

Freeing Entanglement from the Iron Cage of Einstein's Realism

Paul Drechsel (2009)

Abstract:

In the early 20th century, Einstein's theories of relativity expanded classical physics, but at the same time the arising quantum physics already questioned some fundamental principles of classical physics. This questioning was intensified when the theoretical concept of entanglement was developed. Einstein opposed it vehemently and invented the so-called EPR-Paradox, which in 1962 was transformed by John Bell into an inequality that allowed empirical tests. Twenty years later, Bell's inequality could be violated by entanglement. In 2007 and 2008 some fundamental experiments based on entanglement radically questioned Einstein's realism and with it nearly all fundamental principles of classical physics including those of the theories of relativity. This article intends to outline a vision of a new quantum reality of entanglement beyond Einstein's classical realism.

The early 20th century witnessed an explosion of new theories and experiments in the science of physics. Albert Einstein invented the Theories of Relativity, Special (STR) and General (GTR) (1905, 1915), thus opening the scope of Newton's classical physics far beyond its former horizon up to the Big Bang, Inflation, Quasars and Black Holes. At the same time Quantum Physics also emerged. With Planck's constant \hbar it questioned right from its beginning the classical paradigm '*natura non facit saltus*'.¹ An even bigger challenge to Quantum Physics was the invention of entanglement, which Einstein derogatorily called 'spooky' and fought for the rest of his life. With Nathan Rosen and Roman Podolsky he formulated his rejection of entanglement in what is now known as EPR-Paradox (1935). He also rejected quantum probability with his famous dictum: 'God is not playing dice'. This rejection appears a little bit strange, because Einstein was awarded the Nobel Prize for his invention of the light-quantum and the 'photon effect', both of them fundamental for quantum physics. His stance against quantum physics seemed even more questionable when he developed a new form of energy, using Planck's constant \hbar : $E = h\nu$. For the classical domain the more familiar form is known as $E = mc^2$.

In the 1960s, John Bell published his famous 'Bell's inequality'. It offered criteria for its experimental verification or violation and marked once and for all a clear line of separation between classical physics and quantum physics, for example everything that is beyond a limit of 2 is non classical. In 1969 and 1974 Clauser et al. were the first to succeed in violating Bell's inequality, but their success was questioned. In 1981, Alan Aspect et al. (1982) at Paris could experimentally establish the fact of entanglement by violating Bell's inequality; the experiment and its result were accepted by the physical community. In 2002, Leggett published a new inequality that could be used for experimental tests of 'Einstein's realism'. In 2003 Antoine Suarez et al. successfully carried out their so-called 'before-before' experiment which radically questions classical time and space. Four years later, in 2007, Anton Zeilinger et al. at Vienna were able to violate 'Einstein's realism' by violating Leggett's inequality. A similar experiment by Nicolas Gisin et al. in 2008 lead to the same result. Also in 2008, Gisin

¹ 'Nature does not progress by leaps.' This means classical nature presuppose a universe based on continuum.

et al. could demonstrate that entanglement violates the principle of the ‘constant speed of light c ’ up to a factor 10^5 , and probably infinitely.

These recent experiments might be controversial, but they all question some fundamental structures of Classical Physics. They challenge the most successful theories physicists ever created, the Quantum Electrodynamics (QED) and Quantum Field Theory (QFT), which are also based on Einstein’s realism! In order to understand what is at stake we need to take a closer look at ‘Einstein’s realism’.

“If one asks what is characteristic of the realm of physical ideas independently of the quantum theory, then above all the following attracts our attention: the concepts of physics refer to a real external world, i.e., ideas are posited of things that claim a “real existence” independent of the perceiving subject (bodies, fields, etc.)...it appears to be essential for this arrangement of the things in physics that, at a specific time, these things claim an existence independent of one another, insofar as these things “lie in different parts of space”. Without such an assumption of the mutually independent existence (the “being-thus”) of spatially distant things, an assumption which originates in everyday thought, physical thought in the sense familiar to us would not be possible. Nor does one see how physical laws could be formulated and tested without such clean separation...For the relative independence of spatially distant things (A and B), this idea is characteristic: an external influence on A has no immediate effect on B; this is known as the “principle of local action,” which is applied consistently in field theory. The complete suspension of this basic principle would make impossible the idea of (quasi-)closed systems and, thereby, the establishment of empirically testable laws in the sense familiar to us.” (Einstein, 1948:331-2)

“If, without disturbing a system in any way, it is possible to predict with certainty the result of the measurement of an observable of the system, then there exists an element of reality associated with the observable in question; the system ‘objectively possesses’ the relative property.” (EPR 1935)

What constitutes this realism? Its fundamental concepts can be listed as follows:

Independency of particles, locality of particles, separation of particles, causality between particles and events, unique trajectories of particles, waves are no particles and fields no particles, and most important, observer independency. However, there is more to be said about Einstein’s realism, we have, for instance to add some fundamental concepts of the theories of relativity, such as: Minkowski 4-dimensional space-time, Principles of relativity, Lorentz invariance, Gravity as space curvature, Constant speed of light c . The logic behind these classical categories is the following: additivity (direct sum) of phase spaces, Boolean algebra/logic, a ‘Tertium non datur’ (Law of excluded middle), determinism, and probability as no knowledge.

The very basis of the iron cage of Einstein’s realism as well as of QED and QFT is formed by these tenets: Observer independency, locality, causality, principles of relativity, Lorentz invariance, gravity, constant speed of light c . Quantum physics differs by observer dependency, no unique trajectories, wave as particle and superposition. These quantum

deviations alone already lead to a radical change in the logic of the classical paradigm. In the quantum domain emerge multiplicity (direct product), non-Boolean logic/algebra, tertium datur, indeterminism, and probability as knowledge; including quantum entanglement, classical locality and causality is also questioned.

For a better overview of the juxtaposed categories, I would like to offer the following table comparing Classical Physics (CM), Quantum Physics (QM) and the Standard Model, and Quantum physics based on entanglement.

CM	QM/QFT/Stand.Model	Entanglement
Independency	Dependency	<i>Dependency</i>
Locality	Locality	<i>Non-locality</i>
Separation	Separation + Connection	<i>Connection</i>
Causality	Causality	<i>Non-causality</i>
Unique trajectories	No unique trajectories	<i>Everywhere</i>
Waves are no particles	WaveParticle	<i>WaveParticle</i>
Fields no particles	FieldParticle	<i>FieldParticle</i>
Observer independency	Observer dependency	<i>Observer dependency</i>
Euclidian 3-dim-space	Hilbert space	<i>Hilbert space</i>
	Superposition	<i>Superposition</i>
	Reflexivity	<i>Reflexivity</i>
STR		
Minkowski 4-dim space-time	Minkowski 4-dim space-time	?
Principles of relativity	Principles of Relativity	?
Lorentz invariance	Lorentz invariance	?
Gravity	Gravity	?
Constant speed of light c	Constant speed of light c .	?
Additivity	Multiplicativity	<i>Multiplicativity</i>
Boolean algebra/logic	Non-Boolean-logic/algebra	<i>Non-Boolean logic/algebra</i>
Tertium non datur	Tertium datur	<i>Tertium datur</i>
Determinism	Indeterminism	<i>Indeterminism</i>
Probability no knowledge	Probability as knowledge	<i>Probability as knowledge</i>

It is easy to see that in the right-hand column some entries are missing. Entanglement questions the principles of classical physics as well as locality and causality referring to the Standard model, whereas it does not seem to question the principles of STR and GTR. But the experiments of Suarez, Gisin and Zeilinger have shown that the violation of basic principles of STR and GTR is also possible. This possibility is also supported by logical symmetry considerations and by the violations of locality and causality that question the other principles of relativity, as the following juxtaposition will show:

Classical

Newtonian or Euclidian 3-dim-space
Minkowski 4-dim space-time
Principle of relativity.
Lorentz invariance.

Beyond Standard Model

→*No such space and time*
→*No such space and time*
→*No principle of relativity*
→*No Lorentz invariance*

Gravity as space curvature.
Constant speed of light c .

→No gravity
→No constant speed of light c .

This heretical juxtaposition will probably be considered outrageous, but the experiments by Suarez, Gisin, and Zeilinger have proven this logic of entanglement. The violation of Bell's and Leggett's inequalities is also a violation of classical gravity. One has to understand the empirical violations of these inequalities as 'irrevocable'. Let me rearrange the table above anew:

		CM	QM/QED/QFT/ Standard Model	Entanglement Beyond Standard Model	
c o n s t a n t S P E E D o f L I G H T c	S P A C E	Independency	Dependency	<i>Dependency</i>	C O R R E L A T E D
		Locality	Locality	<i>Non-locality</i>	
		Separation	Separation + Connection	<i>Connection</i>	
		Causality	Causality	<i>Non-causality</i>	
		Unique trajectories	No unique trajectories	<i>Everywhere</i>	
		Waves are no particles	WaveParticle	<i>WaveParticle</i>	
		Fields are no particles	FieldParticle	<i>FieldParticle</i>	
		Observer independency	Observer dependency	<i>Observer dependency</i>	
		Euclidian 3-dim-space	Hilbert space	<i>Hilbert space</i>	
			Superposition	<i>Superposition</i>	
		Reflexivity	<i>Reflexivity</i>		
		Minkowski 4-dim space-time	Minkowski 4-dim space-time	<i>No-Minkowski space</i>	I N S T A N E O U S I T Y
		Principles of relativity	Principles of Relativity	<i>No Relativity</i>	
		Lorentz invariance	Lorentz invariance	<i>No Lorentz Invariance</i>	
		Gravity	Gravity	<i>No Gravity</i>	
		Constant speed of light c	Constant speed of light c .	<i>No const. speed of light c.</i>	
		Additivity	Multiplicativity	<i>Multiplicativity</i>	
		Boolean algebra/logic	Non-Boolean-logic/algebra	<i>Non-Boolean logic/algebra</i>	
	Tertium non datur	Tertium datur	<i>Tertium datur</i>		
	Field of real numbers	Complex numbers	<i>Imaginarity</i>		
	Determinism	Indeterminism	<i>Indeterminism</i>		
	Probability no knowledge	Probability as knowledge	<i>Probability as knowledge</i>		

The heresy will not end here; I also suggest to separate the field of real numbers for classical physics from the field of complex numbers for quantum physics and entanglement. I rather expect the community of physicists to reject my concept of a speed that exceeds the constant speed of light c because they assume signal transfer to be limited by c . Fact is, however, that Gisin's experiment in 2008 violated this speed of light. We should also keep in mind that, if we define information classically, we deny the possible existence of other types of information, for example based on quantum entanglement.

The order of the physical categories in the table above is based on logic of a contrary symmetry between the CM and the Entanglement column. Present day QM and QFT is a mixture of CM (including STR) with QM. The mutual and contrary relationships of the

categories can be represented in the following order:

Classical Physics	Quantum Physics	Entanglement
Relativistic CM	Relativistic QM	Non-relativistic Quantum Physics without Space and Time
STR, GTR	QED, QFT	

Conclusion:

I am aware that my vision of a science of physics outside the iron cage of Einstein’s realism can and will be challenged or even outright rejected. Especially the questioning of the significance of gravity for a future quantum theory will probably encounter fierce resistance, because nearly all physicists believe in a quantum theory with gravity and are looking for a ‘quantum graviton’ or, as in String Theory, for a synthesis of GTR and QM. In my mind, these endeavors are undermined by the results of the empirical experiments by Gisin, Zeilinger, and Suarez. They are further undermined by the violation of Bell’s and Leggett’s inequalities, and last but not least, by the fundamental contrary symmetry of basic physical principles displayed in the last two tables above.

I, too, cannot imagine a universe without time and space, but there was a time, not too long ago, when human beings could not imagine that the earth revolved around the sun. To support my call for a physics freed from the constraints of ‘Einstein’s Realism’, let me quote Nicolas Gisin and Antoine Suarez. Nicolas Gisin claims that

“in relativity there is space-time out there. In quantum mechanics there is entanglement”;

he then goes on to argue that

“...either space-time is an illusion, or free will is an illusion, or there is some communication. We call this hypothetical “message” quantum information...”

Gisin comes to the following conclusion:

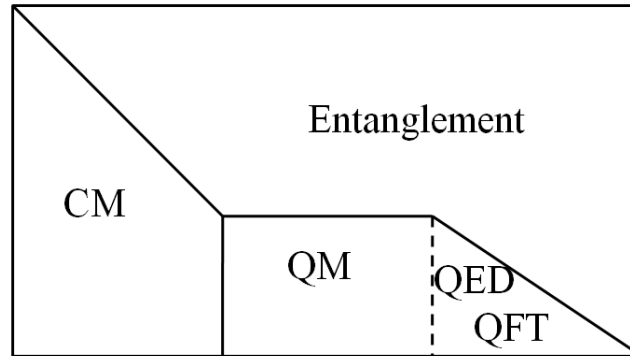
“If the speed of quantum information is indeed infinite, or non-existing, then we are left with the two remaining alternatives: Either space-time or free will is an illusion. I am tempted to vote for the first one!” (2002:4)

In a private mail, Antoine Suarez explains that

“...the result of the before-before experiment does not mean that ‘our universe is without time and space’, but rather that in our universe phenomena occur, which

*come from outside space-time, or, in other words, do not have any material observable origin”.*²

Entanglement, the condition of this ‘before-before’-experiment, is such a phenomenon outside space and time! But how could we imagine it? The following figure suggests a possible approach to a visualization of the development of entanglement:



I admit that the internal logic of the development of theories should be depicted inversely, but then the relevance of entanglement would not be seen properly. Ironically, the most striking empirical proves of entanglement were presented when the Standard Model of quantum physics was at its best.

But the question remains: what can entanglement be beyond a very strong correlation? For an answer I would propose to perceive the figure as it is, because then it will become evident that entanglement is ‘No-thing’ compared with concepts of CM, STR and GTR, and also QM and QED or QFT, because they are based on locality, causality etc. Logically seen as a ‘No-such-thing’ it can only be the CONTRARITY to what we know as certain, that is, seen physically. I suggest the best expression for entanglement could be the VOID.³

² Private Mail from 30. July 2008. Also in “History. The Story behind the Experiments” In: <http://www.quantumphil.org/history.htm>, he writes at the end: “The final results of the experiments with moving measuring devices rule out the possibility to describe the quantum correlations by means of real clocks, in terms of “before” and “after”; nonlocal quantum phenomena cannot be described with the notions of space and time. This means there is no time ordering behind nonlocal correlations, so the causal order cannot be reduced to the temporal one. Quantum correlations somehow reveal dependence between the events, or logical order. Experiments show that this dependence, or logical order, is beyond any real time ordering. In the realm of the nonlocal quantum phenomena, things come to pass but the time doesn’t seem to pass here.”

³ One should not confuse it with the quantum vacuum, which is based on locality!

Literature:

- Aspect, Alain et al.: Experimental Realization of Einstein-Podolsky-Rosen-Bohm Gedankenexperiment: A New Violation of Bell's Inequalities, A. Aspect, P. Grangier, and G. Roger, *Physical Review Letters*, Vol. 49, Iss. 2, pp.91-94 (1982)
- Aspect, Alain et al.: Experimental Test of Bell's Inequalities Using Time-Varying Analyzers, A. Aspect, J. Dalibard and G. Roger, *Physical Review Letters*, Vol. 49, Iss. 25, pp. 1804-1807 (1982).
- Bell, John S.: On the Einstein-Podolsky-Rosen Paradoxon. In: *Physics* 1, 1964, p.195-200.
- Clauser, J. F.; M.A. Horne, A. Shimony and R. A. Holt: Proposed experiment to test local hidden-variable theories, *Phys. Rev. Lett.* 23, p. 880-884 (1969).
- Clauser, J. F.; M. A. Horne: Experimental consequences of objective local theories, *Phys. Rev. D* 10, 526-35 (1974).
- Einstein, Albert; Podolsky, Boris; Rosen, Nathan: Can quantum-mechanical description of reality be considered complete? In: *Physical Review*, 47, 1935, p.777-780.
- Einstein, Albert: "Quantenmechanik und Wirklichkeit", *Dialectica* 2, 1948 , p. 320-324. [Howard's 1989 translation].
- Einstein, Albert: *Relativity. The Special and the General Theory*. New York. 1961.
- Fine, Arthur: *The Shaky Game: Einstein Realism and the Quantum Theory*. Chicago. 1996
- Gisin, Nicolas: "How come the Correlation?" In: arXiv:quant-ph/0503007, March 2005.
- Gisin, Nicolas: "Can relativity be considered complete? From Newtonian nonlocality to quantum nonlocality and beyond. " In: arXiv:quant-ph/052168v1 20. December 2005.
- Gisin, Nicolas et al. Testing spooky action at a distance . Daniel Salart, Augustin Baas, Cyril Branciard, Nicolas Gisin, Hugo Zbinden in: *Nature*, 454, 2008, p.861-864 .
- Gisin, Nicolas et al.: Testing quantum correlations versus single-particle properties within Leggett's model and beyond . Cyril Branciard, Nicolas Brunner, Nicolas Gisin, Christian Kurtsiefer, Antia Lamas-Linares, Alexander Ling, Valerio Scarani. In: *Nature Physics* Vol. 4, 2008.
- Leggett, A. J.: Testing the limits of quantum mechanics: motivation, state of play, prospects. In: *L. Phy. Condens Matter* 14, 2002, p. 415-451.
- Leggett, A.J.: Nonlocal Hidden Variable Theories and Quantum Mechanics: An Incompatibility Theorem. In: *Foundations of Physics*, 33, 2003, p.1469-1493.
- Suarez, Antoine et al.: Quantum Correlations with Spacelike Separated Beam Splitters in Motion: Experimental Test of Multisimultaneity. André Stefanov, Hugo Zbinden, and Nicolas Gisin - Antoine Suarez. *Physical Review Letters* volume 88, 2002 number 12.
- Suarez, Antoine et al: Quantum Correlations with moving Observers.N. Gisin, V. Scarani, A. Stefanov, A. Suarez, W. Tittel and H. Zbinden, *Optics & Photonics News*, 51, 2002.
- Suarez, Antoine et al: Quantum entanglement with acousto-optic modulators: Two-photon beats and Bell experiments with moving beam splitters. André Stefanov, Hugo Zbinden, Nicolas Gisin and Antoine Suarez. *Physical Review. A*, Vol. 67, 2003, 042115.
- Zeilinger, Anton et al.: Experimental test of non-local realistic theories without the rotational symmetry assumption, T. Paterek, A. Fedrizzi, S. Gröblacher, T. Jennewein, M. Zukowski, M. Aspelmeyer, A. Zeilinger *Phys. Rev. Lett.* **99**, (2007).
- Zeilinger, Anton et al.: An experimental test of non-local realism. S. Gröblacher, T. Paterek, R. Kaltenbaeck, C. Brukber, M. Zukowski, M. Aspelmeyer, A. Zeilinger, *Nature*, Vol. 446, 2007, p.871-875.