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Adirectional Temporal Zones in Quantum Physics and Brain Physiology

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Change in space and time of an observed object creates a logistical problem for our brain because the temporal central availability is undefined. As solution we claim the existence of elementary integration units (EIUs) which are defined as zones of simultaneity; i.e., within such an EIU the before–after relationship has to be abandoned. Experimental evidence points to a duration of the EIUs of the order of 30 msec. In considering a delayed choice experiment in physics, we propose that a similar renunciation of the before–after relation leads to a deeper understanding of the individuality of processes in quantum theory. In short, "time" may be more momentous than its usual appearance as a real-valued parameter demonstrates.

1. INTRODUCTION

In a scientific analysis we are used to considering objects or systems which are located in space and which keep their identity in time. We then classify their properties or define their states and try to make predictions about the development of the states. Predictions of states are predictions in time. The ability to make successful predictions implies the presence of a law, i.e., a causal relationship between causes and effects. Thus, space-time description and causality go together. But this classical concept has to be questioned by quantum theory and a closer inspection of the mechanisms of our brain.

In physics, quantum theory gives probability predictions for the outcome of measurements, but space-time descriptions of the processes under

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consideration may lead to contradictions. We want to point out that in brain physiology analogous irregularities may occur. The change in space and time of an object with respect to an observer and the different time course of transduction of the stimuli for different sensory channels like vision and audition create a logistical problem for the brain because the temporal availability of information from the different channels is undefined (Pöppel *et al.*, 1990*b*). How can an observer in such a situation refer to an object as *one* object or *one* cause for perceptual representation?

Why do we discuss the inconsistencies caused by space-time descriptions of quantum systems and the question of temporal central availability of stimuli in the brain together? We want to suggest that the indicated difficulties in both areas point to fundamental problems with one of the most basic concepts in science, the *concept of time*. The question we would like to ask is whether the problems in these two domains of scientific endeavor are of equivalent nature, which might deepen our understanding of time.

The concept of "system," which implies stability in time, the concept of "state," which indicates a collection of properties of a system at a given point in time, and the notion of "time" itself are entangled with each other in a way which is by no means clear. We think that spelling out some similarities between physical and psychological systems may lead to a better understanding of the nature of time or at least our concept of time. In what follows we describe a temporal problem of brain activity in some more detail and propose as solution for this problem the creation of elementary integration units, i.e., zones of *simultaneity* for the entire brain. Then we consider a delayed choice experiment in quantum theory and discuss the concept of "individuality of processes." Finally, some questions are raised resulting from this interdisciplinary discussion.

2. ATEMPORAL BRAIN STATES

It is sometimes useful to stress the obvious; we would like to point to one behavioral aspect of living organisms, namely that they move around. Take a human who not only spends his time in a sedentary position at his desk but is occasionally ambulatory. In order to go somewhere he can go only left *or* right, and not left *and* right. The obvious fact is that we move as a unit and not in parts; and a choice, sometimes voluntary, sometimes involuntary results in a movement in only one direction. Why mention this? Because this leads to a logistical problem of sensory information processing of such an organism. In order to move around by responding to stimuli appearing somewhere in the environment, the central information processor of the organism (the brain) has to integrate information from different sensory channels. Most organisms are equipped with a number of different senses; take, for instance, the visual and auditory system. The motor program initiated by the brain of an organism has to use the sensory information of the different channels by monitoring them continuously.

In order to simplify the argument, we will consider only these two channels, i.e., vision and audition. The necessity to keep track of information in the two systems results in a practical problem that can be characterized in the following way. If stimuli are emitted in the two sensory domains, their *temporal central availability* (TCA) is undefined (Pöppel *et al.*, 1990*b*). This is the case because the transduction processes for vision and audition are different in principle. Whereas transduction in the auditory modality is less than 1 msec, this process lasts considerably longer in the visual modality, and is (in the latter case) systematically dependent on light intensity. If a moving object characterized both optically and acoustically has to be monitored in order to initiate a movement toward or away from it, TCA is both a function of physical distance, as the speed of the sound has to be taken into account, and a function of optical contrast. A close object has a rather early TCA in the auditory domain compared to the TCA in the visual domain.

Using simple reaction time measurements, the temporal interval for the TCAs between the two channels for high-intensity stimuli has been estimated to be of the order of 30 msec. This interval corresponds to roughly 10-m sound travel time, i.e., at approximately 10-m distance TCA is identical for the visual and auditory channels. Measurements under ecological conditions indicate that a two-log-unit difference in light intensity may correspond to approximately 20-msec difference in TCA. This means that an object with parts of higher or lower reflectance has to be integrated in the brain also in the time and not only in the space domain in order to be perceived as one object, as the different parts have different TCAs.

These observations lead to the conclusion that the different time delays result in temporal uncertainty as to the arrival time of the stimuli. A monitoring system that collects information from different sensory channels in order to allow the collected information to be used for a command to launch an appropriate reaction has to overcome this temporal uncertainty. There are certainly several ways to deal with this logistical problem in a satisfying way; the question is what the brain most likely does.

It is proposed that the brain creates and is characterized by *elementary integration units* (EIU) which define adirectional temporal zones for the entire brain. Such zones would be characterized by a particular feature, i.e., cotemporality (or simultaneity) of stimuli from the different sensory channels (Pöppel *et al.*, 1990*b*). Technically, such EIUs can be created by neuronal oscillations which have been demonstrated or suggested experimentally (Galambos *et al.*, 1981; Gray *et al.*, 1989; Pöppel, 1970). A number of experiments using different paradigms have shown that such EIUs are of the order of 30 msec duration. Such data come from studies on single nerve cells in the brain, from neuronal populations, or from behavioral studies using psychophysical techniques (Pöppel, 1978). In one such paradigm on the temporal order threshold (Hirsh and Sherrick, 1961) it has been shown that the before–after relationship for different stimuli is not defined in temporal intervals of approximately 30 msec and these thresholds are the same in visual, auditory, or tactile modality.

3. UNDEFINED PHYSICAL STATES

Common sense about reality suggests that there exist well-defined objects which can be localized in space and time. This implicit notion on reality worked well for classical mechanics, but it leads to problems in quantum mechanics. Let us consider a split-beam experiment with delayed-choice (Wheeler, 1980) (Figure 1). An electromagnetic wave (a photon) comes in at A and is split by the half-silvered mirror M into beams B_1 and B_2 of equal intensity. The two beams are then reflected by mirror M' to a crossing point C. Now we have a choice. Either we locate two counters P_1 and P_2 past the crossing point (Figure 2) telling us by which route an arriving photon has come; or we insert a half-silvered mirror M at the crossing point (Figure 3), which creates destructive interference of B_1 and B_2 on one side (zero beam) and constructive interference on the other side (beam D, intensity as original beam). Every photon that enters the whole apparatus is registered then in counter P_1.

In the naive picture of reality we use in every-day life we ascribe the photon a definite space-time behavior. We would say: In arrangement I we can determine by which route the photon came; in arrangement II we measure the photon traveling both ways.

But it is our choice to put in the mirror M at C or not and we can delay the choice until the photon has already passed point A.

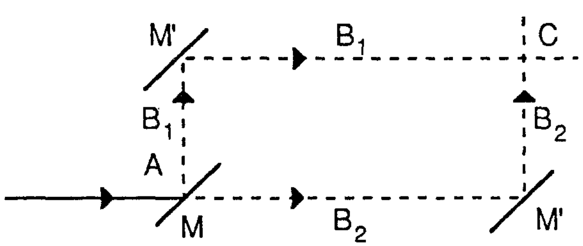

Fig. 1

(I)

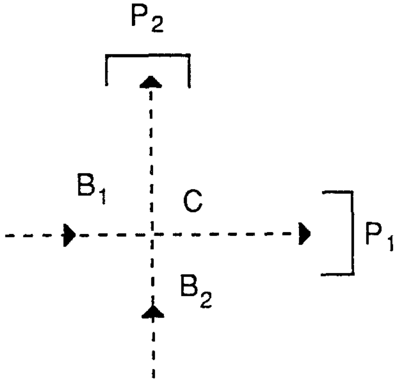

Fig. 2

If we stick to the usual space-time description, we have to conclude that present choice influences past dynamics, which contradicts the concept of causality. But if we advocate causality—as is done with the quantum theoretical formalism—we are not able to give a continuous space-time description.

Consider again Figure 1: The photon enters the measuring apparatus at point A. Quantum theoretically, its state is then given by the sum of the states $|B_1\rangle$ and $|B_2\rangle$ multiplied by some complex numbers. This does *not* imply that the photon travels both ways; it only implies that it is in a superposition of the two states, being a superposition of possibilities, not of facts. But being registered with a measuring device (I or II), the system collapses from its superposition of possibilities into one definite factual state influenced by the mode of measurement we choose. The measurement defines the individual process considered (Bohr, 1935). We have no disturbance of

(II)

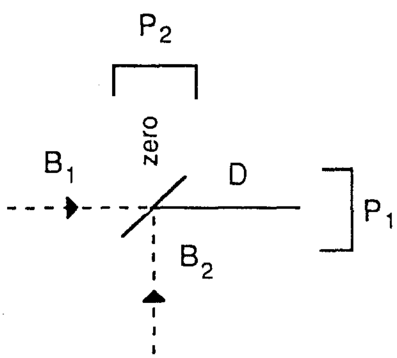

Fig. 3

causality between beginning and end of the measurement process, but we pay the price that we are no longer allowed to visualize a definite space-time behavior of the photon.

Therefore, we are confronted with the confusing situation that the idea of space-time description and the idea of causality cannot be fulfilled simultaneously. One way out of this confusion was suggested already by Niels Bohr with his concept of complementarity (Bohr, 1958). Space-time description and causality are complementary; they are two aspects of the description of physical phenomena, the combination of which characterizes classical physics.

In the considered experiment, we can choose our mode of measurement before or after the photon has passed point A of the measuring device. But the direction in time we, the experimenters, are aware of is not reflected within the individual process. Inside the individual process there is no sense of a direction of time. The renunciation of continuous space-time monitoring leads to a causal development of possibilities which lasts until the act of measurement turns possibilities into facts in an irreversible manner.

Recently there has been a debate concerning the description of a quantum mechanical system *within* the time interval between two measurement events (Aharonov *et al.*, 1964; Aharonov and Albert, 1980; Albert *et al.*, 1985; Bub and Brown, 1986; Sharp and Shanks, 1989). It appears that in the interval between two measurements, quantum mechanical systems are contextual, i.e., dependent on the "context" of the measurement. These *gedanken*-experiments confirm our thesis that "within" an individual process the before–after relation should be abandoned.

4. CONCLUDING REMARKS

In a discussion of possibly related problems in physics and physiology we try to show that "time" may be more momentous than its usual appearance as a real-valued parameter demonstrates. The basic building blocks in the two areas of discourse are individual (i.e., indivisible) processes which lack internal time, i.e., the before–after relation. We are aware of the fact that talking about "processes" seems to presuppose "time," but we want to postpone a discussion of this type of nontrivial circularity.

At a first glance there seems to be an important difference between physical and physiological individual processes with respect to our considerations. In physics, we describe the behavior of objects as seen by an observer. The observer sets up the measuring device and its registration projects the quantum mechanical system from its superposition of states into a definite state. But our brain—controlling the functioning of a living organism—does not wait until someone forces it into a definite state. The brain, in order to deal with the sensory information in an autonomous way, defines its own elementary integration units, i.e., its individual processes. In quantum theory, considered as universal quantum theory which has to be applied to the measuring device and the observer itself, a similar kind of self-referentiality would be postponed to the universe as a whole.

The nature of this difference and the striking conceptual similarities between the two areas suggest further investigations. From the discussion on brain physiology it has become apparent that "time" in our experience is created and that this creation is dependent on brain mechanisms (Pöppel, 1988). The way time is created may at first glance appear strange, i.e., by introducing adirectional temporal zones as elementary integration units, but only by doing this can the world around us be causally structured and understood. This time- and structure-creating process and the observed non-localized interactions occurring in the network of neurons lead us to the supposition that the functioning of the brain cannot be understood using classical concepts and that abstract brain theory has to be based on abstract quantum theory. Our brain is not a static entity and we do not live in a static world. The central point of brain dynamics as described here is the continual generation of its own "*Gestalt*;" the dynamics of the world is the irreversible transfer of quantum theoretical possibilities into classically describable facts. This "measurement problem," i.e., the collapse of a superposition of possibilities into a factual state, is not yet understood. A recent proposal (Haag, 1990) to introduce the transmutation of possibilities into facts as a new postulate into physics seems unsatisfying to us. Instead, we claim that the appearance of time as real-valued parameter is only one aspect and that the question whether there is also a "time-creative process" on the level of the quantum theoretical description has become unavoidable.

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