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Quantum Theory as Universal Theory of Structures – Essentially from Cosmos to Consciousness

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1. Introduction

Quantum theory is the most successful physical theory ever. About one third of the gross national product in the developed countries results from its applications. These applications range from nuclear power to most of the high-tech tools for computing, laser, solar cells and so on. No limit for its range of validity has been found up to now.

Quantum theory has a clear mathematical structure, so a physics student can learn it in a short time. However, very often quantum theory is considered as being "crazy" or "not understandable". Such a stance appears reasonable as long as quantum theory is seen primarily as a theory of small particles and the forces between them. However, if quantum theory is understood more deeply, namely as a general theory of structures, not only the range is widely expanded, but it also becomes more comprehensible (T. Görnitz, 1999).

Quantum structures can be material, like atoms, electrons and so on. They can also be energetic, like photons, and finally they can be mere structures, such as quantum bits. Keeping this in mind it becomes apprehensible that quantum theory has two not easily reconcilable aspects: on the one hand, it possesses a clear mathematical structure, on the other hand, it accounts for *well-known experiences of everyday life*: e.g. a whole is often more than the sum of its parts, and not only the facts but also the possibilities can be effective.

If henadic and future structures (i.e. structures which are related to unity [Greek "hen"] and to future) become important in scientific analysis, then the viewable facts in real life differ from the calculated results of models of classical physics, which suppose elementary distinctions between matter and motion, material and force, localization and extension, fullness and emptiness and which describe any process as a succession of facts. From quantum theory one can learn two elementary insights:

1. *Not only facts but also possibilities can influence the way in which material objects behave.*
2. *The elementary distinctions made in classical models are often useful, but not fundamental.*

Quantum theory shows that there are equivalences between the concepts of matter and motion, material and force, localization and extension, fullness and emptiness, and so on, and these equivalences can be reduced to one fundamental equivalence: the equivalence of matter, energy and abstract quantum information.

2. How to understand the laws of nature?

Mankind searched for laws of nature to be braced for future events and to react on them. A rule and even more a law is only reasonable for a multitude of equal events. For a singular and therefore unique event the idea of a rule is meaningless because of the lack of a recurrence. The required equality for applying rules or laws will be achieved by ignoring differences between distinct events. Therefore, as a matter of principle, laws of nature are always approximations, eventually very good approximations at the present time. If a law of nature is expressed in the form of a mathematical structure - which is always the case in physics - then this structure may conceal the approximate character of the law. This can lead to confusion about the interpretation of some laws and their correlations. One should keep this in mind when interpretational questions of quantum effects are to be deliberated.

3. What is the central structure for an understanding of quantum theory?

To understand the central structure of quantum theory one has to inspect how composite systems are formed.

In classical physics the composition of a many-body system is made in an additive way. The state space of the composed system is the direct sum of the state spaces of the single particle systems. This results in a "Lego world view" of smallest building blocks – of one or another kind of "atoms". In this view the world has to be decomposed into ultimately elementary objects – which never change - and the forces between such objects. This picture about the structure of reality was generally accepted for more than two millennia.

Composite systems in quantum physics are constructed in a fundamentally different way. The state space of a composed quantum system is the tensor product of the state spaces of the single particle systems. *To explain quantum theory we have to start with this structural difference.* However, "tensor product" is a very technical concept. Is it possible to relate this concept to something familiar in every day live?

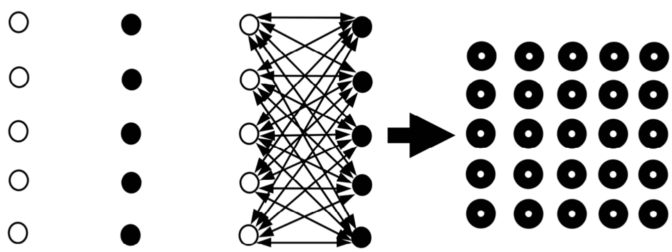

Fig. 1. The additive composition of two objects in classical physics, the states of the parts are outlined by white and black circles. The relational composition in quantum physics, marked by arrows, create the new states of the composed object. They are neither black nor white.

Let us recall that "relations" create a product structure. One can say that the new states of a composed object are the relational structures between the states of its parts. Therefore *quantum theory can be characterized as the physics of relations;* it can be seen as a clear mathematical implementation of a familiar experience of life: A whole is often more than the sum of its parts.

Up to now this central aspect of quantum theory is often misunderstood. In physics, and also in the philosophy of sciences, one speaks, for example, of "particles", i.e. electrons and so on, in a weakly bound system. This is certainly useful from a the practical point of view, but does not apply to the basic issue. In principle, two interacting electrons are "one object with charge -2" – and not two independently existing particles.

Relational structures create networks, in the essence they are plurivalent. In such a network many different connections between two outcomes are possible. This leads us to a further characterization of quantum theory, namely, *quantum theory as "the physics of possibilities".*

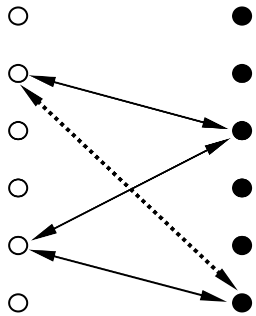

Fig. 2. Relations are not unique, they constitute possibilities.

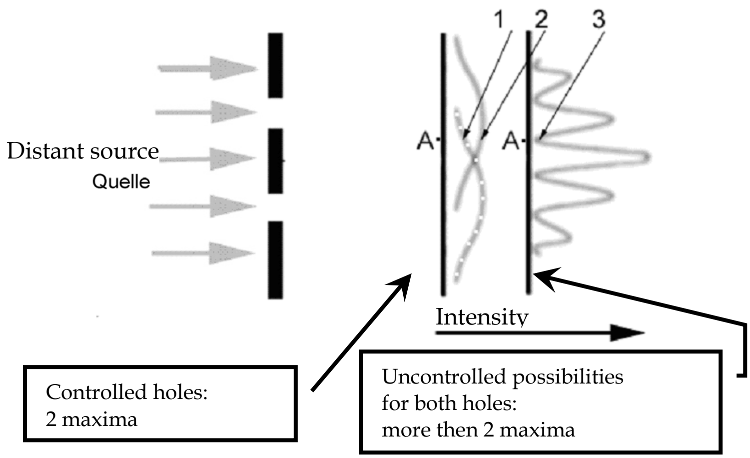

Fig. 3. When quantum particles have the possibility to go through both slits without controlling their passage, then one will find more then two maxima on a screen behind the slits. Position "A" can be reached if one of the holes is open, but no longer if both are open and not controlled.

In our daily life we are influenced not only by facts of the past but also by future possibilities, which we anticipate, wish for, or are afraid of. Quantum theory deals with possibilities only. We have to understand that also possibilities can have an impact – not only facts.

If in a double slit experiment quantum particles have the possibility of going through both slits without controlling their passage, will find more than two intensity maxima on a screen behind the slits. If the passage through the slits is controlled, which means that the passage through one of the slits becomes a fact, then only two maxima will result. This is comparable to experience of our everyday life: control restricts possibilities and thereby influences human behavior.

4. The indissoluble relation between classical physics and quantum physics: The dynamic layering-process

There are some popular but insufficient ideas about the distinctions of quantum physics and classical physics. One misleading distinction concerns the scope of application to microphysics and macrophysics, respectively. It is true that in microphysics only quantum theory is applicable; nevertheless there are also many macroscopic quantum phenomena. Another topic is the difference between continuous and discontinuous effects, the former being attributed to classical physics. However, it should be recalled that many operators in quantum physics have continuous spectra. Popular but false is also the distinction between a "fuzzy" quantum theory and a "sharp" classical physics. It ignores that quantum theory provides for the most accurate description of nature we ever had. Classical physics nourishes the illusion of exactness. Its mathematical structure is based on the assumption of “arbitrarily smooth changes” of any variable. While this is a precondition for calculus, it is by no means always afforded by nature. At very high precision the quantum structure will become important anyway, as *quantum physics is the physics of preciseness*.

Often there is no need for the precision of quantum theory. At first sight most of the processes in nature appear to be smooth. However, upon closer inspection, all actions are quantized, they appear in discrete “numbers” or “steps”. One may say that, strictly speaking, all changes are quantum jumps. So a quantum jump is the smallest non-zero change in nature - which may explain why this concept is so attractive in politics and economics.

Since the early days of quantum mechanics Bohr has insisted that classical physics is a precondition for speaking about quantum results. It is impossible to ignore that for humans; there are not only possibilities but also facts. For an adequate description of nature we need both parts of physics, classical and quantum physics. Its connection can be described as a “dynamic layering-process”. The classical limit transforms a quantum theoretical description into a classical one, the process of quantization converts classical physics into quantum physics.

It seems evident that quantum theory is the foundation of classical physics. The existence of all the objects handled so successfully by classical physics can only be understood adopting quantum theory. It may be recalled that the existence of atoms, having opposite charges inside, is forbidden by classical electrodynamics. On the other hand, classical physics is a precondition for the appearance of quantum properties. The quantum properties of a system become visible only if its entanglement with the environment is cut off. Such a cut can be modeled mathematically only in classical physics.

The laws of classical physics ignore the relational aspects of nature. While thus being inferior to the quantum laws, they are potentially much easier to apply. For large objects, the relational aspects are very small, so that often there is no need to employ a quantum description.

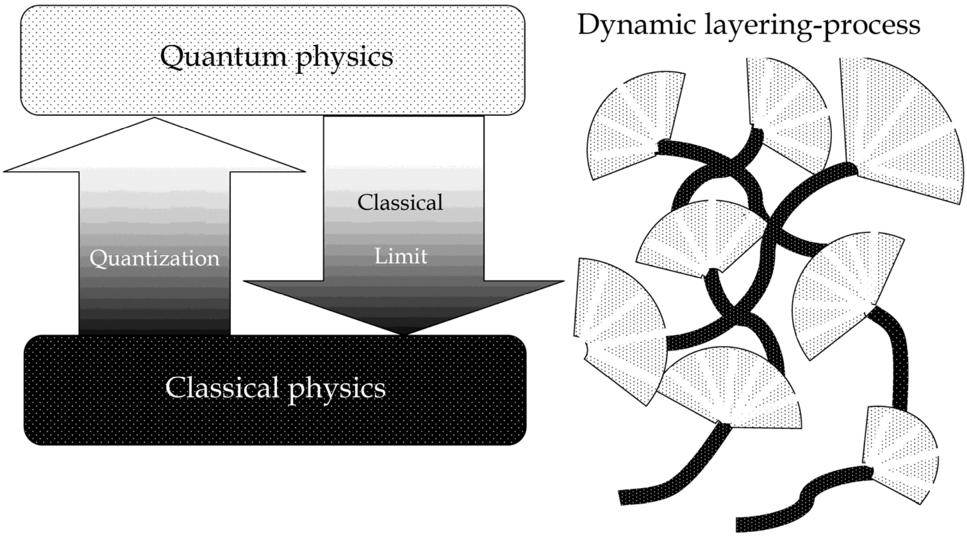

Fig. 4. Dynamic layering process between classical and quantum physics.

5. The meaning of quantization

Concerning quantization many concepts have been proposed (a good overview can be found in Ali & Engliš, 2005), and one may wonder whether here a simple fundamental structure can possibly be established.

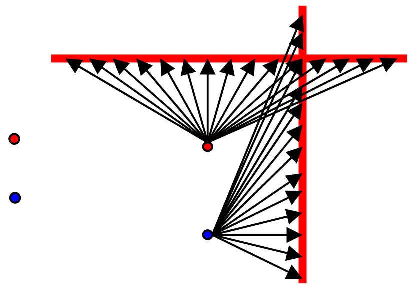

Fig. 5. Quantization of a bit: From the two states {0,1} of a bit to a two-dimensional complex state space of a qubit.

Ignoring for the moment the canonical quantization, a general structure can be inferred from the quantization of a bit with its two states {0,1} to a qubit: here quantization is obtained by constructing all complex-valued functions on the set of two points, resulting in a two-dimensional complex space C^2.

In a related way, path-integral quantization can be interpreted as constructing all functions on the set of the classical pathways. At first glance, second quantization seems to be different. However, the construction of a state of the quantum field in terms of states of quantum particles is analogous to the construction of an analytical function in terms of powers of the variable. The analytical functions are dense, e.g., in the set of continuous or measurable functions, and even distributions conceived as limits of analytical functions. So, in a certain sense, the analytical functions represent “all functions”, and a quantum field can be interpreted as “the functions on the set of quantum particles”.

In conclusion, we may say: *Quantization is the transition from the manifold of the facts to the possibilities over the facts* – where the possibilities are given in the form of functions on the manifold of facts. It even seems possible to state: “*Quantization is (actually) second quantization*.” In this sense Einstein’s invention of photons was the first demonstration of quantization.

How can the canonical quantization of classical mechanics, characterized by a bisection (“polarization”) of variables, be interpreted in the present context?

The explanation can be given as follows: Mechanics is the classical limit of quantum mechanics in that all operators commute. In quantum mechanics the position operator acts multiplicatively on wave functions over position space, while the momentum operator acts multiplicatively on wave functions over momentum space. A duplication replacing $\Phi(x)$ or $\Psi(p)$ by $R[x,p]$ allows for the commutation of position and momentum. Accordingly, in classical mechanics positions and momenta are the fundamental variables; the polarization reverses this duplication.

The essence of quantization can summarized in the sentence: Quantization is the transition from the facts to the relational network of possibilities associated with the facts - mathematically represented by a linear space of functions defined on the set of the facts.

A further characterization is as follows: The quantization of a system is the transition from a nonlinear description in a low-dimensional space, where the system may have many or infinitely many degrees of freedom (e.g. classical mechanics or electromagnetic fields), to a linear description of many or infinitely many systems with few degrees of freedom in an infinite-dimensional space (e.g. quantum bits, photons, or other field quanta). This reminds of the exponential map and its conversion of products, being nonlinear, into sums, which are linear.

6. Quantum theory relativizes distinctions

Quantum theory is consistent with everyday experience indeed, but in non-living nature quantum effects become essential only at a high precision scale. At high precision, though, effects may appear that are not so evident from the everyday experience in the world around us.

Already in school the so-called wave-particle-duality is a subject. According to quantum theory, one and the same quantum object can act, depending on the circumstances, more like a wave or more like a particle, that is, as a more extended or more localized object. As we have discussed, quantum states can be understood as extended functions on facts, and it is thus an essential non-local theory. We may say: *Quantum physics is the physics of non-locality*. A strict distinction between locality and non-locality is relativized by quantum theory.

Quantum theory demonstrates that transformations between matter and motion or between force and material are possible. Of course, Einstein's famous formula $E = mc^2$ was found in special relativity, but in any related experiment antimatter is involved. This genuine quantum concept shows that the transformation between matter and motion is an effect of quantum theory.

Motion is often declared as a *property* of matter, but *quantum theory shows that matter and motion are equivalent*. This happens always in the large accelerators, but it is also related to the central philosophical aspect of second quantization: The distinction between object and attribute depends on the context. One and the same quantum particle is an object in quantum mechanics and is an attribute of a quantum field. Therefore we can state that *quantum theory discloses an equivalence between objects and attributes*. That quantum theory has relativized the distinctions between objects, structures and attributes (or tropes as some philosophers say) is also of philosophical relevance.

Matter is visible and inert, forces are invisible and not impenetrable. From the quantum point of view, however, the distinction of force and matter reduces to the difference between quanta of integer or half-integer spin. In the large accelerators, those quanta are transformed among each other. So *quantum theory unveils an equivalence between forces and matter*.

The model of the Dirac sea shows up that even *the distinction between emptiness and plenitude is relativized by quantum theory*.

7. The quantum theoretical equivalence of matter, energy and quantum information

In addition to what was discussed above, quantum theory allows for a completely new perspective on the three entities matter, energy and quantum information. Already since 1955 C. F. v. Weizsäcker has speculated on the possibility of founding physics on quantum information. His "Ur-Theory" grows up from the intention "Physics is an extension of logics" (Weizsäcker, 1958, p. 357). As the basis for the envisaged reduction he has proposed quantized binary alternatives referred to as "Ur-Alternativen" or urs. Werner Heisenberg wrote about Weizsäcker's concept "… that the realization of this program requires thinking at such a high degree of abstraction that up to now – at least in physics – has never happened." For him, Heisenberg, "it would be too difficult", but v. Weizsäcker and his coworkers should definitely carry on. (Heisenberg, 1969, p. 332) For a long time, however, v. Weizsäcker's project was hardly appreciated, and one may wonder about the lack of recognition.

One reason may be that the concept was far too abstract. Moreover, there were almost no relation to experimental evidence. At that time, the quantities v. Weizsäcker proposed were beyond the imagination of the physicists. That one proton is made up of 10^{40} qubits is a hard sell in physics even today. Another serious problem was that v. Weizsäcker's models were inconsistent with general relativity at that time.

As essential step forward, it proved necessary to go beyond the urs. v. Weizsäcker (1982, p. 172) proposes „An »absolute« value of information is meaningless". But this is a contradiction to his claim (1971, p. 361): "Matter is information". Matter has an absolute value, as zero grams of matter is a clearly defined quantity. Therefore, with regard to *an equivalence of matter and information, the latter must have an absolute value* as well. So there was the need to extend the concept of »information« to one which is "absolute". At that absolute level, one must do without reference to an "emitter" or "receiver", and – even more important - dispense with the concepts of meaning or knowledge, at least initially. This is the basic precondition for establishing the equivalence of matter and information.

Here it proved necessary to make a connection to modern theoretical und empirical structures of physics, especially Bekenstein's and Hawking's entropy of black holes, and a rational cosmology. Physics is more than an »extension of logics«, and, in physics information differs from destination, or meaning, or knowledge. Meaning always has a subjective aspect too, so meaning cannot be a basis for science and objectivity.

If quantum information is to become the basis for science it must be conceived as absolute quantum information, free of meaning. It is denominated as "Protyposis" to avoid the connotation of information and meaning. Protyposis enables a fundamentally new understanding of matter which can seen as "formed", "condensed" or "designed" abstract quantum information. Absolute quantum information provides a base for a new understanding of the world ranging from matter to consciousness. Protyposis adds to $E=mc^2$, that is, the equivalence of matter and energy, a further formula (Görnitz, T 1988[2], Görnitz, T., Görnitz, B. 2008) :

$$N = m\, c^2\, t_{cosmos}\, 6\pi/\hbar \quad (1)$$

A mass m or an energy mc^2 is equivalent to a number N of qubits. The proportionality factor contains t_{cosmos}, the age of the universe. Today a proton is 10^{41} qubits. A hypothetical black hole with the mass of the universe would have an entropy of order 10^{123}. If a particle is added, the entropy of the black hole increases proportionally to the mass-energy of the particle. If a single proton is added to the cosmic mass black hole, the entropy will rise by 10^{41} bits. These 10^{41} qubits "are" the proton, and only very few of those qubits will appear as meaningful information. All the others are declared as mass or energy. The cosmic mass black hole has an extension corresponding to the curvature radius of the universe. If the hypothetical proton disappears behind the horizon, any information on the proton is lost, and thus the unknown information, that is, the entropy, becomes maximal.

8. Relativistic particles from quantum bits

For a precise definition of a particle one has to employ Minkowski space. Here, a relativistic particle is then represented by an irreducible representation of the Poincaré group. Such a representation can be constructed from quantum information by Parabose creation and destruction operators for qubits and anti-qubits (urs and anti-urs) with state labels running from 1 to 4.

Let be $|\Omega\rangle$ the vacuum for qubits, p the order of Parabose statistics and r,s,t $\in\{1,2,3,4\}$. The commutation relations for Parabose are

$$\begin{array}{ccc} [\hat{a}_t,\{\hat{a}_r^+,\hat{a}_s^+\}] = -2\delta_{rt}\hat{a}_s^+ - 2\delta_{st}\hat{a}_r^+ & [\hat{a}_t^+,\{\hat{a}_r,\hat{a}_s\}] = -2\delta_{rt}\hat{a}_s - 2\delta_{st}\hat{a}_r & [\hat{a}_t^+,\{\hat{a}_r^+,\hat{a}_s\}] = -2\delta_{st}\hat{a}_r^+ \\ [\hat{a}_s,\{\hat{a}_r,\hat{a}_s\}] = 0 & [a_s^+,\{a_r^+,a_s^+\}] = 0 & \hat{a}_s\hat{a}_r^+|\Omega\rangle = \delta_{rs}p|\Omega\rangle \end{array} \quad (2)$$

If we make the following abbreviations:

$$\{\hat{a}_r^+,\hat{a}_s^+\} = 2f[r,s] \qquad \{\hat{a}_r,\hat{a}_s\} = 2w[r,s] \qquad \{\hat{a}_r^+,\hat{a}_s\} = 2d[r,s] \quad , \quad (3)$$

then the operators for the Poincaré-group get the form:

Boosts

$$\begin{aligned} M_{10} &= i\,(\,w[1,4] - f[4,1] + w[2,3] - f[3,2]\,)/2 \\ M_{20} &= \;(\,w[1,4] + f[4,1] - w[2,3] - f[3,2]\,)/2 \\ M_{30} &= i\,(\,w[1,3] - f[3,1] - w[2,4] + f[4,2]\,)/2 \end{aligned}$$

Rotations

$$\begin{aligned} M_{21} &= \;(\,d[1,1] - d[2,2] - d[3,3] + d[4,4]\,)/2 \\ M_{31} &= i\,(\,d[2,1] - d[1,2] - d[3,4] + d[4,3]\,)/2 \\ M_{32} &= \;(\,d[2,1] + d[1,2] - d[3,4] - d[4,3]\,)/2 \end{aligned} \quad (4)$$

Translations

$$\begin{aligned} P_1 &= \;(-\,w[2,3] - f[3,2] - w[1,4] - f[4,1] - d[1,2] - d[2,1] - d[4,3] - d[3,4])/2 \\ P_2 &= i\,(-w[2,3] + f[3,2] + w[1,4] - f[4,1] - d[1,2] + d[2,1] - d[4,3] + d[3,4])/2 \\ P_3 &= \;(-w[1,3] - f[3,1] + w[2,4] + f[4,2] - d[1,1] + d[2,2] - d[3,3] + d[4,4])/2 \\ P_0 &= \;(-w[1,3] - f[3,1] - w[2,4] - f[4,2] - d[1,1] - d[2,2] - d[3,3] - d[4,4])/2 \end{aligned}$$

The vacuum of Minkowski space $|0\rangle$ is an eigenstate of the Poincaré group with vanishing mass, energy, momentum and spin. The Minkowski vacuum can be constructed (Görnitz, T., Graudenz, Weizsäcker, 1992) from the vacuum of the qubits $|\Omega\rangle$. In conventional notation (with $\hat{a}_i^+$) it looks like:

$$|0\rangle = \sum_{n_1=0}^{\infty} \sum_{n_2=0}^{\infty} \frac{(-1)^{n_1+n_2}}{n_1!\cdot n_2!} \left(\frac{\hat{a}_1^+\hat{a}_3^+ + \hat{a}_3^+\hat{a}_1^+}{2} \right)^{n_1} \left(\frac{\hat{a}_2^+\hat{a}_4^+ + \hat{a}_4^+\hat{a}_2^+}{2} \right)^{n_2} |\Omega\rangle \quad (5)$$

With respect to the Minkowski-vacuum a massless boson with helicity –σ in z-direction and momentum m can be constructed as follows:

$$\Phi(m,\sigma) = \sum_{n_1=0}^{\infty} \frac{(-m)^{n_1}(2\sigma+p-1)!}{(p-1+n_1+2\sigma)!n_1!} \left(\frac{\hat{a}_1^+\hat{a}_3^+ + \hat{a}_3^+\hat{a}_1^+}{2} \right)^{n_1} \left(\hat{a}_1^+\hat{a}_1^+\right)^{\sigma} |0\rangle \quad (6)$$

For a photon is $|\sigma| = 1$.

A massive spinless boson at rest, constructed on the Minkowski-vacuum $|0\rangle$, with rest mass m = P0 $\neq$ 0, momentum P1=P2=P3= 0, and Parabose-order p >1 is given by:

$$\Phi(m)=\sum_{n_1=0}^{\infty}\sum_{n_2=0}^{\infty}\sum_{n_3=0}^{\infty}\frac{(-1)^{(n_1+n_2+n_3)}m^{(2\cdot n_1+n_2+n_3)}(p-2+n_1+n_2+n_3)!}{(p-1+2\cdot n_1+n_2+n_3)!(p-2+n_1+n_3)!(p-2+n_1+n_2)!}\bullet$$
$$\bullet\frac{1}{n_1!\cdot n_2!\cdot n_3!\cdot}\left(\frac{\hat{a}_4^+\hat{a}_2^+ + \hat{a}_2^+\hat{a}_4^+}{2}\right)^{n_3}\left(\frac{\hat{a}_4^+\hat{a}_1^+ + \hat{a}_1^+\hat{a}_4^+}{2}\right)^{n_1}\left(\frac{\hat{a}_3^+\hat{a}_2^+ + \hat{a}_2^+\hat{a}_3^+}{2}\right)^{n_1}\left(\frac{\hat{a}_3^+\hat{a}_1^+ + \hat{a}_1^+\hat{a}_3^+}{2}\right)^{n_2}|0\rangle \tag{7}$$

Another example (Görnitz, T., Görnitz B., 2002) is a massive fermion at rest with spin 1/2, constructed on the Minkowski-vacuum $|0\rangle$, with mass m = $P_0 \neq 0$, $spin_z$= -½, momentum P_1=P_2=P_3= 0 and Parabose-order p >1:

$$\Phi(m)=\sum_{n_1=0}^{\infty}\sum_{n_2=0}^{\infty}\sum_{n_3=0}^{\infty}\frac{(-1)^{(n_1+n_2+n_3)}m^{(2\cdot n_1+n_2+n_3)}(p-1+n_1+n_2+n_3)!}{(p+2\cdot n_1+n_2+n_3)!(p-2+n_1+n_3)!(p-1+n_1+n_2)!}\bullet$$
$$\left[\hat{a}_1^+ + m\hat{a}_2^+\left(\frac{\hat{a}_4^+\hat{a}_1^+ + \hat{a}_1^+\hat{a}_4^+}{2}\right)\right]\frac{\left(\frac{\hat{a}_4^+\hat{a}_2^+ + \hat{a}_2^+\hat{a}_4^+}{2}\right)^{n_3}\left(\frac{\hat{a}_4^+\hat{a}_1^+ + \hat{a}_1^+\hat{a}_4^+}{2}\right)^{n_1}\left(\frac{\hat{a}_3^+\hat{a}_2^+ + \hat{a}_2^+\hat{a}_3^+}{2}\right)^{n_1}\left(\frac{\hat{a}_3^+\hat{a}_1^+ + \hat{a}_1^+\hat{a}_3^+}{2}\right)^{n_2}}{n_1!\cdot n_2!\cdot n_3!\cdot(p+1+2\cdot n_1+n_2+n_3)\cdot(p-1+n_1+n_3)}|0\rangle \tag{8}$$

Indeed, matter can be seen as a special form of abstract quantum information.

The possibility to create relativistic particles via quantum bits is essential for many aspects in the scientific description of nature. The change of the state of such an object amounts to a transformation associated with an element of the Poincaré group. In this operation the number and structure of its qubits will be changed. Interactions between matter – i.e. fermions – is effected by exchanging bosons. On the basis of the theory outlined here, this always appears as an exchange of qubits.

For everyday purposes, one may state:

- *Matter is inactive, it resists change.*
- *Energy can move matter.*
- *Information can trigger energy.*

9. The relationships between quantum information, particles, living beings and consciousness

Einstein's equivalence, $E=mc^2$, does not imply that the distinction between matter (having a restmass) and energy is always dispensable. Pure energy, e.g. massless photons, behave differently than massive particles. However, particles with mass can emit and absorb such photons. On the other hand, photons of sufficiently high energy can be transformed into particles with rest mass.

Analogous relations apply to quantum information. If it should be localized then the mathematical structure implies that this information must have an material or at least an energetic carrier. However, a qubit needs not to be fixed to such a carrier. Here it should be recalled that the carriers themselves are special forms of the protyposis, in the same way as material objects can be understood as being special forms of energy.

A further aspect is even more interesting: there is an analogy to the conversion of the energy of motion of a massive body into massless photons. The photons can separate from the mass and travel apart, but then they are no longer localized in space, only in time, as the structure of a rest mass in Minkowski space any longer applies. Of course, the equivalence $E=mc^2$ is not affected by this.

Qubits too may change a carrier or separate from it. In the latter case, they are no longer localizable in space and time, because neither the structure of an energy nor of a rest mass in Minkowski space applies any longer. While qubits can form particles with and without mass – and therefore fields – there is no reason to assume that they always have to form particles. Obviously, quantum information does not necessarily become manifest in the form of particles or fields.

The autonomous existence of the protyposis, of absolute quantum information, can solve some of present problems in science. The dark energy in cosmology, for example, could be a non-particle form of protyposis, as will be addressed below.

In connection with a living body qubits can become meaningful. For animals, meaning not only depends on the "incoming" information, but also on the respective situation and the particular living conditions of the animal.

Meaningful information can change its carriers, for instance from a sound wave to electrical nerve impulses, and allows for control unstable systems, such as living beings. Obviously, this finding will greatly influence the scientific understanding of life and mind. (see Görnitz, T., Görnitz, B., 2002, 2006, 2008). Mind is neither matter nor energy, rather it is protyposis in the shape of meaningful quantum information.

For a scientific understanding of the mind a dualistic conception would be in contradiction to all science. Concerning the materialistic alternative, mind is clearly no matter, and a reduction of mind to small material particles will not succeed. Protyposis, more specifically, the equivalence of protyposis, matter, and energy, and its eventual manifestation as meaningful information, offers a solution to this problem.

Life is characterized as control and timing, enabled by quantum information. Only unstable systems can be controlled. Living systems are unstable because they are far from the thermodynamical equilibrium. In the self-regulation of organisms – extending even to consciousness in the later stages of the biological evolution – quantum effects can become operational at the macroscopic level.

Consciousness is quantum information carried by a living brain, it is quantum information that experiences and knows itself.

This is not an analogy, but rather a physical characterization. It means that it is no longer required to perceive the interaction between quantum information in the shape of matter and quantum information in the shape of consciousness as a phenomenon beyond the field of science.

The scientific description of consciousness opens also the way to extend the Copenhagen interpretation of quantum theory. Usually it is stated that a measuring process has happened when an observer has notified a result. But as long as the observer and his conscious mind are not subjects of physics, a theory of measurement seems to be beyond physics as well. Here, the central role of quantum information will become important. In an abstract way, a measurement can be seen as the transition from a quantum state comprising all its possibilities to a conclusive fact. Generating a fact by measuring, results in the loss of information on all other potential states. The quantum eraser experiments show that a virtual measurement can produce a real fact only if the information on the quantum possibilities is lost.

However, before addressing the intended extension of the Copenhagen interpretation, we take a closer look to the structure of the cosmic space, as there is an essential connection.

10. Quantum information and the introduction of the cosmic position space

The Minkowski-space is a very good approximation in the domain of our laboratories and our environment. However, while the Minkowski-space is essential for an exact description of particles, the real position space in cosmology is different from this idealization. Since Einstein we know that the physical space can be curved.

The idea of understanding position space as a consequence of the symmetry of quantum bits was first proposed by von Weizsäcker (1971, p. 361; 1982, p. 172). He and Drieschner (1979) showed how qubits can explain that the space of our physical experience is three-dimensional. This was the first attempt to establish the dimensionality of physical space from first principles. (As an aside, to argue that space has in reality 10 or even 26 dimensions is not really convincing.) However, their models were not consistent with general relativity. This problem can be overcome by group theoretical considerations.

Any decision that can scientifically be decided, can be reduced to quantum bits. The states of a quantum bit are represented and transformed into each other by its symmetry group. The symmetry group for a quantum bit is spanned by the groups SU(2), U(1), and the complex conjugation. The essential part of the quantum bit symmetry group is the SU(2), a three-parameter compact group. Any number of quantum bits can be represented in the Hilbert space of measurable functions on the SU(2), which as its largest homogeneous space is an S^3. This Hilbert space is the carrier space for the regular representation of the SU(2) that contains every irreducible representation of this group. The three-dimensional S^3 space is identified with the three-dimensional position space.

Using group theoretical arguments, a relation can by established between the total number of qubits and the curvature radius R of the S^3 space (Görnitz, T., 1988). A spin-1/2-representation of the SU(2) group, the representation of a single qubit, is formed from functions on the S^3 space having a wave length of the order of R. If the tensor product of N of such spin-1/2-representations – i.e. of N qubits - is decomposed into irreducible representations, then representations associated with much shorter wavelengths can be found. The multiplicities of such representations increase with decreasing wavelengths. They are high up to functions with a wavelength in the order $R/\sqrt{N}$. Here the multiplicities reach a maximum. Because of an exponential decrease of the multiplicities, the shorter wavelengths seem not to be of physical relevance. An N-dependent metric on this S^3 is established by introducing a length related to this maximum:

$$\lambda_0 = R/\sqrt{N} \tag{9}$$

as the length-unit is introduced.

If the S^3 space is identified with the position space, a cosmological model results using three physically plausible assumptions (Görnitz, T. 1988²). They correspond to the basic assumptions in the three fundamental theories of physics , i.e. special relativity, quantum theory, thermodynamics:

1. There exists a universal and distinguished velocity.
2. The energy of a quantum system is inversely proportional to its characteristic wave length.
3. The first law of thermodynamics is valid.

The first assumption introduces the velocity of light, c. The second assumption is the familiar Planck relation, $E=h\nu=hc/\lambda$, while the third allows us to define a cosmological pressure p according to $dU+pdV=0$.

The result is a compact Friedman-Robertson-Walker-Space-Time. Measured in units of the fundamental length λ_0, the cosmic radius R grows with the velocity of light. Therefore in this model the horizon problem as well as the flatness problem are absent. The horizon problem is related to the fact that the background radiation from opposed directions in space is entirely identical, whereas according to most cosmological models those regions could never have been in causal contact. As a remedy, inflation was invented. However, the *ad hoc* assumptions necessary here violate an important energy condition (Hawking, Ellis, 1973). This suggests that another solution of the horizon problem should be sought. More recently, the inflation concept has been criticized on other grounds, too (Steinhart, 2011).

By the group theoretical argument, the number of qubits increases quadratically with the age of the universe, i.e., with the cosmic radius R. The energy attributed to a single qubit is inversely proportional to R. Therefore, the total energy U rises with R and the energy density decreases with $1/R^2$. According to the first law of thermodynamics, the resulting state equation for the cosmic substrate, the protyposis, follows as $\mu=-p/3$.

From the metric of this model the Einstein-tensor G_i^k can be computed, and, using the relations between energy density and pressure, the energy-momentum-tensor T_i^k is obtained. Both tensors appear as being proportional to each other.

If it is demanded that this proportionality between G_i^k and T_i^k is conserved also for local variations of the energy, Einstein's equations of general relativity emerge as a consequence of the abstract quantum information. If a smallest physical meaningful length – the Planck length – according to $\lambda_{Pl} = \lambda_0 \cdot\sqrt{3}/2$ is introduced, one obtains with $\kappa= 8\pi G/c^4$:

$$G_i^k = \kappa \; T_i^k \tag{10}$$

In this cosmological model the dark energy can be interpreted as protyposis, i.e., as absolute quantum information, that is homogeneous and isotropic, and not organized in the form of quantum particles.

11. The measuring process – reinterpreting the Copenhagen interpretation

After the clarification of the relation between abstract quantum theory and space, we will turn to the strangest concept in quantum physics, namely the measuring process. Here the strongest discomfort results because the unitary time evolution of a quantum system appears to be interrupted.

A comprehensive review on the different attempts to solve this problem has been given by Genovese (2010). In this review most of the modern attempts are addressed, but fundamental earlier work, e.g. by Heisenberg or v. Weizsäcker, is not cited. I think, "the transition from a microscopic probabilistic world to a macroscopic deterministic world described by classical mechanics (macro-objectification)" is less of a problem, and also one should not say that the Copenhagen interpretation "is weak from a conceptual point of view since it does not permit to identify the border between quantum and classical worlds. How many particles should a body have for being macroscopic?"(Genovese, 2010).

Rather the problem seems to stem from the conceptual fixation of physics on the more than 2000 years old notion of "atoms" of one or another kind as basic structures. Quantum theory opens the possibility to recognize that more abstract structures – quantum information – should be viewed as the fundamental entities. This will open a new perspective for the measuring process as well.

As already mentioned, the measuring process is often seen as the most controversial aspect of quantum theory. The "normal" time evolution in quantum theory is a unitary process. In the Schrödinger picture the time-evolution of the wave function is given by

$$\Phi_{Schr}(t) = \hat{U}(t)\Phi_{Schr}(0) = e^{-\frac{i}{\hbar}\hat{H}t}\Phi_{Schr}(0) \tag{11}$$

where $\hat{H}$ is the Hamiltonian of the system under consideration. In an equivalent way, referred to as Heisenberg picture, the time- dependence can be shifted to the physical operators:

$$\hat{A}_{Heis}(t) = \hat{U}(t)^{\dagger}\hat{A}_{Heis}(0)\hat{U}(t) = e^{\frac{i}{\hbar}\hat{H}t}\hat{A}_{Heis}(0)e^{-\frac{i}{\hbar}\hat{H}t} \tag{12}$$

The time evolution according to the Schrödinger equation of the system conserves the absolute value of the scalar products and does not change the total probability. In the measuring process, by contrast, the so-called "collapse of the wave function" is no longer unitary. There has been much discussion about this disruption in the description of the regular time evolution and whether that disruption can possibly be avoided. Let me very briefly recall the essential aspects.

If a quantum system is in a state Φ, then in the measuring process every state Ψ can be found if

$$< \Phi \mid \Psi > \neq 0 \tag{13}$$

The probability ω to find Ψ if the system is in the state Φ is given by

$$\omega = |< \Phi \mid \Psi >|^2 \tag{14}$$

The so-called many-worlds-interpretation of QM assumes that there is no break in the unitary time evolution. It is postulated that any possible Ψ will be a real outcome of the measurement, but for every Ψ there is a separate universe in which this outcome is realized as a factum. For most people this interpretation is not acceptable because of the fantastical ontological overload thereby introduced. However, with a simple "one-word-dictionary" (Görnitz, T., Weizsäcker 1987) it can be translated into the normal world view: just replace "many worlds" by "many possibilities".

The Copenhagen interpretation introduces an observer who is responsible for stating that a result has been found. If the observer can verify that the process has occurred, the result can be seen as a factum. Given that any description of reality needs a person to do the description, the introduction of an observer into the description of nature does not seem to be a serious constraint. However, the problem here is that this construct does not allow one to include the observer himself in the scientific description, which ultimately has to be based on physics, that is, quantum theory. In a conversation, reported to me by v. Weizsäcker about the necessity of a "cut" between quantum and classical physics and the movability of that cut, Heisenberg argued that the cut cannot be moved into the mind of the observer. According to v. Weizsäcker, his friend Werner Heisenberg said: "In such a case no physics would remain ".

This point of view is easily understandable, because at that time the range of physics was limited to material and energetical objects, but did not yet extend to quantum information. Since then much experimental and theoretical work on quantum information has emerged, indicating the mind can be understood as a very special form of quantum information. Therefore it is no longer warranted to keep the mind totally outside the realm of physics. (see Görnitz, T., Görnitz, B., 2002, 2008) However, for a scientific description of the observer and even of his mind, the original Copenhagen interpretation has to be extended.

What is the role of the observer. Let the quantum system be in a state Φ. After the measuring process the observer has to realize that all the possible states Ψ did not turn into real facts except for the final Ψ_f, which is associated with the actual outcome of the measurement.

But left with Ψ_f , the information about the former state Φ is no longer available. The only remaining information on Φ is that Φ is not orthogonal to Ψ_f. Obviously, this only very vague and imprecise information as, in general, infinitely many states will be not orthogonal to Ψ_f.

If the observer comes to know the result of the measurement associated with Ψ_f , he will use this new wave function for the future description of the system. It is useful to describe this change of the wave function as a result of the change in the observer's knowledge. (Görnitz, T., v. Weizsäcker 1987, see also: Görnitz, T., Lyre 2006). The measurement provides new knowledge and the observer can take that into account.

Now the intriguing question is how does a fact come about in physics if there is no observer to constitute it?

In a pure quantum description no facts can arise (at least when one does not resort to infinite many degrees of freedom, as done in the algebraical description by Primas (1981)). While classical physics does describe facts, the classical description does not make any difference between past and future facts, all events being determined in the same way. More specifically, in classical physic the "real character" of time with its difference between past and future does not appear. Neither in classical nor in quantum physics the irreversibility of a factum is a consequence of the respective mathematical structure. Both theories have a reversible structure, and the irreversibility encountered, for example, in thermodynamics is attributed to the describers imperfect knowledge of the microscopic configurations of the system. However, imperfect knowledge cannot be the cause of a physical occurrence.

Information plays the central role in the measurement process. However, as long as information is only understood as being “knowledge”, a human observer has to be supposed. My proposal is to expand the role of information, which will allow us to explain how facts arise in the scientific description of nature, even without supposing an observer in the first place.

Apparently, only in the measurement, i.e. in the transition from the quantum to classical description, physics does discriminate *before* the event and *after* the event. This means that the problem of how events occur must be solved. In this regard, I think the experiments with the quantum eraser (Scully et al., 1991, Zajonc et al., 1991, Herzog et al., 1995) may shed some light on the role of the observer.

The first such experiments were "double slit" experiments. If it is possible—at least in principle—to get the “which-way” information about the slits, there will be no interference; otherwise, interference patterns should appear.

As the quantum eraser shows, it is not a disturbance by the observer which causes the measuring process; rather, the crucial factor here is the loss of information concerning the original state Φ. As to Scully and Walther (1998) state: “It is simply knowing (or having the ability to know even if we choose not to look at the Welcher-Weg detector) which eliminates the pattern. This has been verified experimentally. Hence one is led to ask: what would happen if we put a Welcher-Weg detector in place (so we lose interference even if we don’t look at the detector) and then erase the which-way information after the particles have passed through? Would such a “quantum eraser” process restore the interference fringes? The answer is yes and this has also been verified experimentally.”

To make clear what happens, it is useful to describe the process somewhat differently.

The authors say “… and then erase the which-way information.” However, the information is not taken out of the system and then destroyed. On the contrary, the which-way information can leave the system only potentially. If indeed the information had left the system, a factum concerning the “Weg” would have been produced and interference would be absent. However, this was not the case; the information was returned into the system and, in fact, not able to leave it. Both “ways” remained possible, no path became factual, and the interference appeared.

Thus, the essential aspect of a measurement is whether some information on the state of the system under consideration is lost.

As long as there is the possibility that the information can come back into the system, no real factum has been created and no measurement has occured. Only if it is guaranteed that the information (or at least a part of it) has left the system for good, a factum has been created and a measuring result can be established.

Each state of a quantum system is “co-existing” with all other states not orthogonal to it. In this huge manifold of states there are eigenstates of the measuring interaction. In the measuring process associated with the respective measuring interaction one of the eigenstates becomes factual when the information on all the other states has been lost.

That the measuring process relies on a loss of information seems contradictory, but, in fact, it is not: in the measurement a huge amount of quantum possibilities is reduced to the distinct classical information on a fact. The information about the measuring result is factual and, that is, classical information which can be replicated. Such classical information can be repeatedly taken out from the system; the measuring result can be read out repeatedly.

How can this loss of information modelled?

An essential step towards a better understanding was accomplished by the theory of quantum decoherence, originating with the work by Zeh (1970). Decoherence can explain how, in an approximate way, a quantum object acquires classical properties. There is a recent and detailed book (Schlosshauer, 2007) to which the reader is referred to for technical details. The central point is that for the composite system of the object, the measuring device, and the environment, the non-diagonal elements in the partial density matrix of the object become exponentially small in a short time. Therefore, the object density matrix rapidly assumes a form reflecting the situation of a classical probability for an unknown fact within an ensemble of possible facts.

It is occasionally stated, however misleadingly, that decoherence solves the measuring problem. This is not the case. Zeh wrote (1996, S. 23) that an environmental induced decoherence alone does not solve the measuring problem; this applies even more to a microscopic environment, where decoherence does not necessarily lead to an irreversible change. Joos (1990) wrote: "that the derivation of classical properties from quantum mechanics remains insufficient in one essential aspect. The ambiguity of the quantum mechanical dynamics (unitary Schrödinger dynamics versus indeterministic collapse) remains unsolved. The use of local density matrices presupposes implicitly the measuring axiom, i.e., the collapse." And he proceeds in his text as follows: "certain objects for a local observer appear classical (so defining what a classical object is), but the central question remains unsolved; why in the non-local quantum world local observers exist at all?"

To answer this question one has to take into account, besides quantum information, the cosmological aspects of quantum theory.

Decoherence in a system is caused by the interaction with a macroscopic device, which in turn is embedded in an even larger environment. As a consequence, information flows out from the quantum object. As long as this information is restricted to a finite volume, there is no fundamental obstacle preventing the information from coming back into the quantum object. However, any environment is ultimately coupled to the cosmic space, being presently nearly empty and dark. This cosmic boundary condition is the reason that in the end, perhaps with some intermediate steps, the information can escape without any realistic chance for ever coming back.

As long as a quantum system is completely isolated, so that not even information can escape, it will remain in its quantum state, comprising all its respective possibilities. Only if a system is no longer isolated, allowing information to escape, which usually will be effected by outgoing photons, a factum can arise.

Of course, mathematically one is confronted with a limiting procedure. To prove rigorously that no information will ever come back, an infinite time limit has to be considered. Alternatively, an environment is needed with actually infinite many degrees of freedom in order to have superselection rules in a strong sense. (Primas, 1983).

As far as an observer of the process is concerned, he may decide that for all practical purposes the appearance of a factum can be acknowledged. In view of the cosmological conditions, dispelling any expectations that the information will come back, one does not have to assume that the creation of a factum depends on the perception of the observer. On the other hand, there may be still a role for the observer, namely, to assure the end of the limiting process. Loosely speaking, one may say that the observer has to "guarantee" that the information on all the other possible states Ψ does not come back and turn the measurement into an illusion.

Usually, outgoing information will be carried mostly by photons. Because the cosmos is empty, dark and expanding with high velocity there is no chance that an outgoing photon will be replaced by an equal incoming photon. As is well known, the cosmos was not always as it is today. In the beginning, the cosmos was dense and hot. Going back to the earliest stages of the universe, it was ever more likely that an outgoing photon was matched by an equal incoming one. This means that the idea of creating facts becomes more and more obsolete when approaching the singular origin. Concomitantly, the structure of time with the difference between past, present and future looses gradually its significance, to disappear completely in the neighbourhood of the singularity. Obviously, without the familiar structure of time the conceptuality of empiricism has no meaning, nor has the concept of empirical science.

The generalization of "knowledge" to "information," more exactly to "quantum information," opens the possibility to extend the Copenhagen interpretation in such a way that the observer and his consciousness can be included in the scientific description. (see Görnitz, T., Görnitz, B., 2002, 2008).

The intention here is not only to describe quantum processes in the brain but also quantum processes of the mind.

That biological processes, like vision, i.e., the absorption of photons in the retina, or the absorption of photons in a plant and the subsequent transport of the electrons in the process of photosynthesis, must be described as quantum processes is already well-known. (Engel et al., 2007).

This suggests that in the brain, perhaps the most complicated organ in biology, quantum processes will play a crucial role, even when decoherence happens just as much. However, the effect of decoherence decreases for decreasing mass of the quantum objects. Decoherence is weakest for massless objects, such as photons. Photons are essential as carriers of information in the brain, as the supporter of thoughts. As a hint at the role of photons in the brain, one may see the forensic fact that the personality of a patient has passed away if photons can no longer be found in the EEG.

12. Conclusions

As all science is approximation, a good description of nature incorporates its decomposition into objects and forces between them and their factual description – done by classical physics – as well as taking into account the possibilities and the aspect of wholeness as done by quantum theory. The dynamical layering-process describes the interrelations between the classical and the quantum approaches.

Quantum theory, being the most successful fundamental physical theory, can be understood as the physics of relations, possibilities, and nonlocality. At the core of quantum theory is the equivalence of locality and nonlocality, matter and force, wholeness and emptiness, and, last but not least, the equivalence of matter, energy, and quantum information.

These fundamental equivalences, based on absolute quantum information, allow for a foundation of the cosmological concepts as well as the inclusion of consciousness in the scientific description of nature.

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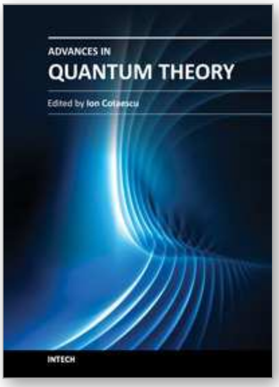

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The quantum theory is the first theoretical approach that helps one to successfully understand the atomic and sub-atomic worlds which are too far from the cognition based on the common intuition or the experience of the daily-life. This is a very coherent theory in which a good system of hypotheses and appropriate mathematical methods allow one to describe exactly the dynamics of the quantum systems whose measurements are systematically affected by objective uncertainties. Thanks to the quantum theory we are able now to use and control new quantum devices and technologies in quantum optics and lasers, quantum electronics and quantum computing or in the modern field of nano-technologies.