The Reality Concept in Physics: An Epistemological Study

Mustapha Oldache, Chams-eddine Khiari
Ecole Normale Supérieure-Kouba, Department of physics, Laboratory of Didactique of Sciences, B.P. 92 Vieux Kouba, Algiers, Algeria
Phone: +231 21 28 79 81 Fax: +231 21 28 20 6 ;

Tayeb Belarbi
University of Algiers 2, Department of Psychology and Science of Education, *Algiers, Algeria*
Emails: musoldache@gmail.com, chamsydine@yahoo.fr, *t_belarbi@yahoor.fr*

ABSTRACT
The objects studied by classical physics are supposed to exist independently of the observer. Furthermore, the description of their movements or their states in a spatial and temporal frame is believed to be complete. In quantum mechanics, however, each measure done on a physical system perturbs the latter inevitably. Consequently, matter, light and their interactions cannot be described by only one aspect, either corpuscular or wavelike. And, finally, Aspect's experiment seems to reveal the existence of a quantum non-locality. All these effects contribute in revealing a *"quantum reality"* radically different from the classical one. We propose here an epistemological analysis of such a quantum reality.

KEYWORDS: quantum mechanics, indetermination principle, quantum entanglement, physical reality

1. Introduction

The problem of "reality" has been raised by philosophy for a long time while it has landed in physics relatively recently. This problem does not arise in classical physics since the objects that it "handles" are supposed to be real: masses, springs, clocks, planets, satellites ... The problem began to arise with the introduction of the "field" concept, originally used to avoid calling for the action at a distance. But the problem has been posed especially with the advent of quantum mechanics, by the introduction of the concept of "wave function" and the principle of indeterminacy. According to Schrödinger (1964), particles do not exist as material bodies but only as matter waves. The Copenhagen School then removed from the wave function any physical meaning to give it the status of a mere "mathematical tool" used to assess the probability of occurrence of different measurement results. In relativistic quantum mechanics, particles are only excitations of quantum fields. Similarly, in general relativity, masses are treated as "singularities" of the gravitational field. Also, is it legitimate to ask: but then, in this case, what does actually exist?

2. Where is reality?

In common parlance, the word "reality" is what actually exists, as opposed to imagination. The word "reality" comes from the Latin "res" which means "thing". Guénon (1976) has defined a material body as follows: "A body is a material form living in space and time". According to Kastler (1976), an object has two fundamental properties: permanence and individuality. But it is clear that permanence is a relative notion because ice is likely to melt and combustible bodies turn into smoke when burned; molecules are broken and formed during chemical reactions, radioactive atoms decay and particles can themselves be created and annihilated in nuclear reactions. Individuality also is relative since the existence of various interactions means firstly that there is no perfectly isolated particle or system and, on the other hand, pairing assembles particles by pairs. Even more fundamentally, quantum non-separability is now well established. Since change is a fact of life in nature, we are led to seek reality, not in things, beings and phenomena in themselves, but in the invariant entities. Classical physics is based, indeed, on the principles of conservation: conservation of energy, mass, momentum, angular momentum, etc.

Table 1: Relationships between conservation entities physical and the corresponding symmetries

Physical entity or transformation retained	**Corresponding symmetry**
Pulse	Symmetries related to translations in space
Energy	Symmetries related to translations in time
Orbital angular momentum	Symmetries related to rotations in physical space
Spin	Symmetries related to rotations in spin space
Space-time interval	Symmetries related to transformations of the Poincaré group
Parity	Symmetries related to change in parity
Permutation of identical particles	Symmetries related to permutations of particles
Transformation of a particle in its antiparticle	Charge conjugation symmetry
Color change	Symmetries related to color generators
Changing a lepton in the neutrino	Symmetries related to weak isospin generators

One is tempted to keep these principles of conservation as the underlying reality. But Noether theorem specifies that conservation of any physical entity corresponds to a given symmetry (Noether 1918). This means that the entity in question is invariant vis-à-vis the corresponding symmetry (see Table 1). In these conditions, we are led to locate deep reality, not at the level of the principle of conservation of physical quantities, but at the level of corresponding symmetries, and those related to space-time, in particular.

3. Independent reality and empirical reality.

Some philosophers have noted that if the independent (or objective) reality existed, it would be unknowable. It is also necessary, according to them, to be content of merely empirical reality, i.e. the set of phenomena that are available to us through our senses and our means of investigation. It is useful, however, in order to make sense of things, to introduce two notions of reality:

- Independent reality: that would be a reality outside consciousness and independent of it.
- Empirical reality: that is revealed by phenomena.

It was noted above that the word actually came from the Latin "res", meaning “object” and we gave a definition of an object as a material being, endowed with form and existing in a spatial-temporal framework. It is of course understood that this definition relates only to physical objects (i.e. physical objects within the empirical reality that we take for "concrete"). Lecomte (1997) actually distinguishes four categories of objects:

- Formal objects
- Objects that are associated with physical concepts
- Objects of independent reality
- Biological objects

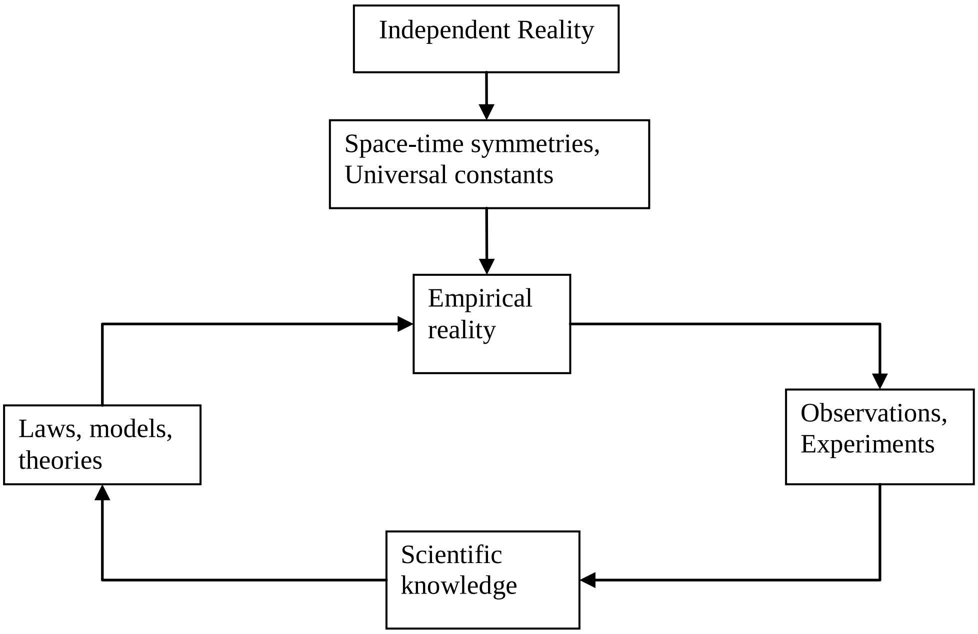

Figure 1: Relationships between reality and scientific knowledge

Formal objects are related to the existence of human consciousness. They are the images of a certain operation of thinking and a rigorous operation of the human mind. As an example, one can mention mathematical objects. Objects that are associated with physical concepts are produced to describe phenomena and serve to put formal objects into association with physical properties. One example is the universal constants that express, according to Cohen-Tannoudji (1991), human limitations in their relationship with independent reality. The objects of independent reality are not knowable. They are not necessarily individualized and escape to the categorization procedure which seems necessary in any process of human knowledge. Biological objects belong to independent reality. Their categorization, individualization and separation are mental operations that do not necessarily reflect the intrinsic properties of these objects.

Thus, independent reality is rationally unknowable. Only empirical reality is knowable and is revealed to us through the events that we can perceive. These phenomena are characterized by regularities, which justifies the fact of assigning to them causes and of stipulating the existence of "laws of nature" and "general principles of physics", in particular the principles of conservation of physical quantities such as energy, momentum, angular momentum, etc.

According to Charon (1974), reality is continuous and it is our knowledge of it that is discontinuous: "What we call reality is a recreation by our minds of a reality that we perceive through rough and discontinuous effects". This discontinuity of our knowledge of the universe is reflected in the existence of universal constants h, c, e ... This means that independent reality is indivisible and that it is the knowledge that we have of it (i.e. empirical reality) that is fragmentary. From this fragmentary knowledge acquired through observation and experience, the physicist makes a generalization (by developing laws, theories or models) to represent reality and give it some consistency (see Figure 1).

The question that arises, however, is "Does reality that is independent of the observer exist?". Physicists class vis-à-vis this issue as "realists" and "empiricists". The first category includes Einstein who believed in the existence of a profound reality hiding behind phenomena. He compared the universe to a clock which can tell the time but in which we have no access to the mechanism. Hence his profession of faith (Einstein and Infeld,1938): "regularities observed in phenomena have their origin in a physical reality whose existence is independent of human observers". We can illustrate the second category by the following quote (Heisenberg 1962): "Reality is a reality perceived by man."

Thus, realism is an objective view of nature while empiricism is a subjective view. But we can ask the question: Is physics objective or subjective? Bohr replied to this question: "Of course it is objective because its statements are valid for anyone."

D'Espagnat (1994) actually distinguishes two types of realism: strong (or close) realism and low (or distant) realism.

- Near realism is a worldview which asserts that all elements of reality are assumed to be adequately described by concepts that are close and familiar to us (e.g. Newtonian mechanics)
- Distant realism is a worldview which asserts that the world is not describable in terms of familiar concepts but only through abstract mathematical representations (e.g. quantum mechanics and relativity).

It should be noted however that the fact that independent reality cannot be known does not mean it does not exist. One should make a difference between the principle that: "What I do not know does not exist" and the principle that: "What I do not know, I have an obligation not to talk about".

4. Logic of the included third and levels of reality.

The logic of contradiction introduced by Bohr in physics has led some authors to replace Aristotle's logic by a new logic. We know that Aristotle's logic (also known as a "the logic of the excluded third") is based on three axioms:

i) The axiom of identity: A is A.

ii) The axiom of non-contradiction: A is not non-A

iii) The axiom of the excluded third: there is no third term that would be both A and non-A.

According to this logic, a proposition A is either true or false. If it is true, then the opposite is false and vice versa. It is impossible for a proposition and it's opposite to be both true or both false. This logic is binary since it is based on two possible logical values: true or false (see Table 2). Lupasco (1951), reasoning, not about proposals, but rather about events, introduced the logic of the third included.

A given event, he said, can be either actuated or potentiated (which does not mean it disappears completely). As an event is actuated, its antagonist (or contrary) is potentiated and vice versa. This logic is dynamic, in the sense that, instead of reasoning about statements, it designs a dynamic of different possibilities. Thus, in addition to the configuration [e A, non-e P] (corresponding to e actuated and non-e- potentiated) and the configuration [e P, non-e A] (corresponding to e potentiated and non-e actuated), there exists a third state T (called included third) which represents an intermediate state between the two previous ones (see Table 3). Bararab (2002), applying this approach to quantum mechanics deduced that affirming that the electron or the photon are simultaneously particles and waves is not anymore contradictory according to this logic. Indeed, if the corpuscular aspect is actuated (in an experiment), then the wave aspect is potentiated and vice versa. Moreover, scientific observations and analyses have revealed that nature presented different aspects depending on the angle or scale or area in which it is studied. It has become clear, for example, that the microscopic world obeys laws that are different from those of the macroscopic world.

Table 2: The values of a proposition A and its opposite non-A in the logic of the excluded third

A	true	false
Non-A	false	true

Similarly, the living seems to obey a different logic from that of the inert since it needs to appeal to the notion of teleonomy (instead of mechanistic causality) and that it seems to defy the principle of growth of entropy stipulated by the second law of thermodynamics. And finally, psychic phenomena have proved irreducible to any physicalism. We should also mention the theory of scale relativity introduced in astrophysics by Nottale (1992). This theory, which states that the universe is structured differently according to the considered scale, is even perceived as a possible candidate among the attempts to unify the fundamental interactions. These considerations mean that it would be futile to reduce reality to a single level, and that it rather makes more sense to distinguish several levels of reality, eachwith its own "logic" and its own laws of causality.

Table 3: Possible values of an event in the logic of the included third

e	A	P	T
Non-e	P	A	T

We can say that the logic of the excluded third is a special case of the logic of the included third. The first applies to a given level of reality but becomes caduceus when changing to a new level. In Figure 2, the values of the logic of the included third are represented by a triangle where the states e and non-e are at the vertices of a base (which represents a level of reality) and the T state (representing the next higher level of reality) at the top vertice. In this perspective, e and non-e are contradictory (i.e. exclusive of each other) only if we stand at the level of reality where they are situated. It is therefore the projection of T on this level that generates contradiction. Taking into account the two levels of reality removes the contradiction.

The above considerations suggest that reality has not a single level but several levels. Two things that are taken for "contradictory" to a given level of reality can be reconciled if we move to a higher level. This view helps to overcome reductionism by taking into account the fact that the laws governing nature differ from one level of reality to another and that, in agreement with the theory of emergence, which considers that (Laughlin, 2005) "the major physical laws cannot be derived from more fundamental principles. "It also overcomes the logic of the excluded third (which is a static logic and whose elements are proposals) in favor of the logic of the included third (which is a dynamic logic and whose elements are events).

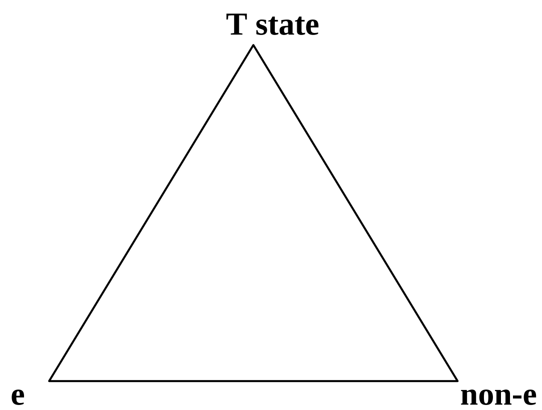

Figure 2: Logic of the included third and levels of reality

5. Is there a quantum reality?

The advent of quantum physics has been characterized from the outset by a controversy between realist physicists (Einstein, Schrödinger, de Broglie...) and empiricist physicists (Bohr, Heisenberg, Dirac...). In his model of the atom of hydrogen, Bohr (1963) was led to suppose the existence of quantized states and that the electron can jump from one state to another by discontinuous and non-causal jumps. This prompted him to say: "We are obliged to renounce giving a causal and spatiotemporal description of atomic phenomena". He systematized his ideas by stating the principle of complementarily according to which quantum reality cannot be exhausted by a single representation. According to him, dual representations, contradictory but complementary, are required. According to the Copenhagen School, reality is purely empirical. This is what claimed Pauli, Rosenfeld, and Weisskopf (1955): "It is now the indivisible whole formed by the system and the observation instruments that define a phenomenon". As a result, the particle does not have its own properties such as position, speed, spin, etc., but it is the process that gives it these properties.

5.1 EPR Paradox and Bell's theorem.

The contradictions of quantum mechanics are due to the fact that one requires that the particle has at all times well-defined properties. The realist authors (Planck, Einstein, Schrödinger...) tried to default the Copenhagen School. Thus, Schrödinger devised the thought experiment called "Schrödinger's Cat" to show the "absurdity" of the Copenhagen interpretation. For Einstein, quantum mechanics is incomplete in the sense that its reality is not exhaustive. He postulated the existence of "hidden parameters" which, if they are known, would restore determinism in microphysics. He conceived in 1935, with his collaborators the EPR thought experiment to support this view (Einstein, Podolsky and Rosen, 1935).

These authors begin by the EPR argument issuing criteria that must characterize any physical theory:

i) Each element of physical reality must have a counterpart in a complete theory.

ii) If the system is disturbed in any way and can accurately predict the value of a physical quantity, then there exists an element of reality corresponding to this physical quantity.

After the formulation of the EPR argument, they had to design an experiment that would work either in favor of quantum mechanics or in favor of the theory of hidden variables. Bell (1966) actually proposed in 1966 a theorem to arbitrate between the two theories. According to this theorem, the predictions of the theory of hidden variables coincide with those of quantum mechanics only for certain orientations of the measuring device (i.e. the device that measures the spin), but a significant difference between the two theories appears for further orientations. The question that arises is: what is the theory that best takes account for events and experiments? Is it quantum mechanics or the theory of hidden variables? The answer to this question was precisely the goal of Aspect's experiment.

5.2 Aspect’s experiment

Technology, when Einstein et al. had imagined the EPR thought experiment, did not allow carrying out the actual experiment. The same can be said about the time when Bell demonstrated his theorem. The experiment, which was indeed very difficult to achieve, was conducted successfully after many frustrating attempts. Clauser, Horne, Shimony, and Holt (1969) demonstrated the feasibility of the experiment and teams from the Harvard and Berkeley universities performed in 1972 experiments that gave conflicting results. Harvard University found that Bell's theorem was verified while UC Berkeley found that it was violated. The University of Houston made its own experiment which confirmed the results of Berkeley. The crucial experiments were carried out by the Aspect team of the Theoretical and Applied Optics Institute between 1980 and 1982. The experiment of 1982 was the one that came closest to the ideal conditions to test Bell's theorem. Aspect (1983) and his colleagues used a photon source of low intensity (100 photons per second), thus limiting the time of the experiment to 100 seconds. The source emitted correlated photons pairs whose wave function is written:

$$\Psi(1,2)=\frac{1}{\sqrt{2}}\left(\left|\uparrow\uparrow\right\rangle+\left|\rightarrow\rightarrow\right\rangle\right)$$

This expression represents an entangled state: the two photons have either vertical polarization or horizontal polarization with probability ½ for each configuration. The polarizers were placed at a distance of 12 meters from one another to avoid any mutual interference between them. A tilting device of the angle of polarization was also used. The polarizers used were two-channel, allowing the detection of vertically as well as horizontally polarized photons. The result of the experiment was that Bell's inequalities were violated. It was the proof that the predictions of quantum mechanics are in good agreement with experiments while those of local hidden variable theories were overturned. At the same time, the existence of a quantum non-locality was proven experimentally. Other experiments were carried out after those of the Aspect’s team. Thus, an experiment was conducted in Geneva in 1998 with detectors 30 km apart, using the Swiss telecommunications network through optical fibers and measuring time with an atomic clock. This experiment confirmed the results of the experiment of the Orsay team with greater precision.

6. Conclusion

The problem of reality is a fundamental one in quantum mechanics. Different interpretations of this physical theory raise the question of whether the wave function is a real physical wave or if it is just a mathematical tool that describes quantum states and predict the results of measurements. The issue of duality of matter and light as well as the phenomena of interference and entanglement reveal a "quantum reality" very different from the conventional reality. The question of whether quantum mechanics is a complete theory or if there are "hidden parameters" remains unsolved. The Aspect experiment showed that the predictions of quantum mechanics were confirmed in the circumstances of the EPR thought experiment and those of local hidden variable theories were overturned. This implies that the only hidden variable theories compatible with experiment are necessarily non-local. Quantum non-locality (or non-separability) is one of the most bizarre aspects of "quantum reality".

References

Aspect, A.(1983). *Trois tests expérimentaux des inégalités de Bell par mesure de corrélation de polarisation de photons*.DoctorateThesis. Paris-Sud University, Orsay.

Basarab, N. (2002). *Nous, la particule et le monde*. Monaco : Le Rocher, Coll. Transdisciplinarité, 2nd edition.

Bell, J.S. (1966). On the problem of hidden variables in Quantum Mechanics, *Rev. Mod. Phys., 38,* 447-452.

Bohr, N.(1963). **Atomic Physics and Human Knowledge**. New York: Interscience.

Charon, J.E.(1974).*Théorie unitaire*, Paris: Albin Michel

Cohen-Tannoudji, G. (1991). *Les Constantes universelles*. Paris: Hachette.

Clauser, J. F., Horne, M.A., Shimony, A. and Holt R.A. (1969). Proposed experiment to test local hidden-variable theories, *Phys. Rev. Lett. 23,* 880-884.

Guénon, R. (1976). *Mélanges,* Paris: Gallimard.

Einstein, A., Podolsky, B. and Rosen, N.(1935). Can Quantum-Mechanical description of physical reality be considered complete ? *Physical Review vol. 47,* 777-780.

Einstein, A., Infeld, L. (1938). *The Evolution of physics*. Cambridge: Ed. of Syndics of the Cambridge University Press.

Espagnat (d'), B. (1994). *Le réel voilé, analyse des concepts quantiques*. Paris: Fayard.

Heisenberg, W. (1962). *La nature dans la physique contemporaine*. Paris: Gallimard.

Kastler, A. (1976). **Cette étrange matière.** Paris: Stock.

Lecomte, P.G. (1997). *Quelle logique pour le vivant ?* Doctorate Thesis, ENV Alford.

Laughlin, R. (2005). **A different universe: reinventing physics from the bottom down**. New York: Basic Books Edition.

Lupasco, S. (1951). *Le principe d'antagonisme et la logique de l'énergie*. Paris: Hermann.

Noether, E. (1918). *Invariante Varlationsprobleme. Nachr. D.König. Gesellsch. D. Wiss. Zu Göttingen, Math-phys. Klasse : 1918,* 235-257.

Nottale, L. (1992). The theory of scale relativity. *Int. J. Mod. Phys. A7,* 4899-4936.

Pauli, W., Rosenfeld, L., and Weisskopf, V. (1955). *Niels Bohr and the development of physics: Essays Dedicated to Niels Bohr on the Occasion of His Seventieth Birthday*. New York: McGraw-Hill.

Schrödinger, E. (1964). *My View of the World*. Cambridge: The University Press.

THE AUTHORS

First author:
Mustapha Oldache was born on 10/29/1951 at Algiers. He obtained a Bachelor's Degree in Sciences in 1972 in Algiers (Algeria) , then a DES (Higher Studies Diploma) in Theoretical Physics at the University of Algiers (Algeria) in 1976, and finally a Master's Degree in Nuclear Engineering at CSTN (Centre of Nuclear Sciences and Technology) in Algiers in 1978. He began working as a Researcher at HCR (Haut Commissariat à la Recherche) in the period 1978-1988 and then joined the ENS-Kouba University in Algiers where he currently works as a Lecturer and as a Research Assistant. He also worked as an Associated Assistant at ENSTP (National School of Civil Engineering) in the period 1996-2009.
Institution: *Ecole Normale Supérieure-Kouba, Department of physics, Laboratory of Didactique of Sciences, B.P. 92 Vieux Kouba, Algiers, Algeria*
Phone: +231 21 28 79 81 Fax: +231 21 28 20 67 ; Email : musoldache@gmail.com

Second author:
Chams-eddine Khiari was born on 08/15/1954 in Algeria. He obtained an Engineering Degree in Electronics at the National Polytechnic School in Algiers (Algeria) in 1979, then a Master's Degree in Nuclear Engineering at The University of Michigan (USA) in 1982, and finally a PhD in the same field at the same university in 1986. He is currently a Professor at ENS-Kouba University, Physics Department, in Algiers (Algeria). He is the President of the Scientific Committee of the Physics Department since many years.
Institution: *Ecole Normale Supérieure-Kouba, Department of Physics, Laboratory of Didactique of Sciences, B.P. 92 Vieux Kouba, Algiers, Algeria*
Phone: +231 21 28 79 81 Fax: +231 21 28 20 67 ; Email : chamsydine@yahoo.fr

Third author:
Tayeb Belarbi was born on 10/29/1951 in Algiers. He obtained a Bachelor's Degree in Humanities in 1972 in Saudi Arabia and a Bachelor's Degree in Psychology and Education Science at the University of Algiers (Algeria) in1976. He then obtained a Master's Degree in Education Science at Cardiff University (U.K.) in 1979, and finally a PhD in Education Science at the same University in 1987. He is currently a Professor at the University of Algiers 2, Department of Psychology and Education Science in Algiers (Algeria). He occupied several administrative positions at this university and was a member of a lot of scientific committees.
Institution: University of Algiers 2, Department of Psychology and Science Education, *Algiers, Algeria.*
Phone: +231 (0)5 61 83 71 68 ; Email : *t_belarbi@yahoor.fr*

Acknowledgments

We would like to thank Pr A. Bentchikou for providing us with valuable insights into the epistemology of modern physics through our many fruitful discussions.