QUANTUM PHYSICS AND THE PHILOSOPHY OF THE COSMONOMIC IDEA[1]

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Introduction

1.1. Due to the development of the theory of relativity and of quantum physics, twentieth century physics has broken with various foundations of the so-called classical physics, as it had developed since Galileo and Newton. This break has led to a crisis in the philosophy of science, giving rise to questions concerning the *meaning* of many conceptions from classical physics, which as far as they were not abandoned, had to be subjected to a reinterpretation in the light of the newer insights.

A closer confrontation of the Philosophy of the Cosmonomic Idea with the starting points and interpretations of modern physics can contribute to a sharper illumination of the former's significance for today's philosophy of science.

We shall especially place emphasis on five basic ideas of this philosophy:

(a) *The dynamic meaning-character* of creaturely existence, wherein nothing exists in and by itself in self-sufficient isolation, but where everything refers above and beyond itself to that which expresses itself in it namely the *coherence of meaning* in the *diversity of meaning* and the radical unity of meaning in the central origin-relation to God, whose image is expressed in *its fullness of meaning* in Jesus Christ as the Word become flesh, through which all things were created.

(b) *The transcendental time-horizon* of human experience, in which the central unity of meaning of all that is created (itself transcending temporal reality) unfolds itself in a rich diversity of modal aspects, in whose coherence of meaning their unity of root is expressed, and within which also time itself shows modal diversity of meaning and intermodal coherence of meaning.

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[1] Translated by H. Kiefte from M. D. Stafleu 'Quantumfysica en Wijsbegeerte der Wetsidee' *Philosophia Reformata* 31 (1966), 126ff.

(c) The correlation of the *law-side* and the factual (subject)-side of temporal reality in subjection to that law-side, which reoccurs in each of its modal aspects and which comes to expression in time itself in the correlation of time-*order* and actual *time-duration*. Within the correlation of law- and factual (subject)-side one meets the subject-object relations of temporal reality; through them, things and events can also function within those modal aspects in which they themselves cannot have a subject function, but in which they nevertheless acquire an object-function in relation to the subject-functions. These subject-functions man has in *all* aspects, while, plants and animals have them in *some.*

(d) The *mutual irreducibility* of the modal aspects in their unbreakable coherence of meaning within the transcendental horizon of time. Their internal meaning structure (in which the modal meaning-nucleus guarantees their irreducibility) and their mutual meaning coherence are expressed in a sequence of analogical moments of meaning qualified by their meaning-nucleus. These moments either point back as modal retrocipations to the meaning-nuclei of the aspects which rank earlier in the transcendental time-order, or point ahead as modal anticipations to the later ones. In the successive order of these analogical meaning moments the entire irreversible order of the aspects is expressed.

(e) The *individuality-structures* of temporal reality, which in principle embrace all modal aspects, but wherein the modal functions in their mutual relation (while retaining their general order) show the typical structural arrangement of an individual whole. The modal functions themselves also take on structural types of individuality, in which the internal structural-principle of the whole is expressed. This structural-principle imparts the typical role of *leading* or qualifying function of the individual whole to one of the modal functions. Such a modal function then displays a structural-individuality-type, which is derived from the just mentioned structural-principle. The individual whole receives a typical *qualification* from its leading function and the latter gives its typical direction to the preceding modal functions in the disclosing of their anticipatory meaning moments. Thus one finds only typically physically qualified individuality structures in the realm of so-called “inorganic nature”, whose leading function is accordingly to be found within the physical aspect. In conclusion there are so-called “enkaptic interlacements” between individuality structures of different types. The latter can come to be realized only in terms of the former. These interlacements do not allow reduction to part whole relationships.[2]

1 2. One must continually realize that modern physics (including astronomy and chemistry) is not only interested in the functional-physical, but is also especially occupied with the structure of the physically qualified subjects: atoms with their nuclei, molecules, crystals, etc. Even though these topics cannot be separated, we should still distinguish between them. In §2 through §4 we discuss the modal structure of the physical aspect. In §2 the meaning-nucleus of the physical, in §3 the physical order of time, and in §4 physical subjectivity.

Since physics wishes to be an empirical science on a mathematical basis, ,the measuring of physical properties plays an important role in physical theory. In §5 we make some general remarks about the physical aspect of experimental observation, and present a survey of the physically qualified individuality structures, while in §6 and §7 we investigate how physical properties are quantized, and hence become measurable. This means an analysis of the mathematical anticipations on the physical law-sphere (§6) and the application hereof to the description of the structure of concrete, typically physically qualified entities: measurement is possible only on actual, thus typically structured "things" and processes (§7).

In §8 we show how concrete physical entities are physically qualified. Immediately related to this is the relative duration of these "things" and processes, and the physical measurement of time. In §9 we briefly discuss the arithmetic, geometric, and kinematic functions of elementary physically qualified subjects.

Finally in §10 and §11 the correspondence principle and the principle of complementarity are investigated.[3]

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[2] See H Dooyeweerd, *A Critique of Theoretical thought*, (Amsterdam); the three systematic parts of this work (the fourth part contains the extensive index) are distinguished by their year of publication, respectively (1953), (1955) and 1957).

[3] For a non-physicist readable survey of modern physics and its philosophical problems see: H Margeneu, *The Nature of Physical Reality*, (New York, 1950). For the philosophical discussion concerning quantum physics W. P. Welten SJ, *Causaliteit in de Quantumfysica* (diss., Fgroningen, 1961). We have also made much us e of the book by: A. Messiah *Quantum Mechanics* (Amsterdam, 1961, transl. from the French).

2. The modal meaning-nucleus of the physical aspect

2.1. As known, the Philosophy of the Cosmonomic Idea used to point to the original meaning moment “motion” as the meaning-nucleus of the physical aspect.

Not until 1953 does Dooyeweerd for the first time distinguish between the kinematical and the physical aspect, by showing that extensive uniform motion cannot be of a modal physical nature. For this he appealed to Galileo’s principle of inertia.[4] Since then, Dooyeweerd designates the modal meaning-nucleus of the physical aspect as “energy-effect.” In “this connection he remarks that “energy implies causes and effects.” Apparently, the term “energy-effect” alone does not approximate the physic cal meaning-nucleus sufficiently. At first sight it seems called for to replace it by “causal mode of action.”

One sometimes meets objections, however, as to the manageability of the concept of “causality”. It is frequently not possible to determine concretely what the causes of a certain event or situation are. However, when one uses the term “causal” to signify a modal structure-moment of the physical aspect, one must not think of concretely real causes and effects, which as concrete events display all aspects of reality in principle. The point in question here is the modal *relation* of cause and effect, the *trait d’union*; not the question: what is the cause? but: in what way does causality work?

Dooyeweerd regards this causal relation as an analogical moment in the structure of the physical aspect, namely as energetic movement; that is, as a dynamic relation between energetic action and its energetic effect; physical causality is then understood to be the causing of changes in the manner of “energy-effect.[5] The causal relation as an analogical structure-moment is found in all post-physical aspects, but, according to Dooyeweerd, only within the context of analogies that refer back to the energy-mode of action. The causal relation can therefore not be the modal meaning nucleus of the physical aspect. It is necessarily qualified by energy in this aspect.

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[4] Dooyeweerd (1944), 99.

[5] Cf; Welten (1961), 34 ff.

Energy as a measurable quantity in the individuality structure of a physically qualified system (see 8) cannot be a modal meaning-nucleus, of course, and is as such never intended...

2.2. The causality principle on the law-side of the physical aspect does not have to lead to complete determination of the events on the factual-side. The causality principle means to say that nothing occurs without cause. But which effect will have a certain cause is not necessarily fixed. The success of the mathematical formulation of the laws of nature in classical physics has led to a great popularity of determinism, which absolutized the causal laws of nature as understood by classical physics, after first having functionalized all that which is actual (factual)-individual.[6] Modern physics has discovered that what actually happens is not strictly determined by its physical aspect. Now often the factual physical side of events is absolutized by those who say that together with determination, the causality principle has also lost its foundation.

Finally it is to be noted, that the modal meaning-nucleus of the physical aspect and the analogical moments of its modal structure (including the causal relation), are discovered not in a metaphysical but in a transcendental empirical manner, in which a confrontation with the fundamental concepts of the special sciences is indispensable. Therefore, when we maintain the causality principle for physics, even though many reject it, after having identified it with determinism, we do not base our argument on metaphysical grounds, as is advocated, for example, by Van Melsen.[7]

2.3. In what follows we shall describe classical physics as the theory which in line with its mainly mechanistic tendency tried to reduce all physical phenomena to mathematical-kinematical motion of charged or uncharged mass points. The most consistent thinkers of the kinematic-mechanistic school of natural philosophers of this period even rejected the concept of “force” as the physical cause of change in motion, and relegated all talk about causality to the realm of metaphysics -- compare Descartes and especially Huygens in the 17th, and Mach, Hertz, and many others in

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[6] Dooyeweerd (1953), 558.

[7] A.G M van Melsen, *Natuurwetenschap en Wijsbegeerte*,(Utrecht, 1946), 55, 134.

the 19th century.[8] Of course this description of the task which classical physics had taken upon itself is too sketchy in order to do justice to its actual development. Many examples could be mentioned in which it departed from this program. Therefore we only spoke of the "main tendency" of its thinking.

> An interesting example of a departure from the mathematical-kinematical model of classical physics is the classical theory of electromagnetism- Maxwell's equations permit two solutions, respectively corresponding with so-called advanced and retarded potentials With the same equations one can for example describe both spreading out of a spherical. electromagnetic wave from a point (a light source), and the contraction of such a wave into a point. The latter does not occur in reality, so that we exclude the so-called advanced potentials; these do appear to be possible in a mathematical-kinematical sense, but they are in conflict with the irreversibility of the physical causality relation. Lewis correctly remarks on this point: "In the whole history of physics, this is the most remarkable example of the suppression by physicists of some of the consequences of their own equations because they were not in accord with the old theory of unidirectional causality.[9]

3. Physical order of time

3.1. When a distinction is made between a kinematical and a physical aspect, it is also necessary to distinguish between their respective aspects of time. We will see, that the irreversibility of the direction of the order of time can be shown for the first time in the physical aspect of time.

The mathematical-kinematical time of motion is reversible in this sense, that every simple kinematical movement, regarded purely mathematically, can also elapse in the reversed direction. This reversibility relates to the law-side of this aspect of time: if in the kinematical time order the forward direction is exchanged with the reversed direction, then this does not affect the validity of the purely mathematical laws of motion. In other words; these laws leave open the possibility of motion in the reversed direction of time; mathematically formulated: if we reverse the sign of time in equations of motion, we get another valid equation of motion again. This

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[8] E;J; Dijksterhuis, *De Mechanisering van het Wereldbeeld*, (Amsterdam, 1950) 456, 474 ff. M. Jammer, *Concepts of Force*, (New York, 2nd edn., 1962), 103ff., 221ff

[9] G. N. Lewis, quoted by G. J. Whitrow, *The Natural Philosophy of Time*; (London, 2nd edn, 1963), 9.

kinematical time-order of reversible succession must not be confused with the real duration of an actual movement. In the latter case the time direction can certainly not be reversed.[10]

> This is the answer to Milne, who asserts that there are also pure kinematical irreversible processes. He mentions for example a system of uniformly moving particles, that can become an expanding system, even though it initially may be coming together: conversely a conflicting system can never originate from an expanding one.[11] Here clearly the reversible kinematical order of time is confused with the irreversible actual lapse of time. The point is, that when one abstractly reverses the order of time in an expanding system it becomes a contracting system - and vice versa.

Initially Dooyeweerd also-called the arithmetical time order of before and after irreversible: counting forward and counting backward as subjective acts were thought to have nothing to do with reversibility of the quantitative time order of numbers.[12] Later he has reconsidered this view by distinguishing between the plus and the minus direction in this time order, these having a reversible quantitative meaning. The mathematical time orders of quantitative before and after, spatial simultaneity, and kinematical succession,[13] are all reversible in our sense.

The irreversibility of the physical time order has a direct bearing on the asymmetrical relation of cause and effect.[14]It does not need any clarification that the cause can never come after the effect.

The relation between irreversibility and causality is so obvious that it is frequently attempted to reduce the one to the other. This has never been done with success.[15]The irreversible physical time order plays an important role in modern physics. We shall discuss a few examples.

3.2. All actual processes that involve a physical change are in principle irreversible. The existence of fundamentally irreversible processes, first discovered in 1824 by Carnot, placed classical physics before insurmountable difficulties. Before the

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[10] Cf. Margenau (1950), 159 ff

[11] E. A. Milne, see Whitrow (1963), 11.

[12] H. Dooyeweerd (1940), *Phil. Ref.* **5** 167.

[13] Dooyeweerd (1955), 79, 85, 102.

[14] H. Reichenbach, *The Philosophy of Space and Time*, (New York, 1958, trans. from the German), 135 ff.

[15] Whitrow (1963), 175, 271 ff.

beginning of modern physics (especially before the discovery of radioactivity) one only ran into these processes in macroscopic systems, consisting of a large number of particle systems, for example a gas, consisting of molecules. It happened therefore that the processes came to be construed as truly reversible in principle (because it had to be possible to reduce them to motion!), but that as actual reversible processes they were extraordinarily improbable, and were therefore never observed in an· experiment. It was nevertheless acknowledged that this construction was more a scientific postulate than a proven theory: it has never been successfully derived kinematically in all of its consequences from classical mechanics.[16]

Modern physics discovered the existence of principally irreversible processes in the microstructures themselves. These occur spontaneously, and always in one direction.

> Next to the radioactive decay of atomic nuclei the distinction between emission and absorption of light by atoms was discovered. Both can occur under the influence of an external electromagnetic field: we then speak of stimulated emission, respectively absorption. Besides that there exists also spontaneous emission, without external influence; but there exists no spontaneous absorption.
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> An atom that is in a non-stationary state will sooner or later go into a lower energy state by means of emission of a quantity of light. Only the lowest energy state is truly stationary; an atom in the ground state will not change anymore in a physical sense except by an external influence Nevertheless, stationary states are also subjected to the physical time order: as long as there is no external influence, one may say that the system will remain in the stationary state, but one can in no way indicate what the system was like in the past.

3.3. The physical time order also plays a significant role in the theory of relativity. The special theory of relativity describes the kinematic aspect of physically qualified subjects in a strictly functional sense: it ignores the individuality-structure of these subjects. One should not confuse the special theory of relativity with the general one, which is actually a theory of gravitation, and which in the line of classical physics attempted to reduce gravitational phenomena to motion in a non-Euclidian space. With the rise of quantum physics the general theory of relativity has receded to the

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[16] Whitrow (1963), 276 ff. 288; in this theory the irreversibility of time is presupposed, cf. L. D. Landau, E.M. Lifshitz, *Statistical Physics*, (London) (2nd edn, 1959, trans. from the Russian), 30, and; O. Costa de Beauregard, *Le Second Principe de la Science du Temps*, (Paris, 1963), 18.

background, while the special theory (which actually is of a more general bearing) remains in force.

The special theory of relativity not only demonstrated that the actual time-difference of two events separated in space and time is measured differently by observers in differently moving systems, but showed as well that in certain cases the time order also depends on the state of motion of the observer, the greater the amount of disorder occurring in a certain system, for another successive, and for a third also successive but in the reversed sequence. This state of affairs must be taken very seriously, since none of these observers is to be preferred: there is no privileged co-ordinate system (the first postulate of the theory of relativity.)

Distinction is made between so-called time-like and space-like intervals. For the first kind one can always find a moving co-ordinate system such that in it two events occur at the same place, but successively. For the second kind there is always a co-ordinate system, in which the two events appear simultaneously, but at different places. These two kinds of interval are mutually exclusive: an interval is either of a spatial or a time nature.

The second postulate of the theory of relativity says that a causal action cannot be propagated with an infinite speed: there is a maximum velocity, the speed of light c, that has the same value for all observers, regardless of their velocity. The second postulate thereby denies the action-at-a-distance, which would indeed require an infinite velocity for the propagation of the action.

This means that there can be no causal relation between two events with a space-like interval. Only to this kind of interval does the above-mentioned arbitrariness in the order of time apply, which is precisely for that reason physically irrelevant. There can exist (but not necessarily) a causal relation between two events with a time interval; for these events the time order is then the same for all observers.[17]

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[17] Whitrow (1963), 273ff.; Reichenbach (1958), 145.

For events separated by a space-like interval, the concept “static or absolute simultaneity has no physical meaning. This does not mean that it has no meaning at all. If one does not take into consideration (abstractly) the physical or the kinematic aspect, then it makes sense to talk about static simultaneity. We are then speaking of the local positions in their simple spatiality as these are studied by geometry, which is related to this modal aspect.[18]

3.4. Van Riessen cannot agree with the distinction proposed by Dooyeweerd in 1953 between the physical and the kinematic law-sphere. He views the kinematical as a “cross-section of the physical obtained by abstraction”, and refers to (non-reversible) change as the meaning-nucleus of the physical. Further he points out, that time belongs to change, and that it cannot claim the universal meaning that it has with Dooyeweerd.[19]

Now, in our opinion, the word “change” has too many meanings to serve as a description of the modal meaning-nucleus of the physical aspect. A physicist calls a concrete irreversible, typical physically qualified change a process, that is: an event in individuality structure (see 5.4). One can indeed say of these processes that they are irreversible: in their physical qualifying function they are subjected to the physical time order. We do indeed agree with Van Riessen that a purely modal, reversible movement does not occur in concrete reality. But not one modal aspect (not the physical either) occurs in concrete reality in a purely modal sense, which would mean abstracted from each individuality-structure. On these grounds one can hardly object to the distinction of a separate kinematic modality, of which one can designate the modal meaning-nucleus as “uniform motion” and the spatial analogy with the adjective “extensive”.

4. Physical Subjectivity

4.1. Physics and chemistry, investigating phenomena within “inorganic nature”, do not only concern themselves with the general functional physical relations between

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[18] Dooyeweerd, (1955), 8l.

[19] H. van Riessen, *On Wijsgerigo Wagen*, (Wageningen, 1958), 81 ff.

physically qualified phenomena, but also especially with the internal individuality-structure of the latter, and with their physically disclosed arithmetic, geometric, and kinematic aspects. Because of this it is not immediately evident what physical subjectivity is.

In a modal physical sense it does not encompass more than the subjective (factual) functions of empirical reality within the physical aspect, which are subjected to the general modal structure-law of the latter. In actuality however, these physical subject functions always function within individuality-structures which express themselves in each of their modal aspects (on their law- as well as on their subject-side) in types of individuality which cannot be derived from the modal structure of these aspects. We shall therefore mean by physical subjectivity, so far as it reveals itself in the world of inorganic nature, natural phenomena which are typically qualified by a physical subject-function in their individuality- structure. Natural science studies these in their general physical-functional relations as well as in the typicality of their internal structure.

We shall henceforth describe each typical physically qualified subject-unity with the scientifically current term “physical system”.

The functional-physical branch of science par excellence is thermodynamics, originally a technical study of heat, which later grew out to be the science which investigated the behaviour of macroscopic physically qualified systems regardless of their internal individuality-structure or external motion. It works with non-structural typical concepts such as volume and pressure, temperature and entropy, heat, work and “internal energy” (which is-never further specified).

Statistical physics relates the functioning of the physically qualified microstructures, which constitute the macrosystems, with thermodynamics. It can therefore not disregard the internal individuality-structure of the systems. Specific heat, for example, in statistical physics gets a different treatment for a solid than for a gas. Thermodynamics speaks only of specific heat, whatever it concerns.

4.2. Both so-called laws of thermodynamics are therefore valid for all physical macrosystems, regardless of their internal individuality-structure. The first is the law of conservation of energy; the second the law of non-decreasing entropy.

In statistical physics entropy is related to the actual order in the system, the greater the entropy·. Order and disorder can, however, never be seen apart from the internal structure of the typically qualified systems. Thermodynamics defines and handles its concept of entropy apart from every consideration of order and disorder. With this concept of entropy abstracted from all individuality, it formulates the second law: the actual state of a physical system can only change so as to increase the entropy. A reversed change, whereby entropy would decrease, is not possible. The second law of thermodynamics thus points implicitly to the irreversibility of the physical time order.

The above-mentioned thermodynamic quantities (energy, entropy, temperature, etc.) are called variables of state. One speaks of the state in ·which a certain system finds itself. In this sense we believe that one can view the state as physical object in the physical subject-object relation, as we will explain in the following paragraphs. A system, whose state does not change (whose entropy is constant) is called "stationary" or "in thermodynamic equilibrium". Within such a system many changes can appear, be it within the possibilities given by the general functional laws and he internal individuality-structure of the system.

4.3 Both laws of thermodynamics are valid only for so-called closed systems. This concept is based on a theoretical abstraction: as we have already remarked, thermodynamics ignores the individuality-structure of the system and each non-physical modality. This is also valid for the concept "closed system", which indicates a purely modal physical subject. The concept contains a spatial analogy, but has modal physical meaning: it refers to the fact that the system does not enter into energetic interaction with its surroundings.[20]

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[20] With respect to this definition of a closed system one might ask whether the first law does not contain a tautology; this is however not the case when one formulates it more precisely in a mathematical respect. Cf. Margenau (1950), 212.

A concrete physically qualified system is never isolated from its surroundings. Nevertheless in many physical problems it is possible to neglect the interaction with the environment, so that the system which is to be investigated theoretically can still be approximately viewed as closed.[21] The same is valid, when we wish to investigate the system experimentally, if indeed we can neglect the necessary energy interaction between the system and the observing subject. In §5 we shall see that this is not possible for microsystems.

5. Observation

5.1. In an experiment the physical subject is objectified in a technical-scientific way: it becomes object to the scientific observer.[22] Physical theory is entirely dependent on experimental verification. The experiment unfolds the physical aspect. It does this (guided by a theoretic model) by objectifying the subjective-physically functioning of physically qualified systems in mathematical symbols, which demand the interpretation of physical science. One does not observe an objective reality “an sich” in the experiment. Such a reality is a hypostatization (substantivization) and as such a meaning-less metaphysical absolutization.

The experimental objectivization occurs under guidance of the theoretical-analytical thought-function of the scientist and with the help of his technical apparatus: an experiment is a theoretically qualified observation with the help of measuring instruments. On the other hand, it is physically founded: observation cannot occur without physical action. Observation according to its physical aspect is itself a physical process, in which physical interaction takes place between the observing

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[21] This is not the same as a theoretical isolation of a problem. One can, for example, theoretically calculate the possible internal energy states of a molecule; then one has theoretically isolated a system (the molecule). To make the theory experimentally verifiable one must realize that concretely speaking, molecules are not found in isolation. It can be shown for example, that the interaction between molecules in a rarefied gas is so slight, that the influence thereof to the previously calculated energy states of the molecule can be neglected. (Another example is the radioactivity of atomic nuclei, which is not influenced by the chemical binding in which the atoms are eventually involved). This then means, that for the experimental verification of the theory the molecules approximately (with respect to each other) cam be regarded as closed systems. With respect to the necessary electromagnetic interaction with the *measuring apparatus*, however, it is *not* valid to say that the molecule may be regarded as an approximately closed system (see 5).

[22] Dooyeweerd, (1953), 561 ff.; (1955), 100, 581 fr.; G.J. Sizoo, (1965), *Geloof en Wetenschap*, 63, 196.

subject and the observed object, and in which energy is exchanged: the object of measurement is not a closed system. This has the important consequence that functional-physical laws, as formulated in thermodynamics, are no longer valid without any further qualifications for the observed object. The observation is an operation that does not leave the observed unchanged.

Classical physics started out from the supposition that one could, in principle at least, make this operation arbitrarily small, so that the observed system was still (with negligible deviation) considered as a closed system. Thus a division was made between the observing subject and the observed object: what the experimenting observer has registered, counted, weighed, and measured with the help of his technical apparatus became regarded as entirely objective, that is, independent of influence from the subjective observing.

Modern physics discovered the incorrectness of this, with respect to microsystems. Every observation changes the system in a non-reversible and often in a non-predictable way. Moreover it appeared that not all subject functions of the system could be objectified at the same time.

5.2. From the viewpoint of the Philosophy of the Cosmonomic Idea we must place full emphasis on the objective-sensory observability as well as on the objective-theoretical knowability of the physically qualified phenomena, which in their empirical reality cannot be equated with their physical aspect. But at the same time we must hold on to the specific modal nature of their physical aspect, that lets itself be reduced neither to their objective-sensory observability, nor to their objective-logical analyzability.

Neo-positivistic natural philosophy reduces the physical aspect of phenomena to what can be observed in a measurable objective-sensory way and identifies the latter with the empirical reality of the phenomena. It scribes meaning to scientific conceptions and judgments only in so far as they indicate methods for their experimental verification.

Neo-thomism proceeds from the metaphysical relatedness of theoretical concepts to the being of things; in keeping with ancient philosophy it proceeds from the thesis: “ens est intelligibile”, and it does so in the sense that being and its intelligibility or logical analyzability are identical. Of course in so doing the observability of natural phenomena is not denied, but being is ascribed to that of which it is decided that it exists on the mere basis of its logically intelligible necessity, independent of any possibilities of experimental verification.

Classical physics pre-supposed the actual existence of a material ether as the spatial-physical substratum of electromagnetic and gravitational phenomena. The special theory of relativity showed that this hypothesis could not be experimentally verified in any manner. Here we meet then a supposed actual physically qualified subject without a psychical object- function. Such metaphysical “independence” cannot actually exist within the temporal world, and it is meaningless to accept its existence only on metaphysical-logical grounds: modern physics has rightly abandoned the ether-concept.[23]

The neo-thomistic natural philosopher Hoenen introduces the ether as “localization medium”, wherein distances result immediately, and he there- by points out: this is not something which follows from perception, no, thereof we have intellectual and immediate insight[24] “Distance” is conceived of here in the static-spatial sense of the abstract Euclidian Geometry. But with regard to physically qualified things and events a distance thus qualified (physically) can have only physical meaning, namely, that of an action distance. For example, the force which two electrons exert on each other is dependent on the distance between them in the physical “action-space”. Because the action does not propagate with an infinite velocity, that is, there is no immediate simultaneous action-at-a-distance therefore an immediately resulting distance has no physical meaning.

In his criticism of the “neo-positivist principle” (“that which cannot be measured ‘in principle’ does not exist”) Hoenen makes use of the ether-theory as well as of the

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[23] E.W. Beth, *Natuurphilosophie*, (Gorinchem, 1948), 125 ff.

[24] P. Hoenen, *Philosophie der Anorganische Natuur*, (Nijmegen, 1938), 140,304.

simultaneity of spatially separated events. There is, however, an important difference. The ether is conceived of as an actual existing “thing”. The simultaneity is, on the other hand, a categorical time relationship, and the thesis of the Philosophy of the Cosmonomic Idea, that all actual existing things must possess an objective-psychical function does not apply to simultaneity as a scientific conception. With respect to the latter one must not ask about its metaphysical being but about its modal meaning. (cf. §3.3.)

5.3. In an experiment one does not only wish to observe the functioning of physically qualified systems by means of the senses, but one wishes especially to measure it: physics explores nature in a quantitative way. This has had as a consequence, that in theories all observable quantities are mathematically formulated. Thus the colour of light has no sensory-qualitative significance in physics, but physics knows that colour as an objective-sensory quality is correlated with the “wavelength” of the light, and this is a measurable, a qualitatively determinable quantity.

Measurements are made on actual physically qualified systems. One cannot by an analysis of the measuring process ignore the internal structure of the latter. We shall, therefore, in the following sections investigate how modern physics mathematically approaches the individuality-structure of a physical subject.

5.4. We note; that the physically qualified individuality structures can be separated into three groups.[25]

(a) That of the elementary components of matter, which in their typical structural unity are arithmetically founded. At the present state of know- ledge, we must accept that the, so-called, elementary particles such as electrons and protons are not built up from still smaller particles (even though there exist indications that this might not be true for protons). We shall in §9 make several remarks about the functional behaviour and the individuality of these elementary units.

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[25] Cf. Dooyeweerd, (1957), 83, 100, 639, 694-714. The classification presented here according to foundation function is, however, not Dooyeweerd’s.

(b) The second group is that of the enkaptic material structure-totalities in which elementary particles of matter are enkaptically bound. They are typically spatially founded, and cannot exist independent of the elementary units; the latter do not completely constitute the totality- structure, but they are directed by it in their enkaptic functioning within the totality. As examples we mention atomic nuclei, atoms, molecules, and crystals with an increasing measure of enkaptic structure-interlacement. In §6 to §8 we shall see in which way these structure-totalities are spatially founded.

(c) The third group is formed by the individuality-structures of" physically qualified events, which are typically kinematically founded, and which can only occur on the substratum of enkaptic structure-totalities. All "physical (or better said: physically qualified) processes" belong to this group: not only, for example, the emission or absorption of a light quantum by an atom (see §8), but also the measuring process, about which we shall speak in §7.

6. Mathematical Anticipations in Physical Theory

6.1. For the philosophy of science the mathematical formalism of modern physics is certainly not without interest. Physics expresses all its findings mathematically, and the language of natural science has a strong mathematical character. This is only possible because the mathematical aspects found the physical, and for that reason this possibility is itself a natural philosophical problem.

In mathematics, through theoretical operations, the anticipations in the modal structure of the arithmetic aspect of the modal meaning-nuclei of the three following aspects disclose themselves repeatedly in a special type of equation. Spatial figures are fixed in arithmetized analytical geometry by an arithmetic equation involving the coordinates of the points which function objectively in the figure. The same type equation is also applied to the trajectory of a moving subject. The kinematic motion itself is represented by a differential equation[26]

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[26] Cf. Dooyeweerd, (1955), 88, 93 ff., 106 ff

Classical physics also thought to be able to account sufficiently for the mathematical formulation of physical processes with differental equations. In modern quantum physics this appears to be impossible. In the description of physical functioning it makes use of “operators” and the “eigenfunctions” and “eigenvalues” that are correlated with them. Just as differential equations quantize continuous changes of variables and their functions, so the discontinuous changes in the physical aspect are quantized by the operator formalism. We shall briefly elucidate this. In this section we reproduce the formalism in its mathematical form, while in §7 we shall point out its natural scientific significance.

> 6.2. An operator is a mathematical operation, which transforms one function (that is a mathematical relation between several “variables”) into an other function of the same variables. We take as an example of a function: $y=\sin x$, and as an example of a mathematical operation “squaring”, ,then the operator, which we can represent by $(\ )^2$, transforms the function into its square: $(y)=\sin^2 x$. The function $z=\sin x$ is now a new function of the same variable x.
>
> The word “operation” already refers to the physical aspect. In addition, the order of two operators, operating after each other on a function, is not in general reversible, this anticipates the physical order of time. We take in the above example as second operator the “addition by 3”, represented by (+3). Then the order of the two operations is not reversible, since $(\sin x+3)^2 \neq \sin^2 x+3$. In the first case we have added first, and then squared; in the second case this order is reversed, and the finally resulting functions are not identical in the two cases.
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> Two operators A and B applied successively to a function form a new operator AB. In general AB/BA. The difference is called the commutator: $(A,B)=AB \neq BA$. In the special case that the commutator is zero, then A and B commute with each other. One can for instance rotate a match box about a certain axis; with each angle corresponds a “rotation operator” (there are therefore infinitely many). Rotations of the box about the same axis commute with each other; it makes no difference whether one first turns it 30° and then 60° around the same axis, or reversed, Rotations about a different axis do not commute. When one turns it 90°, for example, first about the north-south axis, then about the east-west, the end result is different than if one reverses the order.
>
> We restrict ourselves further to a certain class of operators; the so-called hermitian operators (named after the French mathematician L’Hermite), whose special property we shall soon point out. We shall yet come back to

another class, to which the above named rotation operators also belong, in §8.2.

6.3 The arithmetic aspect can only anticipate the physical via the geometrical and the kinematical.[27] The spatial character of the operator formalism comes to expression in the following discussion of the so-called superposition principle of the “eigenfunctions” of the operator. These are defined by the eigenvalue equation”: $Qf = qf$. Q is the operator, f an eigenfunction, and q the corresponding “eigenvalue”, an ordinary real number. f and q are found by solving the equation by means of a given operator Q (which is therefore the starting point). One then finds an unlimited number of solutions for f and q, which are all generated by Q.

The operator thus transforms· an eigenfunction f into another function Qf which is a multiple qf of it; formulated different: each function which is transformed by Q into a multiple of itself, is en eigenfunction of the operator, and the multiplication factor is the matching eigenvalue. It is not possible to find eigenfunctions with real eigenvalues for each arbitrary operator; the operators for which this is possible are called “hermitian”.

The eigenfunctions of the operator are all functions of the same variables. Now, the superposition principle says that one can write *each* function of these variables as a linear combination of the eigenfunctions .We say, therefore, that the eigenfunctions of a (linear hermitian) operator form a complex (orthogonal) system: the eigenfunctions define an infinite-dimensional, linear, complex vector space (a so-called Hilbert-space).

This may become somewhat clearer, if we see that the supposition principle is valid for all space in any sense, regardless of whether it has the simple spatial sense of static continuous extension, or that of a physical action-space; or that of a formal-logical space. Thus, in a flat plane one can represent each point by two numbers, the co-ordinates. For this purpose, one chooses a (right angled) coordinate system, an x-axis and a y-axis. The intersection is called the “origin”, and the line segment of the origin to the point in question we call a “vector”. Along each axis one chooses a unit, the unit vector. Each vector is the spatial sum (or “linear combination”) of the unit vectors, each multiplied by a number (= one of the two coordinates), This can be clarified by an example. If one first goes three kilometers (three times the “unit. vector”) in a northerly direction, and then four km in an easterly, then one has covered a distance of five km in an approximately north-easterly direction as the crow flies. Thus, here “3 + 4 = 5” is not an algebraic sum but a spatial one.

The Hilbert-space is entirely of an imaginary (formal-logical) nature. Not spatial line segments, but the above-mentioned eigenfunctions appear as vectors; the number of dimensions is infinite: and the coordinates are not real but complex numbers. In the Hilbert-space (and in physics) the “inner product” of two vectors plays an important role. The definition of this

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[27] Cf. Dooyewcerd, (1955), 169 ff.

> depends on the nature of the vectors. The inner product of two different unit vectors is always zero, and of a unit vector unit with itself one. The inner product itself is not a vector, but a complex number.
>
> 6.4. When one multiplies *all* vectors in the Hilbert-space by a constant “phase factor” the inner products do not change. A phase factor is a complex number with an absolute value of 1. Such a number can always be written as the “imaginary exponential function”: $\exp ix = \cos x + I \sin x$ (where x is a real number). This function is a so-called periodic function of x: $\exp ix = \exp i(x + 2\pi) = \exp i(x + 4\pi)$ etc., regardless of the value of x. The possibility of multiplying the entire Hilbert-space by a phase factor, without thereby changing its internal structure, determines the kinematic character of the operator formalism. An important consequence of this is the so-called wave nature of elementary physical particles.

Besides the operator as a mathematical approximation of a physical operation we have now met three numbers: the real eigenvalue, the complex inner product, and the exponent in the phase factor. In the following section we shall see how these quantitative magnitudes are handled in physical theory.

7. Measurements on Structured Systems

7.1. In physical theory such an imaginary many dimensional, complex filbert-space, the so-called state-space, is connected to every physical system With each point in this space corresponds to a possible state of the system --in other words: to the points of the state-space correspond the *actual* states of an unlimited number (an “ensemble”) of *similar* systems.

The meaning or signification of the state-space is indicated in the word “similar”: the Hilbert-space is a mathematical-logical approximation of the law for the structure concerned; each point indicates a possible realization. Thus all hydrogen atoms correspond to the same state-space, and they can be in very many different states.

The possibility of describing the internal individuality-structure of physically qualified entities by means of a state-space is based on the experimentally verified superposition principle, the so-called second postulate of quantum mechanics, which is thus an expression of the intended individuality-structure.

Classical physics also attached to each system a so-called configuration-space, with just as many dimensions as there are “degrees of·freedom”. The actual states of similar systems were also indicated by points in this space. He shall not go into the similarities and differences with the quantum-physical Hilbert-space, perhaps but to note, that the classical configuration-space was completely defined or determined by dynamical variables (position and momentum), while the modern state-space is “spanned” by the eigenfunctions of the energy operator (see §8).

7.2. The use which quantum physics makes of the operator formalism described in §6 is set forth in four postulates (the so-called fifth postulate will be treated later):

1. Corresponding to each measurable quantity is an hermitian operator.
2. The eignfunctions of this operator form a coordinate system in the Hilbert-space, such that each state-function can be written as a linear combination of the eigenfunctions.
3. The only result which can be found by measuring is an eigenvalue of the operator.
4. The probability or chance that a certain eigenvalue is found is proportional to (the absolute value of) the inner product of the corresponding eigenfunction with the actual state-function of the system.

7.3. Actually the third postulate is the most important, since this indicates how a physical quantity is quantized. But it is the fourth postulate which has always drawn the most attention, since the word “chance” occurs in it: the measurement result is not completely determined by the state-function.

> With measuring, the state of the system passes into an eigenstate of the operator. In other words, in the state-space the state-vector is “rotated” until it lies along one of the coordinate axes. Along which axis? This cannot be predicted with certainty. When the original state vector has a large component along a certain axis, then the chance is great that it will be turned just to this one. The closer it lay to this axis, the larger the chance. This only becomes certainty in the special case that it originally lay along a certain axis. Then only does the measuring produce a certain result, otherwise only a probable result.

> Probability is not a vague concept in physics: it is exactly defined and is calculated and measured with great precision when it occurs.[28] When one measures the same quantity in a large number of similar systems, which are originally in the same state, then the mean r0sult is called the expectation value. This is the so-called matrix element of the operator: the inner product of the original state-vector and the vector, which originates (mathematically!) by letting the operator act on it.

7.4. When we, for example, measure the position of the electron in a hydrogen atom, then we transpose the state into a position-eigenfunction. It is meaningless to assign a position to the electron when its state is not an eigenfunction of the position operator. It then has a "potential"[29] or "latent",[30] position. By measuring "we force the electron to occupy a particular position",[31] but we do not dictate which position that will be.

The objectifiable properties of physical systems are always physically qualified. When being concerned with the position of an electron, one must always realize that this can only have physical meaning. The electron in this sense takes a position if it is actually involved in an action there , whereby the position becomes objectified. As long as this does not occur the position of the electron only has a potential physical meaning. This does not mean that the position is meaningless or not definable.[32]
It is a definitely (and doubtlessly positivistically influenced) undue conceptual limitation that the postulates of quantum physics so strongly emphasize measuring. The fourth postulate is valid for every physical process in which the subject manifests itself at a particular position-- not only for measuring processes.

We have already seen that the superposition principle makes possible the mathematical-physical approximation of the individuality-structure[*] of material physical systems with the help of a state-space. We now observe, that this structure does not determine the physical processes the individuality of the latter is indeed also determined by the initial state of the material system, but not exclusively so; the physical processes have their own individuality-structure, which are founded on those of the material physical systems (see §5.4). Just as the structure-law by means of the

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[28] Margenau, (1950) 250; Welten (1961) 135ff

[29] Heisenberg, *Physik und Philosophic*, (Stuttgart, 1959), 38.

[30] Margenau, (1950), 175, 335.

[31] P. Jordan, quoted by Welten, (1961): 19.

[32] Cf. P. Groen, (1943), *Phil. Ref.* **8**, 51

[*] Due to a misprint this part of the sentence was skipped in the original text.

superposition principle indicates the *possible* states, one of which is realized, so the fourth postulate indicates, which measuring results are possible, without it being determined which one will be actualized.

7.5. From the viewpoint of physics, the measuring process is physi cal process, and is thus subjected to the physical time order. The transition of the initial state to an eigenstate of the operator is therefore indeed irreversible. This has an important consequence in the so-called Heisenberg uncertainty relations: if two operators do not commute, the corresponding magnitudes cannot be measured together with unlimited accuracy.

To two non-commuting operators correspond different sets of eigenfunctions, hence different coordinate systems in the same state-space. The uncertainty in the measuring result is indicated by the “distance” of the initial state vector to the coordinate axes. The closer this vector lies to the axis of the one operator, the more certain is the measuring result; but the further it will lie at the same time from the axes of the other operator, and hence the less certain the measuring result of the second quantity. The mutual uncertainty is given by the commutator of the two operators (see §6.2).

The uncertainty relations are the result of the fact that two non- commuting operators cannot be objectified simultaneously, since a state- rector cannot be transformed into two different eigenvectors simultaneously. The final state is therefore indeed an eigenstate of the last measured quantity, and hence depends on the measuring sequence. Only in the special case that the two operators commute do they have the same eigenfunctions not the same eigenvalues!), and in that case the accuracy of measurement of the one quantity is not restricted by that of the other; now both magnitudes can be objectified simultaneously.

7.6. The Heisenberg relation between the position and the momentum operator has always attracted the most attention, since for one, this has included the possibility of the reduction of all physical phenomena to motion. Even in this uncertainty relation they remain dynamical variables, one form of the operators depending on the nature of the motion. But the same Heisenberg relation is always valid, which, as must be the case, relates to the external motion of the system, and not to its internal structure.

> A uniform motion of a system with respect to an observer can also be regarded as a uniform motion of the observer with respect to the stationary or resting system (that is the relativity principle of Galileo, in this respect merely amended by the special theory of relativity). His observation can only differ from that of a stationary observer by a phase factor (see 6.4.), which is identical for all vectors of the Hilbert-space of the system. For observations of the latter's inner structure in that case do not vary. However, the position of the system relative to the moving observer is indeed variable; the latter ascribes a total velocity (better: a total momentum) to the system, which depends on the dynamical state of the observer relative to the system, (or reversed), but which does not depend on the internal structure of the latter.
>
> A mathematical analysis shows that the phase factor concerned contains the product of the position and momentum operator as an exponent. It appears further that the Heisenberg uncertainty relation exists between these as a fixed relationship.[33] One can generalize this deduction to non-uniform motion. The operators then obtain another form, but the Heisenberg relation remains valid. In this manner one can also deduce the uncertainty relations between the different components of the angular momentum.
>
> From the above it follows that the periodic character of the motion (the so-called wave nature) can be regarded as a consequence of the mathematical anticipating the physical aspect.

8. Energy. Time Duration

8.1. The most important operator is the so-called Hamiltonian, the energy operator. It is different for systems of different individuality-structures: for a hydrogen atom different than for a helium atom. To all hydrogen atoms, however, correspond the same Hamiltonian and the same Hilbert-space. The latter is defined by the former: it is the energy eigenfunctions which "span" the state-space.

The Hamiltonian is the "qualifying" operator for the system. Any other operator is always referred to the Hamiltonian--especially the commutation relations between the latter and the other concerned operators are always of much interest. As qualifying operator, the Hamiltonian at the same time determines the durability of the states, in which the system can be.

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[33] F.A. Kaempffer, *Concepts in Quantum-mechanics*, (New York, 1965), among others chapter 9.

8.2. A special (but often occurring) case comes up when the same energy-eigenvalue belongs to two or more different eigenfunctions. In that case for example, a measuring of energy cannot yield a distinction between the two eigenfunctions. Now, it always appears possible to find another operator, which has different eigenvalues for the same eigenfunctions as those of the energy. A measuring of this quantity will thus distinguish between the eigenstates. It can be shown that always only a limited number (a so-called complete set) of mutually commuting operators is sufficient to be able to distinguish all the eigenfunctions by their eigenvalues. Such a situation is always connected with one or more symmetry- properties of the system. That is to say, that the system in a physical sense, that is in its energy action, does not change, if one does change it, for example, in a spatial sense (non- spatial symmetries also exist).

> A square material object for example does not change in a physical sense when it is rotated by 90°. The Hamiltonian must remain invariant under such operations, just as the eigenvalues and inner products between the vectors of the state-space; the vectors themselves are again multiplied by a phase factor (cf. §6.4 and §7.6). These operations which in turn have operators corresponding to them again, however of an entirely different nature than the hermitian operators) form a "group" (that is, a mathematical relation between the concerned operators), and group-theory is successfully applied to many physical problems. Often the Hamiltonian of a system is so complicated that one is not able to take it into account; often it is even completely unknown. The symmetry-properties, however, already give very much information concerning the structure, often satisfactory enough to interpret the results of natural scientific experiments.
>
> It is to be noted, that the symmetry-properties do not add anything new to the Hamiltonian: they are implicitly included therein.

We have said that the phase-factor formalism can always be applied to *transformations* or *changes* of a system which leave the internal structure untouched, and therefore gives rise to the formulation of "conservation laws".[34] We point out that the term "change" has at least three meanings in physics. The one refers to a simple, namely, kinematic motion like that of position-change. The second is that of a real, physically qualified process (see §5.4). The symmetries, mentioned in this section, have to do with a purely *thought* structural-lawful change, which is not of a kinematical but for example of a theoretical-geometrical nature. The concept

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[34] Kaempffer, (1965), 169.

"transformation" is clearly of a spatial origin; one can also regard motion as a succession of infinitesimally small spatial transformations, but this is merely a (albeit extremely fruitful) spatial approximation of the original kinematical motion.

8.3. The Hamiltonian not only describes enkaptic structure-totalities such as atoms, atomic nuclei, molecules, and crystals, but also enkaptic interlacements which do not give rise to a new structure unit, such as gases and liquids, enclosed in a container. Also the interaction between non-interlaced physical subjects is governed by a Hamiltonian. The same Hamilton operator describes the interaction between an electron and a proton, regardless of whether together they form a hydrogen atom or not. There is however an important difference: in the atom the energy-eigenvalues form a "discrete spectrum": they can be numbered. When the elementary particles in question do not form an atom their eigenvalue spectrum is continuous.

There thus exists a sharp distinction between so-called bound and unboundsystems. The first are always related to enkaptic interlaced structures, even though they do not need to be bound in a new structural unit. When a bound system is not a structure-totality, then one can no longer speak of the energy state of the system: it is then a mixture of the energy states of the component structure-totalities.

With respect to the unbound systems, we can note, that the Hilbert- space formalism makes little sense here. The state-space now has a non- countable (continuous) number of dimensions, which is presumably an antinomy. The unbound systems indeed belong to the group of the "elementary units" (see §5.4), whereof the structure is not spatially, but arithmetically founded, and between which only a so-called "correlelative enkapsis" is possible.[35]

8.4. The Hamiltonian also determines the actual subjective duration of the state in which the system finds itself--but not in a deterministic way. Of an individual system it cannot be predicted with certainty how long it will remain in a certain non-stationary state. The Hamiltonian le rely determines the mean duration of a state, the

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[35] Cf. Dooyeweerd, (1957), 698.

durability, in the form of the so-called half-life time: the chance that the system "decays (or falls)" into another state within this time duration is 50%.

The so called fifth postulate of quantum mechanics not only leads to the "time-dependent Schroödinger equation" for the change of energy, but it is at the same time related to the change in the course of time of the expectation values (see §7.3.) of all measurable quantities. This change is, however, related to the Hamiltonian, via the commutation relation between it and the operator under consideration. A variable which commutes with the Hamiltonian has the same time dependence as the Hamiltonian has. A variable which does not commute with the Hamiltonian changes in the course f time even if the system itself is in a stationary state: a stationary state is not invariable.

8.5. The durability of a state is directly related to the corresponding energy-eigenvalue, the actual energy of the system. If the state is staionary, an external observer will always have to come up with the same energy. Also now (cf. §7.6.) the state vectors can only change in the course of time by a phase factor, The latter is comprised of the product of the energy and the time; from this it follows that the energy must possess the characteristic of a frequency, a periodic variation in time.

In contradistinction to the cases which we met in §7.6, energy and time are not operators in this phase, factor: they are the actual energy and the subjective time duration. The corresponding Heisenberg relation (see later) indeed has a completely different character therefore than the one mentioned earlier: there is no corresponding operator for time; time is not an operation. For those who regard time as an aspect or "category" on a level with all others, in particular comparable to space, this is unsatisfactory.[36]

The relation between the energy *E* (expressed in one or other measure of energy) and the frequency *f* (expressed in seconds) is the Planck- Einstein law: $E = hf$; where *h* is Planck's constant. This law is universally valid, and Planck's constant is defined thereby; its magnitude depends excusively on the system of units being used. It is

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[36] Cf. Beth, (1948), 123 ff. O. Costa de Jeauregard, *La Notion de Temp*s, (Paris, 1963), 126 ff., 146.

possible and not unusual to express the energy in units of time, or the time in units of energy. In both cases, Planck's constant "disappears" from the formulas, that is to say, $h = 1$.

This is a generalized description of the Planck-Einstein law, which is better known in the following form: if one has light of a particular frequency f, then the energy consists of packets of magnitude hf. This is how the law was first formulated by Planck and Einstein *c.* 1900, and the generalization was not given until 1925 by De Broglie.

We have dealt with this law as a consequence of the mathematical anticipations of the physical aspect. One should not regard this as an (whether or not philosophical) "explanation" of this law: it is not at all certain that the operator formalism best approximates the physical aspect. The entire natural scientific theory rusts, just as the theory of the modal aspects, on empirical (regarding the latter, on transcendental-empirical) data and is therefore indeed continually open to improvements. Neither physics nor the Philosophy of the Cosmonomic Idea stands in need of a metaphysical "explanation" of physical phenomena.

Planck's constant is the same for all microstructures, and belongs, as do the velocity of light and the elementary charge e, to the universal natural constants. These express the unity of the "realm" of physically qualified things and events and give a physical definition of what the philosophy of the Cosmonomic Idea calls their "radical-type".[37]

> 8.6. One cannot measure the energy of a system which is not in a stationary state with unlimited accuracy. One can measure a frequency only in whole numbers: it is a number of variations in a duration of time. In every actual measurement there is therefore an inaccuracy of ± 1/2: the number of variations in the duration of time Δt is $(n \pm \frac{1}{2})$. The measured frequency is thus $f = (n \pm 1/2)\ \Delta t$, with an inaccuracy Δf. The time-energy uncertainty relation is thus $\Delta f\,.\ \Delta t = 1$. This is the best that one can do: generally
> $f\,.\ t > \Delta 1$.
>
> In the uncertainty relation of position and momentum: $\Delta p.\ \Delta q \geq 1$, q and p both represent the inaccuracy in the measuring of position and momentum respectively. In the one of time and energy Δf alone is an inaccuracy; Δt is

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[37] Cf. Dooyeweerd, (1957), 83, 93.

> the actual time duration of the measurement. The longer one measures, the smaller the inaccuracy in the measurement of the frequency.
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> When one wishes to measure the energy of a system in a non-stationary state, one can measure no longer than the duration of that state. Thus one can, for such *n* state, calculate the average uncertainty of the energy-eigenvalue from the mean time duration, that is, the half-life time.

8.7. We have seen in §7.4 that with the measuring of a physical quantity one forces the system to come to an eigenstate of this operator. Since there is no operator that corresponds to time, this is not applicable to the measuring of time. To measure the duration of a single system or the average duration of a curtain state of the latter, we must simply wait until the system changes into another (lower) energy state. This always goes hand in hand with the omission of a quantity of energy, for example in the form of a light quantum. One can observe this emission and can thus conclude that the system has passed into another state. The measuring of the time duration is thus based upon an autonomous process, which as such is not influenced by the external measuring (this process has after all its own time duration!). We meet here the internnl "sphere-sovereignty" of the system, which by virtue of its individuality, as it were "freely determines" the actual subjective dura tion of its energy states within the possibilities of its internal structure.

We cannot find ourselves in the dilemma: natural necessity or chance, as Van Melsen puts it,[38] (after having eliminated "free will", as .not applicable to natural occurrences, as a third possibility). Both are thereby understood in a strictly functional sense, even though natural necessity does not mean mechanistic determinism for Van Melsen. He understands chance in the sense of absolute arbitrariness, in relation to which not a single conditionality can be set up, not even a probability law. He does not appear to have an eye for the individuality of physically qualified systems which, within the boundaries posed by the physical causality principle and by their internal typical structural law, implies some margin of "freedom" in their behaviour which must in no case be identified with "chance". For it is a 'consequence of the individuality 'of microsystems in their real or actual existence which cannot be reduced to their law-side, however much these two arc correlated.

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[38] Van Melsen, (1946), 1~7 ff.; A.G.M. van Melsen, *Natuurfilosofie*, (Antwerpen, 1955), 285 ff.

Ven Melsen also talks about the “nature” of for example hydrogen and says that only this is an object of science: the chemist, he remarks, is only interested in the properties of hydrogen as such, not so much in those of the quantity of hydrogen which he happens to be dealing with. However true this may be, modern physics has discovered that one cannot unlimitedly pass over the individuality of micro-systems, and finds itself forced to give account of it. Van Melsen only has an eye -for the law-side of the natural phenomena and even then only for its “natural neccessity” aspect.

It is understandable that in this framework of thought the dilemma “chance” or “natural necessity” is posed and that then the first is rejected.[39]

9. Elementary Particles, Fields and Waves

9.1. Even though in general the position operator does not commute with the Hamiltonian, the position state-vectors play an important role in physics. In classical physics, position is always related to the motion of “mass points”. In modern physics position is related to the energy action of a physical system: the position of an electron is manifested, for example, in that it makes a black spot on the photographic plate.

The state-vector does not give the actual position of the electron, but it does give the probability of meeting it there for every point in (ordinary three-dimensional) space--that means to say the chance that it exercises a causal action at that place. One therefore calls the position state-vector (as a function of the spatial positions) a field.

> The concept “field” was introduced by Faraday in the previous century to describe electromagnetic phenomena. Thus the electric field of a charge at any point indicates the force acting on an other charge which could be there (Coulomb’s law). One distinguishes complex and real fields; the former are the complex state-vectors of physical systems; the latter have a relation to the interaction between these systems. There are many kinds of real fields, that can be reduced to four so-called fundamental interactions: gravitation, electromagnetism, strong and weak nuclear forces. The field-concept has proved to be very fruitful, and we now describe with it all spatial behaviour of physical subjects.

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[39] Van Melsen, (1946), 166 fr.; (1955), 300.

9.2. When an electrically charged system is in motion it brings about not only a static electric but also a magnetic field. According to the theory of relativity one cannot ascribe an absolute motion to any single physically qualified thing, so that the electric and the magnetic field cannot be separated. Together they are governed by Maxwell's laws, which can be derived from Coulomb's static law and the laws of motion of relativity theory. Maxwell's equations exhibit a wave nature: the field magnitudes vary periodically both in space and in time.

The wave nature appears whenever there is motion associated with the field. For the case of complex fields, the position state-vector, we have already seen this in §7,6. The momentum as a unit for the motion therefore has the form of a (inverse) wavelength.

The natural scientific term "wave" has caused much confusion since it easily leads to thinking of a material substratum (for example, ether) which carries the wave, in the same manner as in the case of waves on a water surface. However, it is not a matter of a waving substance, but of a periodically varying field strength; in other words, here also the kinematic aspect is physically qualified.

9.3. The word "particle" has replaced the word "atom" as the common name for micro-material components, since the physically qualified units indicated by the word "atom" are not in the least "indivisible". In using the word "particle" in its physical sense one should not associate it with divisibility, dimension, shape, or whatever other spatial property. It means no more than a quantity (a quantum) of charge, of mass, of energy, of momentum. This "quantity", therefore, is physically opened up as well, determined by its physical action.

Classical physics regards the material units as (charged or uncharged) mass points moving in an external, non-physical, so-called absolute space. In addition, it described light as propagation of a disturbance (a wave) in this space. In quantum physics the distinction between material-particle and wave are maintained; however, it seems that all elementary material components exhibit not only the character of a particle, but also that of a wave.

This, in addition to the fact that since Einstein's light-quantum theory the properties of both mass and momentum, which were after all regarded as fundamental properties of material quantities, have also been attached to a light quantum with its energy *hf*, has led to a theoretical levelling of the distinction between for example, electromagnetic fields and their correlated light quanta on the one hand, and the elementary material particles (for example, the electron) with the position state-vector related to them on the other hand. Still, there remains an essential distinction, which will not let itself be eliminated scientifically.

The theory of relativity teaches that the subjective duration of an elementary particle or of the state of a physically qualified micro-enkaptic structure-unit such as an atom is equivalent to the objective duration, as measured by an external observer, only if the observer is at rest with respect to the particle. If· the observer moves with respect to the particle, then the objective, observed duration is always longer than the subjective duration, the so-called "eigentime" of the particle. If in a similar manner we calculate the eigentime of a light quantum it appears to be zero: hence there is no subjective duration for a light quantum, even if the observed, objective passage of time between its emission and its absorption is greater than zero.

9.4. The light quantum begins and ends its existence in the individual process we call "emission and absorption". It does not have a micro-thing-structure (see §9.5), but it is a quantized moment of a radiation-event in the interaction between physically qualified subjects.

There is a tendency in physics to describe all kinds of phenomena with the help of so-called quasi-particles. We wish to clarify this with an example. In a crystal, the state as it exists at the absolute zero point of temperature, is regarded as a thermodynamically inactive ground state. At higher temperatures the atoms of the crystals vibrate; however, not individually but collectively: the crystal ns a whole has come to be in a higher energy state. It now appears possible and fruitful to describe this state as consisting of the ground-state with a number of "phonons" (=acoustic quanta, not to be confused with photons = light quanta).

The significance of phonons only becomes clear when there are processes taking place in the crystal which must be described (the scattering of an electron, the absorption of a light quantum). In that case phonons are either “annihilated” or “created”. Phonons are manifest in no other way than by these processes. Thus, a distinction was implicitly made between the crystal and the individual processes which can occur in the crystal.

There are as many kinds of quasi-particles as there are “excitations”.[40] Light quanta, too, are quasi-particles. We conclude that the quasi-particles do not possess any micro-thing-structure (see §9.5), but stand in relation to individual, physically qualified processes, which take place between physically qualified elementary material-components with a micro-thing-structure or within physically qualified enkaptic structure-totalities.

9.5. Since the rise of quantum physics the question: “Is the electron a wave or a particle?” has almost become a classic, and it is often answered with: “both”--sometimes there is even talk of “‘wavicle” (wave + particle). For philosophy this answer poses the new question: “What then gives ‚the electron its unity?”. According to Dooyeweerd the unity of a whole, given in its individuality-structure, can never be found by scientific analysis; this whole is pre-supposed in all structure-analysis; science derives the idea of the unity of a “thing” from pre-scientific, so-called naive experience.[41]

The difficulty for physicists is that electrons do not appear in naive experience, so that we can only analogously come to the idea of its unity as individual whole, and thus to “reconcile” the wave nature with the ‚particle character. We therefore make use of the term “micro-thing”. The concepts particle, field, and wave have, as we have seen earlier, no relation to the individuality-structure of the electron as a real whole. They are general functional, not structure-typical concepts of mathematical physics.

10. The Correspondence Principle

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[40] Kaempffer, (1965), chapter 16.

[41] Dooyeweerd, (1957), 56, 66, 98 ff.

10.1. We have explained in the previous paragraphs why modern physics had to break with classical physics, in so far as the latter tried to reduce all physical phenomena to the continuous motion of mass points. We have seen that the physical aspect according to its modal structure is not qualified by the meaning-nucleus of the mathematical mode of continuous motion, but by that of energy-action; further, that a general, strictly functional description of natural phenomena is not satisfactory, since it does not do justice to the structural individuality of physically qualified systems.

We must, however, establish that although modern physics has broken in principle with the thought-model of classical physics, yet most physicists have not done this in full consistency. We wish to explain this in the light of two concepts which play a role in every quantum theoretical discussion: the correspondence principle and complementarity (in §11).

10.2. When abandoning classical physics, one cannot neglect all the achievements of this theory. One ought to account for the experimentally verified results of the latter. This is done by means of the correspondence principle, which is formulated as follows by Messiah: "One may therefore assert that *Classical Theory is 'macroscopically correct'*, that is to say, it accounts for phenomena in the limit where quantum discontinuities may be considered infinitely small; in all these limiting cases, the predictions of the exact theory must coincide with those of Classical Theory ... In order that this condition might be fulfilled, one establishes in principle that there exists a formal analogy between Quantum Theory and Classical Theory; this 'correspondence' between the two theories persists down to the smallest details and must serve as guide in the interpretation of the results of the new theory."[42]

Here two things are asserted: first that classical physics is a limiting case of quantum theory, and second that there is a formal analogy between both. Now the order (first quantum physics; then classical physics as a limiting case) is reversed by (the desire for) deducing all operators in quantum physics from the classical position and

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[42] Messiah, (1961), 29; italics by Messiah.

momentum functions. We shall advance objections especially against this reversal of the proper order.

10.3. The correspondence principle is first of all not critical with respect to the historical development of classical physics. We shall not go into its details, but merely mention that the deduction of the formulation of quantum physics from that of classical physics refers back to the so-called Hamilton formalism of the latter. This is one of many, and in the nineteenth century it was certainly not regarded as the most important. It is connected with the so-called least-action principle: one defines a certain quantity (the action) and demonstrates that with the motion of a mass point (under the influence of external forces) the traversed course is such that the action is a minimum (or, more general, an extremum); by every other route the action would be greater. The formal analogy of this principle with Fermat's principle for electromagnetic radiation caused Schrödinger to refer back to this formalism in 1925--and successfully so.[43] To this we owe the name of the energy-operator.

Even though there is thus a possibility of Hamilton formalism in classical physics, it is going a bit far in our opinion to base a formal analogy between classical and modern physics on this.

10.4. The correspondence principle is also uncritical with respect to the pretended simplicity of the classical theory. There is a feeling that the latter gives a better hold than modern physics, which is so much more complicated. It is overlooked that this complication is especially the result of the study of the internal structures of the physically qualified things, a study which was impossible in classical physics, and which hence does not occur there. The quantum physical solution of problems which can also be solved classically is in principle no more difficult than the classical.

In the classical Hamilton formalism a fixed relation exists between the position and the momentum function, which in quantum physics is replaced by the commutation relation between the respective operators. It seems to give a happy feeling to be able to derive the latter relation from the first. But it is then forgotten that the classical

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[43] E. Schrödinger, *Was ist Ein Naturgesetz?*, (Munchen, 1962), 86 ff.; Margeneau, (1950), 184 ff.

relation must in turn be derived from the least-action principle. In classical as well as in modern physics the form of the position and momentum-functions and operators depends on the forces to which the moving system is subjected. In classical as well as in modern physics one can find this form only intuitively. When the quantum physical operators are deduced from the classical functions with the aid of the' correspondence principle, it is forgotten that the latter were also found intuitively.

It is indeed very well possible to do quantum physics without referring to the classical. Kaempffer's recent book has shown this. This author correctly motivates his method by stating that students of quantum mechanics derive no benefit from being led through all historical pitfalls.[44]

10.5. The rule according to which the quantum operators arc deduced from classical quantities is, moreover, not univocal and not complete. When the product of, for example, the position and the momentum function occurs in a classical Hamilton function the sequence in that product is irrelevant. But quantum-physically this sequence is indeed important. It becomes, therefore, necessary to add a relatively arbitrary but stringent condition to this rule, to make it univocal.[45]

More serious is the incompleteness of this rule: not all quantum-physical quantities can be deduced from the classical. *The* example for this is the angular momentum. If one deduces this from the classical analogue then the eigenvalues are found to be whole numbers: 0, ±1, ±2, ... When one introduces this operator directly quantum-physically, namely via the Heisenberg relations, then also "half-integer" eigenvalues are found: + ½ , ± 3/2,± 5/2, .., which were first found experimentally. Not in any way can the correspondence principle come to these half-integer so-called spin eigenvalues.[46]

It should be noted, that the non-univocity and the incompleteness come to fore only when the order: first classical, then modern physics is used. If one maintains the

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[44] Kaempffer, (1965), Preface.

[45] Messiah, (1961), 70.

[46] Messiah, (1961), 541

correct order, by regarding classical physics actually as limiting case, then these objections disappear.

10.6. The correspondence principle does not do sufficient justice to the distinction between the general functional and the typically structural. It states that classical theory is “macroscopically correct”. In so far as one only pays attention to the external functioning of macroscopic subjects, their motion and their thermodynamic properties, this is without any doubt correct. But for typically structural properties this is not valid. The specific heat and the electrical and heat conductivity of metals, for example, one can hardly call microscopic properties. It is, however, in no way possible to explain these in a classical way. When one, on applying the correspondence principle, thinks only of atoms and molecules, it is easy to disregard their individuality-structure, since this is microscopic. For solids this is not possible.

10.7. In conclusion we wish to attempt to formulate the correspondence principle in another manner. We have already pointed out that it is valid for the external motion of physical subjects, provided that one uses the correct order between quantum physics and classical physics. In §7.3 we mentioned the “expectation value” as a statistical mean of a large number of measurements of an operator with respect to systems with the same initial state. This expectation value makes it possible to “identify” operators. Thus it is, at first glance, not easy to recognize the differential operator $\frac{h}{2\pi i}\frac{d}{dx}$ as the momentum operator of a freely moving subject. The expectation value, however, yields nothing else but the velocity of the particle multiplied by the mass, i.e. the classical momentum.

The correspondence principle, thus applied, leads to an analogy of quantum physics with everyday experience which is wrongly identified with classical physics! In so far as an analogy exists between modern and classical physics, both are analogous to everyday experience. Now that we have come to this conclusion, we can reject the thought that there must exist a formal analogy with a theory whose foundations have appeared to be incorrect.

11. Complementarity

11.1. In contrast to the correspondence principle the principle, of complementarity, now to be discussed, is not generally accepted~ It was first formulated by Niels Bohr, and is part of the so-called Copenhagen interpretation of quantum physics, which is followed by most, but not by all physicists. An extensive discussion of the Copenhagen school and her defenders is given by Welten.[47] In this article we shall restrict ourselves to a discussion of the complementarity principle as rendered by Messiah,[48] which may well be called representative.

11.2. Messiah's argument can be summarized in three points.[49]

The first is that one can give account of every physical phenomenon only in classical terms. The instruments with which a scientific experiment is carried out, are macroscopic, and an unambiguous use of language is necessary to avoid any element of uncertainty on the part of the observer since the experiment must be reproducible, and its progress must be independent of the observer.

Secondly there is the state of affairs that on a microscopic level one cannot make a sharp separation (as is required by the ordinary concept of observation) between the natural phenomena and the measuring instrument. Only when the magnitude of Planck's constant can be neglected is such a separation possible. This sets a limit to the analysis of phenomena in classical terms; any attempt to push beyond this limit requires a modification in the experimental arrangement which introduces a new interaction between the object and the measuring instrument.

From this it follows in the third place that the results obtained under different experimental conditions cannot be comprehended within a single picture. They must be regarded as complementary, in the sense that only the totality of the measured results reproduces the possible information.

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[47] Welten, (1961), chapters 2 and 3.

[48] Messiah, (1961), 149-159; cf. the contribution of N. Bohr in: P.A. Schilpp, *Albert Einstein, Philosopher-Scientist*, (New York, 3rd ed. 1959), 201-241; this paper is also published in N. Bohr, *Atomic Physics and Human Knowledge*, (London, 1958), 32-66.

[49] Messiah, (1961), 152 ff.

11.3. To the argument summed up in the first point we can apply the criticism of the previous section: macroscopic experiments must not be described in classical-physical terms but in those of everyday experience. Messiah's[50] example illustrates this amply: the observer reports that this pointer has stopped on this dial at that point and at that moment.

It is, to be sure, not unimportant to point this out. Because if one wants to describe the experiments of quantum physics in classical-physical terms, it must necessarily be done in terms of motion: one must then describe all phenomena with the aid of the position and velocity of the micro-objects at that moment. Position and momentum are therefore called complementary (and similarly every pair of operators which do not commute with each other), since different measuring arrangements are necessary for their measurement. In this sense Messiah indeed comes to a closer definition of the principle of complementarity: "The description of the physical properties of microscopic objects in classical language requires pairs of complementary variables; the accuracy in one member of the pair cannot be improved without a corresponding loss in the accuracy of the other member."[51]

This statement is without any doubt correct. But it is not in the least necessary to render the physical properties of micro-units in classical terms of motion. In one breath with his closer definition of the complementarity principle Messiah mentions the existence of a complete set of mutually commuting operators (see §8.2.) for any system, which is a complete representation of its functioning. These observable magnitudes, which can all be measured simultaneously without their measurement accuracy being mutually influenced, are not complementary; but usually they indeed do not refer to classical physics.

11.4. The above-mentioned complementarity principle has been extended in different directions, even though there exists less agreement about the correctness of these extensions than about the principle in its original formulation. Thus Bohr speaks about a complementarity of a time-space description on the one hand, and a causal

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[50] Messiah; (1961),153.
[51] Messiah, (1961), 154.

description (by momentum and energy) on the other hand, referring to the Heisenberg relations of position and momentum and of time and energy.[52] He thought that all other uncertainty relations could be deduced from these, which however has not appeared to be possible.

Often, one talks about a complementarity of particle and wave.[53] Born, for example, has objected to this, since in every measuring process the quantitative as well as the spatial aspect plays a role, so that in this case he would rather speak of "duality".[54] In §9. we have seen that one can even better speak of particle, field, and wave-nature, which terms then do not indicate concrete realities, but have only abstract functional significance.

We restrict ourselves to a critical consideration of the original complementarity concept, and point to the emphasis which is placed on measuring and on sensory observation. This clearly betrays the positivistic origin of the Copenhagen school (even though its followers are not all rigorous positivists). Welten describes the positivistic way of thought, which underlies the complementarity conception, as follows: "From the fact, that position and momentum of a particle cannot be measured simultaneously with unlimited accuracy, it is concluded that the concepts "exact position" and "exact momentum" cannot be used in a meaningful way for the same particle at the same time. *"Position" and "momentum" must be defined, with the aid of their respective methods of measurement*, so that wherever the measurements are mutually exclusive, the concepts also cannot simultaneously be meaningful."[55]

We can grant the Copenhagen school that only experiment can determine which quantities describe physical phenomena meaningfully. But the positivistic view that the physical meaning of phenomena themselves is determined by measurement and sensory observation is unacceptable. The meaning of the physical does not lie in the sensorily observable and measurable; the physical aspect has "modal sphere-sovereignty" as such, and its meaning can thus not be reduced to that of other aspects

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[52] N. Bohr, quoted by Welten, (1961), 25.
[53] Messiah, (1961),155 ff.
[54] M. Born, *Natural Philosophy of Cause and Chance*, (New York, 1964), (2nd ed.), 105.

[55] Welten, (1961) 20; italics by M.D.S.

(see §5.2).

Strictly formulated, the principle of complementarity says only that complementary quantities appear in the description of physical phenomena in classical terms. If all one is after is the motion of micro-subjects, one can leave it go at that. But it is then realized insufficiently that quantum physics pays precisely the greatest attention to the individuality-structure of physically qualified things and processes, which cannot be described in an exclusively functional manner, let alone functional-kinematically. More specifically, one then has no eye for the internal "sphere-sovereignty" of every individual system. We have seen in §8 that among other things, this comes to expression in the internal autonomous processes of systems in a non-stationary state. The mutual uncertainty of the energy and ·the eigen-duration of an unstable state has no relation to an external observation. The explicit or implicit reference of the principle of complementarity to measuring and sensory observation in this case makes no sense.

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NOTE ADDED TO THE TRANSLATION

The problem of individuality in physics has been discussed by the present author, and some aspects of Quantum physics and thermodynamics by G. Horsman in D.M. Be.kker c.s. *"Reflexies", Opstellen aangeboden aan* Prof, Dr. J. P. A. Mekkes, (Amsterdam, 1968).

A paper on the problem of time in modern physics by the present author will be published soon.

It is inevitable that at some minor points the views of the author expressed in the above article have been changed since its publication. No attempt has been made to incorporate this in the translation.

I like to express my sincere admiration and thanks to Mr. H. Kiefte for his careful and close translation.

M. D. Stafleu
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