AJOU-DM-04/11/2016

A Wave-Particle Duality Interpretation Based on Dark Energy

Wook Koh

Dept. of Digital Media, Ajou University
Suwon, South Korea

Soonhoi Ha

Dept. of CS, Seoul National University
Seoul, South Korea

Abstract

Every elementary particle or quantic entity may be partly described in terms not only of particles, but also of waves. It expresses the inability of the classical concepts "particle" or "wave" to fully describe the behavior of quantum-scale objects [3]. In this paper, we show that X-particles of dark energy [1][2] can create the wave appearance of a quantum-scale particle, and argue that the particle is indeed a "particle". Our theory is deterministic and local, and is based on classical mechanics. Double-slit experiment and quantum entanglement are explained by the X-particle interpretation.

Keywords: dark energy, X-particle, interpretation, wave-particle duality, uncertainty principle, double slit, quantum entanglement

1 Introduction

Wave-particle duality is an ongoing mystery in modern physics. Most physicists accept wave-particle duality as the best explanation for a broad range of observed phenomena. However, it is not without controversy [3]. In this paper, we present an interpretation that X-particles of dark energy can create the wave appearance of a quantum-scale particle, and argue that the particle is indeed a "particle". Our theory is deterministic and local, and is based on the classical mechanics. Double-slit experiment and quantum entanglement are explained by the X-particle interpretation.

Dark energy is an unknown form of energy that is hypothesized to permeate all of space, tending to accelerate the expansion of universe [4][5][6][7][12][13]. As an origin of dark energy, an X-particle with repulsive force proportional to energy density has been proposed [1]. An X-particle is postulated to have only relativistic mass (zero rest mass), and act like a particle that has a definite position and momentum. In this model, the main cause of anomalies in quantum mechanics is postulated to be dark energy. Thus most parts of classical mechanics would be valid if we add dark energy, spacetime, and Lorentz transformation in the model [2].

The theory postulates that an X-particle has a mechanism to form the gravitational field and to convert it to a gravitational force [2]. And the X-particle passes the gravity signals to its neighboring X-particles at the speed of light to form the ubiquitous gravitational field. Since all particles in the universe exist within the sea of X-particles, each particle's position and momentum are affected by the interaction with X-particles around them. Thus the uncertainty principle could arise due to the interaction with X-particles which form the gravitational field.

In the X-particle interpretation, dark energy can create the wave appearance of a quantum-scale particle as in the Schrödinger's equation. The equation is a practical way of dealing with the probabilistic nature of X-particles which guides the particle. The paradoxes of double-slit experiment and the quantum entanglement are explained by the X-particle interpretation.

The rest of the paper is arranged as follows. In section 2, the previous works on the X-particle are presented. In section 3, we describe the relation between the X-particle theory and Schrödinger equation. In section 4, we present the X-particle interpretation on double-slit experiment and quantum entanglement. Finally, we end with some remarks and future research topics in the last section.

2 Previous Work

2.1 X-particle

The X-particle theory postulates that dark energy exists in the form of X-particle and permeates all of space [1]. Like photon, the particle is a boson that has only relativistic mass (zero rest mass) and acts like a particle with a definite position and momentum.

Suppose there are X-particles i, j with distance l_{ij}. If we squash them, there is a large repulsive force that pushes them apart. On the other hand, if we pull them apart, there is an attractive force field. When the attractive force is equal to the repulsive force ($F_a = F_r$), we define l_{ijo} as the "stable distance". At the same time, m_{io} and m_{jo} are defined as the "stable " for X-particle i, j. Throughout the universe, each X-particle exerts force to one another (negative pressure) to reach its stable distance l_{ijo}. We postulate the repulsive force to be proportional to energy density

$$F_r = G_r \frac{m_i + m_j}{{l_{ij}}^3}, \tag{2.1}$$

where G_r is a repulsive variable, and l_{ij} is the distance between particle i, j. The gravitational attractive force between particles i, j with G as the gravitational constant is

$$F_a = G \frac{m_i m_j}{{l_{ij}}^2}. \tag{2.2}$$

The relation between the repulsive variable G_r and the gravitational constant G is

$$G_r = G \frac{m_i m_j}{m_i + m_j} l_{ijo}. \tag{2.3}$$

Therefore the "net" repulsive force F exerted on the particle can be defined as

$$F = F_r - F_a = G\frac{m_i m_j}{{l_{ij}}^2}(\frac{l_{ijo}}{l_{ij}} - 1). \tag{2.4}$$

As l_{ij} decreases (less than l_{ijo}), there is a large repulsive force F that pushes particles apart. On the other hand, as l_{ij} increases (larger than l_{ijo}), an attractive force F dominates. As l_{ij} increases to infinity, F approaches to zero. When l is equal to the stable distance l_{ijo}, particles i, j will experience zero force. We can observe an analogical example in electromagnetic forces between atoms, where at the radius of an atom, two atoms may experience nearly zero force.

When particles have a same mass, we can simplify variables as

$$m = m_i = m_j, \qquad l = l_{ij}, \qquad m_o = m_{io} = m_{jo}, \qquad l_o = l_{ijo}. \tag{2.5}$$

And the net repulsive force equation becomes

$$F = G(\frac{m}{l})^2(\frac{l_o}{l} - 1). \tag{2.6}$$

We postulate that the angular frequency of X-particle as ω_x that satisfies

$$E = mc^2 = \hbar\omega_x, \tag{2.7}$$

and

$$c = l\omega_x. \tag{2.8}$$

From Eq.(2.7) and Eq.(2.8), we can obtain the key equation of X-particle that shows the relation between m and l

$$mlc = \hbar. \tag{2.9}$$

It is important to note that, assuming $\hbar$ and c are constants, the product of m and l (ml) is constant. We can get l as a function of m from Eq. (2.9) and vice versa

$$l = \frac{\hbar}{mc}. \tag{2.10}$$

The X-particle model was originally developed to explain the accelerated expansion of the universe [1]. And the theory has been expanded to accommodate the following X-gravitational field model [2].

2.2 X-Gravitational Field

In a field model, rather than two particles attracting each other, the particles distort space-time via their mass, and this distortion is what is perceived and measured as a "force". In such a model one states that matter moves in certain ways in response to the curvature of spacetime [11].

In the X-gravitational field model, a gravitational field can be formed with the X-particle distribution [2], and Newtonian's gravitational equation is postulated to be valid if we add dark energy and Lorentz transformation into the model. In order to simplify the problem, one dimensional array of X-particles is considered as an approximated model.

Suppose X-particles from $X_1..X_\infty$ lined up from left to right with mass M ($M \gg m_i$) at the leftmost. For each X_i there is a gravitational attractive force $F_a[i]$ between M and X_i

$$F_a[i] = G\frac{Mm_i}{{R_i}^2}, \tag{2.11}$$

where m_i is the mass of X_i, and R_i is the distance between M and X_i. As X_i is attracted to M, Newton's third law of "action equals reaction" is applied between X_i and X_{i-1}. Here X_i exerts a force $F_a[i]$ on the X_{i-1}, and the X_{i-1} will push back on X_i with an equal repulsive force $F_r[i-1, i]$ in the opposite direction

$$F_r[i-1, i] = G\frac{m_i m_{i-1}}{{l_{i,i-1}}^2}(\frac{l_o}{l_{i,i-1}} - 1), \tag{2.12}$$

where $l_{i,i-1}$ is the distance between X_i and X_{i-1}. For i from 2 to ∞, if we apply Newton's third law of action equals reaction, we get

$$F_a[i] = F_r[i-1, i]. \tag{2.13}$$

The model can be applied to a three dimensional space with multiple mass objects under the law of superposition. For any X-particle X_i, there are gravitational attractive forces and repulsive forces exerted by neighboring X-particles and other masses. Based on Newton's third law, the attractive forces and repulsive forces of X-particles balance each other by adjusting the distance l with neighboring particles. Therefore it creates quantized distribution of X-particles and spaces between them by forces of gravitational attraction and repulsion.

In that process, each X-particle i has the gravitational force field $g[i]$ information at the current position. From Eq.(2.11) we can get

$$g[i] = \frac{F_a[i]}{m_i} = G\frac{M}{{R_i}^2}. \tag{2.14}$$

We postulate that an X-particle has a mechanism to form the gravitational field and to convert it to a gravitational force. And the X-particle passes the gravity signals to its neighboring X-particles at the speed of light to form the ubiquitous gravitational field throughout the universe. For instance, if we place a mass $\hat{M}$ at the position of X-particle i, the force exerted by the gravitational force field i to the mass $\hat{M}$ is

$$F_{\hat{M}} = F_g[i] = \hat{M}g[i] = G\frac{M\hat{M}}{{R_i}^2}. \tag{2.15}$$

The signal that reflects the change of $\hat{M}$ will reflect the spacetime concept and reach mass M after some time delay

$$t_i = \frac{R_i}{c}. \tag{2.16}$$

Therefore X-gravitational field is formed from the dark energy distribution of X-particles, where the quantized gravitational field can be obtained from Eq.(2.14).

2.3 Uncertainty Principle

The quantized X-gravitational field, created by the dark energy, could be the cause of the uncertainty principle [2]. In quantum mechanics, it states that the more precisely the position of some particle is determined, the less precisely its momentum can be known, and vice versa [16].

$$\Delta x \Delta p \geq \hbar/2. \tag{2.17}$$

where $\hbar$ is the reduced Planck constant, Δx and Δp are the error in our knowledge of the position and the momentum respectively of the object we are measuring.

Suppose you try to measure a particle with mass M and momentum P in the sea of X particles. The uncertainty of momentum is caused by a collision between the measured particle and the X-particle. Conservation of linear momentum is implied by Newton's laws and it also holds in general relativity. Therefore the uncertainty of momentum in the X-particle should be equal to the uncertainty of momentum in the measured particle. The average magnitude of momentum for X_i is $p = m_i c_i$. The uncertainty of momentum occurs depending on the relative direction of momentum at the time of collision

$$\Delta p \geq m_i c_i. \tag{2.18}$$

The effect of the uncertainty of position arises depending on how far M is from the nearest X-particle. If we define l_i as the average distance between neighboring particles, we get

$$\Delta x \geq l_i/2, \tag{2.19}$$

If we combine Eq.2.18 and Eq.2.19, we get

$$\Delta x \Delta p \geq (m_i c_i l_i)/2. \tag{2.20}$$

From Eq.2.9, since mcl is equal to $\hbar$

$$\Delta x \Delta p \geq \hbar/2, \tag{2.21}$$

Thus we get the same result as the Heisenberg uncertainty principle. It describes an inherent fuzziness that must exist in any attempt to describe nature [8].

3 X-Particle Wave

We postulate that an X-particle move approximately in a circle at the angular frequency of ω_x, and it transfers gravitational field signals to its neighboring cells, and creates a 3-dimensional X-particle wave. In analogy, deep-water waves that are formed from particles move in circles. Water molecules move in circular orbits when the wave passes by them [8]. In the event in which a (quantum-scale) particle pass from an initial state to a final state in the sea of X-particles, the particle is guided by X-particle waves in a deterministic and local way. The principle of locality states that an object is only directly influenced by its immediate surroundings [21]. X-particle wave is "local" because the wave is created only by neighboring X-particles. On the other hand, de Broglie-Bohm theory is "non-local" because the wave-function depends on the boundary conditions of the system, which in principle may be the entire universe [19].

Let's suppose a series of X-particles X_i that move approximately in circles at the angular frequency ω_x as defined in Eq.(2.7) and Eq.(2.8). A simple circling wavefunction of X_i is of the form

$$\Psi_i = A_i e^{-i(\omega_x t+\theta_i)} = A_i e^{-i(E_x t/\hbar+\theta_i)} \ , \tag{3.1}$$

where A_i is the amplitude, θ_i is a systematic phase shift from circle to circle. We postulate that the systematic phase shift creates an X-particle wave for a quantum-scale particle

$$\Psi = A e^{-i\omega t} = A e^{-iEt/\hbar} \ , \tag{3.2}$$

where ω is the angular frequency of the particle guided by the X particle wave.

According to the relativity theory, a particle at rest in one inertial system can be in uniform motion in another inertial system. In the rest frame of the particle, the probability amplitude is the same for all x, y, and z but varies with t, and the magnitude of the amplitude is the same for all t, but the phase depends on t. Thus a particle guided by X-particles, using the Lorentz transformation [10], the wavefunction of Eq.(3.2) can be represented as

$$\Psi = A e^{i(\mathbf{k}\cdot\mathbf{r}-\omega t)} = A e^{i(\mathbf{p}\cdot\mathbf{r}-Et)/\hbar} \ , \tag{3.3}$$

where the A is the amplitude, $\mathbf{k}$ is the wavevector, $\mathbf{r}$ is the position, and $\mathbf{p}$ is the momentum. In general, physical situations are not purely described by plane waves, so for generality the superposition principle is required.

Eq.(3.2) is equal to Schrödinger's insight which was to express the phase of a plane wave as a complex phase factor. From this point forward, the derivation of X-particle's wave equation is the same as that of Schrödinger's equation. The first order partial derivatives with respect to space is

$$\nabla\Psi = \frac{i}{\hbar}\mathbf{p}A e^{i(\mathbf{p}\cdot\mathbf{r}-Et)/\hbar} = \frac{i}{\hbar}\mathbf{p}\Psi, \tag{3.4}$$

and with respect to time is

$$\frac{\partial\Psi}{\partial t} = -\frac{iE}{\hbar} A e^{i(\mathbf{p}\cdot\mathbf{r}-Et)/\hbar} = -\frac{iE}{\hbar}\Psi. \tag{3.5}$$

Quantum mechanics postulate that all observables are represented by linear Hermitian operators which act on the wavefunction, and the eigenvalues of the operator are the values the observable takes. In terms of derivatives with respect to time and space, acting this operator on the wavefunction Ψ leads to time independent Schrödinger equation [15]

$$i\hbar\frac{\partial\Psi}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\Psi + V\Psi, \tag{3.6}$$

and to the general form of the time independent Schrödinger equation

$$E\Psi = \hat{H}\Psi. \tag{3.7}$$

The most general form is time dependent Schrödinger equation which can be derived as [22]

$$i\hbar\frac{\partial}{\partial t}\Psi(\mathbf{r},t) = \hat{H}\Psi(\mathbf{r},t). \tag{3.8}$$

Generally, derivations of the Schrödinger's equation has demonstrated its mathematical plausibility for describing wave-particle duality, but to date there has been no universally accepted derivations of Schrödinger's equation from appropriate axioms [15].

In quantum mechanics, the analogue of Newton's law is Schrödinger's equation for a quantum system. It is a linear partial differential equation, describing the time-evolution of the system's wavefunction. In the X-particle interpretation, the quantum-scale particle is a particle (not a wave), and the Schrödinger's equation is a practical way of dealing with the probabilistic nature of X-particles which guides the particle. The ideas of probability are certainly useful in describing the behavior of particles or molecules, for it is impractical even to attempt to write down the position or velocity of each one of them. When probability is applied to such problems, it is considered to be a way of dealing with very complex situations [8]. Therefore, for the X-particle interpretation, the most precise description of nature is still in terms of probabilities.

4 X-Particle Interpretation

The Stanford encyclopedia of philosophy article on quantum decoherence categorized "approaches to quantum mechanics" into five groups of interpretations, such as collapse approaches, pilot-wave theories, Everett interpretations, modal interpretations, and Bohr's Copenhagen interpretation [25]. The X-particle interpretation is different from any one of them in that it is deterministic and local, and is based on the classical mechanics. The following "double-slit experiment" and "quantum entanglement" are good examples to show the characteristics of X-particle interpretation.

4.1 Double-Slit Experiment

The double-slit experiment has been an illustration of wave-particle duality. In the event in which a quantum scale particle pass from an initial state to a final state along two possible paths, the duality principle states that "the simultaneous observation of wave and particle behavior is prohibited" [18]. Whereas wave behavior is associated with the observation of interference fringes, particle behavior generally corresponds to the acquisition of "which-path" information by means of coupling the paths to a measuring device or part of their environment [20].

In the X-particle interpretation, the wavefunction is defined at both slits by X-particles, but each particle has a trajectory that passes through exactly one of the slits like pilot-wave theories [19]. The final position of the particle on the detector screen and the slit through which the particle passes is determined by the guiding X-particles' position and momentum that can only be determined statistically. In each experiment, it is impossible to repeat the same initial condition for X-particles, and an appearance of randomness occurs in the pattern of detection. The X-particle wavefunctions through two slits interferes with itself and guides the particles via the X-gravitational force field in such a way that the particle is attracted to the regions in which the interference is constructive, and avoid the regions in which the interference is destructive, resulting in the interference pattern on the detector screen. If we modify this experiment so that one slit is closed, there is no interference of

X-particle wavefunction. Therefore no interference pattern is observed at the screen.

If a particle detectors are positioned at the slits, showing through which slit a photon goes, the interference pattern will disappear [10]. In the X-particle interpretation, the interference result depends on how you set-up the detector. For instance, quantum eraser experiments demonstrate that wave behavior can be restored by erasing or otherwise making permanently unavailable the which-path information [23]. A simple do-it-at-home demonstration of the quantum eraser phenomenon was given in an article in Scientific American [24]. If one sets polarizers before each slit with their axes orthogonal to each other, the interference pattern will be eliminated. The polarizers can be considered as introducing which-path information to each beam.

In the X-particle interpretation, an X-particle move approximately in a circle at the angular frequency of ω_x, and it transfers gravitational field signals to its neighboring cells, and creates a 3-dimensional X-particle wave. Therefore, if each slit is polarized differently, X-particle wave will be polarized in that direction and the interference between two slots may not be destructive to each other any more, because polarized circle directions are different from each other. This explains why the destructive zone and the interference pattern disappear after polarization of 90° relative to each other.

Introducing a third polarizer in front of the detector with an axis of 45° to the other polarizers "erases" the detected information. As polarization effect is reduced, destructive interference begins to form, which allows the interference pattern to reappear. In the X-particle interpretation, when you set-up the detector for a double-slit experiment, it is essential not to disrupt the interference mechanism of X-particles. Otherwise the destructive zone and the interference pattern will disappear. It seems that no one has succeeded in finding such detector yet.

4.2 Quantum Entanglement

Quantum entanglement is a physical phenomenon that occurs when pairs or groups of particles are generated or interact in ways such that the quantum state of each particle cannot be described independently. Instead, a quantum state must be described for the system as a whole. Measurements of physical properties such as position, momentum, spin, and polarization, performed on entangled particles are found to be appropriately correlated [28].

However, this behavior gives rise to paradoxical effects. Any measurement of a property of a particle can be seen as acting on that particle by collapsing a number of superposed states and will change the original quantum property by some unknown amount. In the case of entangled particles, such a measurement will be on the entangled system as a whole. It thus appears that one particle of an entangled pair knows what measurement has been performed on the other, even though there is no known means for such information to be communicated between the particles separated by arbitrarily large distances. Such phenomena is known as the EPR paradox [27][28].

In the X-particle interpretation, a separated particle of an entangled pair "does not know" what measurement has been performed on the other, and there is "no communication" between them. It is not possible to transmit classical information at faster-than-light speeds. As described in Eq.(2.18) and Eq.(2.19), the uncertainty of quantum state comes from the "initial" condition of X-particles and their gravitational force field. Once quantum scale particles are generated or interact to form the system as a whole, a new gravitational force field of X-particles is created as in Eq.(2.14) so that physical properties are correlated. Therefore when two entangled particles are separated far apart, neighboring X-particles may move together with the entangled particle as a whole. Thus the uncertainty which comes from the initial condition of X-particles is removed, which maintains the quantum state correlation.

5 Conclusion

In this paper, we showed that X-particles of dark energy [1][2] could create wave-properties of a quantum-scale particle, and argued that the particle is indeed a "particle", and is not a wave. The theory is deterministic and local, and is based on the classical mechanics. It is different from any other existing interpretations [25].

As an origin of dark energy, an X-particle theory with repulsive force proportional to energy density has been proposed [1]. In this model, the main cause of anomalies in quantum mechanics is postulated to be dark energy. Thus most parts of classical mechanics would be valid if we add dark energy, spacetime, and Lorentz transformation in the model. In the X-gravitational field model, a gravitational field can be formed with the X-particle distribution [2]. Based on Newton's third law, the attractive forces and repulsive forces of X-particles balance each other by adjusting the distance l with neighboring particles. Therefore it creates quantized distribution of X-particles and spaces between them by forces of gravitational attraction and repulsion. The theory postulates that an X-particle has a mechanism to form the gravitational field and to convert it to a gravitational force [2]. And the X-particle passes the gravity signals to its neighboring X-particles at the speed of light to form the ubiquitous gravitational field throughout the universe. Since all particles in the universe exist within the sea of X-particles, each particle's position and momentum is affected by the interaction with X-particles around them. Thus the uncertainty principle could arise due to the interaction with X-particles which form the gravitational field.

In the X-particle's interpretation, the quantum-scale particle is a particle (not a wave), and the Schrödinger's equation is a practical way of dealing with the probabilistic nature of X-particles which guides the particle. An X-particle is postulated to move approximately in a circle at the angular frequency of ω_x, and it transfers gravitational field signals to its neighboring cells, and creates a 3-dimensional X-particle wave. And the quantum-scale particle is guided by the wave in a deterministic and local way. The systematic phase shift creates an X-particle wave for a quantum-scale particle, which leads to Schrödinger's equation.

The X-particle interpretation is deterministic, local, and is based on classical mechanics. The paradoxes of double-slit experiment and the quantum entanglement are explained by the X-particle interpretation. The future research topic will be a computational modeling and simulation of the wave-particle duality created by dark energy based on the X-particle theories.

References

[1] Koh, W.; S. Ha. (2016). "Repulsive Force Proportional to Energy Density as an Origin of Dark Energy". http://www.vixra.org/abs/1605.0108

[2] Koh, W.; S. Ha. (2016). "Dark Energy Forms a Gravitational Field Resulting in the Uncertainty Principle". http://vixra.org/abs/1605.0133

[3] https://en.wikipedia.org/wiki/Wave-particle_duality

[4] Peebles, P. J. E.; Ratra, Bharat (2003). "The cosmological constant and dark energy". Reviews of Modern Physics 75 (2). :559606.

[5] Filippenko, Alex. "Dark Energy and the Runaway Universe". University of California Television (UCTV). (https://www.youtube.com/watch?v=vPkGEVgOJK0).

[6] Penrose, R. (2007). The Road to Reality: A Complete Guide to the Laws of the Universe. Vintage. ISBN 978-0679776314.

[7] Greene, B. (2005). The fabric of the cosmos : space, time, and the texture of reality. Vintage. ISBN 978-0375727207.

[8] Richard Feynman (1970). The Feynman Lectures on Physics Vol I. Addison Wesley Longman. ISBN 978-0-201-02115-8.

[9] Richard Feynman (1970). The Feynman Lectures on Physics Vol II. Addison Wesley Longman. ISBN 978-0-201-02115-8.

[10] Richard Feynman (1970). The Feynman Lectures on Physics Vol III. Addison Wesley Longman. ISBN 978-0-201-02115-8.

[11] Geroch, Robert (1981). General relativity from A to B. University of Chicago Press. p. 181. ISBN 0-226-28864-1.

[12] Lapuente, P. (2010). Dark energy: observational and theoretical approaches. Cambridge University Press. ISBN 978-0521518888.

[13] Amendola, Luca; Tsujikawa, Shinji (2015). Dark Energy. Cambridge University Press.

[14] Sen, D. (2014). "The uncertainty relations in quantum mechanics" (PDF). Current Science 107 (2): 203-218.

[15] https://en.wikipedia.org/wiki/Schrödinger_equation

[16] Heisenberg, W. (1927), "Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik", Zeitschrift fr Physik (in German) 43 (34): 172-198.

[17] https://en.wikipedia.org/wiki/Double-slit_experiment

[18] M. O. Scully, B.-G. Englert, and H. Walther. (1991) "Quantum optical tests of complementarity". Nature 351, 111 - 116

[19] https://en.wikipedia.org/wiki/De_Broglie-Bohm_theory

[20] Eliot Bolduc, Jonathan Leach, Filippo M. Miatto, Gerd Leuchs, Robert W. Boyd.(2014) “A fair sampling perspective on an apparent violation of duality”. arXiv:1402.6487 [physics.optics]

[21] https://en.wikipedia.org/wiki/Principle_of_locality

[22] Briggs, J. S.; Rost, J. M. (2001) “On the Derivation of the Time-Dependent Equation of Schrdinger”. Foundations of Physics. Volume 31. Issue 4. pp 693-712

[23] https://en.wikipedia.org/wiki/Deterministic_system

[24] Hillmer, R.; Kwiat, P. (2007). ”A do-it-yourself quantum eraser”. Scientific American Magazine. Vol. 296 no. 5. pp. 9095.

[25] http://plato.stanford.edu/entries/qm-decoherence/

[26] Matson, John (2012). ”Quantum teleportation achieved over record distances”. Nature.

[27] Kumar, Manjit (2011). Quantum: Einstein, Bohr, and the Great Debate about the Nature of Reality (Reprint ed.). W. W. Norton & Company. pp. 305306. ISBN 978-0393339888.

[28] https://en.wikipedia.org/wiki/Quantum_entanglement