The World is Realistically Four-Dimensional, Waves Contain Information Embodied by Particles Codedly, and Microphysics Allows Understandable Models (Part II)

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ABSTRACT. As already indicated in the *Abstract* and the *Introduction* of Part I, we, in Part II, go more detailedly into how the quantum formalism can be explained in a realistic way by a) the four-dimensional point of view that, *inter alia*, involves the new action metric and, b) the conception of matter waves as a realistic alternative (that is, coded) way of integratedly storing physical information about (that is, properties of) particles.

It appears that it is exactly the "deformation" of space-time (of distances) which corresponds to the introduction of action metric, in conjunction with the rather fundamental "deformation" of wavelike particles as is implied by the coded-information theory, that makes the quantum formalism understandable. That is: such formalism – wave functions, operators, representation spaces, ...– appears to precisely have reference to *realistic* physical entities playing a part in the micro-sphere, in particular to wavelike coded data and action distances as they integratedly appear.

6. Nature aims at optimum simplicity; waves do not carry redundant information; the Least Action Principle

As is well-known, not only the classical but also the quantum equations of motion can be derived by varying the action function with respect to variables figuring in it (see, e.g., Ref. 18, pp. 160 ff.). In our four-dimensional and action-centered conception of the world, as discussed in part I, this is no longer only a mathematically beautiful and expedient way to derive such equations, but also realistically reflects the structure of the Universe: Action is primary and the laws of Nature essentially relate to action. The current equations of motion are secondary and more long-winded ways of formulating reality from our limited three-dimensional point of view. The proper, four dimensional, natural law underlying them is the Principle of Least Action.

Now the gist of the present theory – of parts I and II– is that we have something similar with quantum mechanics in general: On going over to a – realistic – four-dimensional event- or action-centered conception of Nature, in which, moreover, action quanta in their simplest, non-interactional slice-like form carry physical information about "particles" etc. in a coded way, quantum-mechanical laws and processes become more comprehensible, allowing understandable models which make the world simpler. We generalize the lesson derived from the Principle of Least Action in another sense, too, viz. by positing that *Nature tends to optimum simplicity in several essential respects*. It does not only use a minimum *number* of action quanta (i.e., least action), but also aspires to optimum *qualitative* simplicity, *inter alia* as regards the points summed up below.

(a) The quantum of action in its "corpuscular" variant is optimally simple.

(b) Neither have quanta in spinor-wave form – defined by the proper spinor and phase factors like $e^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})}$ – more characteristics (variables) than are inherent to the most general covariant waves: frequency ν, wavelength λ, intensity and (among other things, a Lorentz-) transformability differentiation that at the same time embodies an information code as to spin and (as discussed in Section 10) as to the kind of the "particle" in question. Note here further that spinors are the most general entities in which Lorentz-covariant equations can be formulated (see, e.g., Ref. 18, pp. 81 and 85). Finally, the relevant waves inherently transmit, or encode, "uncertainty margins" to be discussed in Section 7.

(c) There is no more information encoded in the waves than corresponds to the variables characterizing them in their simplest, and still general spinorial, form. The direct contact we called "zigzag" makes further complication of the waves unnecessary.

For the rest, we can generally expect that, the tendency to optimum *quantitative* simplicity having radical consequences – the equations of motion follow from it, i.e., from least action – , the complementary tendency to optimum *qualitative* simplicity has so, too, and that in the shape of the fact that quantal waves reduce to their simplest possible form. This, in turn, allows important phenomena as the "interference of entire atoms" and other interference processes that make the coded-signal way of information transmission and processing possible in the simple and coherent way we see appear. Generally, such qualitative simplicity greatly contributes to making the quantum formalism understandable as a *mathematics of information-code symbols carried by still realistic action-quantal waves*, as will become even clearer in the following sections. It is certainly in this connection that we have to think of Feynman's words: "Truth is to be recognized by its beauty and its simplicity".

(d) The equations of motion satisfied by the waves appear to be of optimum simplicity, too: (i) linear, (ii) of the lowest possible order (at most the second), (iii) so that the field-solutions are local in the sense that the state of a field at a given point-event is completely determined by the field functions and their derivatives there. Note that this does not exclude nonlocal phenomena: all *field strengths* being locally defined, there may nevertheless be nonlocal influences, say, between two correlated EPR systems. Additionally, a smooth correspondence with the macro world requires that (iv) $E^2 = p^2c^2 + m_0^2c^4$ follows from the equations, also for $m_0 = 0$, and that the correspondence principle holds more generally.

If we require these restrictions to be fulfilled [compare also (j) below], the simplest and most general Lorentz-covariant field equations are precisely the well-known 1-, 2-, ... component spinor equations for the known scalar, pseudo-scalar, vector, pseudo-vector and spinor particles of zero and non-zero mass; that is, for mesons, photons and fermions (see, e.g., Ref. 18, pp. 101-112). In a completing simplifying integration, Nature at the same time manages the spinor components, whose number thus plays a part in characterizing, codifying, the nature of a particle, to function as a code for spin as well, via their phase relations (as we discussed), therewith making use of an elementary intrinsic property of Lorentz-covariant (spinor) waves.

For the rest, the fact that the field equations are in spinors simply corresponds to that the elementary internal action-quantal constituent (quantity): the field strength, transforms as, is, a spinor. It seems no accident that the most elementary covariant *metrical* entities in Minkowski space – elementary spinors of order $1, 2, ...$ – precisely correspond to the most elementary *physical* entities: the field strengths forming action quanta. (There seems to be nothing more elementary in Nature.) More complicated spinors can be derived from the elementary ones, from the metrical as well as from the physical point of view; as to the latter: everything physical derives from (the internal processes in) action quanta, viz. from the wave function ψ.

(e) As yet we have no (periodic movement of a) corpuscular model that is isomorphic with the waves (fields) of other types of "momentum carriers" than Dirac particles. It may be (or is even probable) that photons indeed never appear as object-like entities but, alternatively to their wave form, only as non-corpuscular local energy quanta, whereas mesons, which have a spin zero, essentially only play a part as force-transmitters between other particles such as baryons. This would make their nature that of singular action quanta as discussed in Ref. 16 and, at the same time, always virtually wave-like. The above would be in conformity with the assumption that the spherical-rotation corpuscular model is only relevant to spin-1/2, Dirac-like and (possible) higher-spin particles and neutrino's, and that we do not need it for other "particles", i.e., photons and mesons.

However, the special situations pertaining to photons and mesons cannot be invoked in trying to make models of both the corpuscular and the wave state of scalar particles such as spinless atoms and other composite particles, or to find what logic underlies the translation, encoding, e.g., of a He-atom into a scalar wave (packet) of the kind $\psi = \int F(\mathbf{p})\, e^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})} d\mathbf{p}$.

As to the corpuscular model of such composite particles, we need no more than assuming indeed a composition by spinning, dumbbell-like constituents.

As regards their wave state, we can here, too, invoke the optimum-simplicity principle referred to earlier, viz. by assuming that if, say, two Dirac "momentum carriers" merge into a scalar one, Nature discounts such merger by making the two spinor components in $\begin{pmatrix}\psi_1\\ \psi_2\end{pmatrix}$, as the resultant wave might look like in the first instance (if we look away from negative-energy states), merge into one scalar wave. Still, the latter does not reflect the detailed structure of the composite particle, but only its scalar nature and the periodic process a series of action quanta embodies here, too (though such process will not be isomorphic with normal spherical rotation now). Not representing superfluous information, the wave process suspends the 2-component character of the spinor as soon as such components no longer have a function as an information code, representation, for the $+1/2\ \hbar$ and $-1/2\ \hbar$ contributions to the total process. For the rest, these contributions in a similar way represent action-metrically contiguous alternatives for the process as do, say, emissions in the directions A, B and C, respectively, from E in Fig. 18 below. They can be simultaneously operative – i.e., all be produced by the emitter – because they are, or can be, too little different for the internal action metric and -physics of the process for their being so much discriminatingly managed by such (emission) process that only one can appear. This does not alter the fact that the conditions of the experiment – slit widths, attenuaters, ... – may selectively favor some alternatives above others. Note further, however, that, in a coded-information conception of waves, a superposition of states (their "being there at the same time") is far more imaginable than in the conventional conception for still another reason than the action-metrical one mentioned. For the "superposition" of, say, alternative spin states *merely amounts, in the former conception, to the superposition or mixture of signals carried by one and the same realistic wave*, in the spin case in the shape of "intermediate" component-phase relations. *Generally, the instrument functions as a wireless receiving-set, selecting one of the alternative signals*; compare, e.g., 3. of Section 5, and see further Section 7. Point 3. of Section 5 is particularly illustrative of how the coded-information conception makes all kinds of proportions possible in a mixture of (say, spin) states, alternatives.

(f) Actually, everything about wave equations and wave functions is more complicated variants of the basic (free-particle, scalar, only partly relativistic) situation represented by $i\hbar\ \partial\psi/\partial t = E\psi$ for the case $\partial\psi/\partial t = d\psi/dt$, with the solution $\psi = C\ e^{-i/\hbar\ Et}$ or, with a "first-order" relativistic correction, $\psi = C\ e^{-i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})}$. ("First-order" correction because $Et-\mathbf{p}\cdot\mathbf{r}$ is relativistically invariant indeed, but we leave negative energies out of account.)

That is, the ψ-functions solving the field equations can be seen as representing action-quantal slice structures in which the plane slices that represent the simplest manifestation of the action $Et - \mathbf{p}\cdot\mathbf{r}$ in Minkowski space are complicated or deformed by three instances: (i) relativistic covariance requirements allow more complicated equations with more-component spinorial solutions that also relate to spin, (ii) the introduction of potentials remodelling the slices, (iii) such particular effect of the action metric that causes action-metrically contiguous *wave series* (e.g., corresponding to alternative emission momenta) to be "emitted at the same time", with which the whole resulting wave pattern still represents *one* action-quantal structure and its internal action-physical contiguity relations. The factor $e^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})}$ still remains very important. Compare the discussion of Fig. 11 in connection with (iii).

Actually, "practical" quantum mechanics is the production and mathematical processing of the variants and transformations as to experimental set-up and the corresponding slice-system, respectively.

(g) The linearity of the wave equations – an aspect of their simplicity – has also a consequence amounting to a sweeping simplicity as to information processing by the corresponding waves, viz. the superposition principle and the associated circumstance that a measurement can simply select information, or make "an eigenstate project", from a relevant wave system. As can be seen, e.g., in Section 5, point 3., the waves are so constructed that they convey such unspecified, or general (which means here: such minimum of), information that it is only the contribution of the instrument – measuring, say, either s_x or s_z – that completes certain definite "properties" of the observed system. That is, Nature ingeniously minimizes the information coded in the waves in such way that a number of "letters" is carried, from which the various kinds of measurements – of $s_x, s_z, E, p_x, ...$ – can construct "words and sentences" that make sense, that answer the question put by the measurement by measurement values or eigenstates.

The wave equations appear to be so that only for eigenvalues of a relevant variable a corresponding, definite-information-carrying, action-quantal structure (represented by an established wave function) can exist. Thus, they reflect an inherent relationship between the wave mode and the quantization of other variables than action, too. Because such mode and action quantization are mutually directly related, the latter and other quantizations are so just as well. (Compare also the discussion of Fig. 12.)

The completion, at a measurement, of the incomplete ("uncertain") information the waves will contain is a four-dimensional, nonlocal, process. E.g., because of the conservation laws, the projection of a momentum (eigen) state from a mixed one at least requires a retroactive influence that adjusts previous momenta – among which can be a recoil – to the one ultimately produced. Because the zigzag communication channel conveying such influence allows communication in both the $+t$ and $-t$ directions, it is obvious to assume the "projection" to be a truly four-dimensional process in which nonlocal hidden variables define a choice, obeying as yet unknown laws. That is, e.g., emission and absorption process constitute a whole (in Bohr's sense) in contributing to the ultimate result.

Note that the wave equations are neither formulated in terms of particles, nor in those of forces or even action quanta themselves, but in terms of the most basic there is: the field strengths (potentials) that are the constituents, elements, of action quanta in their wave state (as we see, e.g., in Fig. 6). Through these field strengths $\psi(\mathbf{r}, t)$ they define the action-quantal structures of which processes consist.

(h) The corner-stone of the present theory, viz. that everything depends on action, is in itself an example of Nature's aspiring to optimum conceptional simplicity. For the rest, taking the four-dimensional character of the Universe dead-serious, and deriving even metrical relations from action, are more revolutionary aspects of the positing of the primacy of action than the mere reduction of all there is to one raw material. For already conventionally everything is reduced to *energy*, which has many kinds of mutually transformable manifestations. Actually, since the action $S = Et$ in a system at rest – $S = Et - \mathbf{p} \cdot \mathbf{r}$ or $S = 1/ic \int_R L \, d\mathbf{r}$ more generally – , *our reduction of everything to action is to a high degree (but not, e.g., as regards making even metric dependent on action, which reflects an even more consistent and radical approach) only a four-dimensional extension of the current reduction of everything to energy.* And, by the way, the transformation of corpuscules into action waves is no more paradoxical than the transformation of matter into energy adopting the form of electromagnetic waves. Neither are the propagation and spreading of matter waves more paradoxical or more difficult to imagine than those of electromagnetic waves.

(i) The present theory may also have to say something preliminary in relation to unified-field theories. For, going into the question what the fields operative in quantal waves may be, we can surmise that they are essentially of a similar nature as the field strengths or potentials with which mesons make nucleons attract each other. Viz. in Ref. 16 we see how mesons transmitting the nuclear force are one-quantal phenomena, the force-transmitting field being the meson matter-wave field *in a similar way as the force-transmitting field of virtual photons is the electromagnetic field.* The fields constituting the internal of the various kinds of action quanta might then be related to the ones embodying various forces between "particles", the electromagnetic field being one among them. This again illustrates the difference between our realistic conception of matter waves and most current ones. The spinorial (and other, compare Section 10) transformability properties of the various fields then still define their difference. Such difference, however, might be less fundamental. For, via one or more interactions the various particles ("fields") and their action quanta can transform into each other.

(j) In Ref. 18, pp. 412-413, it is summarized how the application of symmetry transformations – spacetime ones (sub-groups of the extended inhomogeneous Lorentz group) as well as others, e.g., charge conjugation and phase transformations – to quantized fields (about which we also refer to Section 11) allows one to

a) Restrict the number of possibilities for constructing field equations [compare also (d) above];

b) Classify the fields and corresponding particles into categories (baryons and leptons,... ; as regards spin and charge,...);

c) Derive a number of conservation laws (energy, momentum, electric charge, baryon and lepton number,...) and selection rules.

As regards point b) we also refer to Section 10.

In fact, all the transformations in question relate to fields, or are considered in view of how fields, that is, action quanta(l structures), behave if we apply them. That is, they amount to practising action physics, and to considering symmetry properties as to action structures in particular. From these, the known physical properties meant in a), b) and c) apparently follow in the simplest way. Again, treatment in terms of the underlying action appears to be primary for finding manifest properties of "objects", the latter properties gaining in simplicity and generality in the process. The circumstance that properties (the kind) of associated particles as well as conservation laws reflect themselves in certain (especially transformation) properties of fields, furthermore, is a general manifestation of the fact that the relevant field properties constitute or correspond to the wave-like coded version or embodiment of such particle properties and laws. (Compare here Section 10, especially its fourth paragraph.)

7. Uncertainty margins reflect incomplete information inherent to the wave data code; how complicated atoms can still interfere; physics and biology

The uncertainty margins do not reflect any fundamental uncertainty, indefiniteness, in the "plan of the Universe". In the first place, the truly four-dimensional character of the world excludes any "fundamentally uncertain" outcome of processes. But in the second place, e.g., a wave packet consisting of Fourier components corresponding to a spread Δp as to the momentum, and which, because the relation $\Delta x \approx h/\Delta p$ holds for quantum wave packets already for purely mathematical reasons, has at the same time such finite length Δx (which represents the "uncertainty" margin for a particle's location), does not as such represent any uncertainty. For, it is what it looks like: a realistic wave structure without any fundamentally hidden corpuscule within. As a three-dimensional section of a four-dimensional action-quantal structure, that also reflects action-metrical contiguity relations, it has no more indefiniteness than, e.g., a definite electromagnetic field. E.g., $\Delta x \Delta p_x \geq h$ only reflects the following situation: A wave packet going with the relevant – detailedly articulate – structure cannot simultaneously *encode* precise information about x and p_x in the way we know the code system works.

Generally, we can say that "uncertainties" are inherent to the wave information code: *by its very nature* it appears to be not in a position to (completely) store both x and p_x, both s_x and s_y, etc., at the same time. We can see the general validity of this by realizing that the commutation relations for dynamical-variable operators are integrability conditions for the field equations (see Ref. 18, pp. 32 and 180-189). That is, such relations, that are equivalent to quantization and the uncertainty relations, are inherent to (eigen) wave patterns corresponding to observations. But then these patterns and the relevant information code cannot indeed contain more precise information than corresponds to the uncertainty relations.

We saw that in the coded-information theory it is by no means so that various alternative processes are in some conventional corpuscular way all present at the same time. There are only alternative, superposed, or rather, *incompletely specified, messages* encoded in the one realistic wave pattern. This means that such messages are "poly-interpretable", giving different communications (results) either upon different kinds of measurement (e.g., of s_x or s_z) or simply because only one coherent signal at a time is consistent with the laws of Nature. E.g., only $s_z = +1/2\hbar$ or $s_z = -1/2\hbar$ is consistent, though the wave signal: the phase relation, may be "intermediate".

It is because one started from old conventions about alternative "particle" states that all would be "partly real", or "fundamentally uncertain", that coherent realistic models remained impossible.

In the above connection, we see various examples of incompletely specified information.

(a) In Eq.(2) of Section 5 the completely definite spinor wave $\frac{1}{\sqrt{2}}\binom{e^{-i\beta/2}}{e^{i\beta/2}}$ carries incomplete information for the decision whether $\mid \hat{x} >\sim s_x = 1/2\hbar$ or $\mid -\hat{x} >\sim s_x = -1/2\hbar$ will result from an s_x measurement (unless β is either 0 or π).

(b) A – definite – wave packet with a spread Δp_x as to p_x carries incomplete information as to the precise definition of p_x.

(c) In the situation of Fig. 18, in which the spherically shaped wave packet represents many action-metrically contiguous processes, it is the emission direction, too, that has not been encoded in the waves. It has not been so by the very form of the wave packet.

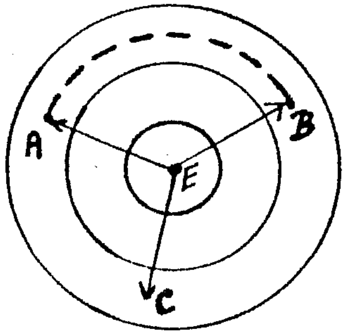

Figure 18. The action-physical difference between particle emissions via EA, EB and EC is zero for the process in question; therefore, Nature indiscriminatingly makes all relevant waves be emitted “at the same time”.

In all the above cases, the information is “too general”. In the (b) and (c) ones, it is incomplete because the wave process does not discriminate between action-physically contiguous alternative processes. The latter are so much equivalent for Nature that it “performs them all at the same time”, i.e., produces all relevant waves.

In connection with the foregoing, the coded-information conception also solves an otherwise insuperable philosophical difficulty: It is impossible to conceive of any reality, physical situation, that is intrinsically uncertain, vague, fundamentally not allowing some rational "blueprint", but it is indeed very well possible to imagine a completely definite wave carrying information which is insufficient, e.g., for reconstructing the value of a spin component or the details of an atomic structure.

Another point clarified by the coded-information theory is the remarkable circumstance that "what we can possibly know" of a system so much appears to have *physical* implications. For this follows from the fact that "what we can know" corresponds to *what information is encoded* in the waves, which is something physically real. E.g., if we are *not in a position to know* the polarization state of each separate photon of an unpolarized beam originating as a random mixture of y- and z- polarized photons, the wave components of such beam have (realistic!) phase relations *different* from those of a beam consisting of a random mixture of y- and z- polarized photons of which we can tell the y's from the z's.

Another "uncertainty" inherent to the wave information code appears if we perform a Young interference experiment with a (complicated) atom. It is not the *atom* that may pass slit A or slit B (or splits up in two halves), but waves carrying information about it pass both A and B, and in interfering they integrate such information according to the superposition principle. Only in this sense the atom "passes both slits", it being translated, reconstructed, into the corpuscular "language" at a relevant measurement. Within the same scope, it can very realistically "reflect on a whole grating".

Note in this connection that already the fact that the wave-length associated with, say, an Ag-atom, $\lambda = h/p$, corresponds to the momentum of the *complete* atom, no trace of the separate nuclear and electronic momenta or even existence being to be found at all in the waves, strongly suggests that the waves themselves do not reflect the "fine structure" of such complicated systems, *a circumstance greatly simplifying our model of relevant interference or grating-reflection processes.* To all appearance, series of slice-shaped action quanta representing complicated systems such as an atom, only consist of "complete-atom-quanta", the fine-structure being washed out in the structure of the information-communication links such series in important respects are. (See Ref. 4 for an explanation of the $\mid \psi \mid^2$ probability rule, also within the scope of interference.)

The various kinds of "unknownness without indefiniteness" discussed above leave one open question: What, in the last resort, determines, say, whether a screen will capture a relevant particle at A, at B or at C of

Fig. 18 ? What does make the choice for some particular corpuscular definiteness? We put two hypotheses:

(a) It is the interaction between the waves and any one out of the potential absorbers that triggers an absorption, i.e., a selection and translation of information at some location, or corresponding to some projected measuring result in general. The action-metrical contiguity of alternative processes then accounts for the "instantaneous collapse or contraction" of the wave packet. (See also Ref. 4.) Note here that such random-choice selection may be completely comparable, also as regards its deterministic nature, with the random-"choice" process governing the falling of dice, with the only difference that nonlocal competition of outcomes and nonlocal communication play a part in the quantum case.

(b) However, we still need the zigzag-communication between emission and absorption events in order to satisfy the conservation laws. E.g., if a particle capture is effected at A of Fig. 18, the recoil at E has to be in the direction AE.

Thus, we have anyhow to invoke a retroactive influence in the process of the determination of an ultimate value of some "uncertain" variable. Of course, it can only operate, define, *within* the relevant uncertainty margin(s) because otherwise causality would be violated. The most obvious assumption is that, in the direct action-physical ("zigzag") contact between absorption and emission events (of which the influence operative in the $-t$ direction is retroactivity), some nonlocal hidden vairable V in the process as a whole constitutes the defining instance. In the hypothetical case that V would obey more specific laws than only being a nonlocal stochastic instance, it may have some *pattern-forming* aspect or influence. E.g., it *might* be the case that its retroactive "component" organizes or orchestrates the "recoils" and other "causes" within various uncertainty margins *in some coherent way.* In this – we repeat, hypothetical – case we would indeed see nonlocal pattern-formation in Nature. Actually the EPR correlation between, say, spin directions constitutes already a simple case of such pattern-formation by a physical law which has a nonlocally coordinating influence.

This means: Really four-dimensional forms of feed-back – feed-back in the $-t$ direction, too – , using the zigzag-communication "pipe-lines", cannot be excluded. It is such feed-back which would give rise to the hypothetical pattern-formation mentioned if its – *naturally more-than-local*, "integrative" – laws would be sufficiently specific and exacting.

It might be that the relevant pattern-forming instances are at the root of essential biological and intelligently coordinated processes. E.g., the human brain might be the most sophisticated example of the nonlocal, process-integrating, coordination that we see in a simple form in an EPR situation.

There are retroactivity and nonlocal communication in "dead" Nature; there are pattern-organizing instances, intelligence and consciousness in the living Nature. Could some possible link exist ? Are we at the root of concepts like organism and purpose here ? Or does consciousness spring from the mere "agglutination of dead atoms" ?

In any case, we can assume that even a "random" definition of measured variables within their uncertainty margins is nonlocally performed by the whole, integrated process (via the zigzag communication). *This* is the "hidden variable". Mind here that the idea that such variables are always completely determined by the *local* interaction between the waves and a measurement instrument, that is, by local hidden variables, cannot be reconciled with the (nonlocal) quantum correspondence between, say, the angular momenta of two correlated EPR systems [8].

Generally, we see that the local action quanta (slices) can be very simple and unspecified as compared to the interaction they play a part in, so that *non*local, partly retroactive, instances have to play a completing part, too. Such completion by "the whole process" relates to both making a definite choice within the uncertainty margins (as to momentum etc.) and the specification of some definite properties of the system "carried" by the waves (e.g., its atomic structure). In both respects the waves contain a minimum of information, they are optimally simple and details are not locally stored in them, but have to be completed by the process as a whole, *which in these respects is a whole in Bohr's sense indeed.*

Mind in this connection that it is more easy and obvious to accept the unspecifiedness of the waves as to, e.g., the detailed structure of atoms – which has actually been introduced by the present theory – after having accepted the waves' other unspecifiedness, viz. the well-known and evident one relating to the traditional "uncertainties" about momentum, spin etc. *We need a nonlocal, process-integrating instance anyhow, which completes information locally encoded in the waves.*

8. The physical meaning of complex quantities; again the factor $e^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})}$; how operators fit into the coded-information theory and correspond to realistic, imaginable models

How can a realistic physical variable be represented by a complex quantity ? We can best explain this by means of a simple example, viz. the four-vector $\mathbf{x}_{(4)} \equiv (x, y, z, ict)$. Does the important part it plays in Nature – in our formulas and laws – mean that there is a realistic physical variable $\mathbf{x}_{(4)}$ or that ict is more realistic than t ? It does not. The important part played by $\mathbf{x}_{(4)}$ only reflects the circumstance that many physical situations and relations can most simply be described and researched by using the facts that (x, y, z, ict) consistently behaves as a "four-vector" whereas (x, y, z, ct) does not, and that $s = \sqrt{x^2 + y^2 + z^2 + (ict)^2} = \sqrt{x^2 + y^2 + z^2 - c^2t^2}$ is a Lorentz invariant figuring in important relations. That is, the physical laws about the real variables x, y, z and t get their simplest form by coordinating them in the "non-realistic", mathematical Minkowski space with orthogonal x-, y-, z- and ict-axes. *Real* four-dimensional space may have the axes x, y, z and t, but physical laws would be more complicated if formulated in it. *In this sense, Minkowski space is the most simple and familiar "representation space"*: Though it does not exist realistically, many physical relations get simpler if we coordinate the relevant variables in it than if we do so in a "realistic" system.

Essentially, we have the same thing with respect to the important complex factor $e^{i/\hbar S} = e^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})}$ appearing in quantum theory. It does not describe some "complex" wave. It actually describes two very real sinusoidal waves:

$$e^{i/\hbar S} = \cos\ \frac{S}{\hbar} + i\ \sin\ \frac{S}{\hbar},$$

in which the waves $\cos\ S/\hbar$ and $\sin\ S/\hbar$ evidently relate to each other in such a way that the laws governing their interference and other behavior can best, most simply and coherently, be formulated by integrating the two in the formula $e^{i/\hbar S}$ [compare x, y, z and t, and their integration in $\mathbf{x}_{(4)}$, in the above example]. In fact, we also see such kind of integration in the electromagnetic field tensor with elements such as iE_x figuring in it, E_x being a field strength. Of course, it is actually the quantum field equations that imply the "strangely complicated" law interrelating $\cos\ S/\hbar$ and $\sin\ S/\hbar$, viz. by their having spinors with the factor $e^{i/\hbar S}$ as solutions.

Nevertheless, there is something inveracious in Nature's relating two simple waves in so "twisted" and unimaginable a way as implied by the prominence of the factor $e^{i/\hbar S}$. We have to remind here, however, of the fact that actually the wave phenomena described by formulas like $\begin{pmatrix} \phi_1 \ e^{i/\hbar S} \\ \phi_2 \ e^{\pm i/\hbar S} \end{pmatrix}$ appeared to be isomorphic translations, encodings, of a spherical rotation. That is, in re-translating the wave structure, or code, of the two interrelated sinusoidal waves into the spherical rotation process, the mutual coherence between these two waves via $e^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})}$ again fits positively into a realistic, understandable model. Generally, one can easily acquiesce in complicated, rather unimaginable phenomena and laws if they actually embody an encoding translation of an understandable and simply coherent model. The rules of human language – also consistently corresponding to natural objects, concepts, etc. by encoding their information – would look pretty well "laboured" and far-fetched if formulated in mathematical language, too.

As to the concrete physical process of the transition of particles from the "double-helix" state discussed in Section 5, point 4. to the wave state we may (very speculatively, because the dumbbell shape is *not* inherent to a spherically rotating entity !) venture that the movements of the two bound photons – which have a phase difference of $1/2\pi$ if we consider one action-quantal period of 2π to correspond of two rotations – correspond to the two waves cos $S/\hbar$ and sin $S/\hbar$, respectively, that have also a phase difference of $1/2\pi$ and are inseparable, too. The "connecting" formula $e^{i/\hbar S}$ of such waves then implies the wave translation of the "photon" binding mechanism. As indicated earlier, the critical point for the translation to the wave-like state will appear when a particle is "set free" and the action-metrically defined "stretching" becomes relevant within the scope of what we discussed with Fig. 17. The double helix may then stretch into a system of two bound sinusoidal waves, as an embodyment of the isomorphism of Section 4.

We now start showing how operators – typical "formalistic" entities hitherto not connected with realistic models – generally fit into the coded-information theory and, therewith, can be integrated into a realistic, understandable quantum theory. Our crucial point is that there is a direct connection between the following two isomorphisms or translations:

(a) The one between the spherical rotation of some manifold and the 2-spinor $\begin{pmatrix} \phi_1 \ e^{i/\hbar S} \\ \phi_2 \ e^{i/\hbar S} \end{pmatrix}$ (or the Dirac 4-spinor), or between the quanta of corpuscular scalar particles and one-component wave-slices characterized by the factor $e^{i/\hbar S}$, and

(b) The one between the classical, macro- or Minkowskian, and the quantum formulation of dynamical variables and influences bearing on or acting on a microsystem. That is, the translation between on the one hand such influences relating to a microsystem that have repercussions for its wave function ψ (coordinate transformations, system translations or rotations, ...), and dynamical variables figuring in equations governing such system $(E, p, x, ...)$, as both of them are formulated in *classical* language, and on the other hand these influences and variables as they are formulated in the *quantal* language of ψ. In the quantum formulation, *(linear) operators acting on the wave function* appear on the scene.

Since the operators originating from the translation at stake also define the eigenvalues of wave equations, the isomorphism in question relates to *measurements* among the above-mentioned influences, too.

We know that the isomorphism of (a) corresponds to a translation into each other of the two alternative ways of manifestation of the elementary event, the quantum of action, and of series thereof (momentum carriers). In order to understand the meaning of (b) we first consider some specific cases.

(i) In differentiating a general wave function

$$\psi(\mathbf{r}, t) = \int F(\mathbf{p}) e^{-i/\hbar(Et - \mathbf{p}\cdot\mathbf{r})} d\mathbf{p}$$

we get

$$i\hbar\frac{\partial}{\partial t}\psi(\mathbf{r}, t) = \int EF(\mathbf{p})\, e^{-\frac{i}{\hbar}(Et-\mathbf{p}\cdot\mathbf{r})} d\mathbf{p} = e\psi(\mathbf{r}, t)$$

$$\frac{\hbar}{i}\nabla\psi(\mathbf{r}, t) = \int \mathbf{p}F(\mathbf{p})e^{-\frac{i}{\hbar}(Et-\mathbf{p}\cdot\mathbf{r})} d\mathbf{p} \approx \mathbf{p}\psi(\mathbf{r}, t)$$

(As to the $\approx$ sign, note that $\mathbf{p}$ is roughly constant in the integration.) From this, we see the correspondences $i\hbar\partial/\partial t \sim E$ and $\hbar/i\nabla \sim \mathbf{p}$ as regards operation on ψ, which appear in consequence of the crucial wave factor $e^{-i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})}$. (We use $e^{-i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})}$ here; in the relativistic case, both $e^{-i/\hbar S}$ and $e^{i/\hbar S}$ can appear.)

Further, e.g., the Klein-Gordon equation directly results from substituting $i\hbar\ \partial/\partial t$ and $\hbar/i\ \nabla$ for E and $\mathbf{p}$, respectively, in $E^2\psi = (p^2c^2 + m^2c^4)\psi$:

$$-\hbar^2\ \frac{\partial^2}{\partial t^2}\psi = -\hbar^2 c^2 \Delta\psi + m^2 c^4 \psi.$$

The essential point is here that *the translation of (a) above remains in a simple way consistent with known laws* (such as $E^2 = p^2c^2 + m^2c^4$) *if we complete if by* $E \rightarrow i\hbar\ \partial/\partial t$ *and* $\mathbf{p} \rightarrow \hbar/i\ \nabla$. [In view of (b) note here that operators acting on ψ in a wave equation such as

$$i\hbar\ \frac{\partial}{\partial t}\psi(\mathbf{r},t) = \left[-\frac{\hbar^2}{2m}\Delta + V(\mathbf{r})\right]\psi(\mathbf{r},t),$$

besides representing dynamical variables figuring in the equation, can indeed also stand for influences on ψ from the outside. Viz. $V(\mathbf{r})$ is an "outside" potential (originating from the macro-environment) that co-constrains, co-enforces, ψ to assume its actual form.]

(ii) In Ref. 12, p. 52 and in Ref. 19, pp. 188-193 it is derived for the wave function that

$$\psi_\alpha(\mathbf{r} - \boldsymbol{\rho}) = e^{-\frac{i}{\hbar}\boldsymbol{\rho}\cdot\mathbf{p}}\psi_\alpha(r),$$

in which $\mathbf{p} = -i\hbar\nabla$.

It is shown that the operators $U_r(\boldsymbol{\rho}) = e^{-i/\hbar\ \boldsymbol{\rho}\cdot\mathbf{p}}$ form a group that is isomorphic to the group of displacement vectors $\boldsymbol{\rho}$. The operators $U_t(\tau) = e^{i\tau H/\hbar}$ (where H is the operator $i\hbar\ \partial/\partial t$) extend this to time displacements, so that general spacetime displacements as a group can isomorphically be translated into operators acting on ψ, that is, operators *referring to the information code going with the wave manifestation of action quanta* and of the "objects" they constitute or represent. Mind that the displacement $\boldsymbol{\rho}$ here may either correspond to a displacement of the physical system or to a coordinate transformation. In both cases the corresponding operator represents what operation on the wave (function) makes it reflect, incorporate, such variation of the physical or the coordinate system.

(iii) E.g., in Ref. 18, pp. 95-97, we see that spatial rotations – again of either the physical or the coordinate system – are reflected in, or translated in the language of, a more-component spinor wave function ψ by that the latter's local variation (the exact definition of which is not relevant here) is

$$\partial^* \psi = \frac{1}{2} \epsilon_{ik} \left[(x_i \frac{\partial}{\partial x_k} - x_k \frac{\partial}{\partial x_i}) + I_{ik} \right] \psi.$$

Here the ϵ_{ik} are infinitesimal rotation parameters and $x_i \frac{\partial}{\partial x_k} - x_k \frac{\partial}{\partial x_i}$ is the orbital angular momentum operator. What is important for us is that the spin matrix or operator I_{ik} rearranges the components of ψ in the rotation considered. Again, both the orbital angular momentum operator and the spin operator reflect transformations of, or repercussions on, the wave function if a "classical" or Minkowskian physical or coordinate transformation takes place which relates to the physical system in question.

As regards example (iii) we see that if one infinitesimally rotates the physical system, the I_{ik} indicate how, as a repercussion, the information contents of ψ – that is, of the action-quantal structure – as to spin adjusts itself to the new coordination situation of the system, viz. by a rearrangement of spinor components.

We can generalize this: "The fact that the generators of infinitesimal symmetry transformations [of the wave function ψ_α] are equal to recognizable dynamical variables in the simple situations thus far considered suggests that they be used to define dynamical variables in more complicated situations" (Ref. 19, p. 197). Within the scope of the coded-information theory this refers to the fact that *generally* the dynamical variables of the macro language or corpuscular code find their counterpart, or translation, in the wave information code in the operators (matrices) the generators are, and of which the operators $i\hbar\, \partial/\partial t$, $\hbar/i\, \nabla$, $x_i\, \partial/\partial x_k - x_k\, \partial/\partial x_i$ and I_{ik} of (i) and (iii) above are examples.

Now, e.g., I_{ik} represents, or is defined by, *information inherent to ψ_α, i.e., the information embodied by how the micro-process M which ψ_α represents reacts to* (in this case) *an infinitesimal rotation.* Such "inherent information" in particular refers here to the *relation* of M to its macro-environment (with respect to which it rotates): How does M *reflect* transformations or variations of variables of the macro-environment. "Reflection factor" or generator I_{ik} represents ψ's, or M's, reaction with respect to infinitesimal rotations and, therewith, also appears to represent the *spin* of M (apart from a factor $\hbar/i$). In our theory, this means: I_{ik}, in corresponding to certain component relations of, or in, spinor wave ψ_α, reflects *how the spin information is encoded in the wave structure M* (viz. by such relations). Similarly, e.g., $\hbar/i\ \nabla$ does so with respect to the momentum $\mathbf{p}$. Let us see in more detail how it does reflect the code $\lambda = h/p$ for p in defining the reaction of M's waves to a translation Δx:

$$\frac{\Delta\psi}{\Delta x} \approx \frac{d\psi}{dx} = \frac{d}{dx}\ Ce^{-i/\hbar(Et-p_x x)} = \frac{i}{\hbar}\ p_x\ Ce^{-i/\hbar(Et-p_x x)} = \frac{i}{\hbar}\ p_x\ \psi$$

(C is an irrelevant factor; for simplicity, we take $p = p_x$ here, and we may write $d/dx = \partial/\partial x$). That is, $\Delta\psi = i/\hbar\ p_x\psi\Delta x$ and $\hbar/i\ d\psi/dx = p_x\psi$. Thus, p_x is represented by $\hbar/i\ d/dx$ because of the wave factor $e^{-i/\hbar(Et-p_x x)}$, *in which $\lambda = h/p_x$ is contained, that is, encoded.* So $\hbar/i\ \partial/\partial x$, discounting how p is encoded in the waves, reflects how the wave system ψ reacts to the variation Δx of x, as an aspect of its relation to its environment and its internal structure.

Generally, the dynamical variable operators, such as for momentum $\mathbf{p}$, energy E and total angular momentum $\mathbf{J}$, constitute a kind of *conversion or "proportionality" factors*, or translation coefficients, between on the one side variations of the complementary variables $\mathbf{x}$, t and $\boldsymbol{\phi}$ (angle) of such $\mathbf{p}$, E and $\mathbf{J}$, respectively, in the macro environment, and on the other side the repercussions thereof on the wave structure, these factors *reflecting the wave information code* for $\mathbf{p}$, E and $\mathbf{J}$. It will appear below that it is not accidental that the "complements" $\mathbf{x}$ and $\mathbf{p}$, etc., have always a product of dimension action.

Well-known theory derives that, similarly to how $\hbar/i\ \nabla$, I_{ik} and J_{ik} are generator-operators of *infinitesimal* variations of the dynamical variables distance and angular position, respectively, the operators $e^{-i/\hbar\ \boldsymbol{\rho}\cdot\mathbf{p}}$, $e^{-i/\hbar\ \boldsymbol{\phi}\cdot\mathbf{I}}$ and $e^{-i/\hbar\ \boldsymbol{\phi}\cdot\mathbf{J}}$ correspond to the *finite* variations $\boldsymbol{\rho}$ and $\boldsymbol{\phi}$; note that $\mathbf{p}$, $\mathbf{I}$ and $\mathbf{J}$ are *operators* here ($\mathbf{p} = \hbar/i\ \nabla$, ...).

In order to get insight into how the translation of macro-variations like $\boldsymbol{\rho}$ and $\boldsymbol{\phi}$ into the action structure represented by ψ_α (that is, into action wave language) proceeds in detail, we consider the simple case in which ψ_α is scalar:

$$\psi(\mathbf{r},t) \to \psi(\mathbf{r}-\boldsymbol{\rho},t) = e^{-i/\hbar\ \boldsymbol{\rho}\cdot\hbar/i\nabla}\psi(\mathbf{r},t) =$$

$$\left[1 - \frac{i}{\hbar}\ \boldsymbol{\rho}\cdot\mathbf{p} + \frac{1}{2!}(\frac{i}{\hbar}\ \boldsymbol{\rho}\cdot\mathbf{p})^2 - \dots\right] Ce^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})} = Ce^{i/\hbar\ \boldsymbol{\rho}\cdot\mathbf{p}}e^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})},$$

where $\mathbf{p}$ is everywhere a three-vector now. [Compare here example (ii) above as the more general case.]

That is, the space shift $\mathbf{r} \to \mathbf{r} - \boldsymbol{\rho}$ simply translates, as to ψ, *as an action "shift"* $\boldsymbol{\rho} \cdot \mathbf{p}$ now, which changes the phase exponent in $e^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})}$ by $i/\hbar\ \boldsymbol{\rho} \cdot \mathbf{p}$. Similarly, we see a time-shift $t \to t - \tau$ translate into *an action shift* $E\tau$ via the operator $i\hbar\ \partial/\partial t$. *Then, we see here that* $\mathbf{p} \sim \frac{\hbar}{i}\nabla$ *and* $E \sim i\hbar\ \partial/\partial t$ *are isomorphisms which very directly join with the one between spherical rotation and spinor waves* [which in our simple scalar case are essentially reduced to the factor $e^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})}$].

In the most general case of, say, angular momentum the corresponding operator $e^{i/\hbar\boldsymbol{\phi}\cdot\mathbf{J}}$ ($\mathbf{J}$ being a matrix operator now) effects two things: (i) similar action-shifts $\phi_i J_i$ in exponents S of factors $e^{i/\hbar\ S}$ figuring in ψ's field components as we saw above (where we had $\boldsymbol{\rho} \cdot \mathbf{p}$ and $E\tau$), and additionally, as a consequence of $\mathbf{J}$'s matrix character, (ii) a rearrangement of such components. Mind that, still, it is a rotation $\boldsymbol{\phi}$ that translates into such two action effects on the wave system via $\mathbf{J}$. (It is now clear why "complementary" variables such as $\boldsymbol{\phi}$ and $\mathbf{J}$ will have a product of dimension action.)

The above example about the operator $e^{-i/\hbar\ \boldsymbol{\rho}\cdot\mathbf{p}}$ ($\mathbf{p} = \hbar/i\ \nabla$), combined with the analogous case $e^{i/\hbar\ \tau H}$ ($H = i\hbar\ \partial/\partial t$), shows again how spacetime shifts $(\boldsymbol{\rho}, \tau)$ in Minkowski space translate into action shifts or distances $E\tau - \boldsymbol{\rho} \cdot \mathbf{p}$, which we saw to be so important in Section 2. The other example, about $\boldsymbol{\phi} \cdot \mathbf{J}$, makes us see that *the translation of spacetime shifts into action-metrical shifts* $Et - \mathbf{p} \cdot \mathbf{r}$ *is only a special case of the more general fact embodying that variations of other Minkowskian variables can be translated into action quantities, into terms of "amounts of occurring" as they play a part in* ψ*, too*, which is crucial for understanding how Nature functions in systems in the wave state. Or: the translation into the more relevant action metric of the Minkowskian one is only a special case of the translation we discuss here. (Of course we can have that the action "repercussion" is zero. This appears, e.g., with a spacetime shift such as PQ in Fig. 4, or can happen in a measurement-operation with which ψ is in an eigenstate of the relevant variable.)

Such translation, via the "conversion" operators, of variations of classical (Minkowskian) dynamical variables – which variations are *events*; e.g., a spatial shift $\boldsymbol{\rho}$ of a micro-system M with momentum $\mathbf{p}$ amounts to an event implying an action $\boldsymbol{\rho} \cdot \mathbf{p}$ – into terms of their action repercussions on the action-quantal structure represented by ψ, makes M fit for our managing its action-physical properties and the action-physical laws directly, in particular in "representation spaces", where influences on and transformations of ψ are translated into rotations of the "state vector" $\mid \psi(\mathbf{r}, t) >$ (see Section 9). Also in view of the preceding paragraph *we saw such direct management already with action metric*, as a special case. The generators, "translation coefficients", which correspond to the spin, momentum, etc. of M, and which define the action repercussions on M of a shift as to the relevant complementary variables $\boldsymbol{\phi}$, $\mathbf{r}$ etc., generally represent therewith *how such spin, momentum etc. are encoded in the waves of* M, as described by ψ.

We have to realize that there is no "unimaginably formalistic" aspect to the fact that, in the "translations" we discuss, the dynamical variables are represented, of all things, by *operators*. For, it is operators that generally represent operations on functions, i.e., repercussions on ψ in our case.

After the above examples and generalizing discussion on the role of operators representing dynamical variables and transformations, we can draw general conclusions about the relation between the two isomorphisms (a) and (b) considered above:

I. Isomorphism (a) translates the information about (series of) action quanta from the corpuscular, "classical", into the wave form, the two forms bearing upon *alternative* physical states of a micro-system M, which do not exist at the same time.

II. Isomorphism (b) by means of the operators translates *influences, operations*, from outside which have relevance to M, and which are formulated in classical language, in an information-conserving way into the wave information code in which M's wave function ψ is formulated, so as to formulate *the repercussions on* M in such code, which at the same time partly means: in terms of action.

Both the classical and the "coded" form of the relevant data now exist *at the same time*; we have two descriptions of the same operation or transformation (such as a rotation of M) which relates to both the macro scheme (and the instrument) and M's quantal structure: The former description bears on the first one, the latter on the second. Or, the relevant outside influence or macro-transformation on the one side plays a part in the macro, Minkowski scheme, and on the other side it interferes with or relates to M's coded data.

III. That is, (a) and (b) are not completely analogous, but complementary translations between two information codes. They complete each other, therewith at the same time guaranteeing a smooth transition between the micro, quantal, language of M and the classical one of the macro environment. Thus, the precise nature of (b) also guarantees that the correspondence principle is satisfied. For, of course natural laws are so that a smooth transition and translation between the two information codes is guaranteed. Both the operators at stake here and the correspondence principle play an important part in this, as mutually interrelated particular cases, or examples.

Within this scope, *inter alia*, we can also say that the translations $p_x \to \hbar/i\ \partial/\partial x$ etc. and $E \to i\hbar\ \partial/\partial t$ make sense "simply" because the operators satisfy the same commutation relations with the coordinates and with each other as the p's and E do, and because we also get an analogy between the classical equations of motion in Hamiltonian form and the quantum equations of motion in the Heisenberg form on translating this way (see, e.g., Ref. 20, pp. 91, 92, 113 and 114). In so translating, we retain the same algebra; that is, the isomorphism of Section 4, or (a) above, bearing on the action quanta, is thus consistently extended and we get two completed corresponding information codes, with a smooth transition between them.

Still, in many cases such extension by (b) operators is rather direct and imaginable. E.g., a rotation of a 2-spinor system M on the z-axis through ϕ is translated, within the scope of (b), into the spinor-wave phase changes and component rearrangements effected by the operator

$$e^{i/\hbar\ \phi J_z} = I + \frac{i}{\hbar}\ \phi\ J_z + \ldots = \begin{pmatrix} e^{1/2\ i\phi} & 0 \\ 0 & e^{-1/2\ i\phi} \end{pmatrix},$$

because $J_z = 1/2\hbar \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$; the phase changes $1/2\ i\phi$ effected in ψ factors like $e^{i/\hbar\ S}$ amount to action shifts of $1/2\ \phi\hbar$. *This translation indeed rather directly links up with the isomorphism (a) between a spherically rotating entity and spinor waves, all this, moreover, making the whole of action physics and the coded-information situation a lot more transparent.*

IV. Nevertheless, we generally need no more asking for *conventional* imaginable models with respect to the operators acting as intermediates here than we need doing so about the wave code at all. We merely need models in a similar sense as we have them in relation to the genetic code mentioned earlier in this connection, or – to make the comparison more direct – with respect to a reorganizing, correcting, intervention into a letter describing a physical situation that (i.e., the intervention) observes the rules of its grammar. Still, the realistic medium of the information in both codes, and the one to which also the operators relate, is the action quanta and the field potentials constituting their fine-structure. These are the basic stuff of the Universe.

V. We on the one side need only require consistency, simplicity and homo- or isomorphism with respect to the two information sets to be mutually translated, and on the other side the smooth correspondence between (or smooth mutual translation of) them, as spoken of in III.

We saw an exemple of such smooth correspondence in (i) above, regarding the correspondence between classical and quantum equations of motion. But such correspondence considerations apply generally (compare again III).

VI. One might think that x in operators like $\hbar/i\ \partial/\partial x$, and $F(\mathbf{p})$ in the formula

$$\psi(\mathbf{r},t) = \int F(\mathbf{p})\ e^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})} d\mathbf{p}$$

as well as, e.g., potentials in the field equations, violate our thesis that everything in the world, and certainly in a micro-process, can be formulated in terms of action. Mind then, however, that the above quantities x and $\mathbf{p}$, though not being derivable from the action structure of *the relevant micro-process*, refer to the macro world or Minkowski scheme which, in turn, reflect the rough result, "common denominator", of all micro-processes combined and, therefore, are also action phenomena in the last resort. Thus, the forementioned x, $\mathbf{p}$ and potentials here represent an aspect of the relation between the micro-process M in question and the macro-environment, too, which aspect may be implicit in M's wave function and equation.

9. Representation spaces as action-structure-based coordinate systems allowing an economical processing of coded information

The wave function $\psi(\mathbf{r},t)$ represents an action structure in Minkowski space which constitutes a micro-process M. Often we only consider its three-dimensional "now"-sections. Now a representation space R is an abstract space or coordinate system (like, e.g., phase space) in which essentially the manipulation of *events*, action, and its constituents: field strengths, is primary, viz. in two respects:

(i) If we have, say, $\psi(\mathbf{r},t) = \sum\ c_i\psi_{E_i}(\mathbf{r},t)$, where the $\psi_{E_i}(\mathbf{r},t)$ are energy eigenfunctions, this illustrates that the simple, linear, superposition and, conversely, decomposition or projection, of field strengths constituting action quanta [and, therewith, of *whole processes* $\psi_k(\mathbf{r},t)$], are elementary operations. That is, events rather than objects are the elements that can most directly and simply be processed. So, the superposition principle is at all a manifestation of the primacy of events and their direct relations. (It is not essential that in practice the above-mentioned now-sections will mostly be used.)

(ii) The other primary operation is rotation of the state vector $\mid\psi(\mathbf{r},t)>$ in R. That is, actions on ψ by operators, as discussed in Section 8, manifest themselves in R as orthonormal matrix multiplications of ψ as a resultant of base eigenvectors. E.g., a rotation of a 2-spinor physical system through ϕ on the z-axis in Minkowski (or Euclidean) space translates in R in such combination of phase ($\sim$ action) shifts and a field-component rearrangement as is represented by the multiplication of $\mid\psi>$ by $\pm\begin{pmatrix} e^{1/2\ i\phi} & 0 \\ 0 & e^{-1/2\ i\phi}\end{pmatrix}$ (compare Section 8, III). A priori, action (phase) shifts and rearrangements of field components or information-chunks (see below) are the basic operations possible on an action-quantal structure (wave function).

Actually, linear superposition and decomposition are similarly the elementary modes or determinants of interaction between action quanta appearing in the wave form – or rather, between their constituents, the field strengths, that are at the same time the primary wave-code information symbols, data elements (compare Section 5) – as conservation of energy and momentum are so in the interaction of objects, e.g., in collisions. *The superposition principle reflects the elementary way of composing data in the wave-like information code.* Note that the field strengths as the elementary data symbols contain *all relevant local information* because ψ does so. [In representations other than the most "realistic", $\psi_\alpha(\mathbf{r},t)$, one – most realistic because it allows forming an idea of action quanta and their structures in Minkowski space – , such as $\Phi(\mathbf{p})$, the information stored in the quantum structure is reflected by another "field strength".]

It is not only the action quanta, but also complete *alternative processes* as represented, e.g., by the ψ_{E_i} that constitute data-"chunk" elements of operation, i.e., superposition or projection. We saw already that the latter is merely a coherent selection of information from the complete coded message. E.g., in the example of Section 5, point 3. we saw (the information about) *two alternative processes*, represented by the spinors $e^{ik}/\sqrt{2}\begin{pmatrix}1\\0\end{pmatrix}$ and $e^{ik}/\sqrt{2}\begin{pmatrix}0\\e^{i\beta}\end{pmatrix}$, respectively, being superposed. Such processes were "the particle passes A" and "the particle passes B". From the result, e.g., $s_x = 1/2\ \hbar$ can be "projected".

We see R appear as a coordinate system in which events can most easily and directly be processed, which again – in view of R's specific usefulness in researching micro-processes – reflects the primacy of events over objects (the latter being not even relevant in R). *R directly refers to action physics and the wave data code.*

Both (i) and (ii) above reflect this. For it is not only the superposition principle, but also the fact that influences from outside (rotations in Euclidean space, measurements,...) on ψ as represented by operators simply translate in R as state-vector rotations, which examplifies that *R is attuned to making action relations, and outside influences on M that are translated into the wave data code, the simplest and the most directly visible and processable.* Thus, the isomorphisms (a) and (b) of Section 8, combinedly embodying a translation of "conventional" process models into action-slice physics and the corresponding data code, give life to the representation-like translation and coordination of events. This explains the function, and usefulness for getting results, of representation spaces. They allow the direct processing of microprocesses and outside influences in terms of action-physical quantities (such as actually the operator $\begin{pmatrix}e^{1/2\ i\phi} & 0\\ 0 & e^{-1/2\ i\phi}\end{pmatrix}$), properties (such as the wave code: $E \sim \nu$, $p \sim \lambda$,...) and laws (such as the superposition principle).

Note here that indeed *both* ψ – the original process – and operators like $\begin{pmatrix}e^{1/2\ i\phi} & 0\\ 0 & e^{-1/2\ i\phi}\end{pmatrix}$ above represent events; the latter operator represents a rotation *process* whereas $1/2\ i\phi$, in coherence with this, represents an additional action term in factors like $e^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})}$ in ψ. Generally, dynamical variable operators represent action effects. So, of course, do measurement-events that may project $\mid \psi >$ into an eigenstate.

Though ψ still really represents an action-quantal structure in Minkowski space, the usefulness of a Hilbert representation space R for studying a microprocess M, as obvious from the foregoing, is even enhanced by the fact that various base-vector systems are optimally appropriate tools for dealing with different kinds of measurements, respectively. This situation appears from the very circumstance that *R directly deals with M in terms of action (events) and its relevant information code*, apparently including those of *measurement*-events. (Mind here that it is action and its information code from which everything in Nature – variables, measurement results,... – derives.) It is by such particular information code, in which information "chunks" corresponding to alternative measurement results are *all at the same time (incompletely) contained in $\mid \psi(\mathbf{r}, t) >$*, that the "projection" phenomenon can take place in measurements. The extremely economic nature of this code allows various internally coherent relevant chunks of information to be selected by an observing instrument. A beautiful example is constituted by the spin one of Section 5, point 3. The chunks correspond to eigenstate-projections of the state vector $\mid \psi(\mathbf{r}, t) >$. The mathematics of finding eigenstates and eigenvalues is included in this physics *which actually is informatics.* The latter – physically consistently – implies that repeated identical measurements on an eigenstate do not change it.

Again, the economics of R's, and action's, way of "data storage and retrieval" appears in that the various base-vector systems, or similar-chunk systems, as mentioned above, can be transformed into each other by applying rectangular matrices. Thus, by simply reorganizing M's information into another superposition of "chunks", its response to another, corresponding, kind of measurement can better be predicted.

We already pointed out that there is a potential implication of retroactivity in the information selection as considered above. E.g., the momentum at an emission has to be attuned to an absorber's "selection". For details see Ref. 11. In particular it is shown there how in a certain experiment only a *combination* of information from two sources consistently produces the information corresponding to a photon helicity of $+\hbar$, so that the latter has to be retroactively produced instead of being classically transported to the location of measurement. For the rest, energy etc. are not classically "conveyed" either.

The properties of wave functions and operators in representation spaces are already implied by the simple form of the wave equations and commutation relations. E.g., the orthogonality of eigenfunctions (also a property of *events*) and the superposition principle are so implied. Thus, the mathematical simplicity and straightforwardness of the *informatics*, in the shape of such equations and relations, define the way of proceeding of the corresponding physical processes and operations on them from outside.

In the foregoing, we considered representation spaces the base vectors of which are "simple" wave functions corresponding to realistic action-quantal structures. However, there is no fundamental difficulty, from an informational-mathematical and *therefore* physical point of view, in operating representation spaces of a more complicated transformational character, say, with base vectors that do not correspond to "realistic" wave functions (which represent a real action-quantal structure) but to products, or derivatives, of such functions. They can equally serve as abstract tools for information processing.

Summarizing, we can say that representations, starting from the isomorphisms (a) and (b) of Section 8, and the corresponding mathematical tools – the state vector representing an action-quantal structure, square matrices representing dynamical variables or transformations, and rectangular matrices changing the base – embody the organization, coordination, and processing of action-quantal slice structures, events, and the information as encoded in them, in such way that the action-physical properties of a micro-process M can more directly be researched, M becoming more transparent by this. Still, such (re)organization etc. generally produce only probabilities, precise outcomes being co-determined by the earlier discussed nonlocal "hidden variables".

After the foregoing discussions, *the connection between our theory* – about the role of events and action (metric), and about coded physical data – *and the current quantum formalism has essentially been made.*

Note again that, in arguing about exercising influences on wave functions, we do not contradict the earlier thesis that "the future is already existent". For each intervention has been counted in such future, as have been retroactive effects. Note further that, though operators may formally deal with a physical system (ψ) at one instant of time, they generally interfere with the process as a four-dimensional action structure, even in cases implying an "instantaneous" contraction of the state vector.

It also became even clearer why quantum theory and its formalism are so “formalistic”, so long resisting all endeavours of really understanding. For, e.g., representation space and its relevant variables, apart from relating to such very realistic entities as wave packets, have more similarity to a frame for the processing of coded data like the ones of computer languages than to traditional models of objects and fields. *This, fundamentally, together with our not realizing the primacy of events and its consequences such as action metric, is at the origin of the impossibility, hitherto, of constructing understandable models and of getting the Aha-Erlebnis.*

The relevant informatics, in dealing with coded data, in particular relates to the rules according to which obervers – or rather, instruments – can derive information from the action structures and “state vectors”. *No “new way of thinking”, complicated sub-quantum levels or quantum potentials have anything to do with it. On the contrary, essentially all of this is simpler than particles could ever behave.* Neither is there any special status of observations in comparison with unobserved physical phenomena other than the fact that phenomena which are or can be detailedly observed will often appear in the “classical” or corpuscular action state. Observations are a special case of “absorptions”, with retroactive aspects included.

To a high degree we can say that the quantum formalism is a translation algorithm for expressing action laws and data codes in classical or otherwise operative terms, such as, e.g., the quantum equations of motion are operative, practicable, translations of an action property, viz. the Least Action Principle. It is in particular the “distortions” often going with such translations – and of which the deforming of Minkowski metric as compared with the action one is a radical example – that frustrated endeavours at constructing understandable models so much, and made many quantum laws and operations look mere formalism. Only after retranslation into action terms of the phenomena as they manifest themselves to us the simplicity and coherence will become visible. Also note here that the indivisibility of the quantum of action – and therewith the typical quantization phenomena in general – becomes much simpler to understand if we think of action quanta as realistic elementary building blocks of four-dimensional events, processes.

The theory of putting action, its metric and its information code(s) first and foremost, offers a radical, all-in-one-strike explanation of the formalistic, unimaginable character of quantum conceptions and operations. In the past half-century, quantum mechanics, field theory, Grand Unification Theories etc. became so complicated that if we conceive them to correspond to some physical reality in any other sense than their largely being the mathematics of information codes, they simply seem too laboured for ringing true. Then, they look too much like the Ptolemaean system.

Generally, optimally economical – that is, intelligent – storage, transmission and processing of information is central in Nature; its laws and language are attuned to it, instead of to conventions based on our usual experiences.

We already compared representation space to Minkowski space. In the latter *abstract* space – think of the axis *ict* – various natural laws and relations get a simpler, more relevant form than in the real space (x, y, z, t). As in quantum representation spaces, orthonormal transformations play an important part in it, which also again accentuates Nature's aspiring at simplicity. In both Minkowski and quantum representation spaces complex quantities and operators only reflect properties of and relations between real entities.

10. Isospace as one more representation space, again examplifying how an abstract formalism can economically process physical information encoded in realistic action quanta

Another example of the fundamental principle of representation spaces can be found in *isobaric* space, in which the mathematical processing of information symbols – e.g., isotopic spin – is again producing physical results. Once more, such processing does not relate to the corpuscular-like physical state, but to variables, e.g., coding in waves whether a corresponding momentum carrier is a proton or a neutron.

As it is more detailedly discussed in Ref. 18, pp. 413-417, there is an "additional intrinsic property of the fields, an additional degree of freedom; and there must exist some further transformation groups, related to these new variables". [Compare also Section 6 (j).]

E.g., if we consider the fields ϕ, ϕ^*, and ϕ_0, going with π^+, π^- and π^0 pions, respectively, and with which ϕ^* is the Hermitian conjugate of ϕ, the electromagnetic gauge transformation for these fields is

$$\phi \to e^{i\epsilon}\phi \qquad \phi^* \to e^{i\epsilon}\phi^* \qquad \phi_0 \to \phi_0$$

Then, upon splitting the complex ϕ and ϕ^* into real parts ϕ_1 and ϕ_2 and putting $\phi_3 \equiv \phi_0$, we get that $\boldsymbol{\phi} \equiv \begin{pmatrix} \phi_1 \\ \phi_2 \\ \phi_3 \end{pmatrix}$ "transforms under a gauge transformation with the phase angle ϵ in precisely the same manner as a 'three-dimensional vector' transforms under a rotation around the 3^{rd} 'coordinate axis' by an angle ϵ. In other words, we are lead to consider the fields ϕ_1, ϕ_2, ϕ_3, which refer to charged *and* uncharged mesons, as the components of a three-vector in some *abstract* space (which is completely *distinct* from ordinary space-time)." (See Ref. 18, p. 414.) This is isobaric space. The charge properties of various sets of particles appear to be related to operations in this isobaric space. Another example is that

$$\begin{aligned} \psi_p &= \psi(\mathbf{x}; s; +1) = \text{ proton state and} \\ \psi_n &= \psi(\mathbf{x}; s; -1) = \text{ neutron state} \end{aligned}$$

behave as a 2-spinor $\psi \equiv \begin{pmatrix} u_1(\mathbf{x}; s) \\ u_2(\mathbf{x}; s) \end{pmatrix}$ in isobaric space on (gauge-related) "rotations" through ϵ in such space. The mathematics of the latter abstract – representation – space is highly similar to the one applying to ordinary spin and spinors belonging to the Minkowski spacetime background, and constitutes one more example of the informatics of coded data. Mind that in the above 2-isospinor – in which $\begin{pmatrix} u_1 \\ 0 \end{pmatrix}$ and $\begin{pmatrix} 0 \\ u_2 \end{pmatrix}$ refer to the proton and the neutron state, respectively – u_1 and u_2 are ordinary 4-component Dirac spinors. So, the general nucleon state function has 8 components. Note that such doubling of the number of components as compared with a Dirac spinor corresponds as much to a doubling of the number of *realistic* eigenstates as the doubling of the number of components of the original Minkowskian 2-spinor did, which number became 4 because negative-energy eigenstates had to be represented, too. Nature, or an absorption process, can in principle equally discriminate between, e.g., the information embodied by the objectively different waves ϕ, ϕ^* and ϕ_0 as it can do so between the eigenstates belonging to, say, $s_z = 1/2\,\hbar$ and $s_z = -1/2\,\hbar$, respectively. Mind here that *phase is a realistic physical entity in our theory.* The physical difference between the complex conjugate fields $\phi = 1/\sqrt{2}\,(\phi_1 + i\,\phi_2)$ and $\phi^* = 1/\sqrt{2}\,(\phi_1 - i\,\phi_2)$ is due to different phase relations between the *realistic* waves ϕ_1 and ϕ_2 with ϕ and ϕ^*, respectively.

The essential point for our theory is here that Nature apparently uses certain internal *phase*, "*gauge*", relation properties of spinor fields for storing and transmitting information about whether, say, a pion is a π^+, a π^- or a π^0. It appears again that an absorption process or measurement can "perceive" certain wave properties, i.e., phase relations. *The relevant perception embodies for such absorption process a recognition of the coded signal as to whether, say, a π^+, a π^- or a π^0 has to be produced*, that is, caught or observed. [Compare again Section 6 (j).] The phase relations in question also determine how the relevant spinor fields (belonging to pions, or fermions,... as regards their *Lorentz* transformation properties) transform under a gauge transformation – e.g., as a three-vector or as a 2-spinor – in "isospace". Such isospace then is a similar abstract tool for, e.g., researching eigenstates (e.g., π^+, π^- or π^0 of a general pion field) as we have in a comparable spin representation space with base vectors ψ_+ and ψ_-.

The gauge transformation properties correspond just as well to realistic inherent properties of the wave packet or action structure represented by $\psi(\mathbf{r}, t)$ as do the Lorentz spinor-transformation properties. Both kinds of properties embody coded information. In our conception, gauge transformations correspond to realistic changes, changing the phase (of components) of spinors in action-quantal slices. Generally, also transformation properties of a field in an *abstract* space, such as isospace, can correspond to *realistic* properties of such (equally realistic) field and its components. In our case we see field components appear that obviously so much differently respond to a gauge transformation that the latter amounts to a rotation of the total field – consisting, e.g., of proton and neutron components – in isospace; such components have objectively different physical properties – carry different information – , so that they are separately recognizable by an instrument. E.g., baryon fields carry coded information about the neutron and the proton state, so that it is also implied what mixture we have among the relevant signals. Therefore, the "communicating-vessel" direct zigzag communication between absorption and emission events needs be invoked here as nonlocally deciding, *choosing*, hidden variable, in contradistinction to, e.g., the situation with the fine-structure of atoms, which it (the zigzag communication) has "simply" to transmit from the emission to the absorption event.

The fact that the relevant phase relation and transformation properties of field components, too, are used for the storage of information, means that

Nature utilizes the data-storage capacity of waves even more economically than was already discussed earlier.

11. Everything in the quantum domain originates from properties of and relations between action quanta and the data coded by them

We already discussed wave functions, equations of motion, operators, representation spaces, and, partly, uncertainty margins and nonlocal hidden variables, and their relations to and dependence on action and coded information stored by the quanta. Also, we know that there are some physical quantities as energy, momentum and spin that are very directly and inherently encoded in slice-like quanta and series thereof.

In order to even more generally show the determination of the whole quantum domain by action-quantal (including coded-data) concepts, we go into some more subjects, viz. physical quantities in general, commutation relations, quantization and, once more, the uncertainty relations. First, we sum up some points:

(a) As is well-known, "the failure of Classical Theory seems to have as sole origin the atomism of action" (see Ref. 12, p. 42). In particular, the uncertainty relations $\Delta P \Delta Q \geq h$, in which P and Q are "complementary" variables, whose product has the dimension of action, have such atomism as their origin (see also the *Remark* below).

(b) The uncertainty relations and quantization in general on the one side, and the commutation relations on the other, appear to be equivalent (see, e.g., Ref. 18, pp. 176 ff.).

(c) The entire algebra of the field operators is contained in the relevant field equations and commutation relations (see Ref. 18, p. 315).

(d) The expectation value of any physical observable is determined by the relevant operator and the field function (see Ref. 18, p. 177).

(e) The four-dimensional wave function $\psi(\mathbf{r}, t)$, as determined by the relevant field equation – "combining" a given macro situation, i.e., potentials, with an initial micro situation – , defines an action-quantal structure in which action-metrical contiguity relations play an important part. By interacting with this structure, which can be considered as a mixture or linear superposition of coded information "chunks" going with the various eigenfunctions, the instrument selects one of the chunks; that is, wave-like messages consistent with the field equation. The eigenfunctions represent action-metrically mutually contiguous physical situations, which we saw is exactly the reason why the relevant waves are all emitted "at the same time".

A conclusion from these points is that the field operators are determined by the field equations (which we earlier found to depend on general optimum simplicity considerations) and by the atomism of action, because by the commutation relations [compare (a), (b) and (c) above].

That is, both the fields and the operators that define expectation values completely depend on action-quantal series and the atomicity of action (besides the simplicity considerations mentioned).

Remark: In connection with (a) above, see also Ref. 21, pp. 29-32 and 36 ff. for a more detailed discussion of the uncertainty relations $\Delta E \Delta t \geq h$ and $\Delta p_x \Delta x \geq h$, which can be generalized to other complementary measurables. Essentially, all uncertainty relations have their origins in that action quanta are indeed atomic. E.g., in a measurement of either the angular momentum L or the "complementary" angle ϕ, an integer number of action quanta has to be completed in the sense that final quanta of the process being measured link up with the apparatus after having been completed up to h. If now, say, L is precisely determined by a measurement, an adjustment with respect to ϕ will be necessary in order that the action $L \times \phi$ corresponds to quantal completion. Without such *attuning* of ϕ to action completion at the link-up, within an adjustment margin, it would be very improbable that L and ϕ in $L \times \phi$ would just happen to correspond to such completion. Actually, we have to formulate it as follows: The preparation of a measurement of L and/or ϕ needs allowing these variables such margins from which the measurement selects the relevant information, that $L \times \phi$ can be completed for the interaction. *The "measurement perturbation" is actually an action-completing adjustment.* (This is a rough argument; see Ref. 21 for details.)

One is further tempted to speculate in this connection that, in simultaneous or subsequent measurements of, say, the complementary L and ϕ, Nature is (retroactively) so economical that the whole action-quantal activity involved is "invested" in (coded information about) L and ϕ, so that, in such measurements, no action-completing adjustments of *other* variables (e.g., energy or location) can appear which could perform the completion without a "disturbance" of L and/or ϕ being needed. Or rather, it may be inherent to the wave information code that two complementary variables cannot be kept out of any action-completing adjustment.

Finally, we remind of two other well-known circumstances illustrating the primacy of action, viz. :

First, the fact that the quantum field equations, too, can be derived from the action integral by variation of the field functions (compare the Least-Action Principle, and see Ref. 18, pp. 160 ff.). Note further that also the coupled field equations, for interacting fields, can be obtained by varying the total Lagrangian L with respect to the contributing fields. Then, because the Lagrangian corresponds to the field energy density, we see in connection with the action integral $S = 1/ic \int_R L\, dx$ that such variation amounts to one of action (see Ref. 18, pp. 165, 203 and 160).

Second, the fact that all dynamical observables are in general bilinear expressions in the field functions – corresponding to action-quantal structures – and their derivatives (Ref. 18, p. 180). We see from this how such dynamical observables can be encoded in the field functions (that is, in the action-quantal, wave, structures) in an unrecognizably "abstract" way. E.g., the energy density of an electromagnetic field is coded as

$$E^2 + H^2 = -(\partial_i A_4 - \partial_4 A_i)^2 + (\partial_k A_l - \partial_l A_k)^2$$

(see Ref. 18, p. 180). At the same time, all physical observables can be derived from the Lagrangian L, which is both a bilinear in the ψ functions and their derivatives and directly related to the action via the above integral $S = 1/ic \int_R L\, dx$ (see Ref. 18, Chapter IV).

12. Conclusion

In conclusion, we summarize the main results of the foregoing theory, also incorporating essentials of Refs. 1-7 that introduce to or co-found it.

1. Both the future and the past exist in a very real sense. *This holds so much really indeed that it (co)determines the relativistic length contraction.*

2. It also holds so much really that the future even can actually retroactively co-determine some present processes within the uncertainty margins left by causality. This in the sense that such present in some experiments can only be understood – that is, produce the *Aha-Erlebnis* in us – if we invoke repercussions on it from, say, future decisions of an observer (unless we abandon conservation laws or realism at all).

3. The world being truly four-dimensional, it is obvious to consider its elements to be events – with space and time dimensions – rather than objects, and its basic stuff to be action rather than energy. In this conception, the quantum of action is the elementary event, the realistic (indivisible) atom of occurring.

4. From this it follows naturally that it is often physically more relevant to measure distances – that is, distances between *events* – by standard amounts of action (e.g., quanta) than to measure distances between objects in terms of standard objects (measuring rods), at least so far as micro-processes are concerned (compare 7 below).

5. Realistically putting events instead of objects first and foremost actually appears to mean integrating spacetime and energy-momentum jointly into action. This is in the produced part of integrating space and time into spacetime, and it has similar relativizing and paradox-solving consequences.

6. One of such consequences results from the "action metric" of 4, viz. that the relevant action distance between two point-events, or rather, between instances which play a part in a specific micro-process, is zero precisely in such cases in which nonlocal mutual influencing appears to be necessary between these point-events or instances in order to explain their coordinated behavior, such as in the EPR and other nonlocality paradoxes.

7. The Minkowski metrical frame appears within this scope as a rough macro coordinate system appropriate in cases in which individual-quantum effects are not relevant, can be neglected. It is a "classical" coordinate system, ordering frame, that has physical relevance for the same reason why classical *objects* have, viz. the circumstance that quantum effects are often *ir*relevant.

In our theory, metric is a property of, is derived from, events, as mass, energy, momentum and other physical quantities, too, are aspects, manifestations, of action.

8. The existences in time of all elementary objects are considered to be sequences in time of elementary events, i.e., action quanta. That is, each of them consists of a periodical process.

9. We argue that there is an *a priori* plausibility of the idea that

a) Action quanta going with particles in the corpuscular state consist, as an elementary process, of one spherical rotation;

b) Action quanta going with particles in the wave state (primarily) consist of a spinor-wave slice.

Now an isomorphism appears to exist between the group of configurations of a spherically rotating entity and a four-dimensional spinor-wave slice as an elementary event.

From this the hypothesis strongly suggests itself that

c) If a momentum carrier transforms from the corpuscular into the wave manifestation, its action-quantal elements of existence, as processes, transform from the spherical-rotation to the spinor-wave mode, the relevant physical information they represent *being translated isomorphically, that is, being essentially conserved.*

10. Thus, matter waves neither are stretched particles, nor do they guide corpuscules, nor are they of a merely immaterial, mathematical nature. Their four-dimensional, (in simplified form) slice-like profiles represent action quanta that are stretched in Minkowski space because of the discrepancy between the Minkowskian and the action metric.

11. The information, *realistically* carried by the waves, and representing the main characteristics of the relevant particle *in another data code* than the one embodied by corpuscules (that integrate many data in one model), can often best be processed in an abstract space: representation space. *Inter alia*, in this space, operators standing for dynamical variables are essentially the coded, translated, representations of influences, operations (among which coordinate transformations), from the macro-world on the micro-process M in question. They make a smooth correspondence and translation between the (Minkowskian, classical, corpuscular) data code of such world and the wave one of M possible, partly because the isomorphic translation between dynamical variables and operators *also smoothly links up with the one between spherical rotation and the spinor wave process.*

12. The wave data medium in some respects only allows, accommodates, incomplete information about a physical system, without this corresponding to some inherent vagueness of the "plan of the world". At impacts or measurements, such information is completed by nonlocal hidden variables (as we already know them to exist in the EPR correspondence) that *may* also have, in their quality as a function of the process as a whole, pattern-forming aspects, which would make such variables more than a mere (deterministic, for the future is already there) nonlocal random mechanism. A possible

pattern-formative aspect might embody a link of micro physics with the natural (*inter alia*, feed-back) phenomena that we call living organisms and consciousness. The above throws a new light on the quantum "uncertainties".

13. The formalism of quantum mechanics is so "formalistic", evasive with respect to understandable models, not because no definite realistic blue-print (plan) of micro reality would exist, but because in the latter our familiar models of natural entities will be represented *in a coded form*, whereas the relevant coded data have to be processed in an unconventional way, not conforming to the laws and models of corpuscule-like objects, forces and Minkowski distances, but to those of a more abstract, mathematical data-processing and/or those of action metric, though the information is still carried by realistic waves. The latter, like the optic nerve, transmit data corresponding to imaginable models by means of an ingenious "Morse code". Or, they carry the constituting properties of particles in a coded way like DNA strings carry genetically coded models of noses, fingers etc.

14. Nature is a mathematician, efficient and economical; in general, it does not store or transmit redundant information.

15. The hypothesis – or rather, logical consequence of the thought experiments of Figs. 1, 2 and comparable ones – of the primacy of events and, therefore, of action metric, solves the nonlocality paradoxes of quantum mechanics, whereas the coded-information hypothesis, to a high degree in coherence with the former, explains the realistic-model-defying and formalistic character of quantum theory. Together, they make coherent models possible, also explaining, e.g., phenomena like wave-particle "duality" and interference.

16. Instead of restoring realism, determinism and understandable models by assuming more (determining) instances, such as sub-quantum levels or quantum potentials, *we do so by abandoning assumptions.* Notably, we abandon absolute, process-independent, four-dimensional space and metric, and the absoluteness of the traditional "corpuscular" information code. *Both abandonments have a common basis: they follow from considering metric (spacetime) as well as mass (energy-momentum) to be mere aspects or manifestations of action and action-quantal structures, lattices.*

These abandonments also contain abandoning the idea that the Universe "roughly" is as we perceive it: A three-dimensional world of objects and forces progressing in time, a new reality continually arising, whereas all the things we coordinate mutually far apart *are* mutually very distant; also abandoned is our *prima facie* perception that Nature always processes objects and information roughly according to, in agreement with, our visual models.

17. The more such conceptions failed, the more many got accustomed to declaring that reality does not exist at all, or is “indefinite”, “uncertain”, or has “dual” ways of manifesting itself (though, the latter gets a new, realistic content and meaning by the present theory). In short, many *evaded* reality as soon as it consistently refused to fit traditional concepts, instead of asking themselves whether it might have a definite blue-print simply not conforming to such concepts. One preferred coining an adjusted philosophy declaring reality at all to be less definite or even less relevant, or restricted to what has actually been measured, and that explaining, understanding, and models are not important after all...

In fact, such attitude prevents one from really encountering paradoxes in (unsuccessfully) trying to construct understandable models that allow experiencing the *Aha-Erlebnisse*-to-detail that are the essence of scientific insight. Actually, however, we *need* paradoxes, which force us to try new hypotheses, to give up assumptions, to frame new, really explaining theories, instead of merely processing measurement results mathematically in order to make right predictions.

Remark: This paper constitutes an elaboration and integration to a complete theory of ideas the author enunciated in his invited lectures at the Conferences of Perugia (*The Wave-Particle Dualism; A Tribute to Louis de Broglie on his 90th Birthday*, 1982), Bari (*Open Questions in Quantum Physics*, 1983) and Urbino (*Microphysical Reality and Quantum Formalism*, 1985).

Références

[19] L.I. Schiff, *Quantum Mechanics* (Internat. Stud. Edition, McGraw-Hill, London, 1968).
[20] P.A.M. Dirac, *The Principles of Quantum Mechanics* (Fourth Ed., Clarendon Press, Oxford, 1981).
[21] C.W. Rietdijk, *On the Explanation of Matter Wave Interference* (Van Gorcum and Comp., Assen, The Netherlands, 1973).

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