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CAN TIME BE A DISCRETE PARAMETER?

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1. POSITION OF THE TIME PARAMETER IN PHYSICS

As it is well known, the time parameter has a very special position among other parameters in physics. Taken as a coordinate, time is the one which cannot be changed voluntarily. Nevertheless, especially with the development of the theory of relativity, time began to take on a meaning which is quasi-similar to that ascribed usually to spatial coordinates: any distance in a four-dimensional space should be expressed by its four components, among which the time interval – multiplied by

$$ic = \sqrt{-1}c \tag{1}$$

– plays the same role as is done by the intervals of the Cartesian coordinates of position. On the other hand – in the framework of the non-relativistic quantum theory – time recovered, in some way, its very special position. Here I have in mind the Heisenberg's uncertainty principle[1], the first part of which connects the intervals of spatial coordinates and the corresponding momenta of a particle expressed in Cartesian coordinates with Planck's constant h. At this point the time interval Δt connects with Planck's constant a completely different quantity than momentum, which is the energy interval ΔE. This is expressed by the following formula:

$$\Delta t\,\Delta E \sim h \tag{2}$$

We can multiply Δt by the light velocity c and simultaneously divide ΔE by c leaving the expression (2) unchanged. Than $c\Delta t$ aquires the

[1] L. I. Schiff, *Quantum Mechanics*, 3rd ed., Mc Graw Hill, New York 1968.

dimension of the space coordinate, and $\Delta E/c$ the dimension of momentum, nevertheless $\Delta E/c$ – a directionless quantity – cannot be considered as a momentum interval in the sense accepted usually for physical phenomena.
If we have a stationary quantum-mechanical state of an atom, then – by definition –

$$\Delta E = 0, \tag{3}$$

so – from (2) – it should be

$$\Delta t \rightarrow \infty. \tag{4}$$

We obtain that the absence of the energy change of the system implies its unlimited duration in a given state, unless an external pertubation will cause $\Delta E \neq 0$; this non-zero energy change will put – according to (2) – an end to the infinite Δt.

2. TIME AS A SUBJECTIVE PARAMETER

Time notion in physics is based evidently on the experience of the everyday life: time can be defined as a parameter that enables two otherwise identical events that occur at the same point in space to be distinguished[2]. Another – more formal – definition can be that time is an independent variable entering the equations of motion of mechanics[3]. In either of these definitions time is something independent of the physical properties of the objects considered. The first limitation of this independence was introduced by the special theory of relativity: the square of an interval of the time variable multiplied by $(ic)^2$ and added to the sum of squares of intervals of the three position variables should remain constant for any time-space reference system moving uniformly with respect to some original system. It is well-known that the above limitation had profound consequences on the mechanics of the moving bodies[4].

Another property of the time notion taken formerly for granted was the idea of an infinite extension of the time parameter. More precisely, it was assumed that time extends from an infinite past, usually labeled as

[2] *A Consise Dictionary of Physics*, Oxford University Press, Oxford 1990.
[3] A. Berliner, K. Scheel (eds.), *Physikalisches Handwörterbuch*, Springer-Verlag, Berlin 1932.
[4] H. Goldstein, *Classical Mechanics*, Addison-Wesley, Reading (Massachusetts, USA), 7th ed. 1965.

$$t = -\infty, \tag{5}$$

to an infinite future labeled by

$$t = \infty. \tag{6}$$

Here a well-known counter-argument – based on the presence of a mass parameter – was provided by the theory of general relativity which limited the time-space continuum (a four dimensional semi-riemannian manifold with Lorentzian signature) to a finite multi-dimensional object.

A very simple argument for a finite extension of the time parameter in a physical system can by given if this system is periodic. For an observer connected with a perfectly periodic system the infinite extension of a time parameter cannot exist. The reason for this is the very fact that all measurements in the system repeat precisely after a time interval – called the period of the system. These repetitions cannot be detected by an observer connected with the system unless he can count the periods, but such counting ability would be against our assumption of the full system's periodicity. In effect, the appropriate time scale for a periodic system is topologically a circle[5] and the length of the time scale which can be established for a periodic system cannot be larger than the length of the system's time period. In fact, in cases when the measuring ability of an observer is smaller than the ability which allows him to measure all parameters of the system, the time scale for the observer can be shorter than the time period of the system. Examples of such systems, and observers connected with them, are presented elsewhere[5]. Here I would like to point only that for periodic system (i) the time scale is essentially of a finite length; (ii) the detected length of the time scale depends both on the physical properties of the system and the measuring ability of the observer.

3. ATOM AS A PERIODIC SYSTEM

According to Thirring[6], an almost periodic time evolution is a general property of small systems. Such systems can be atoms. In the old non-relativistic quantum theory which was applied, for example, to the hydrogen-like atoms, these atoms were considered as perfectly periodic systems in which an electron moved about the

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[5] S. Olszewski, *Time Topology for Some Classical and Quantum Non-Relativistic Systems*, Studia Philos. Christ. 28 (1992), 119-135.

[6] W. Thirring, *Lehrbuch der Mathematischen Physik*, Band 4: *Quantenmechanik grosser Systeme*, Springer Verlag, Wien 1980.

nucleus, repeating infinitely its position and momentum after some definite period of time. In quantum mechanics, the time notion for any stationary state of an atomic system loses its sense because of formulae (3) and (4): there is no measurable change in the system in its stationary state[1]. Nevertheless, the circular character of the time scale seems to be supported by quantum mechanics: the application of a collision theory to an atomic system along a scale of time leads to a correct expression for the quantum-mechanical (Rayleigh-Schrödinger) perturbation series for energy on condition that the time scale – supplemented by some elimination principle for the case of equal times – used in the calculations is circular[7]. In this way the well-known postulate of the old quantum theory that all atomic systems can be considered as periodic ones[8,9], found its co-partner in the circular topology of the time scale applied in the perturbation theory.

4. ENERGY QUANTA AND TIME QUANTA: AN EXAMPLE

In Sec. 2, we pointed out that the time scale, in general, is essentially dependent on the properties of a given physical system, and for the periodic systems its length does not exceed the time period of such a system. The close connection between the length of the time scale (the time period) and the system properties – together with the fact that the time interval Δt and the energy interval ΔE enter Heisenberg's uncertainty relation (2) on equal footing – imply that the time interval characteristic for a given system can be considered similarly to the portions of energy represented by the energy quanta. For example, in a hydrogen atom we have well-defined energy levels and – following the old quantum theory – well-defined time periods of the electron motion corresponding to these levels[9]. The energy levels are well-known as leading to energy quanta in the course of transitions between these levels, so we may try to represent the time periods corresponding to these levels, and their differences, as proportional to some time quanta. The check of validity of the time periods considered as proportional to the time quanta – similar to the energy quanta – can be done via an examination of the process of transitions between the level position occupied by an electron in the atomic system[10]. If E_m and E_n are two different energies in the levels m and n, and T_m and T_n are two different time periods of the same

[7] S. Olszewski, *Time Scale and its Application in Perturbation Theory*, Zeitschrift für Naturforschung, 46a (1991), 313-320.
[8] S. I. Tomonaga, *Quantum Mechanics*, Vol. 1, North-Holland, Amsterdam 1962.
[9] A. Sommerfeld, *Atombau und Spektrallinien*, Vol. 1, Vieweg, Braunschweig 1931.

levels, then the electron transition from m to n ($E_m > E_n$) is connected with the energy change (emission) of energy quantum $E_m - E_n$. A similar change (emission) of the time quantum, proportional to $T_m - T_n$, can be expected in the course of the same electron transition from level m to level n; here also $T_m > T_n$. Then, the intesity of the energy decrease (emission) $E_m - E_n$ within the time interval proportional to $T_m - T_n$ is given by the ratio[10]

$$\frac{E_m - E_n}{\alpha (T_m - T_n)} \tag{7}$$

where α is an unknown constant. Expression (7) could be compared satisfactorily with the emission intensity given by quantum mechanics, the data of which represent a very good approximation to the data observed in experiments[11].

5. DISCRETE CHARACTER OF THE TIME PARAMETER

The results given in Sec. 4, show a rather different than usual behaviour of the time parameter. The important point is that in the emission process represented in Sec. 4, time as a discontinous entity. Classically, in the calculation of the intensity of the energy emission, we usually assume a certain interval of time Δt within which an amount of energy ΔE is delivered continuously by a body (an atom). The quantum theory changed profoundly our view on the character of ΔE by stating that in any process this ΔE can be only a sum of definite discrete quantities called energy quanta; there is no possibility for a system to assume the intermediate stationary states between the levels defined by the energy quanta. A similar supposition may be made for time; namely, we assume that the differences between discrete time parameters (time periods) which characterize the energy levels can behave like some time quanta, similar to the energy quanta emitted in the process. This assumption stems from the fact that the spectrum of the values of the time parameter charcateristic for a given system cannot be continuous but is discrete: any state has its „own" time represented by some time period, and the change of any state means a sudden (discontinuous) change of the time period characteristic for it.

[10] S. Olszewski, T. Kwiatkowski, *Semi-classical Approach to Intensity Spectrum of Atomic Hydrogen*, Zeitschrift für Physik D – Atoms, Molecules and Clusters 21 (1991), 201-204.

[11] H. A. Bethe, E. E. Salpeter in: *Encyclopedia of Physics*, ed. by S. Flügge, Vol. 35 (Atoms I), Springer Verlag, Berlin 1957.

The discontinuity of the time parameter has been raised recently by Le Poidevin[12,13] in the context of his criticism of the temporal aspect of the universe model proposed by Hawking[14]; a similar problem of the disconnectedness of time was discussed by Earman[15]. Le Poidevin's idea was that if we assume a fully closed, or circular, scale of time, then the time scale has no direction: „the closed time hypothesis must define directedness in terms of something more fundamental..."[12]. Le Poidevin's proposal is that we should allow for a period of empty time on the time scale if we need to allow a direction in the scale of closed time[12]. Therefore, the discontinuity of time, or an empty time, is a consequence of both the circular time scale and the time directedness.

6. SUMMARY

We stressed in this paper that time can be considered as a subjective parameter, the characteristic of which depends both on the physical properties of a given system and the observing ability of an observer. For a perfectly periodic system the time scale consistent with the system is topologically a circle, having a finite circumference, the length of which does not exceed the system's period.

If an atom is considered a perfectly periodic system, then the discrete time parameters can be ascribed to the individual atomic states having different energies. The discrete character of time parameters is similar to the discrete character of energies of the atomic states. We assumed that the differences between the time parameters characteristic for the atomic states are proportional to some time quanta which can be used in the calculation of the energy intensity dispensed by an atom in the course of an emission process. A comparison with the data checked by experiment supports this view[10].

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[12] R. Le Poidevin, *Creation in a Closed Universe or, Have Physicists Disproved the Existence of God?* Rel. Stud. 27 (1991), 39-48.

[13] R. Weingard, *Space-Time and Direction of Time*, Bantam Press, New York 1988.

[14] S. W. Hawking, *A Brief History of Time*, Bantam Press, New York 1988.

[15] J. Earman, *How to Talk About the Topology of Time*, Noûs 11 (1977), 211-232.