Why Quantum Correlates of Consciousness Are Fine, But Not Enough

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Abstract

The existence of quantum correlates of consciousness (QCC) is doubtful from a scientific perspective. But even if their existence were verified, philosophical problems would remain. On the other hand, there could be more to QCC than meets the sceptic's eye:

• QCC might be useful or even necessary for a better understanding of conscious experience or quantum physics or both. The main reasons for this are: the measurement problem (the nature of observation, the mysterious collapse of the wave function, etc.), ostensibly shared features of quantum phenomena and conscious phenomena (e.g., complementarity, nonspatiality, acausality, spontaneity, and holism) and connections (ontology, causation, and knowledge), the qualia problem (subjectivity, explanatory gap etc.). But there are many problems, especially questions regarding realism and the nature and role of conscious observers;

• QCC are conceptually challenging, because there are definitory problems and some crucial ontological and epistemological shortcomings. It is instructive to compare them with recent proposals for understanding neural correlates of consciousness (NCC). QCC are not sufficient for a quantum theory of mind, nor might they be necessary except perhaps in a very broad sense;

• QCC are also empirically challenging. Nevertheless, QCC could be relevant and important for the mind-body problem: QCC might reveal features that are necessary at least for behavioral manifestations of human consciousness. But QCC are compatible with very different proposals for a solution of the mind-body problem. This seems to be both advantageous and detrimental. QCC restrict accounts of nomological identity. The discovery of QCC cannot establish a naturalistic theory of mind alone. But there are also problems with QCC in the framework of other ontologies.

Key Words: Quantum Theory, Measurement Problem, Quantum Correlates of Consciousness, Consciousness, Mind, Brain, Mind-body Problem, Free Will, Realism, Ontology

1) Introduction

Quantum theory, along with the theory of general relativity, is one of the main pillars of physics and our (scientific) worldview. Within the history of science, no other theory has been so precisely confirmed experimentally. Nevertheless, Richard Feynman said that – except for all practical purposes – "nobody today understands quantum mechanics". While the theory agrees incredibly well with experimental results and is of profound mathematical beauty, it "makes absolutely no sense" according to Roger Penrose. And Niels Bohr even said that if we are not profoundly disturbed by quantum phenomena, we have not begun to appreciate its implications. Too paradox and bizarre are the results, predictions and interpretations (see, e.g., Barrett, 1999, Brown, 1988, Baumann and Sexl, 1987, Davies and Brown, 1986, d'Espagnat, 1995, Ghose, 1999, Greenberger, 1995, Herbert, 1985, Norris, 2000, Omnés, 1994, Schommers, 1989, Selleri, 1994, Wick, 1995): Hermaphrodite-like states (superpositions) of waves and particles; apparently self-interacting or interfering particles (two-slit experiment); uncertainty of properties like momentum (mass multiplied by velocity) and position, or energy and time; spatially or temporally "smeared" states; reversible measurements; "spooky" (Albert Einstein) actions at a distance between entangled quantum systems; teleportation (of states) of photons, atoms and even large molecules like fullerenes without any loss of time; apparently superluminal signal transmission (and even delayed-choice possibilities with backward causation?), acausal events (spontaneous energy jumps, tunnel effects, radioactivity, matter-antimatter pair creation); and the infamous "collapse" or reduction of the wave function.

In this paper, I would like to sketch briefly of some important issues concerning the philosophical and scientific investigation of quantum correlates of consciousness, QCC for short, and the reasons for postulating the existence of QCC as well as arguments for the connection of quantum physics and consciousness in general (see, e.g., Vaas, 2000b, 2001e, Wechsler, 1999, for an introduction). Unfortunately, I will only occasionally be able to go into details, because my main point is trying to survey this diverse field.

There are different motivations and kinds to connect quantum and mental phenomena:

• by analogies or alleged shared features like complementarity, nonspatiality, acausality, spontaneity, and holism;

• by postulating quantum mechanisms for the rise of conscious states, e.g. entanglement, quantum condensates, or holographic phenomena allowed by quantum field theory;

• by postulating mechanisms for interaction between mind and matter, e.g. the collapse of the wave function or quantum tunnel effects.

2) Are There Common Features Between Quantum Physics and Consciousness?

One way to associate quantum phenomena and conscious phenomena is in terms of their ostensibly shared features (cf., e.g., King, 1997, Rosenblum and Kuttner, 1999, Stapp, 1995; for critical remarks see, e.g., Ludwig, 1995):

• *Complementarity:* This suggestion goes back to Niels Bohr who extended his principle of complementarity from physics to biology and even mental phenomena. For example he stressed "the impossibility in psychical (i.e. psychological) experience to distinguish between the phenomena themselves and their conscious perception clearly demands a renunciation of a simple causal description on the models of classical physics, and the very way in which words like "thoughts" and "feelings" are used to describe such experience reminds one most suggestively of the complementarity encountered in atomic physics" (Bohr, 1958, p. 21). John Smythies argued that complementarity corresponds to an aspect dualism of the mental and physical, i.e. mind and brain are in some sense complementary. "The justly immense prestige of Bohr has let to the mention of complementarity in most text books of quantum theory. But usually only in a few lines", John S. Bell (1987, p. 189) commented. "Not to resolve these contradictions and ambiguities" of wave and particle, quantum and classical systems etc., "but rather to reconcile us to them, he put forward a philosophy which he called 'complementarity'. He thought that 'complementarity' was important not only for physics, but also for the whole of human knowledge. […] He seems to insist rather that we must use in our analysis elements which contradict one another, which do not add up to, or derive from, a whole. By 'complementarity' he meant, it seems to me, the reverse: contradictoriness. Bohr seemed to like aphorisms such as 'the opposite of a deep truth is also a deep truth': 'truth and clarity are complementary'" (p. 189 f). However, complementarity is ultimately even more mysterious than what is meant to describe and explain. But for some this is just the right condition to put consciousness into the picture. According to Smythies (1994a, p. 276), "a brain could present one set of properties to another mode of observation – the neurosurgeon's – and another set of properties to another mode of observation – that of the person, or perhaps we should say, the brain itself. Thus to complain that a neurosurgeon cannot find 'pictures' in the brain is logically equivalent to complaining that an electron, when observed under the 'wave mode', won't behave like a particle. Thus we can say that our sensations, as we introspect them, are complementary to certain patterns of activity in the nerve nets of the brain." (Elsewhere, Smythies, 1994b,c, has even promoted an interactionistic dualism and displaced mind into higher dimensions beyond our ordinary space-time.) While complementarity was central to the Copenhagen interpretation, it can now be regarded as a historical makeshift. Recent experiments have shown that it need not be viewed as thoroughly fundamental but as a feature based on quantum physical entanglement (Dürr, Nonn and Rempe, 1998, and Vaas, 1999a).

• *Nonspatiality:* Some have argued (e.g., Port and van Gelder, 1995) that the mind is not a spatial three-dimensional system like the brain. This leads to a nonphysical or even Cartesian concept of the mind, i.e. a different category, which seems (at least explanatorily) incompatible with classical physics, i.e. not understandable in terms of moving particles. However, mental activities are not without or beyond time, thus there is temporal dynamics. It was proposed to treat mental processes as quantum processes to overcome both Cartesian dualism and the limits of classical physics. Thus, one might still hold some sort of naturalism (see, e.g., Lockwood, 1989) even without classical causal relations (cf., e.g., Pereira Jr., 2001). For some, quantum nonlocality seems to be related to nonspatiality. But while the framework Newtonian spatiality has already been ruled out against the background of general relativity, quantum objects or states nevertheless are spatial (entanglements could even reach macroscopic dimensions). Furthermore, even if undisturbed quantum states would be "delocalized" in some way, there is at least a probability to localize a particle in a certain volume of space, and decoherence rapidly destroys widely smeared nonlocal states (see below).

• *Acausality:* Although certain quantum effects (e.g. tunneling) might be acausal, quantum dynamics does not necessarily contradict causality. This depends, obviously, on the concept of causality. If one takes, e.g., causal relations based on the transfer of conserved quantities like energy, momentum, angular momentum etc. (cf. Vollmer, 1981) or as an "insufficient, but nonredundant part of a condition that is an unnecessary but sufficient condition of the effect" (Mackie, 1974), neither the linear evolution of quantum systems according to the Schrödinger equation nor a measurement nor coherent quantum processes like the spreading of entangled states are noncausal.

• *Spontaneity:* At least since Immanuel Kant (1781), spontaneity is considered to be a characteristic feature of the mind. This is only a problem for naturalism if spontaneity is taken to be both intentional and acausal. But then, it was argued, quantum physics might still apply due to the reintroduction of indeterminism. Indeterminism could indeed be a property of nature and even a kind of loophole for the intervention of a nonphysical mind. However, quantum processes are not sufficient (at least not for dualists). And they are even part of the problem, not its solution, as far as they are uncontrollable (see below).

• *Holism:* The phenomenologically apparent wholeness and unity of consciousness, e.g. meaning holism, perceptual unity, fusion of mental images etc., has been connected with quantum coherence, inseparability and entanglement. Even if this analogy holds, it remains unclear whether there is a deeper connection, e.g. whether specific coherent quantum states correlate strictly with specific kinds of conscious states, and – if so – which of them necessitates the other. Furthermore, quantum coherence seems not be a sufficient condition. For it is very unlikely that, e.g., the states found in laboratory experiments or industrial application (e.g. laser, superconductivity, suprafluidity, Bose-Einstein condensate) are or represent conscious states. And it seems doubtful whether quantum coherence is even necessary for integration: The binding problem and top-down processing are serious tasks for modern neurophysiology. But there are powerful models and empirical data to explain them with, e.g., the synchronization of neural activities at different scales (see Singer, 1996, and Engel, Fries and Singer, 2001, for recent reviews). And despite our phenomenal impression that our consciousness is indivisible and maybe even not spatial, lesions show that it is possible to lose consciousness not only completely, but also in bits and pieces. Thus, consciousness has aspects of divisibility and spatiality even if we cannot recognize them by introspection. This is a strong argument against global holism. Take for example visual consciousness, which is already well studied. It is in some sense modular and not exclusively dependent either upon a single cortical area (or multiple, but intimately connected areas) or upon the healthy functioning of the entire system. Studies of lesions due to stroke, ischaemia, injury, tumor, carbon monoxide poisoning and so on are very instructive: For a person with cerebral achromatopsia due to a lesion of brain area V4 in the fusiform gyrus it is sometimes not only impossible to perceive colors anymore but also to imagine, remember and dream them. Bilateral damage of the parieto-occipital lobe (the "where-system") leads to an inability to localize visual stimuli in space and to accurately describe the location of familiar objects or landmarks from memory, whereas bilateral damage of the inferior temporal lobe (the "what-system") causes impairment of perceiving object identity from appearance and describing object appearance from memory. Furthermore, some patients with lesions in area V1 but spared subcortical pathways, are able to perceive motion in their otherwise blind fields (but they do not see stationary objects). In contrast to "blindsight", where subjects are able to discriminate visual stimuli which they are not consciously aware of having seen, patients are conscious of residual motion vision without being forced to guess whether there is motion or not. Some patients can only detect fast-moving stimuli, whereas others can only detect very slowly moving ones. These examples suggest, as Semir Zeki (1997, p. 143) has pointed out, that "there may be many more or less separate consciousnesses for different attributes at least of the visual world, based on activities in separate visual areas." He even speculated "(a) that the processing systems are autonomous with respect to one another, (b) that activity at each node reaches a perceptual end point at a different time, resulting in a perceptual asynchrony in vision, and (c) that, consequently, activity at each node generates a microconsciousness. Visual consciousness is therefore distributed in space and time" (Zeki, 2001). This limitation of holism also questions the assumed nonspatiality of consciousness (see above).

3) What Kinds of Connections Exist Between Quantum Theory and Consciousness?

Quantum physics is complex and mysterious, and consciousness is also complex mysterious. But this alone is no argument why they should be connected in any close and systematic way. On the contrary, it would seem surprising if often wildly counter-intuitive properties and events on microscopic scales could have anything illuminating in common with a macroscopic (or perhaps even nonspatial) feature with which we are extremely well familiar "from the inside", though it is very difficult to understand "from the outside". Nevertheless, there are at least three main connections between quantum phenomena and consciousness:

• *Ontology:* Quantum theory is about matter and energy, and as far as consciousness arises from matter and energy, or is caused by them, quantum phenomena and consciousness are somehow associated – thus, there should exist some kinds of QCC which might illuminate this association or are at least necessary for a deeper understanding. But it has also been claimed that quantum theory implies mind-matter dualism or some kind of idealism (see below) – if so, this would either undermine the reason to believe in QCC or at least one account to explain or understand consciousness from the perspective of QCC (analogous to NCC).

• *Causation:* Consciousness might be effective, i.e. it might do causal work. Whether and how this could be true, is a matter of debates. But if consciousness is not epiphenomenal (i.e. causally inert), if it has a function (e.g. a selective advantage in evolution), it must be either a part of the physical world or at least have an impact on it. Then, quantum physics has to deal with such effects. And indeed, there is another side of the coin, because measurement, observation and consciousness play an important role at least in some interpretations of quantum theory.

• *Knowledge:* Quantum theory might not be relevant to explain (the origin or nature of) consciousness, but nevertheless it might have to do with the *content* of consciousness. Generally speaking, this aspect is not specific to quantum theory but refers to all kinds of scientific and also folk-psychological theories and models – it is about whether, how and in which way there exists an external world as well as a connection with our mental representations of it. This is one version of the infamous, millennia-old *realism problem*, which goes way beyond the scope of this paper. But there is a more restricted aspect of it, which is related to quantum theory only – namely, whether quantum theory is in a more specific sense a theory about reality, or about our experience or knowledge of reality, or only about (invariants in) our experience.

Far from being independent of each other, these three connections between quantum phenomena and consciousness are intimately intermingled. Therefore, a coherent, satisfying and promising interpretation as well as any proclaimed solution of the puzzles of quantum theory has to address all of them, at least implicitly.

4) Quantum Theory And Realism

One of the central debates regarding quantum physics and philosophy is, whether quantum theory is a theory about reality, or about our experience of reality, or only about (invariants in) our experience. This question goes back to the early years (1920's and 1930's) of quantum physics when theorists like Louis de Broglie, Paul Ehrenfest, Albert Einstein, Max Planck and Erwin Schrödinger argued that quantum theory has to be either realistic or wrong (i.e. incomplete), while others like Niels Bohr, Max Born, Paul Adrian Maurice Dirac, Werner Heisenberg, Pascual Jordan and Wolfgang Pauli doubted that quantum theory is about a mind-independent reality or whether there is such a reality at all (cf., e.g., Born, 1953, Heisenberg, 1958, Selleri, 1984).

There are at least three main (and interconnected) problems here (cf. Selleri, 1984, p. 139):

• *Reality:* Do the fundamental objects of quantum theory – namely electrons, photons and atomic nuclei – exist independently of us or, more generally, observers and measurements?

• *Comprehensibility:* Can we understand the structure and development of quantum objects and processes in such a way that they represent reality?

• *Causality:* Do all observed effects have causes, and can we describe these causes in terms of some laws of physics?

Regarding QCC, the reality problem is obviously the most alarming one. However, it is not merely a matter of philosophical discussion or even taste, but experimentally relevant. Central to this question is the *EPR paradox*, named after Albert Einstein, Boris Podolsky and Nathan Rosen (1935), who first described it. They argued that, roughly speaking, either quantum theory is incomplete (and must be completed with hidden variables) or certain entangled quantum systems have states, e.g. the spin or polarization of photons, where a measurement of one state instantaneously determines the other state regardless of the distance between the photons, i.e. without the possibility of a causal interaction. This unseparability or nonlocality is incompatible with classical realism which is strictly local. But experiments have demonstrated that quantum physical systems do not exist in isolation from each other and, strictly speaking, cannot be described independently (except by crude approximations) (see Aspect, 1999, Tittel et al., 1998, Rowe et al., 2001, and Weihs et al., 1998). The entangled quantum states – the *EPR correlations* – show that nature is in a certain, strictly definable sense, nonlocal and inseparable.

An important consequence is that at least one of the following three statements must be wrong (cf. Selleri, 1984, p. 139):

(1) *Realism:* (Sub)atomic objects do exist independently of (human) observations.

(2) *Locality:* Spatially distinct objects are separated from each other and cannot causally interact superluminally (i.e. action at a distance).

(3) *Completeness:* Quantum theory is correct and complete; there are no hidden variables.

To give up realism might not seem philosophically outrageous, because antirealism or idealism has a long and respectable tradition. Nevertheless it would perhaps be the most radical result of science (or philosophy of science) and the end of a naturalistic world view. Worst of all would be solipsism – a consistent position, but pragmatically self-contradictory (why should I torment myself writing this article?), explanatory useless (how could theories ever be wrong?), and against the principle of mediocrity (also known as the extended Copernican principle), which was and still is one of the most successful principles of science (cf.

Livio, 2000). A less radical way out seems to be positivism; but from a philosophical point of view this might be insufficient as soon as we ask what physical and other statements refer to – a question which easily leads back to solipsism or to some sort of radical relativism which is, in a sense, incompatible with science. A rearguard action is ultimately not helpful either. Of course one can move back to exclusive epistemological matters, as Niels Bohr and Werner Heisenberg proposed: "There is no quantum world. There is only an abstract quantum mechanical description. It is wrong to think that the task of physics is to find out how Nature is. Physics concerns what we can say about Nature" (Bohr, quoted by Jammer, 1974, p. 204); "in the experiments about atomic events we have to do with things and facts, with phenomena that are just as real as any phenomena in daily life. But the atoms of the elementary particles are not as real; they form a world of potentialities or possibilities rather than one of things or facts" (Heisenberg, 1958, p. 160). But this is not sufficient, because if the quantum world is in some specific sense fictional (in contrast to its description and to the physicists who find such a description!), it must nevertheless be explained why it is the way it is, why we should "believe" in it, on what it refers to or is projected to. It is true that the philosophy of objectivistic realism is not a necessary part of the foundations of physics (cf. d'Espagnat, 1995, 2001, Norris, 2000). But not everything could be fictional or merely phenomenological, the above mentioned solipsistic alternative still lurks behind the corner. Ontology is here to stay. If the quantum world is purely epistemic, the subject could (or must) be nevertheless real, and this would be an, albeit controversial, argument for quantum consciousness conceived as reality. – In any case, the problem of realism is not only a crucial one by itself, but also has to do with the nature and content of consciousness. If any kind of scientific realism is wrong, our interpretations regarding conscious content, meaning, reference, intentionality etc. need to be radical revised.

To give up locality is also hard to swallow. But it is probably the most harmless alternative. And experiments actually suggest that locality is refuted – at least under certain conditions: Inseparability and entangled states are already measured over distances of more than ten kilometers; experiments entangling more and more (and also larger) systems have been successful; and it is even possible to teleport states and transport signals superluminally, i.e. apparently instantaneous. Fortunately, this seems not (necessarily) to violate special relativity. However, nonlocal realism is not necessarily saved by giving up locality, and it has to be modified at least. This is also a question regarding consciousness. For, if nature is in a strictly definable sense nonlocal and inseparable, a complete description of reality independent of observers – the goal of classical physics – is not possible (cf. Primas, 1993): Our distinction of individual objects and the Cartesian division of subject and object are merely pragmatic abstractions and idealizations. Bohr's (1923) correspondence principle might help in making the understanding of the transition between the strange microscopic world of quantum phenomena and our meso- and macroscopic everyday world intelligible. But this does not alter the fact that ultimately everything – including the human body – is based on quantum physical processes. Thus, entanglement as well as other features of quantum physics might help us to overcome the Cartesian subject/object division (cf. Schmahl, Vaas, and von Weizsäcker, forthcoming); and decoherence (see below) might prevent us from adopting a radical, unintelligible holism. Nevertheless it deeply affects our notion of reality. However, according to Frank Tipler, it could turn out that nonlocality is "an artifact of the assumption that observers obey the laws of classical mechanics, while observed systems obey quantum mechanics", and "that, at least in the case of Bell's Theorem, locality is restored if observed and observer are both assumed to obey quantum mechanics, as in the Many-Worlds Interpretation. [...] Thus, experiments confirming 'nonlocality' are actually confirming the MWI" (Tipler, 2000, p. 1). If this is correct, realism is not refuted either but radically altered and extended.

To give up quantum theory, last but not least, would be a huge step forward if only we could find a better, i.e. more powerful theory. But it is unlikely that such a successor would throw the main principles of quantum theory away – most probably it will include them as approximations or special cases. And a successor theory might not only preserve quantum strangeness but even outdo it. Most of the proposals for a Grand Unified Theory or Theory of Everything have nonreducible quantum ingredients. But perhaps ordinary quantum theory is not complete. However, most of the hidden-variable theories are already falsified by EPR experiments. And the remaining ones are even more nonlocal, e.g. David Bohm's (1980) version. So in this respect, nonlocality also seems here to stay. But there is a possible loophole in Bell's theorem which assumes that hidden parameters do not depend on time and are governed by a single probability measure independent of the analyzer settings. It was recently proved that Bell’s inequalities are not compelling if time-like correlated parameters and a generalized probability density are considered (Hess and Philipp, 2001ab). Thus, all the EPR measurements could, in principle, still be compatible with hidden variables, and quantum theory is still not definitively proven to be complete. And there is another reason why nonlocality or quantum theory as a whole might be wrong, i.e. only a temporary makeshift: Bell's theorem is not derivable and the completeness of quantum theory not experimentally testable without some assumptions on free will. "In the analysis it is assumed that free will is genuine, and as a result of that one finds that the intervention of the experimenter at one point had to have consequences at a remote point, in a way that influences restricted by the finite velocity of light would not permit. If the experimenter is not free to make this intervention, if that also is determined in advance, the difficulty disappears" (John Bell in Davies and Brown, 1986, p. 47). This is an issue which is mainly ignored because it hits the experimentalist's paradigm at the center; however, there are strong philosophical reasons to dismiss a strong (i.e. Libertarian) kind of free will (Vaas, 2001c).

Now, because this article is about quantum theory, consciousness and QCC, we shall assume at least for the sake of argument that the main ingredients of quantum theory are correct and cannot be overcome to easily. And this is, of course, a condition for discussing any explanatory relevance of QCC and illuminating connections between quantum physics and consciousness.

5) The Measurement Problem

Central for quantum theory is the *Schrödinger equation*, i.e. the wave function or psi (Y)-function. (It can even be generalized to describe the whole universe; this is the Wheeler-de Witt equation.) For anything but very simple systems, the wave function (and its special relativistic generalization, the Dirac equation) can only be solved approximately, but there is no doubt that it describes, in principle, every material configuration including, e.g., a group of howler monkeys in the jungle (von Weizsäcker 1985, p. 628; but see below). However, in the standard formulation of quantum theory (by John von Neumann and Paul Dirac), there are two dynamical parts:

(1) the *linear wave equation* describes in a deterministic and continuous way the time-evolution of all unobserved systems (in a superposition state), but

(2) the *random collapse dynamics* describes what happens whenever an observation is made and accounts for the fact that we always find systems to have determinate properties whenever we observe (measure) them; this reduction or collapse of the wave function is stochastic and discontinuous.

The infamous *measurement problem* results from the fact that these two dynamical laws are mutually incompatible, and furthermore that no system can obey both the deterministic and stochastic dynamical laws simultaneously if one supposes that measuring devices are ordinary physical systems just like any other. Central to this problem is that quantum theory does not tell us what constitutes a measurement. But quantum theory works very well, and for all – or at least many – practical purposes this problem can be ignored. Although it is still unclear what the Schrödinger equation exactly means, Max Born soon recognized that the absolute square of the wave function represents the probability for observation of a certain result, e.g. the probability for finding an electron within a certain volume of space. There is almost a complete consensus between physicists on this level of interpretation in the narrower sense, i.e. on the level of formalism and its application. Nevertheless, already in the early days of quantum theory the situation – the level of interpretation in a broader sense, the world view – was recognized as confused. With a short, mocking poem Erich Schrödinger's friend and colleague Erich Hückel hit the nail squarely on the hat:

Many things Erich can calculate

with his wave function, proudly and straight.

But one would really like to know

what it is all about, what it might show. [1]

Schrödinger himself was dissatisfied. He soon illustrated one of the crucial problems with his famous *Gedankenexperiment of Schrödinger's cat* (Schrödinger, 1935, p. 157 and 812 resp.): "One can even set up quite ridiculous cases. A cat is penned up in a steel box, along with the following diabolical device (which must be secured against direct interference by the cat): in a Geiger counter there is a tiny bit of radioactive substance, so small, that perhaps in the course of one hour one of the atoms decays, but also, with equal probability, perhaps none; if it happens, the counter tube discharges and through a relay releases a hammer which shatters a small flask of hydrocyanic acid. If one has left this entire system to itself for an hour, one would say that the cat still lives if meanwhile no atom has decayed. The first atomic decay should have poisoned it. The Y -function would express this by having in it the living and the dead cat (pardon the expression) mixed or smeared out in equal parts."

The parable of Schrödinger's cat was not only meant to be an illustration to show how quantum theory could be misinterpreted and how inappropriate a transfer of microphysical phenomena (e.g. entangled states, i.e. superposition) to macroscopic objects (e.g. cats) apparently is, but it is also as an expression of Schrödinger's problems to understand why macroscopic properties are not infected by microscopic indeterminacy due to collapse dynamics. Schrödinger argued that the abrupt change in the quantum state Y cannot be taken to represent the real physical state of affairs (p. 158); he hoped that the reduction of the wave function is "only a convenient calculational trick", and he exclaimed "If one has to stick to this damned quantum jumping, then I regret having ever been involved in this thing" (cf. Pais, 1988, p. 261, see also Bitbol, 1996). But many physicists and philosophers took Schrödinger's cat seriously.

However, does it really make sense to assume that there is a cat in the box which is simultaneously dead and alive – or neither of the two – as long as it is not observed? Or does observation cause an unequivocal state of the cat, and must this observation be related to consciousness? This radical view actually got popular. And it leads straightforwardly (but perhaps not necessarily) to philosophical *idealism*. "Esse est percipi", George Berkeley claimed. But then serious problems obviously emerge: Where does the observer come from? Why can't he perceive the world in the a way he would like to; why is this world often so unpleasant? Does the cat's superposition state devolve on the observer?

Assume a man opens the box and looks at the cat: Next door there are journalists waiting to learn whether the cat is dead or alive. Is the man – for them or in principle? – also in a superposition state of someone who saw a dead cat and somebody else who saw the cat alive? On the other hand: Couldn't the cat, assuming it is also conscious, observe itself and therefore avoid superposition? Furthermore it is questionable whether the Schrödinger equation is applicable to cats at all for they consume energy and are therefore not a closed system. And couldn't an observer find out the moment of death subsequently, e.g. by measuring the oxygen consumption within the box? Besides, at macroscopic scales quantum effects are usually much too small. For instance, the measurement inaccuracy of a tennis ball due to Heisenberg's uncertainty principle on the order of $1:10^{-16}$, the inaccuracy of neural action potentials in the order of $1:10^{-9}$ (cf. Scott, 1996). In other words: The influence of quantum effects on the brain does not seem to be stronger than somebody stamping his foot onto the ground influences earth's orbit. In addition, quantum effects like the radioactive decay usually cannot be amplified without destroying superposition.

Of course the crucial point is what we consider to be a *measurement*. John von Neumann (1955, pp. 419 f) illustrated this with the example of a temperature measurement. He traced the causal chain from the physical system whose temperature is being measured to the glass of the thermometer containing the mercury, to the length of the mercury column, to the path of the light reflected off the column, to the column's image on the observer's retina, to the optical nerve tract, and to the physiological changes in the observer's brain. He concluded that at some point in this causal chain we must speak of what is perceived by the observer. Hence, we must always divide the world into the observed system and the observer. But to a very large extent, those two different parts have an arbitrary boundary: One could interpret the observer's eyes and optic nerve tract (and the whole brain?) as a part of the observed system, or one could include the thermometer as a part of the observer – "but this does not change the fact that in each method of description the boundary must be put somewhere, if the method is not to proceed vacuously, i.e., if a comparison with experiment is to be possible" (p. 420). So one important aspect of the measurement problem is where the measurement begins and ends, and where the observer begins and ends.

And here appears a tension: On the one hand physics should be exhaustive (Jaegwon Kim, 1998, speaks of the "principle of physical closure") and include the observer and its mental states, e.g. knowledge; therefore the boundary between the observer and the observed system should be arbitrary, and this is what von Neumann (1955, pp. 420 f) actually has assumed: "the danger lies in the fact that the principle of the psycho-physical parallelism is violated, so long as it is not shown that the boundary between the observed system and the observer can be displaced arbitrarily in the sense given above", i.e. in the temperature example. On the other hand he introduced "psycho-physical parallelism" explicitly and thus opened the door for many different interpretations of the mind-matter relationship within the context of quantum theory. According to von Neumann (pp. 418 f) "it is a fundamental requirement of the scientific viewpoint – the so-called principle of the psycho-physical parallelism – that it must be possible so to describe the extraphysical process of the subjective perception as if it were in reality in the physical world – i.e., to assign to its parts equivalent physical processes in the objective environment, in ordinary space."

The term "psycho-physical parallelism" is ambiguous, for it often means identity (e.g. Moritz Schlick's psycho-physical parallelism can be interpreted as a predecessor of mind-matter identity theories developed in the late 1950s and early 1960s, especially by Herbert Feigl, John Jamieson Carswell Smart and Ullin T. Place), but it is also a form of noninteractionistic dualism either of substances (in the tradition of Gottfried Wilhelm Leibniz) or of descriptions and aspects (see, e.g., Linke and Kurthen, 1988). Von Neumann only wrote "that the measurement or the related process of the subjective perception is a new entity relative to the physical environment and is not reducible to the latter. Indeed, subjective perception leads us into the intellectual inner life of the individual, which is extra-observational by its very nature" (p. 418). Hence the observer's mental states are *epistemologically* irreducible (this is a version of the well-known problem of other minds) and therefore it is the observer relative to its environment – "we must always divide the world into two parts, the one being the observed system, the other the observer" (p. 420). But this does not necessarily mean an *ontological* irreducibility, e.g. a substance dualism, because it is compatible with nonreductive physicalism. In a footnote referring to Niels Bohr, von Neumann (p. 420) only spoke of "the dual description which is necessitated by the formalism of the quantum mechanical description of nature" and left it open whether what he had in mind were different entities or only different ways of describing "the physical nature of things" – or if this distinction is useful at all. For if we only must divide the world into the observed system and the observer and if the boundary is arbitrary this does not exclude that there is, ontologically speaking, only one *undivided* system. But on the other hand von Neumann wrote that "it must be possible so to describe the subjective perception as if it were in reality in the physical world – i.e., to assign to its parts equivalent physical processes in the objective environment, in ordinary space" (p. 419), which can be read as an indicator for ontological dualism (contrary to a widely held view that quantum physics overcomes a Cartesian mind-matter division), i.e. that subjectivity is not part of the physical world.

Here, the measurement problem finds itself at a crossroads: Either the observer plays a crucial role for the collapse of the wave function (*subjectivist view*), or it does not (*objectivist view*). Following von Neumann, the subjectivist view was quite popular in the 1930s (see Jammer, 1974, pp. 160 ff, 479 ff) and most clearly defended by London and Bauer (1939). According to John von Neumann (1955, p. 420) "experience only makes statements of this type: an observer has made a certain (subjective) observation; and never any like this: a physical quantity has a certain value." According to Niels Bohr (1958, p. 59), "The indivisibility of the quantum of action implies that it is not possible to separate the observer (or the observing instrument) from the system." Henry Stapp (1993) also repeatedly argued (based on Werner Heisenberg) that classical mechanics strives to keep the observer out of physics, and succeeeds at it, while quantum mechanics tries, but fails to do this. For him, quantum theory is explicitly and irreducibly about observers and observations.

Before discussing the measurement problem and a few important proposals for a solution in some detail, it might be helpful to give a short overview about the main interpretations of quantum physics (related to the measurement problem) and some popular speculations about quantum consciousness.

6) First Survey: Interpretations Of Quantum Physics

• *Copenhagen interpretation* (Niels Bohr, Werner Heisenberg, Léon Rosenfeld): only relations between observables are relevant; observations depend on classical measurement instruments; the process of measurement cannot be analyzed exhaustively as a physical process; the quantum world cannot be known independently of measurements, but they do not necessarily come along with consciousness; dualism of description between classical and quantum objects; the wave function refers to individual systems and expresses the best possible knowledge of their states; quantum objects only have relational properties with respect to certain measuring instruments (no objectivity in a classical sense but objective in the sense of an independence from actual measurements); corpuscle wave dualism

• *ensemble interpretation* (Dimitrij Iwanowitsch Blochinzew, Albert Einstein, Alfred Landé, Paul Langevin, Henry Margenau): quantum physical statements do not refer to singular systems but are statistical statements about ensembles of identically prepared systems; no reduction of a single measurement; no collapse of the wave function but a preparation of new ensembles

• *stochastic interpretation* (Erwin Schrödinger): quantum mechanics is a classical theory with probabilistic nature

• *propensity interpretation* (Leslie E. Ballentine, Karl R. Popper): propensities are inherent relations of systems which are defined with respect to a measurement arrangement but exist independently of this; realistic interpretation of quantum states as theoretical properties which are testable using experimentally determined frequencies

• *quantum logic(s)* (Garret Birkhoff, John von Neumann, David Finkelstein, Carl Friedrich von Weizsäcker): the classical law of excluded middle (the tertium non datur) and the law of contradiction are only of restricted validity or the distributive law is invalid; a new three-valued or many-valued logic is necessary

• *bare theory* (David Albert): von Neumann-Dirac formulation of quantum mechanics with the standard interpretation of states but stripped of the collapse postulate; observer typically fails to have any determinate records or beliefs concerning which specific sequences of results he recorded

• *causal interpretation* (Louis Victor Pierre de Broglie, David Bohm, Basil Hiley): on the one hand, the wave function contains the information about the most likely position of a particle while it influences it on the other hand via an accompanying pilot wave; no collapse of the wave function but statistical assumptions about the distribution of particles

• *transactional interpretation* (John G. Cramer): state vector as a real physical wave emitted as an "offer wave" based on the preparation procedure of the experiment; closure of the interaction through the emission of the "confirmation wave" (collapse of the wave function) by an unexplained input; the quantum particle is the finished transaction

• *decoherence* (Heinz-Dieter Zeh, Erich Joos, Wojciech H. Zurek): interaction with the environment destroys superposition of quantum states

• *quantum state diffusion* (Ian Percival, Nicholas Gisin): continuous accidental collapse of the wave function due to quantum fluctuations

• *spontaneous localization* (Philip Pearle, Gian-Carlo Ghirardi, Alberto Rimini, Tullio Weber): alteration of the Schrödinger equation by a stochastic correction term which causes rarely but over and over again a local collapse of the wave function so that macroscopic objects escape superposition quickly

• *objective reduction* (Roger Penrose): yet undiscovered effects of quantum gravity lead to gravitationally induced state-vector reductions

• *relative-state* or *many-worlds interpretation* (Hugh Everett, John Archibald Wheeler, Bryce S. DeWitt): no collapse of the wave function but the universe divides itself (including its observers) permanently, realizing all possible alternatives; from then on, every universe runs through its own, practically independent evolution (parallel universes)

• *many-histories interpretation* (Richard Feynman, Murray Gell-Mann, James Hartle): there are alternative lines of evolution with different probabilities (consistent histories); only one is accessible for observation; the superposition states are washed out on a coarse-grained inspection; decoherence with the environment

• *subjectivistic, mentalistic and dualistic interpretations*: see next survey:

7) Second Survey: Quantum Consciousness

Some prominent examples for speculative attempts to explain mental processes by means of quantum physical processes and vice versa:

• quantum theory is basically a theory of knowledge (or information); it describes what an observer can know about the microscopic realm (Niels Bohr, Anton Zeilinger)

• quantum theory takes the existence of conscious observers into consideration (Werner Heisenberg, Wolfgang Pauli)

• quantum theory contains a theory of consciousness because it deals with observers and therefore in the end with subjective experiences (Henry Stapp)

• *dualism* of world and observer (John von Neumann, Henry Stapp)

• complementarity corresponds to an aspect dualism of the mental and physical (John Smythies)

• physics is not comprehensible without taking consciousness into account; postulate of a nonphysical individual and universal consciousness (Euan J. Squires)

• *idealism:* consciousness determines being i.e. the results of measurements (John von Neumann, Fritz London, Edmond Bauer, Eugene Wigner)

• nonphysical conscious processes bring ideal quantum objects into reality or determine the collapse of the wave function, respectively (Amit Goswami, Ludvik Bass)

• free will is based on an epistemic indeterminism due to Heisenberg's uncertainty relation (Max Planck)

• quantum leaps are necessary for human free will in the strong, libertarian notion (Pascual Jordan, John Eccles, David Hodgson)

• *participatory anthropic principle:* consciousness and the physical world determine and constitute each other in a reciprocal way (John Archibald Wheeler)

• *many-minds interpretation:* there is no collapse of the wave function when quantum physical measurements are made, but the conscious observer is divided into different observers, each of whom represents a different measured value (David Z. Albert, Brian Loewer, Matthew J. Donald, Don N. Page, Euan J. Squires, Heinz-Dieter Zeh)

• *neutral monism:* hidden variables, implicate order and wholeness (David Bohm); quantized information (John A. Wheeler) or Uren i.e. primordial alternatives (Carl Friedrich von Weizsäcker)

• *quantum reductionism:* consciousness is based on the identity of spatial wholes, e.g. Bose-Einstein condensate (Ian N. Marshall)

• brains as quantum computers (Michael Lockwood)

• quantum effects in synapses as loopholes for the intervention of nonphysical minds into the causal routes of physical nature (Pascual Jordan, Henry Margenau, Hans Jonas, John C. Eccles, Friedrich Beck)

• consciousness as a product of open and closed channels within neural membranes which are quantum physical devices (Matthew J. Donald)

• consciousness is based on quantum computational processes around NMDA channels and associated enzymes; quantum coherence is created or prepared by classical neural mechanisms (Armando Freitas da Rocha, Alfredo Pereira Jr, Francisco Antonio Bezerra Coutinho)

• quantum coherences of water dipoles within neurons (Mari Jibu, Kunio Yasue)

• dissipative quantum dynamics underlie the brain's macroscopic phenomenology, and memory can be modeled as coherent condensation of certain quanta in the brain ground state (Giuseppe Vitiello)

• quantum coherences in microtubules as carriers of consciousness (Stuart Hameroff, Roger Penrose)

• a new physics (theory of quantum gravity) is necessary for the understanding of consciousness (Roger Penrose)

• *panpsychism:* conscious is everywhere, even in elementary particles (Alfred N. Whitehead, Freeman Dyson, Andrew A. Cochran, Abner Shimony)

• overcoming of the psyche/soma dualism in medicine (Friedrich Schmahl, Carl Friedrich von Weizsäcker)

• quantum theory as an explanation for psi phenomena (Robert Jahn, Brian Josephson)

• everything is connected with everything and full of reason and meaning (Fritjof Capra)

8) Quantum Theory And Conscious Observers

In quantum theory, the observer plays a central role – a role which is way beyond classical physics – even if the (ontological) nature of observers remains puzzling. At least that is what many quantum physicists advocate – sometimes even that quantum theory is ultimately a theory about observations and observers (cf. Stapp, 1993). Depending on the experimental design, an observer might measure the velocity or position of a particle to arbitrary precision, but according to Heisenberg's uncertainty principle the other quantity is necessarily blurred. And in experiments on diffraction, refraction, polarization and interference behind a double-slit, photons, electrons, neutrons (and even molecules) reveal themselves as waves, but in the photoelectric effect, Compton effect or Geiger-Müller counter or comparable measurement devices they manifest themselves as particles. Thus, it is the observer who influences the appearance of nature by the experimental method. And according to the Copenhagen interpretation it is neither possible nor reasonable to search for properties of quantum systems as such; since we can only communicate what we have measured by using the classical way of talking, questions concerning properties of quantum systems are meaningful only as questions about classical properties of a classical apparatus.

Following Franco Selleri (1984, pp. 126 ff), it is useful to distinguish three parts of the relationship between observers and quantum objects:

(1) The knowledge that the observer has (at least in his own opinion) about the quantum object,

(2) the wave function Y, which describes the object, and

(3) the real physical structure and behavior of the object.

At best there is a one-to-one correspondence between (1) and (2) as well as (2) and (3). So different degrees of knowledge about the object correspond to different Y and vice versa; and different Y correspond to different physical entities with at least one different objective property. Thus, given a specific Y an observer has perfect knowledge about the object. Therefore, one can state that

(a) two different degrees of an observer's knowledge of an object correspond to two different Y, and

(b) two different Y correspond to two objectively different physical objects.

Thus, if it is the observer's knowledge which causes the reduction of Y (e.g. by looking at Schrödinger's cat in the box), we must conclude that, due to (a), a change in the observer's knowledge can alter the physical object. Therefore, the observer does not learn something about the object but determines the object's observed property – which comes very close to parapsychological capabilities. (Note that experiments have been made regarding mental causation, e.g. the influence of observations on radioactive decays, but no effect was recognized; cf. Hall et al., 1977; for a different view cf., e.g., Radin and Nelson, 1989.)

To avoid this conclusion we have to weaken (a) or (b). However, we cannot give up (a) if we want consider quantum physics to be true. If we give up (b), two different Y can correspond to the same (identical) object. Then, according to (a), Y only describes the mental states of the observer and their changes. Thus, the mental states would develop causally and continuously until an observation is made; such an observation would lead to the sudden, acausal reduction of Y. But then we could not ever learn something about the world out there (if there is any at all) and physics would just be a science for studying mental states.

Nevertheless, this kind of idealism appears as a coherent solution of the measurement problem and is similar to what Eugene Wigner has actually proposed. He claimed that "Consciousness was needed to complete quantum mechanics." (Wigner, 1962, p. 169) It is the conscious observer who reduces the wave function by doing the measurement; "the being with a consciousness must have a different role in quantum mechanics than the inanimate measuring device" (p. 177). So for Wigner, it does matter when the collapse occurs. It matters because there would not be a complete causal story without knowing this, and because there might be empirical consequences which were not considered by von Neumann. According to Wigner (pp. 180 f) one could, at least in principle, even perform experiments to determine which systems are conscious and which are not, although he noted that it may be impossible in practice to ascertain the difference between certain mixtures and some pure states if the system is sufficiently complicated (see Bohm, 1951, sects. 22.11, 8.27 and 8.28). If Wigner was correct, it would have tremendous implications. Consciousness would really matter, maybe we could find strict forms of QCC and even build a "conscious-meter" (Chalmers, 1998). But there are also tremendous problems. "Wigner tried to solve the measurement problem by saying precisely what it is that distinguishes observers from all other physical systems: observers are conscious. But when you think about it, this does not really provide a very clear rule for when collapses occur. Would a cat cause a collapse? A mollusk? A rhododendron? Further, is it really necessary to introduce something extra-physical (in this case minds) in order to solve the measurement problem?!" (Barrett, 1999, p. 55). Furthermore, there is the problem of "Wigner's friend" who is looking at a box with a conscious observer measuring a quantum superposition state. The friend inside the box, although conscious, would also be in a superposition state for the physicist outside (i.e. one who measured one quantum state or the opposite). Wigner confessed that this "appears absurd because it implies that my friend was in suspended animation before he answered my question" and did not want to go that far to deny that his friend has determinate impressions and sensations, because "to deny the existence of the consciousness of a friend to this extent is surely an unnatural attitude, approaching solipsism, and few people, in their hearts, will go along with it" (pp. 177 f).

John Archibald Wheeler (1977, 1980, 1990) has even gone so far as to interpret quantum phenomena as elementary acts of creations and has proposed a *participatory anthropic principle*. According to this, our universe is caused or produced in some sense by observers. This can be interpreted in an idealistic manner – even in a theistic one with God as the ultimate observer (cf. Corey, 1993, pp. 189 ff). Here is a humorous illustration by Ronald Knox (quoted from Russell, 1972, p. 648):

There was a young man who said "God

Must think it exceedingly odd

If He finds that this tree

Continues to be

When there's no one about in the Quad."

– Reply:

Dear Sir: Your astonishment's odd;

I am always about in the Quad.

And that's why the tree

Will continue to be,

Since observed by *Yours faithfully,* God.

According to another interpretation, which also seems to be the one Wheeler holds, the observer is only as important for the existence of the universe, or properties of it, as it is the universe for the existence of observers. The universe is a "self-excited circuit" (Wheeler, 1990, p. 308). "Beginning with the big bang, the universe expands and cools. After eons of dynamic development it gives rise to observership. Acts of observer-participancy [...] in turn give tangible "reality" to the universe not only now but back to the beginning" (p. 308). The observer decides about "what feature of the object he shall have the right to make a clear statement" (p. 311) and even constitutes the past in a certain sense: "'the past has no existence except as it is recorded in the present', or more generally, […] 'Reality is theory'" (Wheeler, 1980, p. 292). Wheeler (1990, p. 304) has illustrated this with a measurement of a photon, which was sent out by a quasar billions of light years away, but it might count as real only if it is measured today – and it is up to us whether it is measured as a particle or a wave packet – and made communicable. (For a critical evaluation of anthropic principle accounts in general, see Vaas, 2000c).

Others were even more radical. According to Euan J. Squires (1996, p. 5) consciousness is not divided in many minds but "must be thought of as being ONE thing"; it is nonlocal and act nonlocally. Thus, the problem of Wigner's friend vanishes, because conscious individuality is ultimately an illusion. Therefore, Squires did not hold a subjectivist view in the strict sense, but it is subjectivist nevertheless – and even a form of interactionistic dualism: "Consciousness is something outside of the laws of physics (quantum mechanics), but it has a real effect upon the experienced world", it selects quantum states and even part of a universal wave function in which it can exist, thus consciousness is "able to change the experienced world" (p. 1 and 4). Therefore, quantum physics or QCC cannot explain consciousness but vice versa: "quite apart from the issue of whether consciousness needs quantum theory, there are good reasons for believing that quantum theory needs consciousness" (Squires, 1994, p. 204); "the whole idea of trying to explain consciousness is probably a mistake: consciousness just is", and "we cannot understand quantum theory without invoking consciousness" (Squires, 1996, p. 1).

But if "the 'mind' is something quite external to the physical body, it is hard to see why so many of its attributes can be very closely associated with properties of a physical brain", Roger Penrose (1994, p. 350) objected; "it is not very helpful, from the scientific point of view, to think of a dualistic 'mind' that is (logically) *external* to the body, somehow influencing the choices that seem to arise in the action of **R** [the state vector reduction]. If the 'will' could somehow influence Nature's choice of alternative that occurs with **R**, then why is an experimenter not able, by the action of 'will power', to influence the result of a quantum experiment? If this were possible, then violations of the quantum probabilities would surely be rife! […] To have an external 'mind-stuff' that is not itself subject to physical laws is taking us outside anything that could be reasonably called a scientific explanation".

Cartesian-style dualism certainly falls into tremendous problems and did so from the beginning. Nevertheless, quantum physics was repeatedly seen as a loophole for interaction (see below). But even if this would be successful, it is no escape from other difficulties. However, there is one more possibility to argue for a subjectivist view without assuming idealism or Cartesian dualism, namely *panpsychism* (which also has a respectable philosophical tradition). This is what, e.g. Evan Harris Walker (1970, p. 175) has proposed in relation to quantum theory: "Consciousness may be associated with all quantum mechanical processes. The uniqueness of our consciousness lies in the fact that it is a part of a logic machine, which in turn is the brain of a particular kind of physical system, a living organism. [...] Consciousness may also exist without being associated with either a living system or a data processing system. Indeed, since everything that occurs is ultimately the result of one or more quantum mechanical events, the universe is inhabited by an almost unlimited number of rather discrete conscious, usually nonthinking entities that are responsible for the detailed workings of the universe." And Freeman Dyson (1979, p. 249) claimed that "mind is already inherent in every electron, and the processes of human consciousness differ only in degree but not in kind from the processes of choice between quantum states which we call 'chance' when they are made by electrons".

This seems to be an exaggeration, and one might wonder how such claims could ever be tested. Furthermore, they are not satisfactory, because they do not (and cannot in principle) explain how consciousness came into being, why it has the properties it actually has etc. If idealism or panpsychism is true, physics would turn ultimately a the study of mental activities. The physical world would be forever hidden or it would even vanish. This can be thoroughly read as a partial declaration of bankruptcy (cf. Selleri, 1984, p. 127). But extraordinary claims require extraordinary evidence. Or are there even promising ways out?

9) Many Worlds, Minds, Histories And Interpretations

Hugh Everett III abandoned hope that one could complete the standard formulation of quantum mechanics by providing a criterion for what constitutes a measurement. He rejected Wigner's approach and said that it "is untenable if we are to consider a universe containing more than one observer. We must therefore seek a suitable modification of this scheme, or an entirely different system of interpretation" (1973, p. 6). For him, appealing to the wave function alone suffices – a single wave function of the whole universe as the fundamental or "basic physical entity with *no a priori interpretation*" (1957, p. 316). Measurements play no special roles here. The wave function provides a complete and accurate description of the state of the entire universe and evolves according to the deterministic linear dynamics. "The general validity of pure wave mechanics, *without any statistical assertions*, is assumed for all physical systems, including observers and measuring apparata. Observation processes are to be described completely by the state function of the composite system which includes the observer and his object-system, and which at all times obeys the wave equation" (1973, p. 8). Nevertheless, Everett had to explain how the subjective appearances of observers modeled as physical systems come into existence according to the statistical predictions of quantum theory. "Whereas before the observation we had a single observer state afterwards there were a number of different states for the observer, all occurring in a superposition. Each of these separate states is a state for an observer, so that we can speak of the different observers described by the different states. On the other hand, the same physical system is involved, and from this viewpoint it is the same observer, which is in different states for the different elements of the superposition" (1973, p. 68). The mechanism behind this is what Everett has called branching. "The whole issue of the transition from 'possible' to 'actual' is taken care of in the theory in a very simple way – there is no such transition, nor is such a transition necessary for the theory to be in accord with our experience. From the viewpoint of the theory *all* elements of a superposition (all 'branches') are 'actual', none any more 'real' than the rest. It is unnecessary to suppose that all but one are somehow destroyed, since all the separate elements of a superposition individually obey the wave equation with complete indifference to the presence or absence ('actuality' or not) of any other elements. This total lack of effect of one branch on another also implies that no observer will even be aware of any 'splitting' process. Arguments that the world picture presented by this theory is contradicted by experience, because we are unaware of any branching process, are like the criticism of the Copernican theory that the mobility of the earth as a real physical fact is incompatible with the common sense interpretation of nature because we feel no such motion. In both cases the argument fails when it is shown that the theory itself predicts that our experience will be what it in fact is." (1957, pp. 320 f).

This sounds radical and straightforward, but Everett's interpretation of quantum mechanics itself stands in need of an interpretation (Healey, 1984, p. 591). "It is tempting to talk as if we were somehow *in* a particular branch and that this is what explains our particular determinate experience, but Everett himself never says this", Jeffrey Alan Barrett (1999, p. 89) complained. "It is unclear exactly how Everett thought of branches. It is also unclear whether and in what way a particular observer is associated with a particular branch. What Everett actually says […] is that there is always a single physical observer, there is no single state of the observer, the different branches represent different subjective experiences of the observer, and all branches exist simultaneously [1957, p. 320]; and he says that since after an observation there are typically many different relative states for an observer, we can speak of different observers described by the different states; but since there is only one physical system involved, there is only one observer who has 'different experiences for the separate elements of the superposition' [1973, p. 68]."

So what does Everett's relative-state interpretation actually mean?

According to what David Albert (1992) has called the *bare theory* it means simply the von Neumann-Dirac formulation of quantum mechanics with the standard interpretation of states but stripped of the collapse postulate (hence "bare"). This is strange, even weird, because a "proponent of the bare theory would believe that a significant portion of the experience of real observers can be explained as this sort of illusion: a situation where an observer (falsely) believes that he has an ordinary determinate experience […] the observer will in fact typically fail to have any determinate records or beliefs concerning *which* specific sequences of results he recorded, so the statistical properties that would report in the limit would not be the statistical properties of any *actual* determinate sequence of results. And this is presumably not what Everett wanted […] the illusions predicted by the bare theory are so radical and would have to be so pervasive that they would ultimately undermine whatever empirical reasons one might think one had for accepting the bare theory in the first place" (Barrett, 1999, p. 98, 107, and 113, cf. also Barrett, 1998).

The best known interpretation of Everett's relative-state interpretation is the *many-worlds interpretation*. However, there are many many-world interpretations. According to the most popular interpretation by Bryce DeWitt and Neill Graham (which was, apparently, at least tolerated by Everett, for he contributed to this anthology), Everett's interpretation "denies the existence of a separate classical realm and asserts that it makes sense to talk about a state vector for the whole universe. This state vector never collapses and hence reality as a whole is rigorously deterministic" (1973, p. v). "The universe is constantly splitting into a stupendous number of branches, all resulting from the measurement-like interactions between its myriads of components. Moreover, every quantum transition taking place on every star, in every galaxy, in every remote corner of the universe is splitting our local world on earth into myriads of copies of itself. […] The idea of 10^{100+} slightly imperfect copies of oneself all constantly splitting into further copies, which ultimately become unrecognizable, is not easy to reconcile with common sense. Here is schizophrenia with a vengeance" (1973, p. 161). These copies – worlds or parallel universes – are mutually unobservable but nonetheless real. (David Deutsch, 1996, p. 223, commented that he "can testify from conversations with Everett in 1977 that, by then at least, he was robustly defending his theory in parallel-universes terms".) Of course, what makes the splitting-worlds interpretation so strange is not the assumption of different universes (or parts of the universe) as such – there are nowadays even more bizarre claims of "many worlds in one" with infinitely many Doppelgänger of us, even perfect ones, if the universe is infinite (Garriga and Vilenkin, 2001, cf. Vaas, 2001b) – but the splitting of worlds. A recurrent criticism is that the many-worlds interpretation is ontologically extravagant and expensive. According to John S. Bell (1987, p. 193 f), "it fails to list the possibilities. […] one is given no idea of how far down towards the atomic scale the splitting of the world into branch worlds penetrates. [… It] seems to me an extravagant, and above all an extravagantly vague, hypothesis." Among others, Bernard d'Espagnat (1971, pp. 445 f) objected that it "has the very unpleasant feature that, in a way, it runs counter to the principle of the economy of assumptions (Occam's razor) which is otherwise known to be so important in science. Indeed it even does so without any restraint, since it goes as far as postulating infinities of completely unobservable worlds or at least states of the universe." (According to Frank Tipler, 1986, the splitting cannot go on for ever "since the information stored in human beings is finite, the set of all possible measurements can split a human being into only a finite number of pieces" – his estimation is in the order of "2 raised to the 10^{26} power" pieces –, but splitting should not be restricted to humans and their measurements.) However, postulating too many entities (worlds) is not the same as postulating too many theoretical assumptions, principles or restrictions or different ontological kinds, and that is what Occam's razor ("Pluralitas non est ponenda sine necesitate; essentia non sunt multiplicanda praeter necessitatem; frustra fit per plura quod fieri potest per pauciora") is primarily about. And it was argued that everything that is not strictly forbidden by physical laws and principles actually exists (Sciama, 1993, p. 108, cf. Kanitscheider 1991, p. 395). Another criticism is that we cannot feel the splitting and that "no experiment can reveal the existence of the 'other worlds'" (De Witt, 1973, p. 165). Others (e.g. Healey, 1984, p. 594, Albert and Lower, 1988, pp. 198 ff, and Lockwood 1989, p. 228) have worried that the many-worlds interpretation is incompatible with the conservation of mass but of course this conservation law might simply not be true. More serious is the question of when a world splits. "According to the splitting-world theory, a world splits when a measurement-like interaction occurs, but according to relativity there is no absolute matter of fact concerning when any event occurs – indeed […] observers in different inertial frames will typically even disagree about the temporal order of events. But when a world splits is presumably a frame-*independent* matter of fact" (Barrett, 1999, p. 159). Furthermore, there is no account of transtemporal identity for branches, and the vast majority of worlds should obey laws very different from the familiar statistical quantum laws or there is even nothing like the conventional probabilities of quantum mechanics, thus the many-worlds interpretation would be incomplete (Albert and Loewer, 1988). "I bet a friend $10 that the Eiffel Tower is in Pittsburgh right now. This is presumably a bad bet, *but why?* The splitting-worlds theory doesn't say. There are worlds where I believe what I believe and the Eiffel Tower is in Pittsburgh, and in those worlds I would win the bet. There are worlds where I believe what I believe and the Eiffel Tower is not in Pittsburgh, and in those worlds I would lose the bet. But there is nothing in the splitting-worlds theory as it stands that tells me which sort of world I inhabit right now or even which sort I should expect to inhabit right now. […] As it stands, then, the splitting-worlds theory does not even explain why one should *expect* to record the usual quantum statistics *right now*" (Barrett, 1999, p. 166). DeWitt (1973, p. 185 and 163) speculated that perhaps life simply fails to evolve in maverick worlds where the usual quantum statistics fail to hold "so no intelligent automata are around to be amazed by it", or "that maverick worlds are simply absent from the superposition" – but then one must change the splitting-world theory or abandon the linear dynamics or Everett's model of measurement e.g. by postulating that one would measure the usual quantum statistics only in most worlds (DeWitt and Graham, 1973, p. 252). Another rescue operation might be the assumption of many worlds without splitting. This many-threads theory is about a specification of the history of a single world. There is a connection rule which ties together states of the same world at different times so that one can make sense of transtemporal identity worlds and hence observers. But "if one tries to fix the splitting-worlds theory by getting rid of the splitting process […], and if one is willing to think of the global wave function as a part of the state of each world, then one naturally ends up with a perfectly ordinary hidden-variable theory" (Barrett, 1999, p. 184).

Curiously enough, consciousness crept into quantum theory again even through the back door of Everett's approach. According to David Z. Albert and Brian Loewer (1988) observers have nonphysical minds, always determinate mental states and a different time-evolution than the usual linear dynamics which provides a complete and accurate description of the time-evolution of the physical world. If the mind does not split, a complete description of the physical world would fail to determine the mental state of an observer, i.e. mental states would not generally supervene on physical states. Therefore, Albert and Loewer do not opt for a single-mind theory but prefer a *many-minds interpretation* with an infinity of minds (for an interesting alternative, proposing *many conscious experiences* rather than minds, see Page, 2001). Here, not entire worlds but only minds split, and they split in such a way that a mind's own beliefs about its past mental states are typically reliable. They are never in superpositions (and therefore not physical) but associated with each of the elements of the superposition of physical states. This might sound counter-intuitive, but that is not a fatal flaw. However, if "one had a successful many-minds theory, then one could always convert it to a many-worlds theory […] and eliminate the mind-body dualism" to which Albert and Loewer are committed (Barrett, 1999, p. 197). (Other many-minds proponents like Michael Lockwood (1989), who advocated a nondualistic, naturalistic many-minds interpretation, are in fact committed to the many-worlds interpretation, cf. Deutsch, 1996). Furthermore, in the many-minds interpretation local mental states do not supervene on observer's physical states, but the observer's global mental state might evolve in a continuous deterministic way and supervene on his physical state. So Albert and Loewer "have purchased supervenience of the mental on the physical at the cost of postulating an infinity of minds associated with each sentient being" (Albert and Loewer, 1988, p. 207). However, this would be bad news for QCC research: "What comfort is it supposed to give me that my global mental state supervenes on my physical state when I don't even know what my global mental state is? If one wants supervenience, the one presumably wants one's local mental state, the state that determines one's experiences and beliefs and the only state to which one has epistemic access, to supervene on one's physical state. And in many-minds theory my local mental state does not supervene on my physical state" (Barrett, 1999, p. 196).

So let's not get weird beyond necessity. At least from the perspective of (scientific) realism an *objectivist* view of measurement seems preferable. And this is the one which is needed to learn something about consciousness from quantum physics and not vice versa. If one rejects many-worlds and hidden variables as well as an alteration of the Schrödinger equation and a Copenhagen "tranquilizing philosophy" (as Albert Einstein called it [2]), one would have had a bad standing for some decades. But in the early 1950s a new approach slowly developed and attracted more and more attention after circa 1970 (cf. Jammer, 1974, pp. 486 ff, d'Espagnat 1976, pp. 186 ff): attempts to describe the collapse of the wave function as a thermodynamical process involving the macroscopic measuring device initially in a metastable state without any need for a conscious observer. Crucial is the interaction of quantum systems and also the measurement instruments with their environment. The strategy of the this objectivist approaches is to describe in a thermodynamical way the process of amplification that occurs during measurement and show that the interference terms characterizing quantum states vanish. Such an environmentally-induced *decoherence* offers new possibilities to handle the measurement problem (Giulini et al., 1996). Besides, this has motivated Wigner (1983, p. 58) even to back off from his earlier subjectivist position.

The states of macroscopic systems – like a measurement apparatus – do not obey the Schrödinger equation because they are never closed systems. "Macroscopic systems are never isolated from their environment. Therefore they should not be expected to follow Schrödinger's equation, which is applicable only to a closed system" (Zurek, 1991). Usually the environment "measures" or monitors a quantum system continuously without requiring the presence of a human observer or even some measuring devices. Decoherence destroys the interference effects and thus provides the observer with an effectively determinate record. "Schrödinger's cat never exists in a superposition of living and dead states, because collapse already happens during amplification of the microscopic signal" (Pessoa Jr., 1998, p. 339). And human observers were not spared, either, because "the process of decoherence is bound to affect states of the brain: Relevant observables of individual neurons, including chemical concentrations and electrical potentials, are macroscopic. They obey classical dissipative equations of motion. Thus any quantum superposition of the states of neurons will be destroyed far too quickly for us to become conscious of the quantum goings-on: Decoherence applies to our own 'state of mind'" (Zurek, 1991, p. 44).

But does this suffice? Does it also explain that the observer did in fact record a determinate result and what the result is? It is useful to draw a distinction (Pessoa Jr., 1998, p. 324): "*Decoherence* is a statistical concept, involving the transition form a pure state to a 'mixture', and the disappearance of interference terms. *Collapse* refers to an individual system, and it describes a transition from a pure state to another pure state." For example, an interference pattern of an electron (wave) on a screen behind a two-slit experiment could be washed out by processes which disturb the coherence of the wave, e.g. turbulence, scattering photons, etc. In contrast to this process of decoherence, a collapse or localization may be associated with the presence of a single electron in some small region of space (e.g. in a detector behind one of the slits). Decoherence is statistical, collapse is individual. Thus, an explanation for collapse implies an explanation for decoherence, but an explanation for decoherence does not imply an explanation for collapse (Pessoa Jr., 1998, p. 325). This does not mean that thermodynamics necessarily fails to explain collapse, but one has to show how it causes it.

So one important question is whether decoherence is a necessary and sufficient condition for collapse or not. If it is only necessary, then there is another condition required for an objectivist account. Why does the observer perceive only one outcome of a measurement? Murray Gell-Mann and James Hartle (1990, pp. 429 f) also argued along the objectivist lines. "In a theory of the whole thing there can be no fundamental division into observer and observed. Measurements and observers cannot be fundamental notions in a theory that seeks to discuss the universe when neither existed." For them, the Everett formulation of quantum mechanics is incomplete. "It did not adequately explain the origin of the classical domain or the meaning of 'branching' that replaced the notion of measurement. It was a theory of 'many worlds' [...], but it did not sufficiently explain how these were defined or how they arose" (p. 430). Gell-Mann and Hartle proposed a *many-histories interpretation* with two rules: One describes which sets of alternative histories of the universe can be assigned approximate probabilities (not in a fine-grained set of histories, that give the precise position, e.g. of every particle, but a sufficiently coarse-grained sets of histories), and the other explains what these probabilities are. But crucial questions remain: Understanding approximate probabilities is problematic. And is "only one history from a particular decoherent set actual? If so, then the usual quantum-mechanical state is descriptively incomplete because it does not tell us which history this is. Or do all histories somehow exist simultaneously? But if this is right, then why do we only experience one history? Is it because different histories describe events in different worlds and we only inhabit one world" (Barrett, 1999, p. 238)? Furthermore, it is also unclear how the theory is supposed to account for our determinate experiences, beliefs and measurement records. Gell-Mann and Hartle (1990, p. 445) explain that "The answer to Fermi's question to one of us of why we don't see Mars spread out in a quantum superposition of different positions in its orbits is that such a superposition would quickly decohere." But how does this work? And why did we record the history we actually have recorded and not one of the many mutually incompatible sets of alternative decohering histories? Perhaps there is "one roughly equivalent group of histories with much higher classicities than all the others", Gell-Mann and Hartle (1990, p. 454) speculated. "That would be the quasiclassical domain, completely independent of any subjective criterion, and realized wihtin quantum mechanics by utilizing only the initial condition of the universe and the Hamiltonian of the elementary particles." However, we do not have an objective notion of what should count as a quasi-classical domain. Even more serious is how the existence of one or many such domain(s) is supposed to account for our determinate records, experiences, and beliefs.

And there are some more reasons to be sceptical. According to Osvaldo Pessoa Jr. (1998, p. 339), "the decoherence approach is able to explain why a system does *not* collapse (its decoherence time is long), but it does not explain why a system does collapse. A system that decoheres is described by a classically behaving mixture, but to describe state collapse for a single system one has also to consider the pure state underlying the mixture." And Heinz-Dieter Zeh (1970, 1993, 2000a,b) never considered that the measurement problem for individual systems, i.e. their state collapse, could be solved simply by considering the environment (and even adopted a version of the many-minds interpretation, see Zeh, 2000a). Collapse must correspond to a modification in the observer's brain state occurring during the timescale of decoherence (see also Zurek, 1993, p. 311). This leads back to the many-minds interpretation of Everett's relative-state formulation – we have moved in a circle.

And there is another problem, because by going on to choose larger and larger systems one finally arrives at the whole universe. If the universe is considered to be a closed system, the decoherence approach runs into troubles. But it is unclear what happens if we assume a spatially but not temporally infinite universe or even universes like the brines in M-theory which are interacting gravitationally through a five-dimensional bulk space. Can nature fend for itself and decohere everywhere, or are we forced to reintroduce observations and must we even assume that the system only loses coherence when we choose what to observe and what not to observe?

What are the options if physicists fail to show that decoherence is a necessary and sufficient condition for collapse? (And such an objectivist attempt should be pressed ahead as far as possible – for reasons of ontological parsimony and because of the principle of mediocrity. Decoherence is, at least, within the reach of experimental study now, cf. Brune et al., 1996.)

Perhaps there are possibilities to change the Schrödinger equation: A stochastic correction term might cause rarely but over and over again a local collapse of the wave function so that macroscopic objects escape superposition quickly. Or yet undiscovered effects of quantum gravity lead to gravitationally induced state-vector reductions

Louis Victor Pierre de Broglie (1925) proposed that the question "particle *or* wave?" should be answered with "particle *and* wave" and showed how the motion of a particle, passing through one of two holes in a double-slit experiment, could be influenced by waves propagating through both holes. This *pilot wave* determines that the particle does not go where the waves cancel out, but is attracted to where they cooperate. Later, David Bohm (1952) developed this account for many particles instead of just one. This straightforward generalization does not need to divide the world into quantum and classical parts, for the necessary classical terms are available already for individual particles and macroscopic assemblies of them. "This idea seems to me so natural and simple, to resolve the wave-particle dilemma in such a clear and ordinary way, that it is a great mystery to me that it was so generally ignored", John S. Bell (1987, p. 191) wondered, and he repeatedly stressed (p. viii) that "all students should be introduced" to the de Broglie-Bohm picture, "for it encourages flexibility and precision of thought". Nevertheless, this interpretation (or is it a different theory?) has problems of its own, makes nonlocality even worse and cannot avoid action at a distance too.

David Bohm's (1952, 1980, see also Bohm and Hiley, 1993) nowadays so-called *causal interpretation* of quantum theory postulates (or derives) a field with – and this is Bohm's interpretation – "objective and active information" which "is similar in certain key ways to the activity of information in our ordinary subjective experience". However, Bohm (1990) does not argue for Cartesian dualism but for "participation rather than interaction": "ultimately mind and matter are at least closely analogous"; "the implicate order may serve as a means of expressing consistently the actual relationship between mind and matter, without introducing something like the Cartesian duality between them […] quantum wholeness is what is primary […] the observing apparatus and the observed system cannot be regarding as separate." Bohm derived a quantum potential out of the Schrödinger equation and interpreted it as an information potential which is totally different from the classical potential: It has no external source, particle and fields are aspects of the same process; its strength in independent of field intensity; its effects do not necessarily fall off with distance, it is not like a mechanical force; it organizes the form of the trajectories of particles; it carries information about the particles' environment and the whole experimental arrangement; it is nonlocal, and there is no collapse of the wave function. Bohm's theory, however, is not a naturalistic one but could better be described as a variant of neutral monism. The "more comprehensive, deeper, and more inward actuality is neither mind nor body but rather a yet higher-dimensional actuality, which is their common ground and which is of a nature beyond both" (Bohm, 1980, p. 209).

But maybe things are much simpler: Perhaps we are just caught within our own prejudices and simply make the wrong assumption. John Bell (1990), e.g., vehemently criticized that concepts like "system" "apparatus", "environment" and "measurement" immediately imply an artificial division of the world. It is questionable whether this division really has to do with conscious subjects. "Does not quantum theory again place 'observers' … us … at the center of the picture? […] I am inclined to hope that we are indeed that important. But I see no evidence that it is so in the success of contemporary quantum theory", John Bell wrote (1987, p. 170). "So I think it is not right to tell the public that a central role for conscious mind is integrated into modern atomic physics. Or that 'information' is the real stuff of physical theory. It seems to me irresponsible to suggest that technical features of contemporary theory were anticipated by the saints of ancient religions … by introspection. The only 'observer' which is essential in orthodox practical quantum theory is the inanimate apparatus which amplifies microscopic events to macroscopic consequences." Nevertheless, the problem is not solved even if we could exclude conscious observers as its source. The problem, as Bell (p. 171 f) is willing to admit, is: "how exactly is the world to be divided into speakable apparatus … that we can talk about … and unspeakable quantum system that we can not talk about? How many electrons, or atoms, or molecules, make an 'apparatus'? […] For me then this is the real problem with quantum theory: the apparently essential conflict between any sharp formulation and fundamental [general theory of] relativity. That is to say, we have an apparent incompatibility, at the deepest level, between the two fundamental pillars of contemporary theory." And (p. 188): "For me it is the indispensability, and above all the shiftiness, of such a division that is the big surprise of quantum mechanics. It introduces an essential ambiguity into fundamental physical theory, if only at a level of accuracy and completeness beyond any required in practice. It is the toleration of such an ambiguity, not merely provisionally but permanently, and at the most fundamental level, that is the real break with the classical ideal. It is this rather than the failure of any particular concept such as 'particle' or 'determinism'."

In conclusion, the current situation of quantum physics is rather uncomfortable – or even a mess. Empirically, quantum theory is overwhelmingly successful and the formalism works fine, but what it actually means is nowadays more mysterious than when quantum theory was advanced. "The fact that an adequate philosophical presentation has been so long delayed is no doubt caused by the fact that Niels Bohr brainwashed a whole generation of theorists into thinking that the job was done fifty years ago", Murray Gell-Mann (1979, p. 29) lamented at the 1976 Nobel Conference. And John Bell (1987, p. 26) argued that "Quantum Mechanics is, at best, incomplete". Thus, either we do not sufficiently understand what quantum theory really means (this is the problem of the correct interpretation), or we have to alter and improve quantum theory, and then our current theory would be, strictly speaking, wrong (this is Einstein's question of completeness). "It is quite hard to accept that we still are in the stage of babies in their diapers", Albert Einstein once wrote to Erwin Schrödinger (in Przibram, 1963, p. 36 [3]).

To sum up it can be said that the reasons for linking consciousness and quantum physics in a straightforward way are far from being conclusive. There might or might not be some common features both for quantum and conscious phenomena. And there might or might not be a close connection between conscious observers and quantum states due to the measurement problem. For some approaches, e.g. many-worlds, many-histories and environment-induced decoherence, consciousness plays no relevant role at all. But it remains an open question whether (a) consciousness is needed to explain the quantum word, or (b) whether quantum physics is needed to explain consciousness, or (3) whether there is no explanatory connection but nevertheless some more or less robust correlation which would be also a remarkable insight.

So it might be useful to distinguish roughly between three kinds of ontological relations and take both the subjectivist and objectivist view of the measurement problem into consideration:

(1) *Mind is created by matter according to an objectivist view:* Then QCC should exist, at least in a very broad sense, and it remains to be seen whether they are explanatory relevant. They could be a necessary condition like in the objective reduction postulate by Roger Penrose (1994, 1997) or the different approaches to interpret brains as quantum computers and mind as a result of such quantum computations (or being identical with them respectively). But they would not be sufficient.

(2) *Matter is created by mind(s) according to a subjectivist view:* Then QCC correspond either with specific conscious states thinking of or representing physical states which are entirely subject-dependent (quantum idealism), or physical states are in some way "released" or "formed" by mental processes, e.g. due to a collapse of the wave function. Therefore, QCC cannot explain consciousness and cannot be explained by physics but must be explained by consciousness.

(3) *Mind and matter are ontologically independent of each other:* Then they could be either distinct (dualism) or both not fundamental (e.g., neutral monism). Therefore, QCC cannot explain consciousness, too, but they might be relevant to understand quantum theory according to a subjectivist view (e.g. by the many-minds interpretation or the participatory anthropic principle or even the von Neumann-Dirac approach if psycho-

physical parallelism requires ontological dualism). If neutral monism is true, QCC might lead us to the common, underlying substrate. And if some kind of quantum panpsychism is true, QCC must exist by necessity and could even avoid the measurement problem – although some Whiteheadian elementary entities (cf., e.g., Shimony, 1997, p. 153, and the response by Penrose, 1997, p. 175) had to be stipulated as a irreducible and unexplainable factum brutum.

In conclusion: While it is too early to make judgments about the existence and explanatory or predictive power of QCC, it would be certainly not wise to dismiss them without strong reasons. Of course the burden of proof lies with the proponent, not the sceptic. Nevertheless, it might be already useful to examine some conceptual issues as well as philosophical restrictions and limitations of QCC.

10) Quantum Correlates Of Consciousness – Conceptual Issues

Let's accept – at least for the sake of the argument – the existence of QCC. Please note the plural which is unavoidable at the moment because there are many different proposals for QCC and perhaps even different instantiations within species. There is a priori no need for QCC to be strictly localized (e.g. within membranes, neurons or even the whole brain) and due to quantum entanglement a precise localization might even be impossible. It is sufficient if QCC take the form of more or less robust spatial and/or temporal distributed relations within the nervous system, but they could also be extended, at least in principle, way beyond the visual boundaries of conscious agents and even occupy the whole universe (that is what e.g. some field theories of universal consciousness claim). However, even this rather weak account is not enough for the more far-reaching and ambitious scientific and philosophical purposes like the understanding of intentionality, phenomenal awareness (qualia), self- and I-consciousness.

Here, a comparison with neural correlates of consciousness (NCC) might be revealing (cf. Vaas 1999b): NCC are helpful to explain phenomenological features of consciousness, e.g. dreaming; NCC can account for phenomenologically opaque facts, e.g. the temporal structure of consciousness; and NCC reveal properties and functions of consciousness which cannot be elucidated either by introspective phenomenology or by psychological experiments alone, e.g. vision. Proponents of QCC might claim similar achievements: QCC are helpful to explain phenomenological features of consciousness, e.g. the unity or holism of consciousness (see above); QCC can account for phenomenologically opaque facts, e.g. the possibility of free will (Eccles, 1994a, Hodgson, 1991, Jordan, 1934, 1938, Stapp, 1993); and QCC reveal properties and functions of consciousness which cannot be elucidated either by introspective phenomenology or by psychological experiments alone, e.g. memory (Yasue, Jibu, and Pribram, 1991, Jibu and Yasue, 1995, Vitiello, 2001). Thus, formally speaking, QCC might, just like NCC, be explanatory powerful regarding specific topics, although QCC are much less elaborated and experimentally well-founded – and NCC are certainly not overwhelmingly successful in those respects yet.

11) Defining QCC

What are QCC? At first sight this seems to be an easy question. Correlation is a concept of statistics and refers to a regularly common occurrence of two states or events which are, for the present, assumed to be independent from each other and can be described quantitatively by means of a correlation coefficient. QCC are quantum states which correlate directly and strictly with conscious states. Whenever some information is represented in QCC it is also represented in consciousness (cf. the definiton of NCC by Crick and Koch, 1998, p. 97). Or, to put it slightly different, a quantum correlate of consicousness is a specific system in the brain (or elsewhere) whose activity correlates directly with states of conscious experience (similar was the NCC definition in the conference programm "Neural Correlates of Consciousness: Empirical and Conceptual Questions", held in Bremen 1998, p. 1; cf. Metzinger, 2000). A more detailed definition might be on this lines (cf. Chalmers, 2000, and Vaas 2001d for similar NCC definitions): A QCC is a minimal quantum system Q such that there is a mapping from states of Q to states of consciousness, where a given state of Q is sufficient, under conditions C, for the corresponding state of consciousness. Or: A QCC (for content) is a minimal quantum representational system Q such that representation of a content in Q is sufficient, under conditions C, for representation of that content in consciousness. The conditions C might refer to normal brain functions or minimal necessary brain functions or any other physical state or process (not necessarily related to neural conditions) which is, as a matter of fact, sufficient for consciousness.

Although this immediately raises other questions, such as: What is a direct correlation, a representation, a conscious state etc.?, I shall mostly restrict myself to the QCC themselves. It is useful to distinguish between three questions: (1) What are QCC? (2) What are the (or our) QCC? And (3) are there QCC at all?

QCC is, first of all, a concept. A concept needs at least a rough working definition to get along, but this definition might change within the course of scientific or philosophical progress. A concept has to do work, i.e. it has to prove its worth: It should simplify communication, and it should have a place within a theoretical framework which has some classificatory advantages, explanatory or predictive power etc. But not all concepts refer to an entity out there, i.e. something in reality (whatever this means). For example, there are unicorns and we can talk about them, dream of them and even make movies about them, but they nevertheless do not exist like trees, brains and electrons; they are imagination, they are fiction. Now a sceptic might argue that trees, brains and electrons are also imagination and fiction, not existing independently of us. This is a complicated philosophical issue. But even if we would subscribe to idealism, there are still entities which are of a different kind of reality than others (e.g. subjects and their mental states). However, most proponents of QCC are realists in some sense or another, i.e. they treat QCC as real, as being "out there" (for if they were be fictitious the discussion would simply move in a circle). Therefore QCC proponents usually assume at least that there are some quantum physical entities (objects or properties or events) and that there is consciousness. This is not enough for a characterization of the relation between quantum physical entities and consciousness, but it is a meaningful hypothesis. It could be wrong. It is possible that there are no QCC. For example it might turn out that quantum theory is wrong after all and we have to give up Planck's constant h someday or reduce it to a yet unknown classical principle; or idealism could be true and quantum physics is an imagination like a unicorn, thus it correlates with consciousness only in the sense that it is created by it. From a realist's perspective however, and even a naturalist's one, quantum and mental states might occur together even if a more specific relationship is unknown. But this is not enough, because QCC require at least a statistical correlation. Therefore, ultimately, we will know if there are QCC only if we know, at least in a broad sense, what the QCC are or, to be more specific and modest, what our QCC are, i.e. which quantum features are correlated with our conscious states, or even necessary, or sufficient, or both for them. We do already have some proposals of such QCC, but it is much too early to be satisfied and sure about that. Thus, we do not know yet what the term QCC actually refers to (beyond its conceptual role within a theoretical framework or language game).

Worse, we do not even have a clear-cut definition of QCC. There are several reasons for that. One is that we are also lacking a clear-cut definition of consciousness. (There are at least three different notions of consciousness, i.e. (1) creature consciousness or consciousness in general as a property in contrast to "being not conscious", (2) background state of consciousness or consciousness as a general state, i.e. a category with different forms like awakeness, dream consciousness, altered states of consciousness, and (3) consciousness as a specific state with a (or individuated by a) specific representational content and some phenomenal character or quality (quale), e.g. the experience of reading this sentence, i.e. understanding the words and having a feeling of what it is like to look at a paper or computer screen. But I won't go into details of these definitions here.)

However, a diffuse meaning of central terms is not an impediment for research in principle. On the contrary: Better scientific hypotheses usually come along with more precise definitions. This was often the case within the history of natural science, think e.g. of concepts like "force", "mass", "energy" in physics or "life" and "heredity" in biology. Thus it would be wise and heuristically advantageous not to restrict research with a demand for too narrow or even ideologically fixed basic terms. Therefore we might (as it was proposed by Rudolf Carnap) better speak of an explication, rather than a definition of consciousness and a fortiori of QCC. Others have argued similarly:

"... in the early stages particularly, the technical equivalent of a common term should conform as far as possible with common usage. The technician's effort to sharpen the concept should at least in principle allow the technical equivalent to be substituted for the term, without violation of basic sense or grammar, in as many contexts as possible." (Donald MacKay)

"Definitions are more helpful after one considers the body of background knowledge to a concept than before." (Lawrence Weiskrantz)

"The idea that if only we could get the words correctly defined then we would understand the phenomenon is seductive but misguided. The words will come to have a more precise meaning as they are more deeply embedded, within the framework of an empirical theory ... [and] some philosophers [e.g. Daniel Dennett] have called the "define-the-words-first" strategy the *heartbreak of premature definition*." (Patricia Churchland)

Nevertheless we have to explain the notion of QCC at least in a crude way. And this is not just a play with words but a demanding terminological (and philosophical) task which might even clarify or reveal problems beyond conceptual issues. (For a detailed discussion of NCC definitions see Chalmers, 2000; cf. also Vaas, 2001d.)

So do QCC exist? The answer is apparently yes if (1) we take QCC very broadly, (2) we grant that some form of philosophical realism is true, and (3) we accept that quantum physics is at least an approximately valid description of some features of our universe, especially the realm of atomic and subatomic particles (only quantum theory can describe why atoms are stable, why the sun is shining, where all the different chemical elements come from etc.). Then, given that conscious states or events also exist, we can argue quite straightforwardly that there are QCC. Because then mental states are in some way related to physical states, and physical states are (whatever else they also might be) quantum states or have them or are instantiated or realized by them or are emerging from them or constituted by them (I do not want to elaborate this kind of relationship further here). Thus, if matter has a quantum physical nature and if consciousness is related to matter in some way there are QCC (Note that this line of thought is rather weak, because it does not exclude most of the proposed mind-matter relationships, see below. And there is one minor caveat, namely the possibility that there are conscious states and quantum states – but unrelated in any (at least statistically) reliable way; thus some sort of parallelism would be true, but of a totally random and not preestablished (Leibnizian) kind.)

Thus, it is reasonable to believe that QCC exist at least in a very broad sense. This is probably not a very controversial statement. But it is, of course, also not very useful and intriguing. It does not help us to understand conscious experience better. It does not solve scientific problems. And it does not give us any insight regarding philosophical issues like the different aspects of the mind-body problem (mental causation, intentionality, self-consciousness, mind-matter relationship, the hard problem etc.). However it is not a trivial statement either, because it shows that QCC could matter. Many philosophers have reservations regarding QCC. But it would be philosophically reckless to ignore QCC or doubt them, at least for any proponent of some form of anti-idealism. If one takes physical states into consideration one ultimately has to deal with and accept the existence of QCC in a broad sense. Therefore, even sceptics should take QCC seriously.

And there could be more to QCC than meets the sceptic's eye, because QCC might be useful or even necessary for a better understanding of conscious experience or quantum physics or both. But there are also some crucial problems and limitations for QCC research, partially related to philosophical issues. This is one reason why metatheoretical reflections are required, which are part of what could be called a *quantum philosophy of consciousness*.

12) Limitations Of Correlations

Correlation does not imply either causation or identity (although it might be interpreted as an indication of one of them). For example, a strict correlation of birth rates and the size of stork populations does not mean that babies are made or brought by storks; and a strict correlation between the movements of soccer-players on a TV screen and in the stadium from which there is a live broadcast does not mean that the pictures on TV are identical with the soccer players (Zoglauer, 1998, p. 106). Thus, QCC alone are not sufficient to prove that our conscious experience is caused by or identical with quantum events. There is even a tension between the ways of talking about causation and identity here. But of course this depends strongly on our notions of causality and identity, which I cannot discuss in this context. In any case, quantum events need not necessarily be identified with mental events or cause them. The correlations are compatible with very different other dependencies and ontologies, e.g., there could be a common cause in the past for both quantum and mental states which are otherwise independent from each other (e.g., Gottfried Wilhelm Leibniz' preestablished harmony), or a continued intervention of a causal agent, e.g. God, synchronizing quantum and mental states (e.g., occasionalism, as it was proposed by Arnold Geulincx and Nicolas Malebranche), or both states are two aspects of one and the same underlying process, or the quantum states are caused by the mental states and not vice versa, or the correlations are just an improbable or unexplainable coincidence. Furthermore, correlation does not imply identity because the simultaneous occurrence of a mental state and a quantum state is also consistent with parallelism and epiphenomenalism. It is not possible to refute a sufficiently sophisticated version of parallelism empirically, for instance by reference to QCC, because there is no way to distinguish between identity and parallelism empirically, as it was already admitted by Herbert Feigl (1958, p. 437 and 463).

13) Restricted Access

There are limitations of empirical access due to the well-known problem of subjectivity, the problem of other minds, and the problem of self-deception. So not only the objective, intersubjective or physical side of QCC, i.e. the quantum part of the correlation, is problematic, but also the other side or direction, which is the subjective part – consciousness. (This is also one of the main problems of NCC).

The problem of subjectivity, also called the "explanatory gap" or the "hard problem" (cf. Bieri, 1992, Chalmers, 1996, Jackson, 1982, Levine, 1983, and Nagel, 1974, 1980), is based on the dichotomy between the – in some sense – irreducible subjective character of our phenomenal experience (qualia) and the quasi-objectivist explanations of science or any third-person description. We will never know "what it is like to be a bat" (or our own twin brother) even if we could know everything physical including all QCC in every detail. But this is not necessarily an ontological problem and therefore a dread for naturalism (taken as an ontology). Mental content just might be *irreducibly subjective* because of our sensory structure – we are systems with centered information acquisition – and specific "mineness" qualia as an effect of proprioception, creating a first-person perspective. This is an epistemological, not an ontological issue. Furthermore, as Michael Tye (1995) has shown, there is a fundamental ambiguity in our notion of "facts": Some facts depend on our familiarity with them, i.e. on sensory experience and the use of phenomenal concepts based upon this experience; and some facts are intersubjective and therefore independent from this kind of phenomenal experience. According to Tye, the difference may be the result of *two different modes of presentation*. It is an *epistemic* and *conceptual* difference, but not an *ontological* one. (Cf. also Pete Mandik's (2001) more recent account of the subjectivity of consciousness by explicating the ways in which mental representations may be perspectival. For another new approach to show how qualia might be causally effective and functionally relevant, see Llinás, 2001, cf. Vaas, 2001a).

The problem of other minds is obviously insurmountable: I cannot inspect the mind of other individuals, because I cannot log into their brains or minds or be part of them. I can only interpret their behavioral and maybe physiological actions and responses (including verbal reports). If they were zombies without inner experiences I would never know. If they were perfect actors or liars with quite different experiences I could not know either. Maybe I could detect contradictory physiological states, but to interpret them as contradictory, I still must compare them with some standard and need an argument why this very case is not just an exception to the rule.

Furthermore, maybe it is even self-deceiving to attribute something like "inner experiences" to others. Perhaps this is just an advantageous "intentional stance" to cope with their complex behavior or some sort of a linguistic illusion or a social construct (cf. Blackmore, 1999, Vaas, 2000a). Maybe it is self-deceptive to attribute "inner experiences" to myself, too. Studies of human development (which are admittedly controversial) give at least some hints that knowledge of one's own mental states is – contrary to common sense – *not* immediately given but as indirect as the knowledge of other minds: the infant must initially learn by inference from its own behavior and the behavior of others in which mental state it is (Gopnik, 1993). Furthermore, there is reason to believe that we are systems which permanently confuse themselves with their own self-model, as Thomas Metzinger (1999) has put it. In doing this, we generate an ego-illusion, which is stable, coherent, and cannot be transcended subjectively, i.e. on the level of conscious experience itself.

But I do not want to propose that consciousness is something which is nothing at all. For in this case we need not look out for QCC. Nevertheless, as e.g. research about the temporal structure of conscious events has shown (Vaas, 2001f), there is reason to believe that our mental states are not always transparent to ourselves. How could we know if the correlations we observe between quantum events and conscious events are not biased in a systematic, misguiding way?

14) Variations And Complexity

Another limitation to the detection of QCC might be interindividual differences in quantum physical structure and dynamics and intraindividual variations over of time. This is also true for NCC. Not even identical twins have identical brains. Individual variations are one of the most important restrictions of a generalization of functional brain-imaging techniques. Furthermore, they undermine a fine-grained, lawful one-to-one correspondence between neural and mental states: If it is possible at all that two persons are exactly in the same mental state at a given moment, this mental state obviously cannot depend on an exactly identical neural state even if we could neglect the environment (which of course we cannot). Thus, conscious states are neurally realizable in different ways.

Interindividual differences could be enormous in cases of developmental impairments and plastic reactions after that. For instance, there are quite normal people who are lacking big parts of their brain due to early childhood surgery. And in the case of hydrocephalus, an increase in the volume of the cerebrospinal fluid could stretch the cortex into a sheet of tissue only a few millimeters thick without damaging it and without impairing intelligence. In a computer tomography scan, the head of a hydrocephalus appears largely brainless.

Investigating the brain on the cellular and subcellular level, it is nearly impossible to get detailed maps of the neural networks and their activities and to handle their complexity. This is a major obstacle for the discovery of sufficiently precise NCC.

These problems of NCC might be easier for QCC since there could be a common underlying principle. Thus, intra- and interindividual variations would occur only at a higher level, at higher orders of magnitude but could share the same quantum basis, e.g. quantum computations via microtubules. This seems advantageous and promising. However, the problem is only shifted, not solved. For if QCC are really relevant they must also be relevant for explaining intra- and interindividual differences. But maybe this is asking too much, because such an attempt of an explanation seems to be – like explanations with NCC – simply too complex even to approach such issues. The QCC probably simply cannot be observed – due practical reasons regarding to NCC and in addition to that also not in principle regarding QCC (due to Heisenberg's uncertainty relation and decoherence). Nor can they be calculated practically due to the sheer complexity and, if Penrose (1989) is correct, also not even in principle.

15) Externalism For A Wider Perspective

Add to this that NCC and QCC cannot be caught by neuroscience alone because of the externalist content of representations (cf., e.g., Burge, 1986, Davidson, 1993, Davies, 1991, and Dretske, 1995) – or at least because of some externalistic components. Therefore, even identical brain states could correspond to different mental states if the environment was different. (But note that it is dangerous to talk about "identical brain states" on some quantum level, because Heisenberg's uncertainty principle gives limits to the notions of spatio-temporally and energetically identical states here.) One might say consciousness is not in the head, but this seems to be throwing the baby out with the bathwater. It is enough to recognize that consciousness is not only in the head (or depends not only on it). And that is because the brain (and mind) is not a closed system. Otherwise reference would be impossible and I would be trapped in total isolation or even have to assume that solipsism is true. Mental states heavily depend on information from the body, its ontogeny and phylogeny, its present and past physical and social environment. There is permanent interaction of an organism with its surroundings (Hurley, 1998), and it is not possible to individuate conscious states without taking these (past or present) interactions at least implicitly or tacitly into consideration. Even if I could study my own NCC with an autocerebroscope (Feigl, 1958, p. 456) together with introspection, by-passing the problem of other minds, my mental contents would still be dependent on external references including a public language. Hence, given that a form of externalism is true, consciousness cannot be reduced to brain states alone. (But of course this does not mean that it could not be ontologically reduced to physical states in general – externalism is a form of naturalism with a wider scope. Therefore, NCC are not *sufficient* for a naturalistic theory of mind.

Nor are they *necessary*, because of the possible existence of conscious artificial and extraterrestrial intelligences. Thus, due to its presumed multiple realizability (cf. Putnam, 1975), consciousness should be viewed not as a product of neural tissues only. This is of course no limitation to NCC research, though it restricts philosophical generalizations about the nature of consciousness. However, although multiple realizability may well rule out a general, uniform mind-matter reduction, it entails the possibility of locally reducing mental states to physical ones – and perhaps this is all the reduction we need or could want (cf. Kim, 1996, p. 234). Explanations, and hence reductions, are domain-relative.

The problem of multiple realizability also applies to QCC. However, externalism and an absence of sufficiency might not be a problem for QCC (or at least a weaker difficulty than for NCC), because according to quantum theory the entire world is quantum physical, and nonlocality reaches out arbitrarily far, at least in principle.

Furthermore, it is an open question which kind of reduction is possible (Vaas, 1995), and which levels of description, abstraction and generalization are most useful for philosophical purposes. Because of the orders of magnitude between the quantum scale and the level of neurons, neural networks, cortical areas, entire brains, organisms and societies, it is doubtful whether QCC are on the right level of explanation. But these restrictions do not imply QCC research is useless or irrelevant for philosophical reasoning. On the contrary, the investigation of NCC and QCC can strengthen or refute empirical arguments for one or the other position in our discussion about the relation between brain and mind and the nature of consciousness. For example, let's take the interactionistic dualism of the late Sir John Eccles, who was a winner of the Nobel prize for physiology in 1963, as a case study.

16) Quantum Manipulations And Ecclesian Selves

Sir John Eccles started brain research for religious reasons (Eccles, 1994a, p. 13, Popper and Eccles, 1977, p. 357) and presented probably the most elaborate neurophilosophical proposal for a place of interactionism in a Cartesian tradition, believing that mind is "independent" and "autonomous" from the world of matter-energy (Eccles, 1994a, p. 102 and 80). He developed his speculations on "the Self and its brain" from 1951 until recent years and claimed "to challenge and negate materialism and to reinstate the spiritual self as the controller of the brain" (Eccles, 1994a, p. X). It is important to recognize that he understood his account "as a hypothesis in Popperian scientific method" (Eccles, 1994a, p. IX; cf. Popper and Eccles, 1977, p. 375), and even saw "empirical evidence" for dualism (Eccles, 1987, pp. 295 ff); therefore Eccles also had to allow (and reckon with) the possibility of an empirical refutation (Vaas, 1997b, 1999b).

For Eccles, only minute fractions of the material world are associated with mental states (subjective experiences): the liaison-brains. It is here where the conscious mind grasps the neural activities like a searchlight, selects and modulates what it is interested in and integrates it into a unified experience. Eccles believes that there are special modules which are linked to the mind like radio transmitters and receivers (Popper and Eccles, 1977, ch. E7). These modules consist of what he called dendrons: a dendron is a composite made of the bunching of the apical dendrites of pyramidal cells found especially in neocortical lamina V. According to Eccles (1994a, p. 136), "each dendron is linked with a psychon, giving its own characteristic unitary experience". There are "forty million psychons for an estimated forty million dendrons of the human brain" (p. 88 and 98). So all mental events and experiences "are a composite of elemental or unitary mental events"; "each of these psychons is reciprocally linked in some unique manner to its dendron" (p. 87). Eccles continues tries to explain the mechanism of mind-brain interaction – for him: the interplay between psychons and dendrons – on the basis of quantum effects and (1994a, ch. 9). The mind becomes neurally effective by momentarily increasing the probabilities for exocytosis within an entire dendron without violating physical laws of conservation. This interaction takes place "at individual microsites, the presynaptic vesicular grids of the boutons" (p. 82). Mental influences "do no more than alter the probability of emission of a vesicle already in apposition" (p. 73); they change synaptic activities on the quantum mechanical level without violating the conservation of energy or momentum and are able to increase (the probability of) exocytosis by quantum tunneling. This holds not only for intentional acts, voluntary commands for instance, but also for attentional acts: Attention can "activate any selected parts of the neocortex at will" and can increase the frequency of the impulse discharges in the pyramidal cells of a dendron (p. 174); this dendron triggers the excitation of its associated psychon to give an increased experience of a sensation, e.g., pain; "conversely, if attention is concentrated elsewhere, there will be less activation of the dendrons of the nociceptive cortex and pain will be alleviated" (Eccles, 1994b, p. 17). "*[C]onsciousness is experienced in the brain where you evoke it by your attention*, which plays on selected areas of the cerebral cortex to give excitation. That excitation leads to amplified dendron responses to sensory inputs and so to psychon activations and consciousness. Superimposed on this simple attentional operation there would be a continuing dialogue between attention by the self and the selected neocortical areas with their sensory inputs" (Eccles, 1994a, p. 176).

Apart from the philosophical problems of ontological interactionism in general and Eccles' dualism in particular, this proposal also runs into empirical difficulties. Some of his proposals are already in contradiction with neurophysiological and neuropsychological findings (cf. Vaas 1999b). But what about the quantum mind-brain interaction hypothesis? Profound problems appear, which are also characteristic for other proposals (e.g. Hans Jonas, Henry Margenau) and thus shall be discussed here in some detail:

Exocytosis depends on large proteins, e.g. the formation of fusion pores (cf. Walch-Solimena, Jahn and Südhof, 1993, Weis and Scheller, 1998). It is unlikely that quantum effects can play a significant role here i.e. trigger configuration changes on the level of macromolecules. Heisenberg's well-known *uncertainty principle* states that the product of the uncertainty of the position (D x) of quantum physical objects, e.g. electrons, and the uncertainty of their momentum (D p), i.e. the product of their velocity and mass, is larger than or equal to Planck's constant divided by 4 pi (D x · D p = h/4pi). This means a radical departure from the principles of classical physics. The same is true for the uncertainty of energy and time (D E · D t = h/4pi). Under the known presynaptic conditions, Heisenberg's uncertainty principle works only for masses in the range of hydrogen atoms and for time scales in the femtosecond regime. It is by no means clear how such tiny quantum effects could trigger exocytosis i.e. could open the presynaptic and vesicle membrane. Even worse, if they really could, it is a mystery why these acausal events do not disrupt the neural activities and hence the organization of perception and behavior.

There is also a tension between mental causation and quantum physical indeterminism, i.e., acausality. Of course, Eccles needs the indeterministic and probabilistic nature of quantum effects to avoid violation of conservation laws. (For the sake of the argument, the indeterministic nature of the quantum world might be taken for granted here despite some other views still under discussion.) This loophole in the causal nexus of nature is necessary but *not sufficient* for interactionistic dualism. According to Eccles, the Self is able to change quantum probabilities (or select specific quantum states) and trigger neural activities in a goal-directed way. So not only must the Self fill causal gaps in nature with mindful interventions but it also needs some sort of nonphysical causal power – i.e., a new ontological type of causality – to explain the occurrence and efficacy of (self-)consciousness. But this implies a violation of the quantum mechanical probability distribution which is purely statistical (at least if there are no hidden variables).

Furthermore, there is the problem of physical laws of conservation despite Eccles' claims that the mind does not violate the first law of thermodynamics. In the interactionistic picture, the mind must exchange information with the brain, but the current state of physics either postulates a transformation of matter or energy along with information processing, or these events do not carry information at all. But even if such intended quantum effects do occur and do not violate conservation of energy because of Heisenberg's uncertainty principle $\Delta E \cdot \Delta t = h/4\pi$ (and would not decrease global entropy!), cortex activities actually do depend on large amounts of energy consumption, even during imagery and "pure" ideation, as scans with positron emission tomography and functional magnetic resonance imaging show. So why should and how could tiny quantum effects trigger the highest brain functions without any energy at all?

Even if they could, how does an Ecclesian Self manage to control the myriads of transmitter-releasing synaptic vesicles without totally disrupting or disorganizing perception, thinking and motor commands? This is the well-known problem of Jordan's amplification theory (Bünning 1935, 1943). Inspired by quantum mechanics, Pascal Jordan (1934, 1938) has developed a similar hypothesis to rescue free will earlier this century. And Eccles must postulate amplification (and explicitly does) because otherwise his hypothetical quantum effects would be ineffective.

Next, in calculating the amplification effects very precisely to avoid catastrophic disorganization and errors in perception and behavior, the Self must know more than even quantum mechanics allows (because of Heisenberg's uncertainty principle). And it must be a little Laplacean demon, computing infinitely fast, because the brain is a complex system showing strong nonlinear (or chaotic) dynamics at many different levels which cannot be predicted in practice (Jirsa and Vaas, 1995, Vaas, 1995).

Even if we would concede such extraordinary capabilities to a Cartesian Self, it must nevertheless act like a hidden variable behind the scenes of quantum processes. For it determines quantum effects in a nonrandom manner, i.e. acausality is just pretended. But this is in conflict with experiments on EPR correlations with suggest that quantum theory is complete, i.e. there are no hidden variables.

Furthermore, although indeterminism is required for Libertarian free will (in contrast to the much weaker compatibilist notion of free will), indeterminism is not sufficient – other features like intelligibility, freedom, and origination are necessary, too (Walter, 2001). *Intelligibility* means that a person's free choices are based on intelligible reasons. *Freedom* means that this person can make different choices under completely identical conditions, i.e. that this person could act otherwise even if all natural laws and boundary conditions (including his or her own physical states) are the same. *Origination* means that the person is able to create his or her choices and acts according to these choices in a nonphysical way. However, even this cannot avoid the dilemma of plunging into an *infinite regress* or abruptly step on the brake at a *mysterious causa sui*. This is because in order for me to be truly or ultimately responsible for how I am, so that I am truly responsible for what I want and do (at least in certain respects), something impossible has to be true: There has to be a starting point in the series of acts that made me have a certain nature – a beginning that constitutes an act of ultimate self-origination. But there is no such starting point. Therefore, even if I can act as I please, I can't please as I please. That is not to say that there are no higher-order volitions, for instance wanting to want not to stay that lazy anymore. But ultimately my reasons, beliefs and volitions are nonconsciously (or subconsciously) determined – by earlier experiences, heredity, physiology or external influences – and therefore not *ultimately* up to me. Therefore, and for reasons beyond the scope of this paper, such a

Libertarian form of free will is untenable and maybe even incoherent (cf. Vaas 1996, 2001c). And quantum physics with all the problems of the amplification process does not help either – it makes things even worse. There is a nice poem by Bernhard Hassenstein which illustrates this humorously [4]:

The Quantum or Pascual Jordan's Amplification Theory

A quantum travels through the town,

it seeks the brain of Mr. Brown.

There it discovers in the pool

of cells a special molecule.

John Brown was just deep in a jam:

"What kind of sandwich: cheese or ham?"

The quant – with self assertive trust –:

"You mean You will, but no: You must!

You never freedom will attain.

but I am free, can you constrain."

Electron "9" spoke: "Make me spring!"

The quant: "Be quiet! Let me think!"

The quant then chose electron "3"

And make it jump acausally.

As a result, then, Mr. Brown

did take the ham and gulped it down

and took the matter – what a thrill! –

As proof for freedom of the will.

The quantum, being shocked, expired,

by its free will from life retired.

17) Quantum Correlates And The Mind-Matter Problem

Despite the problems and shortcomings of QCC I have just reviewed, QCC are of some relevance and importance for the still rather notorious mind-body or mind-brain problem, which could be more precisely called the mind-matter problem, and for various philosophical issues, e.g., the nature of perception, representation, decision-making, action, consciousness and self-awareness (cf., e.g., Kim, 1996, and Rey, 1997, for an introduction into the mind-matter problem). Neuroscience, among other scientific disciplines, is now able to suggest experimentally constrained hypotheses of philosophical relevance. Philosophers cannot speculate fruitfully on these issues in ignorance of the data. On the other hand, neuroscience becomes necessarily more and more involved with philosophical issues. Therefore, a transdisciplinary teamwork is required. But it seems safe to say now, at least from a scientific point of view, that neuroscience – along with cognitive psychology, computational science, linguistics etc. – is the most promising candidate for bridging the mind-matter gap empirically. In that respect, QCC research is way behind. But a *conservative QCC approach* could participate in (or be parasitic on) NCC research – for if there are fine-grained NCC, say patterns of neural activity, it might be in principle possible to reduce them to a lower level at which quantum effects are relevant. Thus one might envisage an even more fine-grained level of description to explain neural activities based on quantum principles. A *radical QCC approach* on the other hand might skip NCC issues altogether by showing that consciousness states are directly related to quantum states, e.g. a super quantum potential. This seems to be science-fiction nowadays, but it is not disproven (and perhaps not even falsifiable). If such a radical QCC approach is true it nevertheless has to make intelligible why there are NCC (if there are NCC at all), why they are not nomologically related to QCC and why they are not explanatory sufficient or superior – issues which radical QCC proponents largely ignore.

It is unclear whether QCC are necessary for consciousness in general because it is unclear whether there are any ontologically and explanatory relevant correlations between quantum states and conscious states at all – except perhaps in the broad sense that matter and fields are necessary for consciousness and, as a matter of fact, have a quantum nature. Not every mind-body theory assumes that such a *minimal quantum materialism* is true. (So let us ignore here possible worlds without quantum physical features or laws., e.g. Newtonian worlds ruled by classical mechanics.) But for all of them who take minimal quantum materialism for true, e.g. naturalists and modern dualists, QCC are less threatened than NCC by the possibility of multiple realizability: If, e.g., robots could be conscious without a nervous system, they do not have NCC but, as material beings, they could still have QCC. However, it does not follow that same kinds of conscious beings necessarily share the different kinds of QCC. Thus, it is possible that some species (or even individuals) have one kind of QCC (e.g. quantum computation in microtubules) while others show a different kind of QCC (e.g. corticons), whereas both kinds of QCC might be sufficient and not reducible to each other. Thus, multiple realizability is still an issue for QCC.

QCC are compatible with very different proposals for a solution of the mind-brain problem. An existence of QCC could and would not prove that a version of the mind-brain identity theory is right, although this existence would be perfectly in harmony with it. But classical dualists would still argue that the correlates are just a consequence or a sign of the brain's interaction with an ontologically independent mind as renowned neuroscientists like Charles Sherrington, Wilder Penfield and John Eccles thought regarding NCC. A parallelism without interactions of quantum and conscious events in the style of Leibniz is still possible, too. And epiphenomenalism, which holds only a one-way influence from matter to mind but not vice versa, would not be falsified by the discoveries of QCC, either. Thus, one may subscribe to the existence of QCC and can still postulate that one dualism or another is true. This seems to be both advantageous (for dualists) and detrimental (for naturalists).

Of course these issues depend on our notion of causality. If for example interactionism is true, causality cannot solely be restricted to physical events like transfer of energy or momentum. On the contrary, a dualist has to postulate the existence of (up to) four qualitatively different cause-and-effect relations: interactions between physical events, interactions between mental events and, furthermore, physical-mental and mental-physical interactions. Parallelism requires the existence of two distinct sorts of causal relations (physical-physical and mental-mental interactions), and so does epiphenomenalism (physical-physical and physical-mental interactions). Naturalism and, perhaps, idealism, needs just one. If we subscribe to a Humean account of causality instead, a description of correlations is all there is. Therefore, the existence of QCC would be compatible with most of the positions regarding the mind-brain problem. (Of course any viable quantum theory of consciousness has to say something about causality – which is even more difficult in comparison to NCC issues because quantum theory questiones causality altogether.)

Please note: I do not say that all these positions are equally plausible. My claim is only that the existence of QCC *alone* cannot prove or disprove any of these positions. Thus, philosophical arguments are needed, and this is just one reason for the importance of some sort of quantum philosophy.

The existence of NCC restricts nomological and identity accounts for the mind-brain problem because of the already mentioned inter- and intraindividual variations and the externalist content of representations. We cannot strictly define identity conditions except by means of potentially infinite – or at least impracticably many – conjunctions. That is also true for NCC and one reason why the modern brain imaging techniques only show some more or less crude categories or types of consciousness (or contents of consciousness) like logical reasoning in the dorsal frontal cortex, different sensory modes for example in different parts of the occipital, temporal and parietal cortices, or memories of different syntactic forms in the temporal lobe – but not the actual content of the logical reasoning or the sensory experience or the words. Thus, strictly speaking, brain-reading will never turn into mind-reading.

Even if we could scan all the brain structures and neural events of an individual with any desired resolution and without destroying it (which seems to be practically impossible), we would still not know what kind of experience or thought this individual exactly had "in mind" at a given moment of time. And this is not only true because we were missing his or her environment and the relevant past and we cannot falsify strange possibilities like inverted or absent qualia, but also because of the chaotic, i.e., nonlinear dynamics of the neural events and the potentially holistic nature of mental contents. These restrictions are true both for NCC and QCC. But there are even more restrictions for QCC, namely Heisenberg's uncertainty principle and the problem of decoherence. Effective QCC must in some way be protected from decoherence. Usually, quantum macroscopic effects in only two kinds of cases: materials kept at ultra-cold temperatures, or quasi-isolated systems composed of a small number of particles. But the brain is warm and noisy (cf. Tegmark, 2000, and on the other side Hagan, Hameroff and Tuszynski, 2001, for a discussion). Furthermore, it remains unclear how quantum effects (e.g. within microtubules) can propagate outside of an individual cell, how quantum coherence could spread out in the brain across distances of the orders of millimetres and centimetres. Also there is no point of consciousness (or a Cartesian theatre, cf. Dennett, 1991) within the brain or elswhere, as it seems, but consciousness is distributed – probably over distances way beyond the quantum scale. A different approach is the search for a quantum-classical interface (i.e. a top-down solution) and the question whether "brains generate the kind of quantum entanglement necessary to the existence of minds" (Pereira, Jr. 2001).

But even if some kind of QCC could be established it would be nevertheless unlikely that we can ever predict mental activities by studying QCC. In this respect, NCC have much more predictive power and explanatory value, because they allow at least some broad kind of mind-reading, e.g. recognizing what kind of objects a person sees by analyzing the neural activity in his or her visual cortices.

18) Toward A Naturalistic Theory Of Mind

The discovery of QCC cannot establish a naturalistic theory of mind alone because of the already mentioned conceptual, empirical and ontological reasons. There is a variety of possible ontologies which are all consistent with the existence of QCC. This is not to say, however, that the discovery and study of QCC is irrelevant for consciousness research and philosophy of mind. It is always easy to construct weird, unfalsifiable metaphysical claims linking consciousness to some spooky angel dust, free-floating ghosts, sentient particles or even blood pressure. As long as there is no empirical evidence, nobody needs to take such strange speculations seriously. It should be evident that proponents of such speculations, not the opponents, have the burden of proof, because they are unfalsifiable. And it is quite wise to apply Occam's razor here – i.e., the principle of ontological parsimony.

In any case, there are some more or less robust neurophysiological correlations of mental activities which provide a better understanding of these mental events. And a lesson of lesions is that there are necessary neurophysiological conditions for the whole range of – at least human – (expressions of) mental events like seeing colors, remembering concepts or planning actions. These are necessary conditions at least if one is not willing to subscribe to idealism or to the view that the mind is still intact behind the stage of a damaged brain like an inaudible chatter behind a broken loud-speaker. Therefore, there are some good arguments for NCC. But these are no reasons for (or against) QCC.

However, pointing to NCC or QCC is not sufficient for a naturalistic theory of mind. Thus, philosophical arguments are needed. Naturalism (sometimes – and somewhat misleadingly – also called physicalism or materialism) requires at least a form of supervenience and a further condition. Supervenience or a version of mind-brain identity theory alone is not sufficient.

An identity theory is not sufficient because it does not say what kind of ontological entity there is. If mental states are (identical with) physical states, one could still choose the varieties of idealism, ontologically reducing matter to mind via identification and not vice versa. Even some neurophilosophers from the camp of radical constructivism seem to get (perhaps not intentionally) into the neighborhood of solipsism which is a kind of idealism. An identity theory is also compatible with neutral monism, ontologically reducing mind and matter to a third "substance", for example, *logos* (Heraclitus), *God* (Baruch de Spinoza), *elements* (Ernst Mach), *the absolute* (Friedrich Wilhelm Schelling), *energy* (Wilhelm Ostwald), *sensibilia* (Bertrand Russell), or an entangled indivisible unity of mental and physical aspects, for instance, panpsychism, hylozoism and panpsychistic identism, (some Presocratics, Giordano Bruno, Denis Diderot, Bernhard Rensch). Thus, we need another condition for a naturalistic theory of mind, e.g., a form of supervenience. Another reason for that is to exclude the possibility that two different mental states (tokens) are realized by or identical with one specific physical state (token).

The central intuition of supervenience is that "fixing" the physical fixes everything, or that nothing could have been otherwise without something physical having been otherwise. Supervenience holds that for every mental change there must occur a (simultaneous or preceding) physical change. Or, to be more precise, a set of mental properties supervenes on a set of physical properties if and only if any two persons that are indiscernible with respect to their physical properties are also indiscernible with respect to their mental properties, i.e., if any two persons that differ with respect to some mental property also differ with respect to at least one physical property. This is still a crude definition because one must clarify the scope of supervenience (cf. Beckermann, 1992): Does it hold in every possible world or even between possible worlds? Is it global or local? If externalism is true we cannot restrict the supervenience of mental events to neural (or bodily) events only, because identical neural events could have different contents in different environments. Thus, local supervenience seems to be too narrow and strong. On the other hand, global supervenience is much too broad and weak, because it does not seem plausible that every physical property within the scope of a person's relativistic light cone is relevant for the mental properties of that person. I do not assume for example that my mental states supervene on the properties of the thunderstorms in Jupiter's atmosphere or an interaction between two hydrogen atoms in the Large Magellanic Cloud at this very moment. Of course, this weak or global form of supervenience does not imply such crazy possibilities, but this example indicates that something must be added or specified. Furthermore, supervenience alone is not sufficient for naturalism and hence a naturalistic theory of mind, because it is also compatible with epiphenomenalism, parallelism and occasionalism. Thus, we need an identity theory for a naturalistic theory of mind to exclude such a dualism, or at least a principle of physical exhaustion. However, as John Haugeland (1984, p. 119) has argued, it might be enough to get rid of "scientifically unmotivated, magically undetectable, and thoroughly bizarre" hypotheses by shifting the burdens of proof to the proponents of those hypotheses and accepting the heuristic rule "Don't get weird beyond necessity".

19) Closing Remarks

As it seems, we are irreversibly expelled from the paradise or nightmare of classical Newtonian physics. Which of the many ways physicists, neuroscientists and philosophers will and should try to proceed in order to solve the mysteries of consciousness and quantum physics will ultimately turn out to be successful is not clear – if sufficient success is possible at all and whether we are not just, as a matter of fact and contingency, cognitively too restricted to solve such questions (cf. McGuinn, 1999). It is even still not clear what the right questions are, and what might count as a type of answer which we could accept as appropriate.

Perhaps many of our contemporary philosophical discussions reach dead-ends while quantum physics – and also neuroscience – proceeds. It is already striking that most of the current debates refer to quantum mechanics and not to the more recent and advanced quantum field theory. And there is plenty of reason to assume that both are not the last word due to the incompatibility of quantum theory and general relativity. Thus a quantum theory of gravitation (which needs not to be the final theory of everything!), e.g. superstring or M-theory, might solve some of the present difficulties – at least regarding quantum theory (measurement problem, nonlocality, realism). Whether there is also anything to learn about consciousness or QCC in a narrow, more interesting sense, remains to be seen.

Future physics like Penrose's (1994) "objective reduction" or changes within the formalism as, e.g., in the explicit collapse models (Ghirardi, Pearle and Rimini, 1990) are of course an ambivalent issue. On the one hand we might shift all our hopes and postulates onto it; but then we are liable to building nothing but philosophical castles into the air or wasting our time. On the other hand we might quarrel endlessly about QCC as long as there are no more known concrete physical and neurophysiological constraints; but then all philosophical speculation approaches shadow-boxing. This is an uncomfortable situation. – However, as it seems, not everybody is unlucky about that, because such a confused landscape is a fruitful ground for quantum crackpots. That is a difficult issue for serious researches and philosophers, because the line between speculative reasoning and getting bogged down is not a sharp one – not even in terms of Heisenberg's uncertainty relation. Therefore, the question is not just whether our ideas are crazy enough to cope with an adequate description of a crazy universe, but also where to stop before going mad. Thus, a sceptical attitude should be maintained and pushed ahead. Specific, explanatory powerful quantum correlates of consciousness are fine, if they exist and if we manage to discover them, but they are not enough to solve all the problems related both with quantum theory and with consciousness.

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Notes

[1] My translation from the German original: "Gar manches rechnet Erich schon / Mit seiner Wellenfunktion. / Nur wissen möcht man gerne wohl, / Was man sich dabei vorstell'n soll."

[2] "Beruhigungsphilosophie" (Albert Einstein in a letter to Erwin Schrödinger, May 1928).

[3] "Es ist einigermaßen hart zu sehen, daß wir uns immer noch im Stadium der Wickelkinder befinden" (Albert Einstein in a letter to Erwin Schrödinger, written on December 22, 1950).

[4] I thank Bernhard Hassenstein for the permission to quote his poem. It was read in German 1944 at a conference in Göttingen on Pascual Jordan's amplification theory and soon admired by many physicists, e.g. Max Planck. The translation is by Richard H. Beyler, Bernhard and Helma Hassenstein from 1994. In the original, Mr. Brown was Mr. von Korf, who is a famous character in many poems of Christian Morgenstern. In German, the poem reads as follows: "Das Wirkungsquant oder: Die Verstärkertheorie // Ein Wirkungsquant fliegt durch das Dorf. / Es sucht das Hirn des Herrn von Korf. / Es findet dort in dem Gewühl / Ein ganz bestimmtes Molekül. / Von Korf ist grad in schwerer Not: / "Eß' Wurst- ich oder Käsebrot?" / Das Quant, das wirft sich in die Brust: / "Du glaubst, du willst! Allein: Du mußt! / Nie kannst die Freiheit du erringen. / Doch ich bin frei und kann dich zwingen!" / Elektron "9" sprach: "Spring' mich doch!" / Das Quant: "Ich überleg' mir's noch." / Dann hat durch es Elektron "8" / 'nen akausalen Sprung gemacht. / Von

Korf nahm daraufhin spontan / Die Wurst und fing zu essen an / Und nahm die Sache ganz im Stillen / Dann als Beweis für freien Willen. / Dem Quant hat das den Rest gegeben: / Frei-willig schied es aus dem Leben."

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