Evolution of the Time Concept in Theoretical Physics

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Abstract: In theoretical physics two concepts of time have been formulated: the absolute time of the Newtonian mechanics and the relative time of the relativity theory. At present the relative time dominates the theoretical approaches in physics. But there are quantum phenomena, as the collapse of the wave function, which cannot be explained by the relativity theory. The future unified theory of quantum fields must reconcile such contradictory phenomena.

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Time can be differently interpreted in almost any field of knowledge, however, in its objective essence it is a fundamental quantity in physics. Therefore we expect physicists to tell us what time is. Although a definite answer is not yet available, physics has been able to reveal some utterly unexpected properties of the temporal evolution of the phenomena in our amazing world. In this article I shall emphasize these incomplete accomplishments of physics and I shall discuss their contradictory nature which testifies that the final solution lays in an uncertain future.

We shall consider only the mature physical theories, acknowledged by the entire scientific community and experimentally verified. We shall not discuss eccentric ideas such as time travel, and we shall ignore even the scientific hypotheses not incorporated yet in a coherent theory and not verified experimentally, as, for example, the possible discrete structure of time and space at the Planck scale. We shall analyze the role played by time in the Newtonian mechanics, thermodynamics, relativity theory, non-relativistic quantum mechanics, and quantum field theory. We shall focus on the related properties of irreversibility and causality.

The first rigorous physical theory, which became a model for all the following scientific theories, was the Newtonian mechanics elaborated at the end of the 17th century.[1] In his equations Newton used the "absolute, true, and mathematical" time, which, according to his definition, "flows equally, without any relation to something external". As it follows from this quotation, the absolute time flows uniformly and nothing can disturb it. Besides, it is irreversible or, as Newton put it, "the order of the time parts is immutable".

Everyday experience shows that the entire reality is irreversible and all observable phenomena can evolve only in one and only one sense. Newtonian mechanical systems are only an idealization of real systems since they are reversible, that is, if at a

[1] Isaac Newton, *Principiile matematice ale filozofiei naturale* (Mathematical Principles of Natural Philosophy) (Bucharest: Ed. Academiei RPR, 1956).

given moment we reverse all the velocities of the mechanical system's components, they move along the previous trajectories but in reverse sense. This contradiction was removed by the second law of thermodynamics which states that macroscopic systems composed by a very large number of microscopic components have an irreversible evolution. As time goes on their entropy cannot but grow, their states becoming more and more disordered. At the same time a new contradiction arose between the reversible description of microscopic components' motion and the irreversibility of macroscopic systems formed by them. To elaborate on these problems and to propose solutions are not the subject of this article.

The concepts of time and space were revolutionized at the beginning of the 20th century when the special theory of relativity was formulated. The following brief discussion is taken from Einstein's exposition on the fundaments of special relativity.[1] He begins the analysis of time by defining simultaneity. Two events occurring at two points, A and B, are simultaneous for an observer placed at rest at the middle M of the segment AB if the light signals emitted from A and B when the events take place arrive at M at the same time. What happens if the observer moves with constant velocity towards A? Since the light velocity is finite, the signal emitted in A arrives at the observer moving towards it faster than the signal emitted in B which the observer moves away from. So, for the observer who approaches A, the event in A occurs before the event in B. On the other hand, if the observer moves towards B, he perceives the occurrence of the two events in reverse order. Hence in the special theory of relativity there are phenomena which do not have a well defined temporal order, independent of the observer. Such problems cannot occur in Newtonian mechanics where absolute time is common to all possible events, which therefore are perfectly ordered in time.

The possibility that the temporal order of events depend on the observer's velocity raises serious problems concerning causality. If one of the two events previously considered is the cause of the other, this would mean that for some observers the effect would precede the cause. Such nonsensical conclusions do not occur in the relativity theory because the link between cause and effect is made by means of a material interaction. Let us assume that the radio signal emitted from a point E is received by an antenna at point F where an electrical circuit turns on an engine. In any reference system the radio signal has a finite velocity equal at the most to light velocity, so that the two events (the emission of the radio wave and the turning on of the engine) cannot be simultaneous. Furthermore, it is proved that the succession in time of such events is the same irrespective of the observer's velocity. Hence in relativity theory the irreversibility of time has been replaced by the causality principle: for any observer in uniform translatory motion the cause always precedes the effect caused by it.

In his theory Einstein abandoned the absolute nature of time and space. For him any physical notion exists only if a method to measure it has been defined. For example, regarding the simultaneity he states that: "one and only one condition should be imposed on the simultaneity definition, namely, it should supply, in any real situation, an empirical procedure to decide if the defined notion corresponds or not to the reality". Newton himself defined, besides the absolute time, the "relative, apparent, and common time" as "the sensible and external measure of any duration determined through motion, which is

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[1] Albert Einstein, *Teoria relativității pe înțelesul tuturor* (On the Special and General Theory of Relativity. A Popular Account), (Bucharest: Humanitas, 2008).

usually used instead of the true time". While Newton chose to build his theory by means of the absolute time, Einstein opted for the opposite. Relating time to the physical phenomena used to measure it, Einstein made time dependent on space (special theory of relativity) and on the quantity of matter and energy (general theory of relativity).

The next critical moment in the evolution of the time concept occured when quantum mechanics was formulated in the third decade of the last century. The absolute Newtonian time was used so that the resulting theory did not obey the principles of the relativity theory. Not long after the Second World War the relativist quantum theory, called "quantum field theory" (QFT) emerged. This theory explains all experimental observations concerning the elementary particles.[1] Taking into account the outstanding achievements of the QFT, the predominant opinion in the scientific community is that the QFT is correct and complete. The only unsolved problem is the formulation of the unitary field theory which should include the gravitational field. In spite of all the hard work within the last sixty years the problem is not yet solved.

Actually, the situation with QFT is not at all as clear as it appears at first sight and it has received a lot of criticism in the course of time. For example the EPR (Einstein-Podolsky-Rosen) paradox[2] challenges the role of time in the QFT. Einstein formulated this paradox in 1935 within non-relativistic quantum mechanics, before the appearance of the QFT. Only in 1982 it was proven experimentally[3] that there exists phenomena of the type described by the EPR paradox contradicting the causality principle previously discussed. Subsequent experiments performed under different conditions confirmed the correctness of the first experiment.

One of the manifestation forms of the EPR paradox is the following. Let us consider that two electrons are simultaneously generated at the point M and then they are moved away in opposite directions. When one of the two electrons arrives at the point A, a measurement is made, for example of its spin (a quantum quantity equivalent to the angular speed of a rigid body). Simultaneously with the measurement at the point A, the state of the second electron, which in the meantime has arrived at point B, is modified. Hence between the two electrons an instantaneous interaction at distance occurs. Such phenomena contradict the relativist principle that light velocity is finite and no physical phenomena can propagate with a greater velocity.

In non-relativistic quantum mechanics the EPR paradox is explained by the so-called collapse of the wave function. The wave function is the solution of the Schrödinger equation and it describes the time-space evolution of a quantum system and has no direct experimental meaning. All experimentally measurable physical quantities are computed by means of the wave function since it supplies the most complete description of the quantum system. The state of the two electrons before the measurement at A is given by a compound wave function since the two particles have no proper individuality and they form a single indivisible system. After the measurement on a single electron the wave function instantaneously changes and the state of the two electrons is given by a

[1] It is expected that the experiments with LHC at CERN result in new observations which will guide theoretical studies, but at the moment of writing this article the particle accelerator was not fully operational.

[2] Albert Einstein, B. Podolsky, N. Rosen, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?", *Physical Review* 47 (1935): 777–780.

[3] A. Aspect, J. Dalibard, G. Roger, "Experimental Test of Bell's Inequalities Using Time-Varying Analyzers", *Physical Review Letters* 49 (1982): 1804–1807.

superposition of two wave functions describing two isolated quantum particles. The collapse of the wave function is this sudden change that is not described by the usual evolution equation, the Schrödinger equation. This phenomenon is not localized in the neighbourhood of the measured electron, but it occurs over the entire space implying an instantaneous transmission of the action generated by the measurement. In non-relativist quantum mechanics such phenomena are permitted since the time is the absolute Newtonian time.

Surprisingly, theoreticians have ignored or have tried to diminish the importance of the EPR paradox's experimental verification for the QFT. None of the basic treatises on the QFT discusses the EPR paradox. As examples we mention here the treatises written by two of the founders of the QFT, Bogoliubov[1] and Weinberg[2]. When the EPR paradox is analyzed from a QFT point of view, the fact is emphasized that the instantaneous interaction at distance takes place only for the collapse of the wave function. Most of the physical phenomena obey the principles of relativity theory and then the EPR paradox would be only a collateral phenomenon, which would not affect the main part of the theory. Such an attitude which does not admit that the existing theory fails to explain all the observed phenomena is inappropriate. This might be one of the reasons why we have a crisis in theoretical physics.[3]

The present situation in theoretical physics is rather upsetting. On the one hand we have phenomena such as those implied in the EPR paradox which request instantaneous interactions and correspond to the absolute time of Newtonian mechanics. On the other hand most physical phenomena evolve according to Einstein's relative time. Hence the theoretical interpretations of reality contain contradictory explanations which exclude one another. Until now such situations have led to the emergence of new revolutionary theories. It is to be seen how the next unified theory will manage to include these conflicting forms of time.

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[1] N. N. Bogoliubov et. al., *General Principles of Quantum Field Theory* (Dordrecht:Kluwer, 1990).

[2] Steven Weinberg, *The Quantum Theory of Fields*, Vol. I: *Foundations*, (Cambridge: Cambridge University Press, 1995).

[3] Lee Smolin, *The Trouble with Physics. The Rise of String Theory, the Fall of a Science, and What Comes Next* (Boston: Mariner Books, 2007).