Time: Physical and Biological Aspects

Insofar as science aims at reconstructing the laws of nature, which describe the temporal development of its physical constituents and allow for predicting future events out of data derived from past events, time is a fundamental and crucial notion of empirical sciences. Science, however, does not deal with time as such, but with changes and events <u>in</u> time. Consequently, what really matters in science "is not how we <u>define</u> time, but how we measure it" (Richard Feynman, <u>The Feynman Lectures on Physics</u>, Vol. 1, p.5/1). Because time constitutes the realm of scientific investigation as such, it is not a scientific object like moving bodies or electrical fields. Its nature and character have to be derived from the interpretation of the basic structure of science and its method itself. And because time does not refer to external objects of investigation, but to the presupposed internal order of physical phenomena, it is closely related to our experience and perception of time, which is the sequential, non-spatial order of events and is structured by the relation of cause and effect. Unlike space, time as this sequential order shows a fundamental asymmetry between the past (fixed in documents, which can be investigated) and the future (still to come and not totally fixed, it can only be predicted). We can remember the past but not the future - we can alter the future, but not the past. Arthur S. Eddington (1882-1944) was the first to speak of the 'arrow of time', which points from the past to the future, to symbolize this fundamental asymmetry.
By this the crucial question of the interpretation of time in physics and biology is posed, whether this asymmetry is due to physical laws or just a subjective illusion due to our experience of time. The laws of classical as well as relativistic physics, but also the basic equations of quantum physics are time reversal invariant and provide no scientific ground for an arrow of time. On the other hand an irreversible directedness of time turns up in empirical sciences related to different phenomena: (1) according to the second law of thermodynamics, disorder (entropy) increases in a closed system from past to future; (2) the measurement of quantum events constitutes an irreversible difference between past and future; (3) biological systems and their evolution constitute a historical development from past to future; (4) the universe is expanding in time. Since time and irreversibility seem to have different meaning in different physical theories, and because the notions of causality involved are a matter of dispute as well, a comprehensive and commonly accepted interpretation of time in natural sciences is neither at hand nor in sight. In the following passages, therefore, we can only refer to some aspects of an ongoing discussion.

1. The Newtonian Time of Classical Physics

In his <u>Mathematical Principles of Natural Philosophy</u> Isaac Newton (1642-1727) distinguishes between <u>absolute</u> and <u>relative</u> time: "Absolute, true, and mathematical time, ... , flows equably without relation to anything external,

and by another name is called duration: relative, apparent, and common time, is some sensible and external (whether accurate or unequable) measure of duration by the means of motion, which is commonly used instead of true time; such as an hour, a day, a month, a year"(p.6). The notion of absolute time is crucial for Newtonian physics, because its first law of motion implies, that a body, on which no forces act, moves uniformly in a straight line at constant speed or is at rest. Only against the background of absolute time and space, rest and equable translation as free from external influence stand out against those deformations of motion, which indicate external forces. Thus absolute time in Newtonian physics is an a priori presupposition and essential for the frame of reference, against which all forces are determined. Newton himself considered, that in reality there might exist no absolutely equable form of motion representing this absolute time: it might not be the time of a particular clock. But still the assumed flowing of absolute time should not be liable to any change.
The laws of classical mechanics, which describe the motions of massive bodies, however, do not distinguish a direction of absolute time: no feature of the mechanical world would change, if time were reversed. Because the basic differential equations of classical mechanics are time reversal invariant, the future development of any mechanical system is in principle derivable from its past state, and vice versa. Thus development from past to future and from future to past are physically equivalent.

2. The Arrow of Time in Thermodynamics

But what we experience in reality are often processes, which appear to be irreversibly 'directed', like the cooling of hot water or the erosion of a rock. Especially inanimate natural systems show a tendency to spontaneously evolve to equilibrium of order, energy, or temperature, where these macroscopic parameters remain approximately stable, and they never leave this state, provided that no external intervention takes place. The physics to describe such processes is thermodynamics. Elaborated in the mid-nineteenth century, classical thermodynamics is based on two laws, the second of which expresses a temporally asymmetric behavior of all isolated (adiabatic) systems, with the universe as the biggest of them, to approach equilibrium in due course of time - the universe thus facing 'heat death', the equilibrium state, in which no energy differences remain and all physical processes come to an end, as its final fate. In order to express this fundamental law, Rudolf Clausius (1822-1888) coined the term 'entropy' (from Greek <u>entropē</u>, turning towards) as a measure of dispersed and irretrievable energy, that becomes unavailable for producing work, and he stated, that the entropy of the universe strives towards a maximum. Because entropy is at a maximum when the molecules of a system are at the same energy level, entropy can be understood as a measure of disorder. Thus the second law of thermodynamics implies the increase of disorder in due course of time, ruling out all re-

verse processes, that could create order spontaneously within a closed system.
When James Maxwell (1831-1879) and others developed the kinetic theory of heat and gases, Ludwig Boltzmann (1844-1906) tried to reduce thermodynamics to mechanical laws and interpret the second law as only statistical: systems generally develop towards states of higher entropy because they are more probable than others. But the discussion about the statistical interpretation of thermodynamics revealed, that the time reversal invariance of the mechanical laws cannot model the irreversible phenomena of macroscopic systems striving towards equilibrium. In the light of classical mechanism the irreversible direction of time from past to future, the arrow of time as indicated by the second law of thermodynamics, seems to rest on no physical ground.

3. Time in Special and General Theory of Relativity

The direction of time from past to future seemed to become even more illusionary, when Albert Einstein's (1879-1955) theory of relativity succeeded in overcoming the Newtonian notion of absolute time. In his 1905 special theory of relativity he stated that the time interval (and the distance) between two events depends on the observer's velocity relative to the events, while the velocity cannot exceed the speed of light.
In Einstein's theory space and time together constitute the four-dimensional spacetime, while each reference frame of an observer divides spacetime differently into a temporal and a spatial component relative to its state of velocity. There is no simultaneity of events and absolute duration of time for every observer, as well as no absolute spatial distance. Still there is an objective causal connection between events, because one event cannot interact with another instantaneously, but only mediated by forces, whose propagation speed is final and equals or is less than the speed of light. Thus temporal as well as spatial intervals between causally related events cannot become zero, and their causal relation cannot be reversed. Relativistic time still represents the order of causal chains.
Shortly after Einstein's discovery, the Russian mathematician and physicist Hermann Minkowski (1864-1909) united space and time into one four-dimensional continuum, the spacetime of the so called Minkowksi-world: "Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality" (Space and Time (1908), p.75). This view of the physical world, in which no independent time exists, suggests, that the world is to be envisioned as a four-dimensional Being rather than a Becoming within three-dimensional space. Then - as Einstein himself stated – for a physicist "the distinction between past, present and future is only an illusion, however persistent" (quoted in P. Davies, God and the New physics, p.128).

4. Time in Quantum Theory

In the Schrödinger-equation as the basic formula of quantum mechanics, time is not an observable, but just a parameter. But although it is time reversal invariant, in its common interpretation it refers to probabilities and does only allow to determine probabilities for certain states. When a state is measured, the Schrödinger wave-function of an object, which is derived from the Schrödinger-equation, 'collapses', and a certain value for an observable is provided. Some physicists interpret this as a new notion of irreversible physical time: „The concept of becoming acquires a meaning in physics: The present, which separates the future from the past, is the moment when that which was undetermined becomes determined, and 'becoming' means the same as 'becoming determined'" (Hans Reichenbach, The Direction of Time, 1956, p.269).
Thus quantum theory seems to include two concepts of time, the one in form of a classical, reversible parameter of continuous time, in which the realm of probabilities unfolds, the other in form of the discontinuous interaction between objects, that reduces our knowledge of possible states into factual, documented knowledge. Because of fundamental theoretical reasons and because of the very precise empirical data we have, a dynamical description of the transition from the probability-description to the factual description cannot be modeled within the theory. Thus quantum-measurement seems to establish a fundamental distinction between past and future within physics, with past and future being closely related, but without the possibility to completely derive the factual future out of the factual past and vice versa.

5. Time and Biological Systems

According to the second law of thermodynamics, flows of energy arise far from equilibrium in order to compensate energy differences and to increase entropy. Our earth is such a place. It receives a constant flow of energy from the sun, which dissipates energy into its cold surroundings. This establishes a direction of time, which can be identified as the source of the temporality of complex systems, biological systems in particular. Such systems are able to exploit energy flows to locally inverse the increase of entropy and to maintain themselves in a steady state far from equilibrium by functional closure against their environment. Thus they may even develop towards states of increased order and organization, as the contingent and irreversible evolution of life on our planet shows. Biological systems can differentiate, interact, and organize themselves, they can form populations, families, and eco-systems, and in the case of human beings begin to establish history as the temporal unfolding of rational, self-conscious, and moral social agency.

6. The Cosmological Foundation of Time

All manifestations of irreversible time can be seen as a consequence of the fact, that the universe started off in the Big Bang in a smooth and organized state of low entropy. The interplay of its expansion with the contracting force of gravitation, that agglomerates matter into bodies of high density, which start to radiate and disperse their energy into the expanding void, is responsible for the cosmos still being far away from equilibrium. Whether cosmic time will end in a final collapse of the universe, when gravitation will have superseded expansion and reversed it into contraction, or whether expansion will go on forever, until all order and structure of the universe will be dissoluted into an ever dispersing radiation field with decaying minimal fluctuations, still is a matter of dispute (cf. Cosmology). But by the expansion of the universe a cosmic time is established, which is the origin of the large-scale arrow of time, in whose due course in a favored niche far away from equilibrium biological systems could evolve and develop into conscious beings, who started wondering, what time is all about.

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