, quantum criticality, and the formation of the Bose-Einstein condensate. Quite strikingly, I found that the critical "stretch" associated with a particle's wave phase transition is equal to the critical value of de Broglie wave length $\zeta(\frac{3}{2}) \approx 2.612$, where $\zeta(x)$ is the Riemann zeta function. This result enables to calculate the Planck's constant, the corner stone of all quantum mechanics, based on a completely deterministic and local theory. The unavoidable conclusion of the present analysis is that Einstein's intuition that "God does not play dice" is correct.



**Keywords:** Relativity, Information, Locality, Matter-Wave, Phase Transition, Bose-Einstein Condensate


### Introduction

In a recent paper [1], I showed that a deterministic theory, termed Information Relativity (IR) is successful in accounting for the entanglement phenomenon observed in a bipartite EPR experiment. The theory rests on two well accepted propositions: 1. the laws of physics are the same in all inertial frames of reference (relativity axiom). 2. Translation of information from one frame of reference to another is performed by a carrier with velocity $v_c$ (information-carrier axiom). A self-evident assumption is that the velocity of the information carrier is higher that the relative velocities between the system's frames of reference. For the case of two frames of reference moving in constant relative velocity $v$ ($v < v_c$) with respect to each other, the theory's resulting transformations (see [1-3]) are depicted in Table 1.

**Table 1**

Information Relativity Transformations

| Physical Term | Relativistic Expression |
|---|---|
| time | $\frac{t}{t_0} = \frac{1}{1-\beta}$ .. (1) |
| distance | $\frac{x}{x_0} = \frac{1+\beta}{1-\beta}$ …. (2) |
| mass density | $\frac{\rho}{\rho_0} = \frac{1-\beta}{1+\beta}$ .... (3) |
| Kinetic energy density | $\frac{e_k}{e_0} = \frac{1-\beta}{1+\beta}\beta^2$ .. (4) |

In the table the variables $t_0, x_0,$ and $\rho_0$ denote measurements of time, distance and mass density at the rest frame, respectively, $\beta = \frac{v}{v_c}$, and $e_0 = \frac{1}{2}\rho_0\ c^2$.

For applications of the theory to high energy particle physics [2] and to cosmology [3] we assume that $v_c = c$, where c is the velocity of light in the observers' internal frame. However, the theory could be applied to the dynamics of classical systems, including thermal, acoustic and other systems, as long as the above two propositions are satisfied.

In the aforementioned paper I investigated the kinetic energy distribution of a body of mass, in its departure from another body's' internal frame. It was shown that the interaction between the two bodies (e.g., particles), even at long distances, is utterly local, because departing bodies are predicted to "stretch" and overlap (see eq. 2). Not only that the theory provided a simple, local ("non-spooky") explanation of entanglement, it also yielded *exact* predictions of L. Hardy's entanglement probability (p = 0.09016994) [4,5], and of quantum criticality at the Golden Ratio discovered experimentally by Coldea et al. [6]. Here I summarize the results discussed in

[1] with regard to the matter energy density distributions, and present a novel analysis of the energy density of the body's wave. In addition to accounting for quantum entanglement, I show that IR is successful in explaining three key quantum phenomena: 1. the matter-wave duality first proposed by Einstein in his theory of light quanta in 1905, and later generalized to all matter by de Broglie [7, 8]. 2. Quantum phase transition and quantum criticality. 3. Formation of Bose-Einstein condensates.

**1. Matter-Wave**

The concept of matter-wave duality is central to quantum theory, ever since 1924, when Louis de Broglie introduced the notion. 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 density of the particle, as function of the relative velocity β = $^{v}/_{v_c}$ (see eq. 4), is depicted by the continuous line in Fig.1. The dashed line in the figure corresponds to the classical Newtonian term. As seen in the figure, at any given velocity the relativistic matter energy is lower than the classical Newtonian energy. The difference, shown by the blue line, corresponds to the energy carried by the body's wave. Formally we define the body's wave energy density at a given velocity as the difference between the matter's Newtonian energy term and its relativistic energy term, or:

$$e_w = e_N - e_k = \frac{1}{2}\rho_0 c^2 \beta^2 - \frac{1}{2}\rho_0 c^2 \frac{1-\beta}{1+\beta}\beta^2 = (\frac{1}{2}\rho_0 c^2)\frac{2\beta^3}{1+\beta} = \frac{2\beta^3}{1+\beta} e_0 \quad \ldots. (5)$$

Where $e_N$ is the Newtonian term and $e_0 = \frac{1}{2}\rho_0 c^2$.

As shown in the figure, the predicted particle's matter energy density is non-monotonic with β. It increases with β up to a maximum at velocity $\beta_{cr}$ , and then decreases to zero at β = 1. In [1] I showed that the maximal matter energy density is achieved at $\beta_{cr}$ equaling the Golden ratio Φ = $\frac{\sqrt{5}-1}{2} \approx 0.618$ [9, 10], with maximum energy density of $(e_m)_{max} = \Phi^5 e_0 \approx 0.09016994\ e_0$.

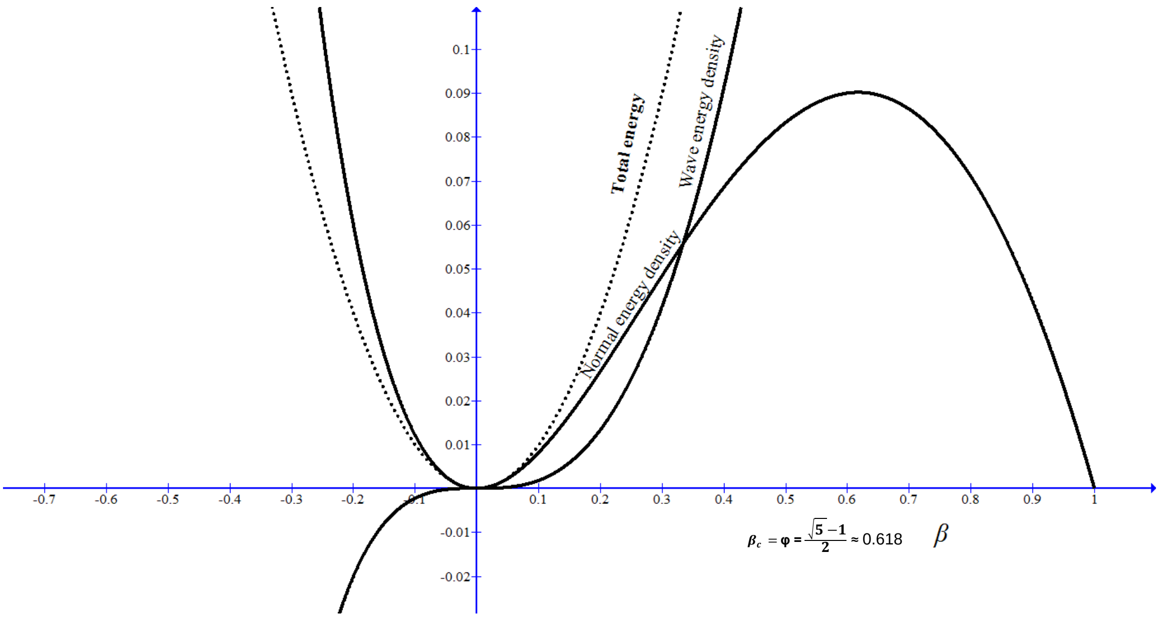


**Figure 1.** Normal matter energy and wave energy as functions of velocity

At any given velocity $\beta = \frac{v}{v_c}$, the particle's total energy density is the sum of its matter and wave energy densities. 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.

## 2. Matter phase transition

A more appropriate from for the present analysis is to describe the matter and wave energy densities in terms of the relative body "stretch" $\hat{l}$, defined as $l/l_0$. From eq. 2 we can write:

$$\beta = \frac{\hat{l}-1}{\hat{l}+1} \qquad \text{.... (6)}$$

Substituting the value of β from eq. 6 in the matter and wave energy densities terms (equations 4 and 5) yields:

$$e_m = \frac{1}{\hat{l}} \cdot \frac{(\hat{l}-1)^2}{(\hat{l}+1)^2} \; e_0 \qquad \text{.... (7)}$$

And,

$$e_w = \frac{2\left(\frac{\hat{l}-1}{\hat{l}+1}\right)^3}{1+\left(\frac{\hat{l}-1}{\hat{l}+1}\right)} e_0 = \frac{(\hat{l}-1)^3}{\hat{l}\,(\hat{l}-1)^2}\ e_0 \qquad \text{.... (8)}$$

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

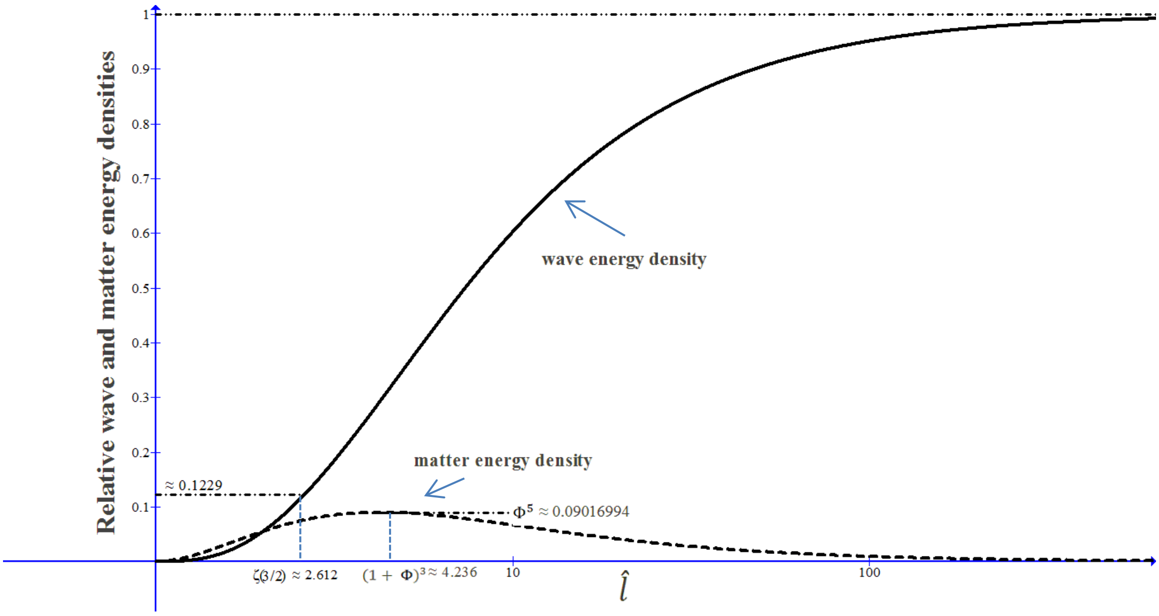


**Figure 2**: $e_m$ and $e_w$ as functions of stretch $\hat{l}$

Inspection of the matter energy density, discussed in more details in [1], reveals very interesting Golden Ratio symmetries. First, the velocity $\beta_{cr}$ at which $e_m$ reaches its peak is equal to the Golden Ratio (see Fig 1). Second, the relativistic length "stretch" at which this peak is reached is equal to the Golden Ratio raised to the power 3, sometimes termed a "silver mean" [11 12], a number related to topologies of the Hausdorff dimension [13]. Third, the maximal matter energy density is equal to $e_0$ times the Golden ratio raised to the power of 5, which if approximated to the eighth decimal digit, is precisely equal to Hardy’s probability of entanglement (0.09016994) [4, 5]. 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. [6] 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.

**3. Wave phase transition**

Figure 2 reveals that the normalized wave energy density $\frac{e_w}{e_0}$ increases rather sharply with the stretch $\hat{l}$, and then levels relatively slowly, approaching 1 as $\hat{l} \rightarrow \infty$. The turning point of the function's slope could be found by deriving $e_w$ in eq. 8 with respect to $\hat{l}$ twice, and equating the result to zero, yielding:

$$\frac{\partial^2 e_w}{\partial \hat{l}^2} = \frac{2\left(5\,\hat{l}^4 - 16\,\hat{l}^3 + 6\,\hat{l}^2 + 4\hat{l} + 1\right)^3}{\hat{l}^3\,\left(\hat{l}+1\right)^4}\; e_0 = 0 \qquad \text{…. (9)}$$

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

$$5\,\hat{l}^4 - 16\,\hat{l}^3 + 6\,\hat{l}^2 + 4\hat{l} + 1 = 0, \qquad \text{…. (10)}$$

Which solves for:

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

With corresponding critical wave energy density of:

$$e_{w_{cr}} = \frac{(\hat{l}_{cr} - 1)^3}{\hat{l}_{cr}\,(\hat{l}_{cr} - 1)^2}\; e_0 \approx 0.1229\; e_0 \qquad \text{…. (12)}$$

The corresponding velocity $\beta_{cr}$, calculated from eq. 6 is:

$$\beta_{cr} = \frac{v_{cr}}{v_c} = \frac{\hat{l}_{cr} - 1}{\hat{l}_{cr} + 1} \approx 0.4463 \qquad \text{…. (13)}$$

Thus, the critical stretch at which the wave energy density undergoes a phase transition is predicted to occur at stretch $\hat{l}_{cr} \approx 2.612375 \approx \zeta(\frac{3}{2})$, where $\zeta$ is the Riemann zeta function [14, 15]. As it is well known, this number emerges in statistical quantum mechanics in connection with the critical temperature *Tc* for the formation of a Bose-Einstein condensate [17-19].

Specifically in the framework of de Broglie's wave-particle model, for a particle with atomic mass *m*, the de Broglie wave length is given by:

$$\lambda_{dB} = \left(\frac{2\pi\hbar^2}{mT_c k_B}\right)^{\frac{1}{2}} = \zeta(\tfrac{3}{2}) \qquad \text{…. (14)}$$

From equation 11 and 14 we can write:

$$\hat{l}_{cr} = \lambda_{dB} \qquad \text{….. (15)}$$

Moreover from equations 14 and 15 the Planck constant could be expressed as:

$$\hbar \approx \frac{mT_c k_B}{2\pi}\, \hat{l}_{cr}^{\frac{1}{3}} \qquad \text{….. (16)}$$

**4. Summary and conclusions**

In several recent papers I have proposed a novel deterministic relativity theory, termed Information Relativity (IR). The theory views relativity not as an ontic representation of reality (as done by Einstein's relativity), but as difference in information (knowledge) between observers who are in relative motion with respect to each other. IR rests on two well accepted propositions: The relativity axiom, plus an axiom specifying the information carrier and its velocity. The theory is deterministic, local. It is also a complete theory, in the sense that each element in the theory is in one-to-one correspondence with reality [16]. In [2] and [3] I showed that IR is successful in predicting the dynamics of high energy particles, and of the cosmology of the intergalactic universe. In a recent paper [1] I demonstrated that IR, without alteration or addition of free parameters, accounts both qualitatively and quantitatively for the entanglement in a bipartite preparation like the one described in the EPR paper [16]. In the present paper I further demonstrated that the theory is successful in explaining the matter-wave duality, quantum phase transition, quantum criticality, and in predicting the point of formation of a Bose-Einstein condensate. Quite strikingly, the critical "stretch" for the phase transition associated with a particle's wave phase transition is equal to the critical value of de Broglie wave length $\zeta(\frac{3}{2}) \approx 2.612$. Even more strikingly, this result enables to calculate the Planck's constant, the corner stone of all quantum mechanics, based on a completely deterministic and local theory. The unavoidable conclusion of my analysis is that Einstein's intuition that "God does not play dice" is correct. Ironically, in order to show that, one must acknowledge that special and general relativity are incorrect.

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