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Quantum Theory of Ur-Objects as a Theory of Information

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The quantum theory of ur-objects proposed by C. F. von Weizsäcker has to be interpreted as a quantum theory of information. Ur-objects, or urs, are thought to be the simplest objects in quantum theory. Thus an ur is represented by a two-dimensional Hilbert space with the universal symmetry group $SU(2)$, and can only be characterized as *one bit of potential information*. In this sense it is not a spatial but an *information atom*. The physical structure of the ur theory is reviewed, and the philosophical consequences of its interpretation as an information theory are demonstrated by means of some important concepts of physics such as time, space, entropy, energy, and matter, which in ur theory appear to be directly connected with information as "the" fundamental substance. This hopefully will help to provide a new understanding of the concept of information.

1. INTRODUCTION

This paper deals with a certain kind of quantum theory—the so-called quantum theory of ur objects developed by C. F. von Weizsäcker and his collaborators (Castell, Drieschner, Görnitz, *et al.*). The ur theory can be regarded as a quantum theory of information. The basic concepts of physics such as time and space are related to the concept of information and classical physical substances such as energy and matter, of which the world consists and which could be regarded as equivalent since special relativity theory, are reduced to information as "the" fundamental substance. A short outline is given of the concept of space related to information and to the connection between information on one hand and energy and matter on the other.

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2. SPACE AS A REPRESENTATION OF INFORMATION

2.1. Urhypothesis and the Concept of Position Space

In ur theory one starts with the elementary assumption that any object which in quantum theory is represented by a Hilbert space spanned by the states of the object can be described in a state space which is isomorphic to a subspace of tensor products of two-dimensional complex spaces. In a more logical formulation this means that the set of n attributes or properties which are necessary to describe a physical object in terms of its possible states can be regarded as an n-fold alternative. In ur theory any alternative will be decomposed into the Cartesian product of elementary binary alternatives—called ur alternatives or ur objects (urs). This leads to a "logical atomism," i.e., the smallest objects in physics are not small as regards their spatial but their logical smallness. Thus an ur object can conceptually only be characterized as representing *one bit of potential information*. In this sense ur theory basically has to be understood as a quantum theory of information and so information acquires a new dimension as the fundamental physical substance.

We repeat the basic postulates of ur theory in a more formal way.

Definition. ur object: An ur is described by a two-dimensional complex state vector

$$|u_r\rangle \in \mathbb{C}^2, \qquad r = 1, 2 \tag{1}$$

Rule of State Spaces. Hilbert spaces of any objects can be represented in a subspace of the tensor product space of two-dimensional Hilbert spaces belonging to urs

$$V^m \subseteq T_n = \bigotimes_n \mathbb{C}^2, \qquad m \leq 2^n \tag{2}$$

Symmetry Group. The universal symmetry group Q of an ur object keeps invariant the unitary norm $\langle u \mid u\rangle = u_1^\dagger u_1 + u_2^\dagger u_2$ and contains the subgroups

$$SU(2) \times U(1) \quad \text{and} \quad K \tag{3}$$

The antilinear transformations $\hat{K} \in K$ act like $\hat{K}|u\rangle = i\hat{\sigma}_2|u^*\rangle$, where $\hat{\sigma}_2$ is the second Pauli matrix and * the complex conjugation.

In ur theory the *three-dimensional position space* is derived as a consequence of these mathematical conditions. This can be explained by analyzing the concept of space. In most cases the spatial distance between objects can be understood as the parameter for the interaction between these objects. On the other hand, the definition of a physical object (e.g., a massive elementary particle) depends on the separation of its typical spatial range. Supposing that all objects consist of urs, the total state of the universe should remain unchanged by transforming all urs with the same element from the symmetry group of the ur, which is essentially $SU(2)$. Thus the interaction between all objects should be invariant and therefore the position space as a parameter space for the strength of interaction should have the same structure as the symmetric space of the symmetry group of the ur. In ur theory therefore the assumption is made that the position space has to be *identified* with the homogeneous space $\mathbf{S}^3$ of the group $SU(2)$. Later the time development of urs will be described by the group of phase transformations $U(1)$ in (3).

2.2. Large Numbers in Physics

The quantum theory of urs gives an argument for deriving the physical position space and for describing its global structure as a space of constant curvature $k = 1$, i.e., a model for an Einstein cosmos. Space in this sense appears as a *representation or realization of information as the physical substance*. In this connection it is useful to remark that we call only those binary alternatives ur alternatives which lead back to *spatial* decisions, i.e., decisions which can only be made in position space (e.g., consider the spin state of an electron: its measurement by using a Stern–Gerlach apparatus will be done by deciding a spatial alternative about the deflection of the electron in an inhomogeneous magnetic field and could therefore be looked upon as the decision of an ur alternative). By using the central assumption in ur theory that all physical objects consist of urs, it follows that all physical attributes or properties of objects, insofar as we are able to decide them empirically, are only measurable in position space. Thus ur theory explains a general and indeed well-known experience of every experimental physicist or manufacturer of measuring devices.

From these considerations the following basic calculations for some numerical values in ur theory become understandable. We refer to considerations made by von Weizsäcker (1971) and later by Görnitz (1988a) to estimate the number of urs investigated in particles. As pointed out, the decision of an ur alternative is thought to be a decision in position space. Thus the simplest decision which can be made on a particle will be to decide if it is localized in the "left" or the "right" half of the cosmos and is therefore the decision of an ur alternative. Now it is well known that the Compton wavelength $\lambda = h/mc$ gives a measure of the size of a massive particle. Because of the empirical fact that the ratio between the cosmic radius R and the Compton wavelength of a proton is about

$$\frac{R}{\lambda_p} = 10^{40} \tag{4}$$

the proton can be considered as containing

$$n_p = 10^{40} \tag{5}$$

urs. From the same argument it follows that $n_e = 10^{38}$ for the number of urs in an electron. Now, how many urs are there in the universe? For a size measurement of the order

$$\Delta x \simeq \frac{hc}{E} \tag{6}$$

a measuring particle with the energy E is needed. Since the main part of the total energy of the universe comes from ponderable matter, i.e., from protons or nucleons (as we know today), the volume λ_p^3 gives an approximation of an elementary cell of volume in which the whole cosmos could in principle be divided simultaneously. Then it follows for the total number of urs in the universe

$$N = \frac{R^3}{\lambda_p^3} \approx 10^{120} \tag{7}$$

It was the first empirical test for ur theory that from this result the correct number of nucleons in the world is given by

$$z_p = \frac{N}{n_p} \approx 10^{80} \tag{8}$$

To verify these results we could imagine a single ur as a wavefunction expanded over the whole cosmic space, i.e., a wavefunction with minimal localization. Thus from the uncertainty relation (6) it follows for the energy of a single ur

$$E_0 \simeq \frac{hc}{R} \approx 10^{-32} \text{ eV} \tag{9}$$

Now this value is indeed compatible with the above results, because for the total energy of the universe we get

$$U = N \cdot E_0 = z_p \cdot E_p \approx 10^{88} \text{ eV} \tag{10}$$

with the proton energy $E_p = 1$ GeV.

On the basis of similar considerations it is possible to derive $n_{\text{ph}} = N^{1/4} \approx 10^{30}$ for the number of urs in a photon. With $z_{\text{ph}} = N/n_{\text{ph}} \approx 10^{90}$ for the number of photons in the world one finds the correct empirically verified value for the photon–baryon ratio $z_{\text{ph}}/z_p \approx 10^{10}$.

It seems reasonable to interpret these results as a proper confirmation of the ur-theoretic estimates, because the correspondence of such large numbers cannot be dismissed as a product of mere chance. The quantum theory of urs as a quantum theory of information originally has to deal with astronomical ur numbers, i.e., the *information content of physical objects in a bit.* Thus ur theory provides a natural way of motivating such enormous physical numbers discussed, for example, by Eddington (1931) or Dirac (1937).

Since the overwhelming part of information is needed to represent a physical object as localized in position space, the existence of large bit numbers cannot be reproduced in standard physics. Only when considering physical extremes, e.g., a particle passing over the event horizon of a black hole, does the knowledge about its whole informational content get lost. In this case ur theory explains a result found in black hole theory: the difference of the Bekenstein–Hawking entropy (Bekenstein, 1973) for a particle of mass m falling into a black hole of mass M is

$$\Delta S = 4\pi[(M + m_p)^2 - M^2] = 8\pi M m_p \tag{11}$$

Now there is a close connection between the concept of entropy and information. As von Weizsäcker (1985) pointed out, entropy has to be understood as *potential information*, i.e., information which can be won if one is interested in the actual microstate of a system. For this reason the entropy of a physical system is of the order of the number of urs in it. Görnitz (1986) has shown that for a proton falling into a black hole the maximal loss of information, which yields $M = M_u$ (mass of the universe), is exactly the ur-theoretic value for the informational content of the proton given above,

$$\Delta S_{\max} = 8\pi M_u m_p \approx 10^{55}\ \mathrm{g} \cdot 10^{-24}\ \mathrm{g} \approx 10^{41}\ m_0^2 \tag{12}$$

where $m_0 = 10^{-5}$ g is the Planck mass. This again shows the important aspect in an information-theoretic interpretation of ur theory that the overwhelming empirically possible amount of information in an object is invested in its spatiality and is therefore not taken into consideration in ordinary physics or information theory. One could say that this information, contributing to the possibility of localization of particles, does not appear in standard physics because it is hidden in the semantics of the concept of a particle, which is presupposed in common physics.

3. ENERGY AND MATTER AS CONDENSATES OF INFORMATION

3.1. Vacuum Energy Density as a Density of Information

From ur-theoretic considerations Görnitz (1988b; Görnitz and Ruhnau, 1989) has derived the existence of a nonvanishing effective cosmological constant, i.e., a time-dependent cosmological term which yields

$$\Lambda(t) \sim \frac{1}{R^2(t)} \approx 10^{-120}\ \mathrm{cm}^{-2} \tag{13}$$

Its numerical smallness, a problem in ordinary cosmology, in ur theory appears as a natural result. Since space has to be regarded as the representation of information, a nonvanishing cosmological constant has to be understood as a necessary consequence. The existence of $\Lambda \neq 0$ is often regarded as indicating the ontological priority of space over matter. This was the reason for Einstein to dismiss his own invention, because the Mach principle, which does not allow the space to have any physical effect, would be violated. But from the ur-theoretic point of view this seems like begging the question. Space is by no means "empty," it is at least filled up with urs. Moreover, its structure as a global $\mathbf{S}^3$ is a consequence of the isomorphic structure of the abstract symmetry group of urs, i.e., space is the appearance of pure information in the world. Apart from this, further appearances of information like energy and matter exist. Hence radiation and massive particles as well as the vacuum energy density will be described by density situations of urs, i.e., of information. In that sense energy and matter can be looked upon as condensates of information in front of a background of urs representing the vacuum.

3.2. Particle Physics in Minkowski Space

In ur theory the global world model is $\mathbf{S}^3$. But according to Wigner the states of elementary particles can be considered as representations of the Poincaré group and therefore the particle concept is only defined in the approximation of a flat Minkowski space. As Castell (1975) pointed out, the complex conjugation in (3) leads to an introduction of anti-urs and, as a consequence, to the new symmetry group $SU(2,2)$ which is locally isomorphic to the conformal group $SO(4,2)$. The Poincaré group is a subgroup of $SO(4,2)$.

In order to build particle representations a quantization procedure is needed to allow annihilation and creation of urs in the tensor Fock space

$$T^{(R)} = \bigoplus_n T_n^{(R)} \tag{14}$$

where $T_n^{(R)}$ is the tensor product space over an R-dimensional complex vector space V^R spanned by the R basis vectors of urs [$R = 2$ as defined in (2)] or of urs and anti-urs ($R = 4$). Now in ur theory a para-bose quantization is used, i.e., the most general commutation relations which are compatible with the Heisenberg equations. This generalization of statistics was first suggested by Green (1953). We use the following abbreviations:

$$\alpha_{rs} = \frac{1}{2}\{a_r, a_s\}, \qquad \alpha_{rs}^+ = \frac{1}{2}\{a_r^+, a_s^+\}, \qquad \tau_{rs} = \frac{1}{2}\{a_r^+, a_s\} \tag{15}$$

and for the number operator

$$n_r = \tau_{rr} - \frac{p}{2}, \qquad n = \sum_r n_r \tag{16}$$

Now para-Bose quantization is done, if the annihilation and creation operators of urs a_r, a_r^+ ($r = 1, \ldots, R$) fulfill the (trilinear!) Green commutation relations

$$[a_r, \tau_{st}] = \delta_{rs} a_t, \qquad [a_r, \alpha_{st}] = [a_r^+, \alpha_{st}^+] = 0 \tag{17}$$

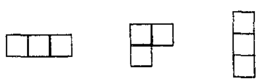
These conditions can be satisfied if the operators a_r, a_r^+ are given in the Green decomposition (the parameter p is called para-Bose order)

$$a_r = \sum_{\alpha=1}^{p} b_r^{(\alpha)}, \qquad a_r^+ = \sum_{\alpha=1}^{p} b_r^{(\alpha)+} \tag{18}$$

with the following commutation relations for the Green components $b_r^{(\alpha)}$, $b_r^{(\alpha)+}$:

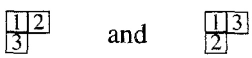
$$[b_r^{(\alpha)}, b_s^{(\alpha)+}] = \delta_{rs}, \qquad [b_r^{(\alpha)+}, b_s^{(\alpha)+}] = [b_r^{(\alpha)}, b_s^{(\alpha)}] = 0$$
$$\{b_r^{(\alpha)}, b_s^{(\beta)+}\} = \{b_r^{(\alpha)}, b_s^{(\beta)}\} = \{b_r^{(\alpha)+}, b_s^{(\beta)+}\} = 0 \qquad (\alpha \neq \beta) \tag{19}$$

A paraboson can be looked upon as an object which consists of p bosonlike subobjects. This can be seen by considering the theory of Young diagrams. One diagram is a frame of n boxes arranged in rows and columns in which the number of boxes per row does not increase downward. The classes of equivalent irreducible representations of the symmetric group S_n can be illustrated by the Young diagrams. For example, consider the diagrams for three objects



(20)

A diagram in which the numbers $1 \cdots n$ are filled in obeying the rule that they increase in each row from the left to the right and also in each column from the top to the bottom is called a *standard tableau.* The number f_k of each type of tableau k gives the number of the irreducible representations of S_n and also their dimension. For example, the two possible tableaux

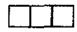


of the mixed-symmetric type ($k = 2$) both correspond to two-dimensional representations (i.e., $f_2 = 2$) of S_3. This leads to the well-known formula

$$\sum_k f_k^2 = n! \tag{21}$$

A diagram in which the numbers do not decrease in each row and increase in each column is called a *standard scheme.* In $T_n^{(R)}$ every diagram defines

f_k irreducible representations of the full linear group $GL(R)$. Each scheme defines the basis vectors for these representations, e.g., a four-dimensional representation of $GL(2)$ in $T_3^{(2)}$ is defined by the diagram



and are given by the tensors

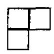
$$\begin{array}{|c|c|c|}\hline 1&1&1\\\hline\end{array} \qquad |\phi_{111}\rangle = |111\rangle$$

$$\begin{array}{|c|c|c|}\hline 1&1&2\\\hline\end{array} \qquad |\phi_{112}\rangle = |112\rangle + |121\rangle + |211\rangle$$

$$\begin{array}{|c|c|c|}\hline 1&2&2\\\hline\end{array} \qquad |\phi_{122}\rangle = |122\rangle + |212\rangle + |221\rangle$$

$$\begin{array}{|c|c|c|}\hline 2&2&2\\\hline\end{array} \qquad |\phi_{222}\rangle = |222\rangle$$

Now, the two-dimensional representations are defined by the diagram



and are given by two tensors in each case

$$\begin{array}{|c|c}\hline 1&\multicolumn{1}{c|}{1}\\\hline 2&\\\cline{1-1}\end{array} \qquad \begin{cases}|\psi_{112}\rangle = 2\cdot|112\rangle - |211\rangle - |121\rangle\\ |\psi_{211}\rangle = 2\cdot|211\rangle - |112\rangle - |121\rangle\end{cases}$$

$$\begin{array}{|c|c}\hline 1&\multicolumn{1}{c|}{2}\\\hline 2&\\\cline{1-1}\end{array} \qquad \begin{cases}|\psi_{122}\rangle = -2\cdot|122\rangle + |221\rangle + |212\rangle\\ |\psi_{221}\rangle = -2\cdot|221\rangle + |122\rangle + |212\rangle\end{cases}$$

The para-Bose quantization procedure only admits tensors of urs which correspond to Young diagrams with maximal p rows. For that reason the number of rows cannot exceed $p = R$. All tensors of higher para-Bose order are linearly dependent on the tensors of order $p \leq R$. It has been mentioned Ohnuki and Kamefuchi (1969) that this is not sufficient to characterize para-Bose statistics completely. The para-Bose procedure picks out only one tensor for every standard scheme, i.e., the multiplicity of the irreducible subspaces of S_n as regards index permutations is always one. For example, in the case of the scheme

$$\begin{array}{|c|c}\hline 1&\multicolumn{1}{c|}{1}\\\hline 2&\\\cline{1-1}\end{array}$$

for $p = 2$ only the tensor

$$\begin{aligned}|\psi_{121}\rangle &= \frac{1}{8}\left(a_1^+a_2^+a_1^+ - \frac{1}{2}(a_1^+a_1^+a_2^+ + a_2^+a_1^+a_1^+)\right)|\Omega\rangle\\ &= 2\cdot|121\rangle - |112\rangle - |211\rangle \end{aligned} \tag{22}$$

can be obtained, which is a linear combination of $|\psi_{112}\rangle$ and $|\psi_{211}\rangle$

$$|\psi_{121}\rangle = -|\psi_{112}\rangle - |\psi_{211}\rangle \tag{23}$$

whereas, for instance, $|\phi_{112}\rangle$ for $p = 1$ is simply given by $a_1^+ a_1^+ a_2^+ |\Omega\rangle$. The other tensors of the higher dimensional representations can be obtained by permutations of the indices, i.e., quantum numbers (place permutations are not well defined). So it turns out as a consequence that the para-Bose procedure corresponds exactly to the physically distinguishable tensors in $T_n^{(R)}$, whereas tensors which can be obtained by permutation of the ur indices are physically indistinguishable.

With the para-Bose quantization one is able to represent Lie groups in the Fock space of urs which is raised over the vacuum state defined by

$$b_r^{(\alpha)}|\Omega\rangle = 0 \qquad \forall r, \alpha \tag{24}$$

and accordingly

$$a_r a_s^+ |\Omega\rangle = p\delta_{rs}|\Omega\rangle \tag{25}$$

The representation of the conformal group $SU(2, 2)$ is given by the 15 generators

$$\begin{aligned}
M_{12} &= i/2\ (n_1 - n_2 + n_3 - n_4)\\
M_{13} &= 1/2\ (-\tau_{12} + \tau_{21} - \tau_{34} + \tau_{43})\\
M_{23} &= i/2\ (\tau_{12} + \tau_{21} + \tau_{34} + \tau_{43})\\
M_{15} &= i/2\ (\tau_{12} + \tau_{21} - \tau_{34} - \tau_{43})\\
M_{25} &= 1/2\ (\tau_{12} - \tau_{21} - \tau_{34} + \tau_{43})\\
M_{35} &= i/2\ (n_1 - n_2 - n_3 + n_4)\\
M_{46} &= i/2\ (n + 2p)\\
N_{14} &= i/2\ (\alpha_{13} + \alpha_{13}^+ - \alpha_{24} - \alpha_{24}^+)\\
N_{24} &= 1/2\ (-\alpha_{13} + \alpha_{13}^+ - \alpha_{24} + \alpha_{24}^+)\\
N_{34} &= i/2\ (-\alpha_{14} - \alpha_{14}^+ - \alpha_{23} - \alpha_{23}^+)\\
N_{16} &= 1/2\ (-\alpha_{13} + \alpha_{13}^+ + \alpha_{24} - \alpha_{24}^+)\\
N_{26} &= i/2\ (-\alpha_{13} - \alpha_{13}^+ - \alpha_{24} - \alpha_{24}^+)\\
N_{36} &= 1/2\ (\alpha_{14} - \alpha_{14}^+ + \alpha_{23} - \alpha_{23}^+)\\
N_{45} &= 1/2\ (\alpha_{14} - \alpha_{14}^+ - \alpha_{23} + \alpha_{23}^+)\\
N_{56} &= i/2\ (\alpha_{14} + \alpha_{14}^+ - \alpha_{23} - \alpha_{23}^+)
\end{aligned} \tag{26}$$

The generators of the Poincaré group are then given by

$$\begin{array}{llll} M_{ik} & \text{angular momenta} & P_i = M_{i5} + N_{i6} & \text{momenta} \\ N_{i4} & \text{Lorentz boosts} & P_0 = N_{45} + M_{46} & \text{energy} \qquad (i = 1, 2, 3) \end{array} \tag{27}$$

To build particle representations, as a first step it is necessary to describe a special vacuum state $|\omega\rangle$ which is invariant under the Poincaré group. This is by no means a state which is empty of urs [like $|\Omega\rangle$ in (24) is], because in general the generators of the Poincaré group change the number of urs. From the information-theoretic point of view the Lorentz vacuum $|\omega\rangle$, a state in which no particle exists, must be regarded as containing a lot of information, i.e., its special Lorentzian space structure. In Görnitz *et al.* (1992) the Lorentz vacuum is given by

$$|\omega\rangle = \sum_{\mu=0}^{\infty} \sum_{\lambda=0}^{\infty} \frac{(-1)^{\mu+\lambda} i^{\mu-\lambda}}{\mu!\,\lambda!} \alpha_{14}^{+\mu} \alpha_{23}^{+\lambda} |\Omega\rangle = e^{i(\alpha_{23}^{+} - \alpha_{14}^{+})} |\Omega\rangle \tag{28}$$

From this Lorentz vacuum state of urs it is now possible to build particle states by applying the operators (15) on it.

For example, the representation of a massless spin-0 particle, which von Weizsäcker calls a "zeron," for $p = 1$, is given by

$$|\psi(s = 0)\rangle = \sum_{\mu=0}^{\infty} \frac{(i\epsilon)^{\mu}}{(\mu!)^2} \alpha_{14}^{+\mu} |\omega\rangle \tag{29}$$

whereas a massless spin-1/2 particle, i.e., a neutrino, is only distinguished from the zeron by applying one additional ur on it producing the spin in the z direction

$$|\psi(s = 1/2)\rangle = a_1 |\psi(s = 0)\rangle \tag{30}$$

These states fulfill the conditions

$$\begin{array}{lll} P_1|\psi\rangle = 0, & (P_0 - P_3)|\psi\rangle = 0 & \\ P_2|\psi\rangle = 0, & (P_0 + P_3)|\psi\rangle = i\epsilon|\psi\rangle, & p_0 = p_3 = \epsilon/2 \end{array} \tag{31}$$

Further representations of massive particles with spin can be obtained in the same manner. This was first done in Görnitz *et al.* (1992), but investigations into these states and their correspondence to the known types of fundamental particles like quarks and leptons are still underway. This is the actual ur-theoretic way to try to find the connection between ur theory and the standard model of elementary particle physics.

4. COSMIC EVOLUTION AS AN EVOLUTION OF INFORMATION

Finally, cosmic evolution should be briefly discussed from the ur and information-theoretic point of view. Evolution can in principle be regarded as a production of more and more complex structures—in a first step the formation of elementary particles, later the formation of atoms, molecules, planets, biological cells, animals, and so on. In information-theoretic language these structures of different complexity could be regarded as different semantic levels. It therefore has to be an aim of ur theory to describe this evolution as an evolution of information, where the formation of higher semantic levels can be explained from the levels below. The elementary objects, urs, represent the lowest semantic level, i.e., simple bits. Now the change into the next level is equivalent to the introduction of a new structural feature which allows the forming of classes of urs. This forming of classes can then be regarded as a new semantic level and exactly this is done by using para-Bose quantization in ur theory, because the para-Bose parameter p is an index for the different types of urs.

In ur theory a method would be needed to describe the change of semantic levels in a general way. This could presumable be done in von Weizsäcker's procedure of *multiple quantization* (in German, *Mehrfache Quantelung*), which has to be regarded as an iteration of complementarity logic (von Weizsäcker *et al.*, 1958). This means that the components of an n-fold alternative correspond to complex-valued truth variables. The question arises of how this procedure can be connected with the para-Bose quantization to reach higher levels. The first three semantic levels so far seem to be: ur alternatives, para-Bose tensors of urs, and elementary particles as described above. Thus a straightforward procedure of multiple quantization could be a mathematical way to explain evolution in the framework of a quantum theory of information as an iteration of semantics.

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REFERENCES

Bekenstein, J. D. (1973). *Physical Review D*, **7**, 2333.

Castell, L. (1975). Quantum theory of simple alternatives, in *Quantum Theory and the Structures of Time and Space*, L. Castell, M. Drieschner, and C. F. von Weizsäcker, eds.

Dirac, P. A. M. (1937). *Nature,* **139**, 323.

Eddington, A. S. (1931). *Proceedings of the Cambridge Philosophical Society,* **27**, 15.

Görnitz, Th. (1986). New look at the large numbers, *International Journal of Theoretical Physics,* **25**(8), 897.

Görnitz, Th. (1988a). Abstract quantum theory and space-time-structure. I. Ur theory and Bekenstein–Hawking entropy, *International Journal of Theoretical Physics,* **27**(5), 527.

Görnitz, Th. (1988b). Connections between abstract quantum theory and space-time-structure. II. A model of cosmological evolution, *International Journal of Theoretical Physics,* **27**(6), 659.

Görnitz, Th., and Ruhnau, E. (1989). Connhections between abstract quantum theory and space-time-structure. III. Vacuum structure and black holes, *International Journal of Theoretical Physics,* **28**(6), 651.

Görnitz, Th., Graudenz, D., and von Weizsäcker, C. F. (1992). Quantum field theory of binary alternatives, *International Journal of Theoretical Physics,* **31**(11), 1929.

Green, H. S. (1953). A generalized method of field quantization, *Physical Review,* **90**(2), 270–273.

Ohnuki, Y., and Kamefuchi, S. (1969). Wavefunctions of identical particles, *Annals of Physics,* **51**, 337–358.

Von Weizsäcker, C. F. (1971). *Die Einheit der Natur,* Hanser, Munich.

Von Weizsäcker, C. F. (1985). *Aufbau der Physik,* Hanser, Munich.

Von Weizsäcker, C. F., Scheibe, E., and Süssmann, G. (1958). Komplementarität und Logik, III. Mehrfache Quantelung, *Zeitschrift für Naturforschung,* **13a**:705.