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

C.W. Rietdijk

Pinellaan 7, 2081 EH Santpoort-Zuid,
The Netherlands

One from the audience : "And what if, in contradistinction to what you suspect, Nature would appear not to function according to simple laws?"

Einstein : "Then I would no longer be interested in it."

ABSTRACT. We abandon two fundamental current assumptions. First, that Minkowski space and metric have some objective existence, up into the microsphere, independent of the processes occurring there. We then establish that the quantum nonlocality paradoxes disappear after our introducing action metric : The most relevant four-dimensional distance between events A and B is the amount of action ("occurring") needed to transform A into B.

Secondly, we abandon the idea that particles survive the wave state as "hidden" corpuscules. Introducing the quantum of action as a realistic four-dimensional "atom of occurring", we identify the existence in time of corpuscules and waves as two alternative manifestations of sequences of such quanta, containing relevant physical information in two different "economical" data codes, respectively. Integration of the four-dimensional (action) and information-code points of view explains the formalistic features of quantum theory (operators, ...) realistically. (The latter explanation will rather detailedly be given in part II in the next issue of the AFLB.) So, our –detailedly argumented– new starting points allow understandable models.

1. Introduction ; the main purposes of this research

The circumstance that constructing understandable models of microprocesses remained highly elusive up to now has been the main cause of the dominance of positivistic attitudes among quantum physicists.

Still, another response to the fact that paradoxes will appear as soon as we attempt to frame such models detailedly is very well possible. The constancy of the velocity of light found by Michelson and Morley also amounted to a paradox at the time. However, the ultimate reaction of physics was the conceptional revolution of Special Relativity, rather than positivism.

This paper in two parts aims at proving that in the quantum case, too, two conceptional changes can definitely end the paradoxical situations referred to. Such changes, moreover, appear to be more than hypotheses happening to solve a problem. The first is proved to be necessary anyhow in Section 2. The second is rather strongly suggested by a mathematical isomorphism to be discussed in Section 4.

Refs. 1 through 7 partly anticipate what is treated here. We summarize their results, mainly in Section 2, so far as we need them. Ref. 6 already gives a partial general theory of microphysical phenomena which, among other things, explains the nonlocality paradoxes of quantum mechanics.

More in detail, the main purposes of this two-parts article are :

a) Elaborating some aspects of such partial general theory in order to make it a logical starting point for the radical extension aimed at here.

b) Introducing such extension : the *coded-information theory* with respect to matter waves, to the effect that the latter are realistic phenomena which neither guide nor even contain corpuscules, but transmit the physical information defining them in a coded way not unsimilar to, say, that in which the optic nerve transmits the information contained in the images of objects we see, or the DNA of reproductive cells transmits hereditary qualities.

c) Integrating both the coded-information conception and the theory of Ref. 6 with the current quantum formalism in order to produce a realistic quantum theory, characterized by understandable models including nonlocal interrelationships. As already has been indicated in the *Ab-*

stract, it is especially this point c) of our program which will be carried out in some detail in part II. [1]

2. A conceptional revolution is inevitable ; the world is truly four-dimensional

In spite of the dominance of positivism, *inter alia* Bell's and Stapp's theoretical and Aspect's experimental work [8,9,10] on the EPR paradox contributed to increasing uneasiness about some paradoxical features –of Nature itself rather than merely of the quantum formalism– among many to the idea that we do not at all understand something very fundamental.

Independent of these problems –but not unrelated to them, as it appeared afterwards, and as will be discussed below– two results were attained that contrasted so much with both conventional thinking and deep-rooted emotions that, though remaining irrefuted on the physical level, they hitherto attracted only limited attention.

The first was a proof from Special Relativity that the Universe is truly four-dimensional, i.e., that past and future really exist (and, therefore, are determined), though outside of our observational scope [1,2,6].

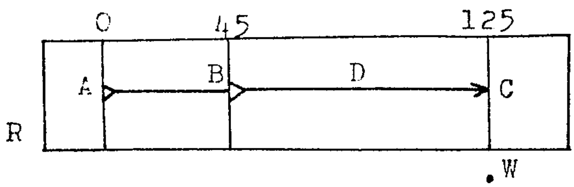

Figure 1. The contracted arrow ; the B passage is in the absolute future of the A one.

A striking argument proving that the (absolute) future actually exists considers the relativistic length contraction of a moving arrow [6,11]. It amounts to showing that the essential reason why some observer W with respect to whom an arrow D moves, sees it shortened, is that part of my future is present for him if I travel with D sitting on its point C, whereas W

[1]Continued numbering has been applied through parts I and II as to Sections, figures and references : 1 through 12 for the Sections, 1 through 18 for the figures, and 1 through 21 for the references.

is at rest with respect to the measuring rod R (see Fig. 1). I.e., for me at rest with respect to D at C, the two (point-)events (i) back-end A passing line 0 of R and (ii) front-end C passing line 125 of it, are simultaneous. (Because of this very fact I find the rest-length of D to be 100 if the factor by which R is shortened for me, because of my movement, is 4/5.) However, for W who beside me experiences the same (point-)event (ii), event (i) is not at all simultaneous with (ii). For him, event (iii) consisting of back-end A passing line 45 at B is simultaneous with (ii). For, W sees D shortened by a factor 4/5, which makes its length for him $4/5 \times 100 = 80$. Because R is not shortened for W, he sees back-end A and front-end C simultaneously pass two marking lines that are 80 units apart from each other. This means that (ii) and (iii) are simultaneous for him. Now (iii) is in the absolute future of (i) on back-end A's world-line. *The crucial point here is that at the moment I know A to pass line 0 "now", the B passage that will occur later in my coordination of events is in real existence too, for it exists for my colleague W who is with me here and now.* The events (i) and (iii), in each other's absolute past and future, respectively, therefore can *both be made as real as a realistic arrow* simply by our considering another observer at (ii). So (i)'s absolute future is there, too. A whole *segment* of A's world-line has a status of reality, which segment can in principle be enlarged arbitrarily. Talking about "relative future" and "metrical problem" cannot detract anything from the physical reality of (iii) at the moment (i) is "now" for me. For W's arrow, its back-end included, is as real as is mine.

The second of the results indicated above was a demonstration that some experiments leave no escape from either giving up conservation of linear and angular momentum or accepting the existence of retroactive influences (from a future that really exists, compare above)[3,5,11].

One way of demonstrating this can be summarized by considering Fig. 2, illustrating a (large-scale) variant of the Young double-slit experiment. In it we have the choice of either catching the momentum carriers approaching from S_1 on screen S_2 or catching them by the plates P whose produced parts contain C between the slits. In principle, we can make our choice after the momentum carriers finished interacting with S_1. That is, after they got their definitive linear momentum. However, if we leave S_2 in place, and region M is an interference minimum, no momentum interactions between the (separately considered) carriers and S_1 appear to correspond to a transmission of the former to M. On the other hand, if we remove S_2 after such interactions have ended, exposing the system P, no avoidance of region M will appear because there is no extinguishing interference on the upper and lower sides of the plates P. If one does not accept violation of momentum conservation, the only alternative is that already at the slit interactions the resulting momenta of some momentum carriers were attuned to my later decision whether I would remove S_2 or not. This means a retroactive influencing of such interactions.

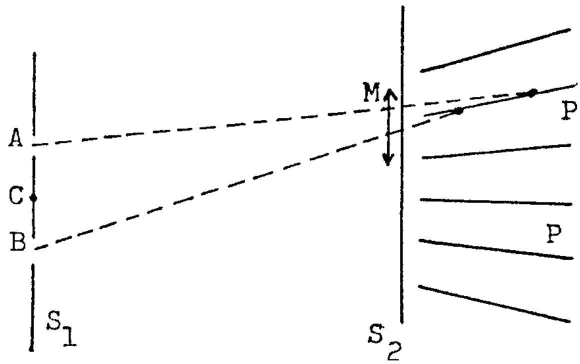

Figure 2. A modified Young experiment ; the plates P make interference minima and maxima disappear if we remove S_2, say, at the last moment.

Some (positivists) will object to the above argument : "It is not justified to argue detailedly about what really happens, in a microprocess, without it being actually measured (such as the momentum transfer from S_1 to a momentum carrier)". We answer :

1 We only applied natural law, i.e., conservation of momentum, which also holds for micro-processes ;

2 Abandoning the research of what really happens (that is, the search for understandable models) means *abandoning articulate thinking.* The usual motive for such abandoning is that we will encounter paradoxes in thinking-to-detail about micro-processes. Now we have essentially two options here : Either we abandon the search for understandable models –which allows us to evade paradoxes indeed– or, in still seeking detailed explanations, we face the relevant paradoxes squarely, being intrigued by them as one earlier was by the constancy of the velocity of light referred to above. Could it be that the first choice : not trying to explain to detail, has as an unconscious

motive an inner resistance against making such changes in our deep-rooted assumptions as more often than not appeared to be required for *solving* paradoxes (instead of evading them) ? Indeed, this paper discusses the abandonment of some fundamental current assumptions in order to solve the encountered paradoxes.

On establishing that past and future do not only exist, but both can have physical influence on our present, we realize one of the implications of such really four-dimensional world, viz. that events, processes with a finite time extent, could be more relevant than three-dimensional objects as the constituents of the Universe and the entities to which physical laws relate. E.g., the Principle of Least Action might be more than an appropriate mathematical device for beautifully deriving "three-dimensional" equations of motion. Mind here that action, of the dimension Et, energy times time, is a physical measure of the "amount of occurring, of processing". This step of substituting events, action, for objects or energy as the real stuff of the –truly four-dimensional– Universe will appear to have radical consequences for quantum-theoretical thinking, too. In a way, it amounts to making a second step in the direction in which Special Relativity was the first. The latter made metric four-dimensional. By integrating space and time distances into Minkowski metric in which $x^2 + y^2 + z^2 + (ict)^2 = s^2$ is essential, s representing a physically more relevant distance than x, y, z and t, Special Relativity also set the first step in making the world four-dimensional. Most physicists did not make the inference that the Universe really *is* four-dimensional, but virtually considered four-dimensional metric as a purely metrical device indeed, a better way to coordinate point-events that, it is true, had also something to do with well-known consequences of Relativity for mass, energy, covariance requirements etc. This means that, *inter alia*, now-at-a-distance was not taken very seriously as a reality, at least in inertial systems other than our own. Essentially, one unconsciously continued to assume an absolute now-hyperplane (one's own, that is), separating an actualized and determined past from a not actualized and undetermined future (as to which, e.g., free will or quantum uncertainties had still various options). Above, and more thoroughly and rigorously in the references mentioned there, it is shown that this is inconsistent and that Universe is four-dimensional in a completely realistic sense.

The indicated second step now consists of considering the world to be so much intrinsically four-dimensional that not only Minkowski metric is physically more relevant than the Euclidean one, but that also events, i.e., action, have to be taken so much dead-seriously as the real contents of the Universe that it has the following consequence :

In the same way as, in three-dimensional space, it is obvious to measure the distance between *objects* A and B by means of standard *objects* (i.e., measuring rods), *so, in the physically more relevant four-dimensional world of events, it is the natural way to measure the (again : most relevant) distance between two events* A' *and* B' *by means of standard events. That is, by establishing how much "occurring", or action, it takes to get from event* A' *to event* B'*, or to transform event* A' *into event* B'. [The natural standard event is the quantum of action h, which appears to be indivisible and functions as an "atom of occurring". For the rest, the fact that the quantization of *action* appears to be at the root of quantization in general (see Ref. 12, p. 42), constitutes one more indication of the particular and fundamental position of action among the other quantities of Nature.]

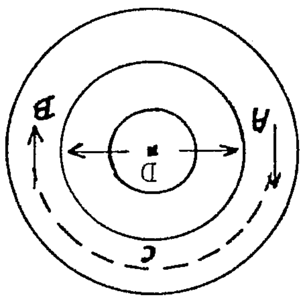

Figure 3. The action distance between measurement-events A and B is zero.

With this, the concept *action distance* is born, which appears to be capable of explaining the nonlocality paradoxes of quantum mechanics, as it is treated extensively in Refs. 4 and 6. In Fig. 3 it has been illustrated how it can explain the paradox of Einstein, Podolsky and Rosen. It is easily seen that the amount of action $S = Et - \mathbf{p} \cdot \mathbf{r}$ "produced" by the two-systems process, reckoned from the joint emission from D, is everywhere the same on the equi-action plane ACB, where A and B are measurement-events ; say, spin measurements. From event A via C to event B it is only an infinitesimal shift in the action metric (of the relevant process), which amounts to a physical contiguity –and mutual influencibility– of the two measurement-events. (It is easily seen that if we take $DA \neq DB$ nothing essential changes.)

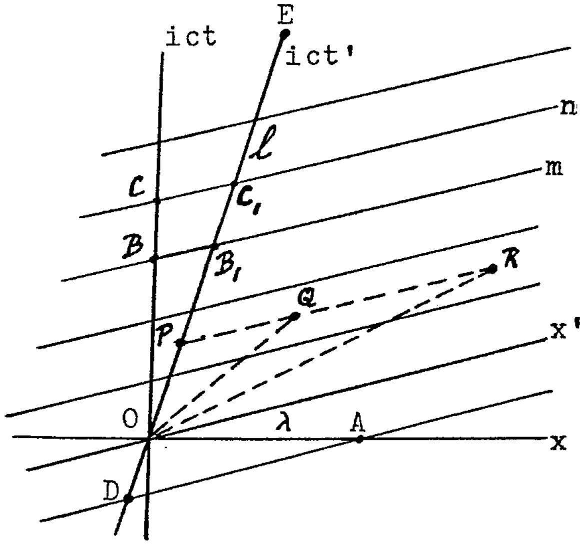

Figure 4. A realistic model in Minkowski space of how the action quanta embodying a free-particle movement, and that are stretched by the relevance of action metric, produce the wave phenomenon, that is, wave-particle "duality".

Action metric also allows us to construct an understandable and realistic model with respect to wave-particle "duality". Again referring to Refs. 4 and 6 for a more complete treatment and explanation, we consider Fig. 4, which represents a four-dimensional picture of the wave system of a particle (momentum carrier) traveling, say, from point-event D to point-event E via world-line l, with a definite momentum, so that our idealized wave packet consists of only one Fourier component. Now the following quantities are most relevant : $B_1C_1 = \frac{1}{\nu} = \Delta t = \frac{h}{m_0c^2}$ is the duration (in the rest system of the particle) of one action quantum, of which the existence in time of the particle is a succession. (Mind $h\nu = m_0c^2$.) $OA = \lambda = \frac{h}{p}$ is the wave length of a "matter wave". Lines like m, n and PQR represent equi-action planes for the process. E.g., in P, Q and R the action for the process is about $2\frac{1}{2}h$, reckoned from the emission-event D ; h is the action unit : one quantum. That is, P, Q and R have mutual action distances zero in the relevant process, or, they are action-metrically mutually contiguous. What happens at P, R "knows". *Inter alia*, the instantaneous collapse of wave packets is made possible by this.

B_1 and C_1, and therefore m and n, marking the beginning and the end of one action quantum in the history of the relevant particle, it is obvious to consider the four-dimensional slice between m and n (that are now-hyperplanes in the inertial system of the particle) as a preliminary model of an action quantum in Minkowski space. B_1C_1 may be considered as the "proper quantum", whereas the rest of the slice between m and n is then the locus of action-metrically contiguous parallel positions of B_1C_1 that, in other words, manifests itself physically over the whole slice extension. (BC is the duration of a quantum in the rest system of an observer ; we further put $c = 1$.)

In a three-dimensional "now"-section, say, according to Ox of Fig. 4, the waves with length λ appear also as slices like C of Fig. 5, with a width λ. Again the action distance between P and Q –more precisely : between the alternative *events* consisting of the particle passing slit P and the particle passing slit Q, respectively– is zero for the process. This means that "it is known at slit P what happens at Q", which in principle explains the paradoxical Young phenomenon that the momentum carrier seems to pass both slits at a time, and "one slit knows whether the other one is open" (see also below).

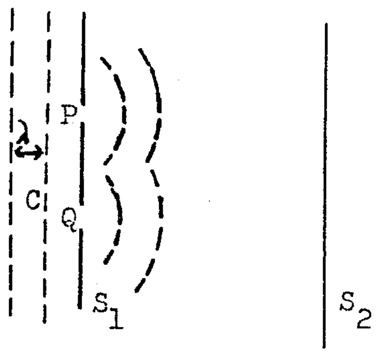

Figure 5. A three-dimensional "now-section" of a slice system such as the one of Fig. 4 accommodates waves as we know them.

Quoting from Ref. 4 we can summarize : Special Relativity integrated space and time (into spacetime), and also matter, energy, and momentum, solving therewith some fundamental problems and paradoxes –e.g., the constancy of the velocity of light– originating from our unjustly conceiving such space, time, etc. as separate, independent "rigid" entities or characteristics of the Universe. *What is done in the foregoing, then, amounts to the in-principle integration of space, time, matter, energy, and momentum, that is, of both spacetime and energy-momentum, jointly into action* $S = Et - \mathbf{p} \cdot \mathbf{r}$, *from which all the other entities and concepts appeared to be derivable and from which they derive their properties, too, becoming less independent, less absolute, and less "rigid" at the same time. And again, this new integration and relativation produce the solution of some fundamental problems and paradoxes –e.g., nonlocality, duality and uncertainty– originating from similar "absolutistic" prejudices as the prerelativistic ones mentioned above.*

In this paper, however, we do not only aim at solving the nonlocality, wave-particle duality and uncertainty problems of quantum mechanics, that is, the elusiveness of understandable models with regard to such nonlocality etc. We now also aim at making the general quantum formalism intelligible. I.e., we want to relate understandable models producing the *Aha-Erlebnis* with wave functions, representation spaces, matrix operators representing observables or transformations, etc., and, generally, to see the realistic processes described by the formalism. The integration of spacetime and energy-momentum, and the introduction of action metric, will appear not to suffice here.

3. Preliminary discussion of the nature of action quanta and of the wave function $\psi(\mathbf{r}, t)$

In Section 2 we already found a rough model of an action quantum that constitutes a stage of duration $\Delta t = h/m_0c^2$ in the existence of a freely moving particle. We saw that the model consists of a slice that actually is the dilated segment B_1C_1 of l in Fig. 4, where the dilation appears because of the discrepancy between Minkowskian and action metric : PQ and PR are zero if measured in the internal action metric of the relevant process, which circumstance makes the slice a compact segment as regards action physics. The total system of world-line l's dilated segments then manifests itself as a four-dimensional wave structure. Three-dimensional, "now", sections give the well-known matter wave trains (see again Fig. 4, and Fig. 6). The matter wave slices are comparable with the electromagnetic ones pictured in Fig. 7. Two apparent differences are (i) the angle of the electromagnetic wave slices with the ict-axis is $\pi/2$, and (ii) the electromagnetic waves are transversal, whereas as yet we do not know whether matter waves are so, too.

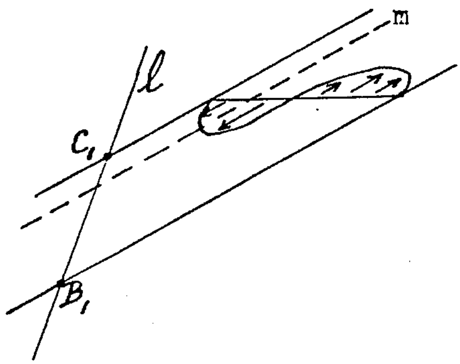

Figure 6. The field strengths of the waves represent "what is going on" in the kind of elementary process an action quantum in the wave state is.

It is clear from the "stretching idea" that the waves, the fields or potentials in the slices, are manifestations of the real process an action quantum consists of and that, from a purely Minkowskian point of view, might be considered to be enacted, e.g., on B_1C_1 of Fig. 4. Because, so far as the process in question is concerned, point-events on equi-action planes such as m in Figs. 6 and 7 are physically contiguous, we see already the processs stretched. For the rest, this means that we are familiar with the stretching concept from Special Relativity. For already in relativistic metric $OA = \sqrt{AA_1^2 - OA_1^2}$ is zero, whereas AA_1 and OA_1 are not. Not only m, but also l and n are equi-action planes in Fig. 7.

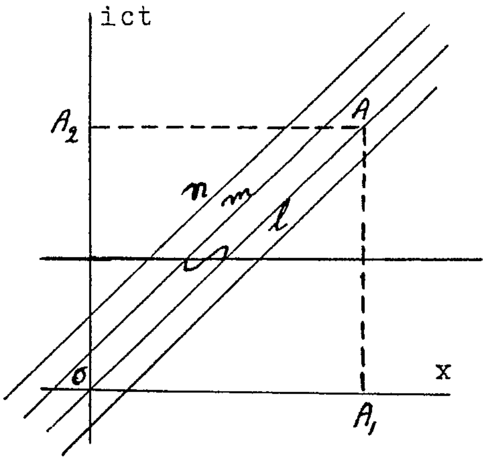

Figure 7. In fact, Minkowski metric, in which $OA = 0$, already reflects action metric for *photons* ; if compared with Euclidean metric, it already contains and illustrates the metrical stretching idea.

In Ref. 4 it is discussed how the Minkowski coordinate scheme and metric can be constructed from the structure or network, "lattice", S of all elementary events (action quanta), as a rough macro ordering scheme. In such macro scheme and metric, the action metrics of the separate micro-processes are "blurred out" *in a similar way as the manifestation of quantum phenomena in general is "blurred out" in the macro domain.* Our theory on the relation between Minkowskian and action metric of Ref. 4 implies *that metric is not an exception in this respect.* As macro-*processes* are merely a "sum" of micro-processes without existing independently, we derive macro (Minkowski) *metric* as merely a rough "resultant" of micro (action) processes and metrics in Ref. 4, without it exists independently. In fact we say : The vacuum is no separate real physical entity, not some "theoretical ether". E.g., the $1/r^2$ dependency of some forces, and other Minkowskian "regularities", exclusively derive from the properties (regularities) of the structure S, and do not refer to some "amount of vacuum" r would correspond with. Besides, any micro-process M has its own, separate, internal action metric, inherent to the particular action-quantal substructure of S by which M is embodied. There is no basis for metric but processes, i.e., action (quanta). That is, we abandon the assumption of a pre-existing space(-time) which would be independent of its real physical contents, i.e., processes and the action-quantal configurations they consist of. (Note here that already General Relativity –less radically– made metric dependent on processes –i.e., existing masses– in the large domain.)

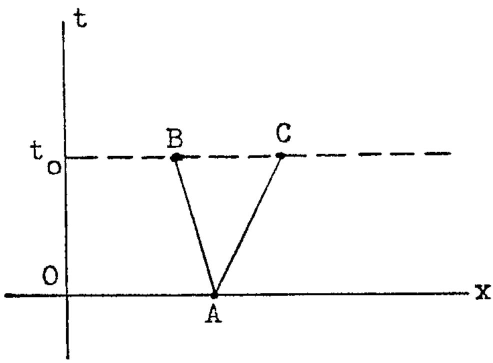

Figure 8. B and C are pure point-events –that is, apart from real events occurring at them– have not even in Minkowski space separate, physically meaningful, identities, e.g., discriminated by "the amount of vacuum between them".

The foregoing implies that, in Fig. 8, say, "vacuum" point-events B and C in a Minkowski scheme rather have abstract, "schematic", than real physical separate identities. In the first place, B and C could be physically contiguous for a process P if they are contained in an equi-action plane of P. In the second place, B and C can each be imagined to be "the same point as A, t_0 seconds later" : An object "at rest" at A can be either at B or at C after a time t_0 without these alternatives can be physically discriminated unless we apply macro coordinating (measuring the distances of stars etc., if we take B and C very isolated).

We already considered a quantum of action as an "atom of occurring", the elementary event. We now suppose that such event is the simplest periodical occurrence that makes physical sense, because of the a priori plausibility of such assumption.

Abandoning any contents- (that is, action-) independent pre-existing space-time, as discussed above, is also relevant to finding such simplest periodical process. For in a world in which only events, action, count in the last resort, ordinary cylindrical rotation of an *isolated* micro-object S, that is, rotation *only with respect to an enveloping vacuum* that does not really exist as a physical entity, is hardly a genuine periodical physical process in which something real physical actually changes. A rotation as a periodical process performed by S with respect to an environment will have to imply a *periodic variation of some physical connection of S with such environment.* Only then something physically real *happens* periodically with S on its rotation.

We now symbolise a micro-system, that is indeed physically connected with a stable environment E, by a sphere S connected with E by one or more strings or, say, by one's arm and horizontal hand on which S lies. We then look for the simplest possible periodic movement of such system (S plus strings or arm). This appears to be the so-called *spherical rotation.* Apart from a brief explanation with Figs. 9 and 10, we refer for this concept to Refs. 13 and 14, from which we essentially derive these figures, and from which we quote now :

"Spherical rotation is the simplest mode in which one part of space [i.e., S plus connections] can spin in relation to another [the environment : E or one's body] without disrupting its continuity [i.e., the strings or one's arm do not "twist"]. (Ref. 13, p. 474.)

"... if two objects [e.g., S and E] are attached by a flexible ribbon, it is obvious that a full turn of one object does not restore the system to its original state : the ribbon ends up with a twist in it. What is not so obvious is that the second full turn in the same direction can bring such a system back to its initial state : the ribbon can be untwisted even though the relative rotation of the two objects undergoes no further change. The effect can also be demonstrated by holding a wineglass in the palm of the hand and rotating the glass about its vertical axis (without moving the body as a whole). After a 360-degree rotation the glass returns to its original orientation, but the arm is twisted ; a further 360 degrees restores the glass and the arm to their initial position" (Ref. 14, p. 99).

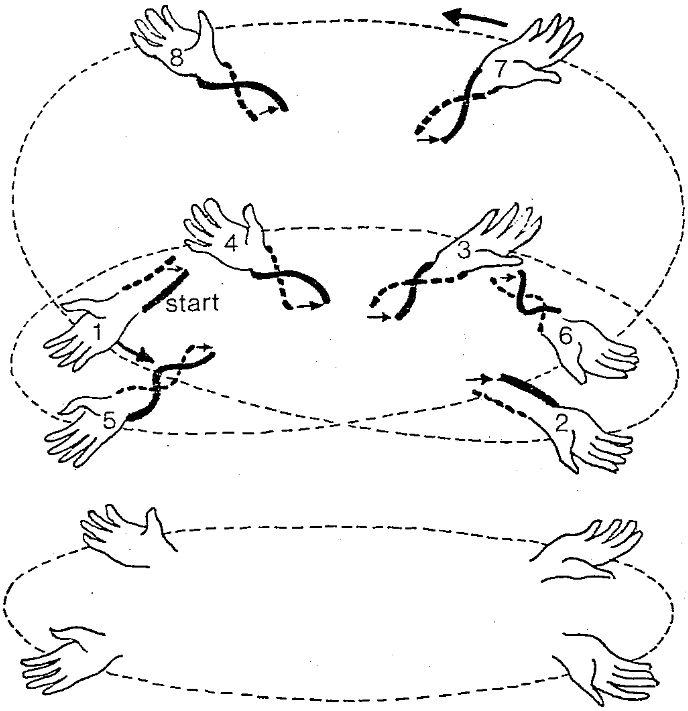

Figure 9. The successive "twists" of one's wrist or arm in performing one spherical rotation, say, with an apple on the hand. The arrows indicate the fixed orientation of the rest of the body. The lowest figure illustrates some positions of the hand separately, as they all appear twice in one spherical rotation.

In Fig. 9 we sketched the successive, intermediate, twists of one's arm in performing two successive 360-degrees rotations with an apple or wineglass, which rotations together constitute one spherical rotation that restores the starting position of both the rotating object and its connection with the environment (i.e., our arm).

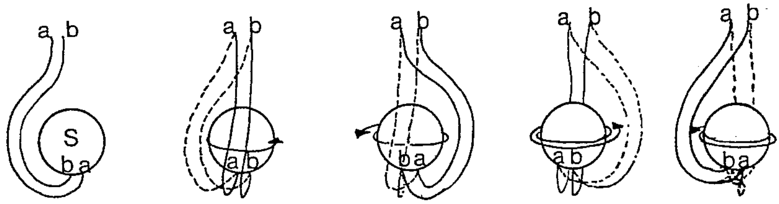

Figure 10. Each *half* turn of S forms a twist in the two tracers (dotted lines), which is undone by their (e.g., subsequent) *quarter* turns (solid lines). Two complete turns of S correspond to one spherical rotation.

Fig. 10 illustrates spherical rotation similarly : after two full rotations of S the complete physical situation has been restored.

Summarizing, we now have two as yet completely nonrelated rough pictures or models of the atom of events that we surmise an action quantum to be : (i) The four-dimensional wave slice as pictured in Figs. 4 and 6 (and, in essence, in Fig. 3, where the ring-shaped slices are three-dimensional now-hyperplane sections of spherically symmetric four-dimensional action slices), and (ii) The spherical rotation of "some entity". (We need not associate mass with such entity ; we see mass as being produced by, as a manifestation of, the action.) The only thing they have in common so far as we can see now is that they can be connected with some complete, periodic event. I.e., one segment of a worldline that somehow is associated with a (stretched) sinusoidal process as sketched in Fig. 6, and one complete spherical rotation, respectively. The problem of the relation between the two models will be solved in Section 4.

As it is discussed in Ref. 4, the slice model of action quanta can be used as a basis for constructing a realistic model of the wave function $\psi(\mathbf{r}, t)$ as it manifests itself in Minkowski space. We partly summarize, partly elaborate the essential aspects of such construction from Ref. 4 so far as we need them here.

1. The total four-dimensional wave packet defined by the function $\psi(\mathbf{r}, t)$ for all relevant $\mathbf{r}$ and t values represents the four-dimensional structure or network of action quanta that together form the process to which $\psi(\mathbf{r}, t)$ relates (say, a particle emitted from a source, which is absorbed some time later).

2. In order to understand this, first consider the series of drawn lines and

the one of dotted lines in Fig. 11 which each mark a series of similar slices as those of Fig. 4 ; that is, each series represents one Fourier component in the integral $\psi(\mathbf{r}, t) = \int F(\mathbf{p})e^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})}d\mathbf{p}$.

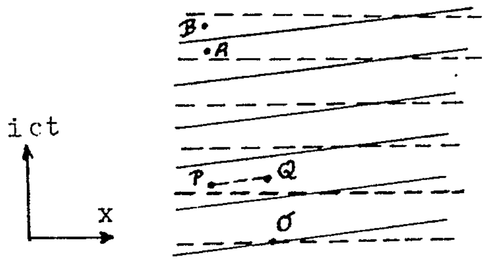

Figure 11. The action distance between the two position-momentum situations A and B, going with the solid and the dotted slice (Fourier) series, respectively, is also zero if both represent, say, an action $4\frac{3}{4}h$: action-physically, the process has only to make an infinitesimal shift to transform situation A into situation B, which, therefore, are essentially mutually contiguous.

In Fig. 11, the action distance between P and Q (as alternative physical stages or situations of a process ; P and Q go with the second drawn slice and each represent both a location and a momentum) is zero for the same reason as it was in Fig. 4. However, the action distance between A as a situation going with the fifth drawn slice, and B as one going with the fifth dotted slice, is zero, too. For, say, reckoned from the emission-event 0, both correspond to an action $4\frac{3}{4}h$ in their respective slice series. In order to transform situation P into Q, Nature has to make an infinitesimal action shift embodied by the spatial shift PQ ; in order to transform situation A into B, it has to alter both the location and the momentum coherently (the latter by changing the drawn-slice momentum into the dotted-slice one). The total action corresponding to this is $4\frac{3}{4}h - 4\frac{3}{4}h = 0$.

3. From 2. we see that the wave structure $\psi(\mathbf{r}, t)$, conceived as a four-dimensional action-quantal structure, consists of the resultant –according to the superposition principle, to be discussed below– of all action-physically contiguous alternatives of the process in question. As formulated in Ref. 4 : Because they are separated by an action distance zero, the various alternatives of the process *all appear to be realized "at the same time" by Nature.*

The result of such course of matters amounts for us to a total wave structure arising from the linear superposition of all Fourier components, each of which represents a different momentum alternative at the emission and during the process. Apparently, *Nature takes the internal action-physical equivalence* (or at least contiguity) *of the various alternative processes so seriously* that it makes some kind of real waves correspond with one as well as with all the others : it really treats them all on the same footing because it *functions* in terms of action ! Now that the internal action process itself makes no real difference between its variants, which can mutually be transformed into each other by zero-action shifts, such variants only differ by their relations to the outside macro structure –reflections, momenta, positions, ...– as they may become measurable in eventual interactions.

The points 1., 2. and 3. mean that the four-dimensional wave packet represented by $\psi(\mathbf{r}, t)$ is nothing but the action structure, series of quanta (elementary events), as they are stretched in Minkowski space, and which together build up the relevant process as a "dilated world-line". Thus the physically essential action metric has been counted in, and in particular its discrepancy with the Minkowski one. Mind in this whole connection that we now discuss $\psi(\mathbf{r}, t)$ as representing a completely realistic (action) phenomenon in *Minkowski* space, not in relation to *representation* space, which will be considered in Section 9.

Actually, the circumstance of the simultaneous existence of the wave trains corresponding to all possible alternative processes (eigenfunctions), as well as, e.g., the phenomenon of the "instantaneous contraction" of ψ to one of the eigenfunctions, in turn constitutes a strong experimental indication that, physically speaking, there is really only an infinitesimal difference between such alternatives. At the same time we see that the analysis of ψ into monochromatic Fourier components is more than a mathematical artefact and has a physical meaning, too. For the components each correspond to an alternative momentum for the system, so that the analysis really distinguishes fundamental physical alternatives.

We can also understand already a simple example of the cooperation of the quantization of action and action metric (the stretching of quanta into slices) in producing eigenvalues and quantization in general. In Fig. 12 we see a wave pattern produce a standing wave and a quantization of energy and momentum, this well-known phenomenon now getting a realistic explanation. The, earlier mentioned, fact that it is the quantization of action that is at the origin of the quantization of other dynamical variables as well furthermore constitutes an additional indication that action is at the basis of all such variables and that the latter derive from action (quanta) and their structures.

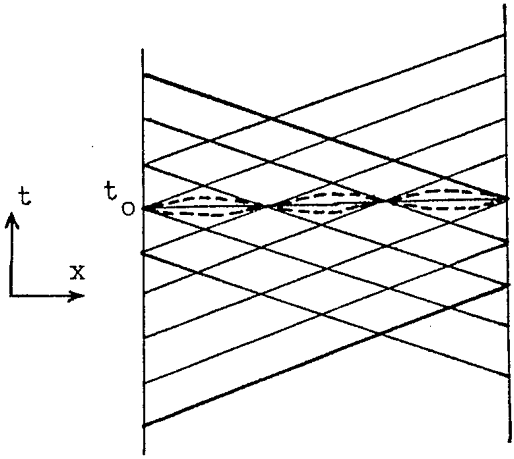

Figure 12. An illustration of how quantization of action and action metric –together producing the slice phenomenon– can make energy and momentum be quantized, too.

4. An insight-provoking isomorphism as regards action quanta

In Section 3 we discussed two seemingly totally unrelated models of the realistic elementary events action quanta are in our four-dimensional conception of the Universe. We produced them by arguing from two different starting points : observation (the waves) considered from a four-dimensional point of view (→ the slices), and an a priori reflection on what could be an elementary event, the "atom of occurring". *Now the surprising thing –strongly suggesting that we are on the right track– is that an isomorphism appears to exist between, on the one side, the group of all possible positions (configurations) of a spherically rotating entity and, on the other, the group of all possible values of a two-component spinor*

$$\begin{pmatrix} \phi_1 \ e^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})} \\ \phi_2 \ e^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})} \end{pmatrix}.$$

Note here that such spinor indeed represents a series of four-dimensional slices as pictured in Figs. 4 and 6. The former figure sketches their mutual positions and the latter gives an indication about their wave-like (sinusoidal) nature as it is implied by the factor $e^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})}$. Mind that *the latter factor implies the stretched form of the plane slices* as in Fig. 4 because the action $Et-\mathbf{p}\cdot\mathbf{r}$ is the same, e.g., in P, Q and R. The proper spinor $\binom{\phi_1}{\phi_2}$ *reflects the Lorentz transformation character of the wave field strength* [the power $i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})$ is Lorentz invariant].

We summarize the proof of the relevant isomorphism as it is given by Battey-Pratt and Racey in a number of steps (compare Ref. 13, pp. 441-447, and also the last paragraph of this Section) :

1. Each configuration of a spherical rotation model can be represented by a point on a four-dimensional Euclidean hypersphere H (the Lie group space) of unit radius. We then can describe the transformations from one configuration to another by a closed unimodular group. If a chosen initial configuration is represented by the vector $(1,0,0,0)$ from the origin to the point of H corresponding to that configuration, then any other configuration will be represented by the vector $(\alpha,\beta,\gamma,\delta)$, where $\alpha^2+\beta^2+\gamma^2+\delta^2=1$. *A rotation in the spherical mode can be represented by any operator that will transform vectors of this type into one another.*

2. The vector $(\alpha,\beta,\gamma,\delta)$ can be written as a quaternion

$$\phi = \alpha + \beta\mathbf{i} + \gamma\mathbf{j} + \delta\mathbf{k}$$

Transformations of this quaternion into any other unimodular quaternion can be effected by multiplying by another suitable quaternion. Thus, unimodular quaternions do duty for both the configuration vector and the rotation operator (See Ref. 13, p. 441).

3. Subsequently, the group of quaternions $\alpha+\beta\mathbf{i}+\gamma\mathbf{j}+\delta\mathbf{k}$ can isomorphically be represented by the group of matrices

$$\phi = \left(\begin{array}{cc:cc} \alpha & -\delta & -\gamma & -\beta \\ \delta & \alpha & \beta & -\gamma \\ \hdashline \gamma & -\beta & \alpha & \delta \\ \beta & \gamma & -\delta & \alpha \end{array}\right).$$

4. The next step shows that, because, e.g., the quadrant $\begin{pmatrix} \alpha & -\delta \\ \delta & \alpha \end{pmatrix}$ is the matrix representation of the complex number $\alpha + i\delta$, the matrices ϕ can isomorphically be represented by the group $SU(2)$ of the special unitary matrices of order 2 :

$$\phi = \begin{pmatrix} \alpha + i\delta & -\gamma + i\beta \\ \gamma + i\beta & \alpha - i\delta \end{pmatrix}.$$

(See for this also Ref. 15, p. 55.)

5. Finally, the square matrices of 4. correspond isomorphically to the column matrices of *spinors* $\binom{\alpha+i\delta}{\gamma+i\beta}$ as a group. They are the operator and the operand form, respectively, of configuration $(\alpha, \beta, \gamma, \delta)$ of the relevant spherical rotation. This means that, if we still take $(1, 0, 0, 0)$ to be the starting position of the latter, which in spinor-form corresponds to $\binom{1+i\times 0}{0+i\times 0} = \binom{1}{0}$, we get the final or transformed position –the operand– $\binom{\alpha+i\delta}{\gamma+i\beta}$ from $\binom{1}{0}$ by applying the operator

$$\begin{pmatrix} \alpha + i\delta & -\gamma + i\beta \\ \gamma + i\beta & \alpha - i\delta \end{pmatrix} \begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{pmatrix} \alpha + i\delta \\ \gamma + i\beta \end{pmatrix}.$$

E.g., $\begin{pmatrix} i & 0 \\ 0 & -i \end{pmatrix} \binom{1}{0} = \binom{i}{0}$ means that the matrix $\begin{pmatrix} i & 0 \\ 0 & -i \end{pmatrix}$ rotates the core of the spherically rotating model (that is, the model without the strings) from the initial position $\binom{1}{0}$ to a position attained by rotating the core 180°about the z-axis. The relation between the operator $\begin{pmatrix} i & 0 \\ 0 & -i \end{pmatrix}$ and the operand $\binom{i}{0}$, that is, between $\begin{pmatrix} \alpha+i\delta & -\gamma+i\beta \\ \gamma+i\beta & \alpha-i\delta \end{pmatrix}$ and the spinor $\binom{\alpha+i\delta}{\gamma+i\beta}$, is clear from this case, in which we have $\alpha = \beta = \gamma = 0$ and $\delta = 1$. Mind here further that rotating the core 180°means rotating the strings only 90°(compare Fig. 10).

6. The net result now is that the group of configurations $(\alpha, \beta, \gamma, \delta)$ of the spherically rotating model is isomorphically represented by the group of spinors

$$\begin{pmatrix} \alpha + i\delta \\ \gamma + i\beta \end{pmatrix}.$$

7. Subsequently, Battey-Pratt and Racey formulate the spinors in spacetime language. First, they consider such rotation of the core about the z-axis as corresponds to a rotation through θ in the Lie group space, which rotation is

represented, in the isomorphism between $(\alpha, \beta, \gamma, \delta)$ and $\binom{\alpha+i\delta}{\gamma+i\beta}$, by taking $\binom{e^{i\theta}}{0}$ for the latter ; that is, $\alpha + i\delta = \cos\theta + i\ \sin\theta$, so that $\alpha = \cos\theta$, $\beta = \gamma = 0$, and $\delta = \sin\theta$. Thus we can make a position of the model correspond to each θ.

Now a rotation about the z-axis as a linear function of time is called spin, and can be represented by $\binom{e^{i\omega t}}{0}$, which is generated from the $\binom{1}{0}$ position by the operator

$$\begin{pmatrix} e^{i\omega t} & 0 \\ 0 & e^{-i\omega t} \end{pmatrix}$$

and corresponds to an angular velocity of ω of the strings and of 2ω of the core. (If $\theta = \frac{1}{2}\pi$, the operand is $\binom{i}{0}$ again.)

8. Second, it becomes clear from their discussion that the spinors

$$\begin{pmatrix} e^{i\omega t} \\ 0 \end{pmatrix} \quad , \quad \begin{pmatrix} 0 \\ e^{i\omega t} \end{pmatrix} \quad , \quad \begin{pmatrix} e^{-i\omega t} \\ 0 \end{pmatrix} \quad \text{and} \quad \begin{pmatrix} 0 \\ e^{-i\omega t} \end{pmatrix}$$

have to be connected, respectively, with spin, inverted spin, anti-spin and inverted anti-spin, which all have a different realistic meaning for spherical rotation (in contradistinction to normal rotation ; the anti-spin states appear to be mirror images of the corresponding normal spin states). These are the four situations corresponding to the four Dirac eigenstates $(E^+, 1/2)$, $(E^+, -1/2)$, $(E^-, 1/2)$ and $(E^-, -1/2)$, respectively.

Then it appears that we can get, e.g., an intermediate spinor state $\binom{\cos\chi e^{i\omega t}}{\sin\chi e^{i\omega t}}$ between (normal) z spin-up and z spin-down by applying $\left(\begin{smallmatrix} \cos\chi & -\sin\chi \\ \sin\chi & \cos\chi \end{smallmatrix}\right)$ to $\binom{e^{i\omega t}}{0}$. Here 2χ is the angle of the rotation axis with respect to the spin-up direction. (Other intermediates between the above four base states appear to be equally possible.)

9. Now an important next step is that, for an observer moving past our system with velocity $-\mathbf{v}$, our spinor gets the form

$$\begin{pmatrix} \cos\chi e^{i\omega\frac{(t-\mathbf{v}\cdot\mathbf{r}/c^2)}{\beta}} \\ \sin\chi e^{i\omega\frac{(t-\mathbf{v}\cdot\mathbf{r}/c^2)}{\beta}} \end{pmatrix} = \begin{pmatrix} \cos\chi e^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})} \\ \sin\chi e^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})} \end{pmatrix} \quad , \quad \beta = \left(1 - \frac{v^2}{c^2}\right)^{1/2} .$$

Battey-Pratt and Racey generalize to four-component spinors by incorporating *all* possible intermediate states between the four eigenstates of 8., with which in the first instance also 2-spinors such as $\binom{\phi_1 e^{-i\omega t}}{\phi_2 e^{-i\omega t}}$ and $\binom{\phi_1 e^{i\omega t}}{\phi_2 e^{-i\omega t}}$ and again operators like

$$\begin{pmatrix} e^{i\omega t} & 0 \\ 0 & e^{-i\omega t} \end{pmatrix},$$

play a part. Further details are not necessary for our discussion, but it is important that the authors succeed in deriving the Dirac equation for the 4-spinors in question. They conclude : "Thus, we have shown that the entity formed by a spherically rotating disturbance of the manifold is a Dirac particle".

In Section 5, point 3. we shall have to consider a 2-spinor in which the two phase factors $e^{i/\hbar S}$, where S is the action, are different indeed. But this needs not be further elaborated in connection with our general theory. It simply refers to a (constant) phase difference between two components of the relevant spinor wave. Also the case of opposite phases of two or more component waves, as discussed in Ref. 13, and which relates to negative energies, is not specifically fundamental for ou wave model and discussion.

In the treatment of Ref. 13 it is the "manifold of strings" and its angular velocity to which the 4-spinors and their factor ω relate, whereas the core of the spherically rotating model rotates with 2ω. Further, the *location* of the core does not appear in such treatment, that is, in the spinor formulation. Battey-Pratt and Racey indeed "somehow" compare or identify the string system with the spinor waves representing a particle in quantum mechanics. However, it remains unexplained, then, (i) how we have to imagine such an extended particle –that is, the waves and the strings– physically, (ii) to what stable environment the "strings" are attached, and (iii) whether the various successive isomorphisms of 1. through 5. above, which transform the spherical rotation group into the group of the 2-spinors $\binom{\phi_1 e^{i/\hbar S}}{\phi_2 e^{i/\hbar S}}$ –or, if we also include the reversed, or anti-spin states, into the group of Dirac bi-spinors

$$\begin{pmatrix} \phi_1 e^{i/\hbar S} \\ \phi_2 e^{-i/\hbar S} \\ \phi_3 e^{i/\hbar S} \\ \phi_4 e^{-i/\hbar S} \end{pmatrix}$$

–, where $S = Et - \mathbf{p}\cdot\mathbf{r}$ is the action, *do not radically physically distort, deform, the classical, imaginable model of "twisting" strings attached to a rotating core* ! If so, the direct identification of the strings with the spinor waves becomes problematic.

In order to (a) produce an understandable model of matter waves corresponding to a (Dirac) particle and (b) explain the connection between the two seemingly unrelated models of action quanta discussed in Section 3, and at the same time account for the isomorphism discussed in 1. through 9. in a physically understandable way, we have to make a bold move, to which the four considerations below lead up :

First, we take due note of the striking fact that there is an isomorphism between the group of spherical rotation positions (in which both core and strings play a part) and that of such abstract things as 2-spinors $\binom{\phi_1 e^{i/\hbar S}}{\phi_2 e^{i/\hbar S}}$ (or of similar 4-spinors if we take into account anti-spin, or the $t \rightarrow -t$ rotation modes that we can make correspond to Dirac's negative energies).

Second, we can conclude that such isomorphism nevertheless *is precisely one between our two different models of an action quantum* as discussed in Section 3, because the 2- (or 4-) spinors as given above differ from the slice pictures of Figs. 4 and 6 only in that the field (potential) "vectors" (as indicated by the arrows in Fig. 6) transform in Lorentz-transformations as 2- or 4-component spinors, instead of like scalars as in one-component (Schrödinger) waves, or like four-vectors as in electromagnetic wave slices as pictured in Fig. 7. Thus, our two models appear to be mathematically isomorphic, though apparently one is "distorted" with respect to the other if both are considered as realistic physical models.

Third, we have to realize that such distortion partly corresponds to the discrepancy between Minkowski and action metric, for it is the (relativistically invariant) factor $e^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})}$ in the spinor (which makes no difference between point-events with a same action $S = Et - \mathbf{p} \cdot \mathbf{r}$) that is responsible for the stretched, "nonlocal" nature of the wavelike model or manifestation. That is, this factor is responsible *for the manifest integration of the action metric into the wave "version" of a spherically rotating manifold*, whereas the proper spinor, like $\binom{\cos\chi}{\sin\chi}$ above, embodies the spinorial transformation character of the field strength. The e-power factor explains the rather paradoxical phenomenon of a local rotation being isomorphically transformed into nonlocally stretched waves. In all, the isomorphism translates spherical-rotational positions, phases, into field strengths, or phases of the two waves $\cos S/\hbar$ and $\sin S/\hbar$ that are contained in the factor $e^{i/\hbar S}$. Both relevant isomorphic processes, the rotation and the wave phenomenon, somehow represent the action-quantal event and that –as we begin to surmise– in two different circumstances. In the noncorpuscular, field, case the action metric is integrated in the phenomenon. This effects that the spinor wave function values that correspond to the phases of the spherical rotation, spin, do so in an *extended* spacetime region.

It is clear from this that *we interpret the mathematical isomorphism definitely differently from Battey-Pratt and Racey, who do not use action metric* ; neither do they consider the isomorphism to relate to *two different states* of a same "rotating" entity, as we will do (see below). Finally, they consider such entity to be a corpuscule, without referring to action quanta or action-quantal processes. Indeed, as it is more and more suggested by the foregoing argument, both spherical rotation and the spinor waves somehow represent the elementary, action-quantal, process ; *clearly, this has the same internal structure in both cases, manifestations.* Of course, then, the existence of the isomorphism is no accident from the physical point of view.

Fourth, we can try to give more concrete form to the two relevant manifestations :

(a) One quantum consists of one complete spherical rotation of some core with outward connection, each rotation being an elementary event in the existence of a particle in the corpuscular state ; if we take the core to be some dumbbell-like entity of radius $\hbar/mc$ it is well-known that it can classically produce the correct spin to a factor 1/2. (Mind here that the Dirac equation implies a *Zitterbewegung* in which an "internal" movement with velocity c results in a velocity $\mathbf{v}$ of the system ; in discussing Fig. 16 we go further into this ; the spherical aspect of the rotation, relating to the "strings", is not important in the first instance.)

(b) One quantum of action, still corresponding to a period of $1/\nu = h/mc^2$ in the existence of, this time, a "wavelike" particle (compare B_1C_1 in Fig. 4), manifests itself as one four-dimensional slice of a system of $1-, 2-, 3-,$ ... component spinor waves (see again Fig. 4, and Fig. 6).

We extensively had to quote from and summarize parts of Ref. 13 in order to both make our announced "bold move" apprehensible –it is to be made in the next section– and really explain the background of the isomorphism between on the one side some spinning entity and on the other spinor-wave slices, which isomorphism and move are crucial for our argument and will now appear to reflect a new basic principle of Nature.

5. Matter waves are neither mathematical artefacts nor do they contain corpuscules ; they realistically transmit physical information in an economically coded form

First, we reject the idea that there are some dumbbel-like or other particles in matter waves, instead accepting that there *is nothing* but the spinor-wave-like slices in the case a momentum carrier is freely moving or otherwise shows wave-like behavior. We confine the dumbbell model to corpuscularly behaving spinning momentm carriers, and simply adopt the hypothesis that

(a) Corpuscules are the most economic model that integrates the physical information Nature conveys at making "objects" interact, e.g., with an observing instrument (producing visual information such as spots on a photographic plate, Geiger-counter clicks, ... ; see also point 8. below);

(b) *Spinor waves are an economic way Nature makes use of to convey, inter alia, the information otherwise contained in a spinning corpuscule, in an isomorphically translated, coded form, in the case of rather freely (non-interactingly) moving "particles", that is, in the traditional wave case.*

The above explains why the isomorphism discussed in Section 4 is so essential : It connects the two principal ways in which Nature encodes or stores information about elementary physical systems (particles, fields, ...), in both cases using the basic stuff of the world, action, which manifests itself in quanta. The latter either consist of one spherical rotation of, say, a dumbbell-like entity (corpuscular form of elementary particles), or are made up of one slice-shaped spinor wave period, such wave element being "nonlocally" stretched because of the discrepancy between action and Minkowski metric, as earlier discussed. As circumstances require, Nature encodes the same basic information – *essentially embodying (a variant of) what an action quantum is as a process* – in either the corpuscular or the spinor-wavelike form, translations between the two modes not meaning changes of the vital information because of the isomorphism in question. As at an emission a "translation" into the slice state appears, so at an impact or relevant observation the reverse translation occurs. The action metric being physically operative, a whole slice-like field can "instantaneously" recondense into a "dumbbell". Note that it is not the *object* which is stretched between emission and absorption, but action quanta constituting its world-line. It is the action quanta that embody the continuity of a system's existence. The equations of motion determine the progress of the wave-like action-quantal series completely, and from such series as “raw material”, e.g., a measurement reconstructs an “object”.

Thus, matter waves are neither smeared-out particles –though one may say that they are a smeared-out manifestation of realistic action quanta–, *nor do they guide or even contain corpuscules, nor are they mere mathematical artefacts describing probabilities.* They embody a form of information storage and transmission that radically differs from the corpuscular one. The information code going with them differs from the one of the corpuscular state in not unsimilar a way as, e.g., the optic nerve signals transmitting the picture of a horse to the brain differ from such picture, or as the genetic code in DNA molecules differs from the organisms built up from its instructions. Nevertheless, matter waves are equally real manifestations of the basic material of the four-dimensional Universe, action, as are corpuscules and as are electromagnetic waves.

Altogether, we again appear to have to abandon a prejudice in order to acquire a new fundamental physical insight : the assumption that corpuscules are the “proper” manifestation of “things”. Actually, action instead of objects appears to be the most fundamental.

We now make some additional essential points in order to elaborate our theory :

1. It is implied by the foregoing that, say, such complicated an object as an Ag-atom is only contained in coded, symbol form in the waves that correspond to it and that are stretched into slices for the metrical reason discussed. This explains how even Ag-atoms, e.g., can be refelected by a whole grating. Furthermore, the integral encoding of relevant data into the action slices pertaining to whole atoms means that $\lambda = h/p$ in such a way holds for the waves that p refers to *the momentum of whole atoms*, instead of the case that nucleus and electrons of the corpuscular model somehow contribute in the form of separate wave structures. There is no solar-system-like entity at all present in the waves, not even in a rough and/or stretched form. (See also 4. below.)

The above conception also explains matter wave interference in the simplest possible way : It proceeds similarly as we imagine electromagnetic wave interference.

2. An example indicating how the code mechanism works can be found in circularly polarized light. One might ask : “How does, say, right-circularly

polarized light transmit angular momentum in portions of $+\hbar$; how is it stored in two orthogonal linearly polarized wave trains with a mutual phase difference of $\frac{1}{2}\pi$?" Answer : Such waves do not store it at all. In arriving at some absorber, the waves (more specifically : the phase difference $\frac{1}{2}\pi$) transmit the message : "We correspond to an angular momentum of $\hbar$; it has to be produced here now". Or rather, the wave packets coded this way *transform* into some entity carrying an angular momentum of $\hbar$ at their "collapse". Because the action distance between emission event E and absorption event A in Fig. 13 is zero, direct physical contact between them makes the transmission "substantially" possible, too. The formulation with the message carried by the waves only serves here to make it understandable in our Euclidean model.

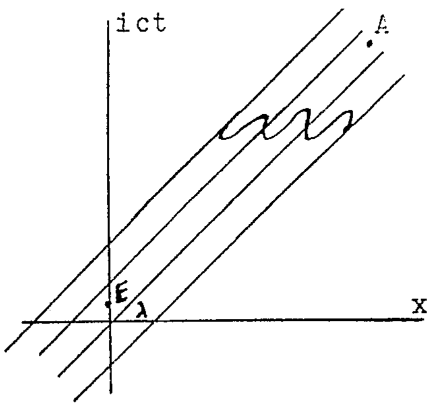

Figure 13. Because the action distance between photon emission event E and absorption event A is zero, they make direct physical contact, so that, e.g., angular momentum needs not be "materially" transported by the waves from E to A.

It is also clear from the fact that the action distance $EA = 0$ in Fig. 13 how "virtual photons" can produce electric attraction and repulsion in a natural and understandable way : They make the two charges *physically contiguous* via connections like EA. So, Euclidean distances can physically be bridged. (Hypothetical) gravitons, having also a velocity c, can be assumed to work similarly in transmitting gravitational forces. (See Ref. 16 for a more "classical" and detailed picture, that is not inconsistent with the above, however.)

We may say : "Virtual" photons transmit only electric forces, but normal ones can transmit, *inter alia*, energy and (angular) momentum.

In electromagnetic waves we have the same situation as in matter waves, viz. that they are realistic action-quantal slices built up from field potentials, without any localized energy quantum (photon) being hidden in them. Such quanta only appear at relevant measurements. Both with light and with matter there are two definitely different states, the localized and the wave one, that do not exist at the same time. They are alternative manifestations of series of action quanta, the choice between which is determined by outside circumstances, i.e., the measure or way of interacting.

3. We now consider a related matter wave spin case. Greenberger [17] considers a Young interference experiment with spin-up and spin-down particles (see Fig. 14). If, on S_2, one measures the z-spin s_z, two one-slit patterns are established. In measuring the x-spin s_x, one finds two (complementary) roughly sinusoidal "interference" patterns for particles having $s_x = +1/2\hbar$ and $s_x = -1/2\hbar$, respectively, one of which has been drawn.

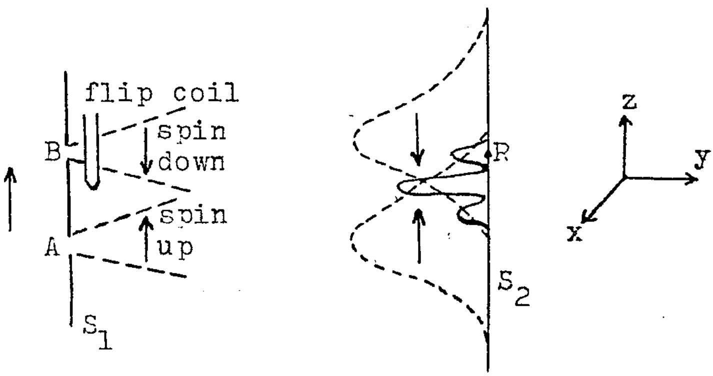

Figure 14. A particle beam polarized in the $+z$ direction passes A and B ; the spin-flip coil behind slit B rotates the spins to a down position. z-spin measurements on S_2 discriminate between A and B particles (no-interference case), whereas x-spin measurements will find the $+x$ particles be distributed according to a maxima-and-minima interference pattern ; the $-x$ particles show a "complementary" pattern.

The wave function at some point of S_2, where the phase difference between the A and B waves is β, is

$$\psi = \begin{pmatrix} \psi_1 \\ \psi_2 \end{pmatrix} = \frac{e^{ik}}{\sqrt{2}} \begin{pmatrix} 1 \\ e^{i\beta} \end{pmatrix} = \frac{e^{i(k+\beta/2)}}{\sqrt{2}} \begin{pmatrix} e^{-i\beta/2} \\ e^{i\beta/2} \end{pmatrix}, \tag{1}$$

where k is an irrelevant phase factor and $\sqrt{2}$ is for normalization. ψ_1 is the A or spin-up contribution and ψ_2 the B or spin-down one. An s_z measurement finding $1/2\hbar$ only registers ψ_1.

In view of s_x measurements we now decompose ψ according to the alternative base consisting of the vectors $\mid \hat{x} >= 1/\sqrt{2}\binom{1}{1}$ and $\mid -\hat{x} >= 1/\sqrt{2}\binom{1}{-1}$, so that (omitting irrelevant phase factors) we get

$$\frac{1}{\sqrt{2}} \begin{pmatrix} e^{-i\beta/2} \\ e^{i\beta/2} \end{pmatrix} = \cos\frac{\beta}{2} \mid \hat{x} > -i \sin\frac{\beta}{2} \mid -\hat{x} > \tag{2}$$

Now the crucial point is that, in measuring, say, consistently $s_x = -\frac{1}{2}\hbar$ for some point R of S_2 (an interference maximum for spin-down particles along the x-axis), we see each time *both the A and the B wave contribute to the result*, because we cannot construct $\mid -\hat{x} >= 1/\sqrt{2}\binom{1}{-1}$ from either merely $\psi = \binom{\psi_1}{0} = e^{ik}/\sqrt{2}\binom{1}{0}$ or merely $\psi = \binom{0}{\psi_2} = e^{ik}/\sqrt{2}\binom{0}{e^{i\beta}}$ elements. We therefore cannot even say that each measured particle came from either A or B, though without our knowing which one came from which slit. We can also see this by noting that, if we measure many s_z values at R, the s_x values *cannot* consistently be $-1/2\hbar$ (otherwise, s_z and s_x would be known). Still, if we measure many s_x values, they are all $-1/2\hbar$. This means that, in measuring s_x, we "invoke" an actual additional x-angular momentum as compared with the case of our measuring one-slit particles. The course of matters can even hardly be considered to harmonize with merely "stretched" particles passing both slits at a time, since the interference produces new (information about) angular momentum, so that, rather than that a mere "recondensation" of it occurs, something fundamental changes (retroactively) at the "particle". This harmonizes with the coded-information picture rather than with a stretched-particle one.

The foregoing implies that, in measuring s_z, we derive information from either only the A or only the B waves, whereas in measuring s_x we derive information from both. If, therefore, we adhere to the particle conception (which we do not), such two alternative measurements enforce the particle to coming from either A or B, and passing through both A *and* B, respectively. This, of course, would also amount to a retroactive effect.

Actually, this point 3. illustrates clearly how it is contributions of *information* carried by realistic quantal waves that in all cases come from both slits and that, say, build up the *information* coded as $\mid -\hat{x} >= 1/\sqrt{2}\binom{1}{-1}$, corresponding to $s_x = -1/2\hbar$ in the case of a relevant measurement. The s_x information is here coded by the intensity and phase relations between the components ψ_1 and ψ_2 of the original spinor wave $\psi = \binom{\psi_1}{\psi_2}$. Generally, spin-related information will be encoded by means of relations between spinor components of the wave. Note in this connection that in (more-component) spinor waves such as

$$\begin{pmatrix} \phi_1 e^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})} \\ \phi_2 e^{\pm i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})} \end{pmatrix},$$

we generally see an integration of the spin transmission code and the stretched, "nonlocal" character of the transmitting medium, (roughly) represented by the $\binom{\phi_1}{\phi_2}$ and the e-power factor, respectively.

We see from the foregoing that it is the measurement that (partly) determines *what piece of information* stored in the waves is derived from them ; e.g., the s_z or the s_x information, or information coming from one or from both slits. In the latter case we see a real blending, or cooperation, of different information elements going with the different "particle states" corresponding to the slits A and B, respectively. This as such tells in favor of the coded-signal theory : A real blending of two particle halves, or, say, the picture of a hidden A particle influenced by (information from) a B wave is less simple and less imaginable. Moreover, our model of the process clearly explains the remarkable quantum-mechanical influence of the (kind of) *measurement* on the "properties of the measured system" : Such measurement discriminatingly *selects a part* of the total information provided [with which, for the rest, conservation laws many only be satisfied by retroactive adjustments of, e.g., (angular) momenta].

We now also have an answer to the intriguing question where and how the angular momentum of a particle is hidden in the wave packet, that is, how we can make a model of this : The only model is the coded signal in the waves. As to photon waves we saw in 2. that, in a way, the wave packet is only a construct of the mind to make the Euclidean picture not too inconsistent, whereas actually (action-physically) angular momentum is directly transmitted from emitter to absorber. From 4. below we shall see that, in a sense, even matter waves are only metrically distorted, stretched, information channels. In any case they do no more "materially" contain angular momentum, something rotating, than they contain real mass.

It is clear from the above that, e.g., conservation of angular momentum does not hold in the traditional sense if we consider wave states, too. It only holds so far as we consider *measurable* entities, which ipso facto are interacting, that is, are generally in some corpuscular-like state. The waves make the relevant events "communicating vessels" as to the conserved quantities so far as they keep the total of the latter constant.

Note in the above connection that, e.g., in a Stern-Gerlach experiment, spin still manifests itself in region A while wavelike momentum carriers pass through (see Fig. 15). Mind here, however, that we have an interaction rather than a monofield situation in A, in which apparently the "corpuscular" code is restored, at least so far as spin is concerned. Or rather, we can say that the waves left of A act as a channel through which angular momentum is codedly, "denaturedly", transmitted to the interaction-event at A.

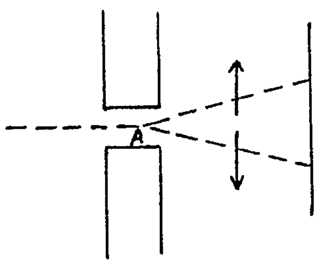

Figure 15. In region A of a Stern-Gerlach apparatus, the spin process re-adopts the interactional mode under the influence of the magnetic field.

More generally, it appears that the wave or quantal structure (retroactively ?) co-attunes its organization to the interactions or measurements relative to them. E.g., in a Young interference experiment, H-atoms are represented by whole-atom waves, but if more detailed experiments are performed on such atoms, separate electron waves going with them carry the information contained in the well-known quantum numbers n, l and m characterizing the atomic state. There are no indications of such separate waves' appearance in the Young experiment.

4. In Ref. 11 it is proved that a variation with photons of the Greenberger experiment discussed in 3. constitutes one out of several with which retroactive effects can be demonstrated. In Ref. 4 a model has been discussed for partly retroactive, "zigzag", contacts between, say, corresponding emission and absorption events. Irrespective of the correctness of such model, the phenomenon of retroactivity, or of direct physical contact between absorption and emission events, that exists in any case (compare Section 2), plays a part in our coded-information theory. We distinguish two categories of physical information transmitted by matter (or electromagnetic) waves, say, from an emission to a measurement event.

(a) Information such as about spin that is contained in the structure of the waves or wave packet itself. Other examples of this category are the energy E, encoded in the waves by their frequency $\nu = E/h$, the momentum p, encoded in them by their wavelength $\lambda = h/p$, the phase of the spin (and action), encoded by the phase of the wave, and the uncertainty margin Δp for the momentum that translates into the well-known spread of the wavelength. One more piece of information that, though implicitly, is contained in the waves "themselves" is, *inter alia*, the validity of the formula $E^2 = m_0^2c^4 + p^2c^2$, viz. via the Klein-Gordon wave equation (which holds for all components of spinor waves separately) and the implied factor $e^{i/\hbar(Et-\mathbf{p}\cdot\mathbf{r})}$ in $\psi(\mathbf{r}, t)$.

It is the nature of wave trains that defines what information can or cannot be encoded in the waves –that is, in action quanta in their simplest, little– or non-interactional shape. Quantities as ν, λ and the spin code are *inherent* to the waves. We saw in 3. that the spinorial (transformation) properties of waves allow them to carry spin signals, as the number of spinor components even encodes whether, say, photons, scalar or Dirac particles are at stake.

Note in the above connection that the essential manifestation or constituent of the quantal process in the wave shape is the field strength, potential. *This* is what can transform as a spinor of order $1, 2, \ldots$ and what *functions as the primary code variable, element, signal, too.*

(b) Starting from assuming optimum simplicity, we suppose that some properties of a momentum carrier –e.g., the structure of an atom– are not transmitted by coding characteristics of the waves themselves but by the direct ("zigzag") communication through the four-dimensional wave packet as a channel. Of course, the alternative hypothesis that such information is hiddenly encoded in the wave packet cannot completely be ruled out. Think of the amount of information that, e.g., electromagnetic waves can transmit ! But given the fact that at least something like the zigzag communication of Ref. 4 is implied by the existence of retroactivity, we prefer simplicity.

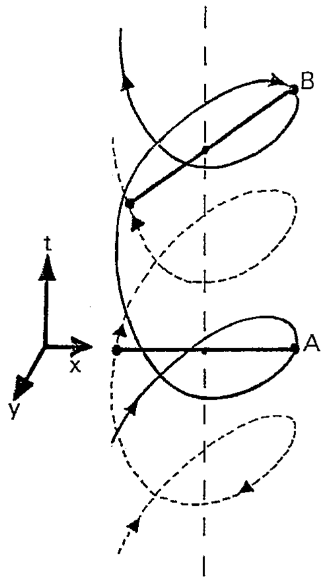

Figure 16. A corpuscule's world-line as a two-"photon" double helix with a radius $\hbar/mc$.

In connection with such communication we also remind of the model given of a "corpuscular" particle in Ref. 7, i.e., a dumbbell whose two "spheres" are photons. An implication of this is the two helical photon world-lines drawn in Fig. 16, which are covered at a velocity c. So, the real physical distance between, e.g., A and B is zero for the same reason why it is zero between O and A of Fig. 7. Thus, the double-helix model of corpuscules *implies a mechanism for partly retroactive direct communication* between events on the same world-line. Now one possibility is that such mechanism does not get lost in the isomorphic translation of "dumbbell" spherical rotation into the wave mode. Mind here that, though the isomorphism of Section 4 actually only relates to the *phases* of the action-quantal process in its two variants, the spirit of our theory implies that it is not only phase properties of the spherically rotating entity that are isomorphically translated into the spinor wave state.

Ref. 4 makes use of uncertainty margins in explaining the direct zigzag communication, which an isomorphic translation of the "helical" mechanism does not. So we (unsatisfactorily) have at least two alternative rough explanation options for retroactivity.

Note in the above connection that the dumbbell picture of Fig. 16 is very tentative and schematic. Actually, the "photons" involved in the spherical rotation may be quarks, gluons and the like. Thus it is not certain whether the "helical retroactivity" will materialize at all. (See, however, the *Remark* at the end of this paper.)

Both the zigzag and the helical mechanisms of retroactivity relate to *metric*, and we may add that generally the essentially metrical nature of (micro)physical phenomena and paradoxes is suggested by the circumstance that the quantum formalism so much concentrates on (metrical) *transformations*. It speaks a metrical language rather than one of objects, e.g., about the transformation of spinors etc. in, and the structure of, our space-time scheme. Indeed, (the form of) waves are a metrical rather than an object-like phenomenon. So are nonlocality, retroactivity, the "instantaneous collapse of wave packets", and, as indicated, spinors. Moreover, we shall see in Section 6(d) that also as regards the fundamental question what field equations appear in Nature, metrical, transformational considerations are decisive.

5. In fact, it is rather obvious why the idea of the coded-information theory of matter waves has not been introduced earlier, that is, before the truly four-dimensional character of the world and retroactive effects were established. For,

(a) In the traditional 3-dimensional development conception of the Universe some mass-like object has actually to be transported by the waves, in order that it be delivered at an instrument or absorber. In a four-dimensional conception, on the contrary, nothing has really to be transported at all : the future is "already" there. The only thing we require in such conception is logical, mathematically coherent connections between the present and a pre-existent future that produce the *Aha-Erlebnis*.

(b) Without the direct physical communication between emission- and absorption-like events that we called zigzag contact and that allows retroactive phenomena –both our two preliminary explanations imply that it is two-sided– *all* physical data of a relevant particle have to be transmitted to the instrument by means of properties of the matter waves themselves, in a coded-information theory. From the standpoint of (optimum) simplicity, however, it is more obvious then to suppose that it is the particle itself that is hidden in the waves, instead of the somewhat far-fetched case that, say, all constituents of a complicated atom have separately to be codedly registered in the waves, as to location, momentum etc. This would be a very roundabout way to convey a particle.

Instead, the coded-information theory as enunciated here plainly assumes that, in non- or very weakly interacting fields, the constituent action quanta of the process (say, a particle's movement) reduce to their simplest slice-like form, in which no "fine-structure" of the particle is retained, as discussed above. For, as we anyhow have some direct physical contact between emission- and absorption-event, the simplest assumption is that the fine-structure is "transmitted" by it, too.

Note in the whole foregoing connection that in speaking about retroactive "influences" as well as "causes" we adjust to the traditional interpretation of the Universe. Actually, in the already-existing four-dimensional world nothing is causally or retroactively produced, in the sense of "created", by something else. Nevertheless, it appears that the mutual relations between events are of such nature that we get the *Aha-Erlebnis* in considering some events and situations in connection with others from a specific point of view we call "causal", causality, moreover, recently appearing to "act" in the $-t$ direction, too, in which case we call it retroactive. Our and other theories aiming at understanding actually do nothing but produce and intensify such *Aha-Erlebnisse* by extending and generalizing the network of causal relations, in both the $+t$ and $-t$ directions.

It became already clear from our discussion that the action-quantal waves do not really *transport* momentum (carriers), which then would "arrive" at the absorber, and that the consequence is a restriction of conservation laws to "interactional junctions" ; the conserved variables are represented in the waves in a similar coded or "hidden" way, though, as is the relevant mass itself. In the traditional sense, they are lacking.

6. It also becomes understandable now why quantum mechanics actually only refers to, and connects, measurables and measuring events, adjudging a special status to them, while leaving intermediate situations and mod-

els thereof out of consideration. For we see now that, though being quite real, the latter situations are of a rather fundamentally different nature, are "written in another language" ; so much so that not even the conservation laws transcend the gap in the familiar way.

Moreover, we already start understanding why more generally the quantum formalism is so "formalistic" indeed, not allowing understandable models, *in the traditional terms*, of what happens between or apart from measurements. (This point will be further elucidated below ; see in particular Section 9.) We see, too, that this has nothing to do with some "new way of thinking" that would be necessary, or with a possible correctness of positivistic philosophy, but only corresponds to the simple, coded and at the same time completely realistic way in which matter waves convey physical information, properties. Traditional models of a kind such as stretched or guided spinning tops, it is true, invariably fail, but this does not preclude realistic models in the form we discussed.

7. Subsequently, we have to ask ourselves what the "strings" connecting a spherically rotating system with the environment are in real corpuscular particles. Of course, they must be physical connections with such environment which, as we say earlier, are necessary in order that any rotational elementary event (quantum of action) makes sense at all. Mindful of the fact that the waves were a translation of the rotation of a core plus strings we see that actually we need the strings only with the *corpuscular* state. Then, the answer is simply : The "strings" are the system of forces –embodied, e.g., by mesons, gravitons, or virtual photons– connecting each particle with its environment, precisely if it is *not* in the free-field, weak- or non-interactional –that is, wave– condition.

Because of the isomorphism discussed, we can expect the presence of the strings to have a counterpart in the relevant wave mode, too, that in particular discriminates the latter from an isomorphic translation of a mere normal, cylindrical, rotation. For the rest, note that spherical rotation would not fundamentally change if we imagine the strings to be "loose", behaving in the same way without making contact. (Think of accompanying mesons or virtual photons which make no external contact.) Then, we would have a periodic real internal change of the system. Matter wave quanta, as "*isolated*" periodic processes, can most directly be seen as isomorphic translations of such "loose-end" spherical rotations.

8. Point 7. makes it even more clear that the crucial circumstance marking a

transition from the corpuscular to the wave-like state is the virtual severance of the particle's "string" connections with its environment. Upon this, the latter can no longer function as a physically manifest reference frame we earlier saw to be necessary in order that rotation makes sense. So, such severance makes Nature go over to the (simpler) wave-like mono-field state for the free(er) particle, contrasting with the interactional state.

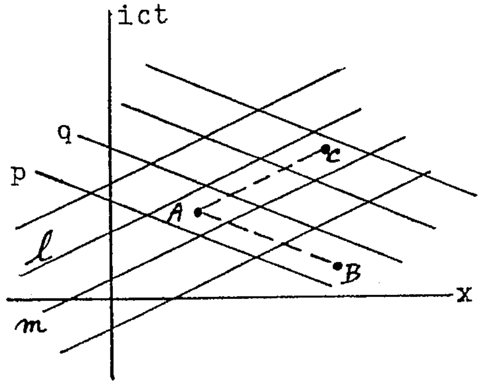

Figure 17. The action physics in interaction processes tends to no longer producing the consistent slice-like stretchings from which coherent wave phenomena originate.

We can see from Fig. 17 why the internal action metric of a (relatively) free field, responsible for the slice-like extension of action quanta producing the wave phenomenon, has no observable consequences in (most) interactions, that is, in typical corpuscular situations. For, if the slice between p and q corresponds to interacting particle P and the one between l and m to interacting particle L, then a shift $A \to B$ may be action-metrically infinitesimal for the P movement process, but it is not for the L one. As to the shift $A \to C$ the converse holds. That is, there are no more Minkowskian finite but action-metrically infinitesimal shifts *for the interaction process* now, at least not in the coherent, wave-generating way we considered, e.g., in Fig. 4. The waves only play a part in the measure in which P and L preserve a degree of independent existence, which still may be high, e.g., in a Compton interaction. If it is low, we no longer see the consistent, straightforward discrepancy between Minkowski and action metric, for the process, that produces coherent wave phenomena. (The above holds even apart from retranslations to the corpuscular state in interactions.)

As regards the corpuscular state, it is important to remind that, because of Noether's theorem, the conservation laws (continue to) hold in the interaction of fields, they appearing to be implied by the field functions and symmetries of the action integral (see Ref. 18, pp. 217–220 ; for the rest, this result again illustrates the predominance of action). Now in the more complicated action situations of interacting, interfusing, fields, corpuscules are just the simplest, most economical, way to store various conserved quantities –(angular) momentum, energy, charge, . . .– on a local basis. And locality and the (rough) Minkowski scheme regain prominence as soon as the typical stretching and separate –quanta-manifestation phenomena cease dominating, which we saw tends to be the case in (intense) interactions. *Again, Nature aspires to optimum simplicity* : in producing corpuscules as well as in producing waves. Both just embody alternative data codes for economically storing information in action quanta, in two different situations. Because our observations will relate to particles *in (intense) interaction*, we unjustly extrapolated the corpuscular model as an absolute into little-interactional situations, too. We did not hit upon the idea that, in "mono"-fields, action reduces to its simplest, most unstructured and unperturbed, that is, wave-like manifestation.

In the measure in which paradoxes are solved by realizing that Nature *varies* its language, or mode of storing and transmitting information –the Universe essentially consists of "modeled action" : the basic stuff action and information carried by it–, so that corpuscules are less absolute than thought previously, in such measure we see again that giving up prejudices (especially prejudices about "absolutes") is often essential in getting new insights. Abandoning the absoluteness of Minkowskian space and metric (as previously the one of the Euclidean), by realizing the role of the action metric derived from the relevant physical process, constitutes the other example of this that is essential with respect to the solution of the quantum paradoxes.

Thus, the nonlocality paradoxes are solved by giving up the assumption of the absoluteness, pre-existence, of Minkowski space and metric, independent of such space's contents, whereas the (other) paradoxes embodied by the impossibility of constructing coherent models of microprocesses are solved (as will become even clearer in following sections) by abandoning the assumption that Nature invariably stores and transmits the information we associate with particles in roughly the same way (i.e., as corpuscules). *The two abandonments are mutually related, both having to do with the primacy of action, over conventional space and metric as well as over conventional objects, mass-concepts.*

In Section 6 of Ref. 7 we go further into the dumbbell model of the corpuscular state of (elementary) particles. It elucidates how, at least in some corpuscules, spin is an integral aspect of the action-quantal process. E.g., in Dirac particles we see each two rotations of the dumbbell core, completing one quantum of action, produce $4\pi \times \frac{1}{2}\hbar = h$ of action by the mere rotation process. This suggests the action to be completely invested in the spin process here.

9. Summarizing about the quantum of action, we can now say :

(a) If one abandons absolute space, rotation of a system S makes only sense as a physical process if it implies an actual periodical change of S or one with respect to an environment that *really interacts with* S. Then, spherical rotation is the simplest periodical process making sense.

(b) Spherical rotation is intrinsically a spatially extended process, also involving "strings" whose situation is periodically restored.

(c) Four-dimensional wave slices with field strengths as symbolically sketched in Fig. 6 constitute structured action quanta as they manifest themselves if the "strings" have been virtually severed. Such quanta as four-dimensional processes are mathematically isomorphic with the simplest "corpuscular" periodical process, that is, contain its information.

(d) The fact that a spin axis rotation through 2π, e.g., in neutron interference experiments, which still restores the *local* situation, makes nevertheless ψ *change* its sign [17], may actually relate to the extended, more-than-local, nature of spherical rotation.

(e) Spherical rotation and the 2- or 4-spinor waves representing it are also inherently connected with spin, are natural carriers of it.

Remark. In this paper, we referred a few times to the dumbbell model of elementary momentum carriers in the corpuscular state as it is discussed in Ref. 7. The dumbbell rotation process, then, is actually conceived as a somewhat more articulate version of the spherical rotation that is so important in our argument, and each of whose completed periods represents one action-quantal process in the existence in time of a corpuscular momentum carrier. After completing the present article we found the well-known *Zitterbewegung* to be the most detailed model of the relevant action-quantal process, two consecutive *Zitterbewegung* rotations representing the physical articulation of what happens during one complete period of the mathematically conceived spherical rotation. In the *Zitterbewegung* we have indeed a (massless) "charge" moving at a velocity c, so that the retroaction mechanism as indicated above in connection with Fig. 16 probably appears indeed. See for all of this my "The Zitterbewegung embodies understandable models of the action quantum and retroactive influencing", in *Problems in Quantum Physics ; Gdansk '87* (Conference proceedings to be published by World Scientific Publishing Comp. Ltd., Singapore, in 1988).

Another paper on this subject –"The Zitterbewegung as a model of the quantum of action ; explanation of retroactive influences"– has been submitted.

Both papers also discuss various properties of the *Zitterbewegung* (which may be seen as a more articulate dumbbell rotation) that exactly represent the correct spin, magnetic moment, action and mass which can also be expected to be generated by *action quanta* embodying the existence in time of the particles in question. That is, the *Zitter*-process has all the required properties of the relevant *action-quantal* process, whereas it appears to have the same period, too.

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(Manuscrit reçu le 15 juin 1987)