Can quantum mechanics solve the hard problem of consciousness?

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Abstract

The hard problem of consciousness is the problem of explaining how and why physical processes give rise to consciousness (Chalmers 1995). Regardless of many attempts to solve the problem, there is still no commonly agreed solution. It is thus very likely that some radically new ideas are required if we are to make any progress. In this paper we turn to quantum theory to find out whether it has anything to offer in our attempts to understand the place of mind and conscious experience in nature. In particular we will be focusing on the ontological interpretation of quantum theory proposed by Bohm and Hiley (1987, 1993), its further development by Hiley (Hiley and

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Callaghan 2012; Hiley, Dennis and de Gosson 2021), and its philosophical interpretation by Pylkkänen (2007, 2020).

The ontological interpretation makes the radical proposal that quantum reality includes a new type of potential energy which contains active information. This proposal, if correct, constitutes a major change in our notion of matter. We are used to having in physics only mechanical concepts, such as position, momentum and force. Our intuition that it is not possible to understand how and why physical processes can give rise to consciousness is partly the result of our assuming that physical processes (including neurophysiological processes) are always mechanical. If, however, we are willing to change our view of physical reality by allowing non-mechanical, organic and holistic concepts such as active information to play a fundamental role, this, we argue, makes it possible to understand the relationship between physical and mental processes in a new way. It might even be a step toward solving the hard problem.

1 Introduction

In our earlier work on mind, matter and quantum theory we have explored and further developed different aspects of David Bohm's (1917-1992) pioneering efforts in this field: analogies between quantum processes and thought[1]; the idea that matter and conscious experience have their ground in a new holistic and dynamic "implicate" order (or "holomovement") that is beyond space and time[2]; and the idea that Bohm's 1952 "causal interpretation" of quantum theory ("the Bohm interpretation", "the ontological interpretation", "hidden variable" interpretation) can be understood in terms of a model where a new type of field containing active information literally informs (rather than pushes and pulls mechanically) the particle or corpuscle that it accompanies.[3] It is tempting to see such active information at the quantum level as providing the long-sought missing link between the mental and physical sides of reality, and perhaps even as a protophenomenal property of living organisms from which conscious experience in a full sense may

[1]Bohm 1951; Pylkkänen 2014.

[2]Bohm 1980; Hiley 1996; Hiley and Pylkkänen 2001; Pylkkänen 2007.

[3]Bohm and Hiley 1987, 1993; Bohm 1990; Pylkkänen 1992; Hiley 2004; Hiley and Pylkkänen 2005, Pylkkänen 2020.

emerge in suitable conditions.

In this paper we first revisit the hard problem of consciousness, review the Bohm-Hiley ontological interpretation and the the role of active information, consider its relevance to understanding consciousness before briefly discussing the notion of implicate order. We then move on to discuss some new developments introduced by Hiley and Callaghan (2012) and Hiley, Dennis and de Gosson (2021) that illuminate the deeper mathematical and physical background of quantum mechanics. What emerges is a more subtle view of quantum objects that is likely to have implications for all attempts to apply quantum mechanics to the mind-matter problem.

2 The hard problem of consciousness and our notion of the physical

The hard problem of consciousness is the problem of explaining how and why physical processes give rise to consciousness (Chalmers 1995). In a recent article, Chalmers (2020b: 223) notes that one has to take materialism seriously in order to take the hard problem seriously as a problem:

> If one is antecedently a dualist, the hard problem will be unsurprising and not especially worth addressing. The mental and the physical are fundamentally distinct, and that is that. One might like to know how they interact, but that leads us to other aspects of the mind-problem such as the interaction problem. The problem of explaining the mental in physical terms does not really arise.

There have been many attempts to solve the hard problem since Chalmers invigorated it in 1994, but he has not been impressed by these, writing in 2010:

> There have been many neurobiological and cognitive models of consciousness, but few of them have been offered as a solution to the hard problem, and when they have, hardly anyone has been convinced. [...] That being said, positive nonreductive theories of consciousness have not had a much easier time of it.

What does it mean to take materialism seriously? It does not necessarily require that one believes that materialism is correct, but one certainly has to feel the pull of materialism. The history of science shows that explanations in terms of physical laws and mechanisms have been very successful in physics and biology. Given that there is clearly a close correlation between mental, conscious phenomena and neurophysiological phenomena in the brain, is it not the most obvious and natural thing to assume that conscious, mental processes are neurophysiological processes - or at least somehow emergent from them? Yet as is well known there are a number of plausible anti-materialist arguments to the effect that we have *no idea* how subjective qualitative conscious experiences could possibly arise from objective, neurophysiological processes (see Levine 2017).

Given that the hard problem is to explain how and why physical processes give rise to consciousness, it might seem obvious that a rigorous scientific and philosophical approach to the question has to consider what "physical" and "consciousness" mean in the light of our best scientific and philosophical theories. Regarding the "physical", would not this require that we give serious attention to what physics has to say about the physical? While this may seem obvious, if one considers the discussions of the hard problem in the philosophical and cognitive neuroscience literature, it is fairly common to completely ignore our best physics, namely quantum theory and relativity, and the theories that build upon them. The reasons for this ignoring are complex, and have partly to do with the difficulties of finding a coherent interpretation of quantum theory. However, as long as we do not tackle the "physical" in the light of our best scientific theories, can we be said to be taking materialism seriously and approaching the hard problem in a truly scientific way?

One of the main challenges underlying our research has been precisely to try to understand the fundamental changes quantum theory and relativity require to our view of the physical world. Our perspective to these issues has been inspired in particular by David Bohm's pioneering efforts. While Bohm worked on different approaches to quantum theory, he was never satisfied with the prevailing instrumentalist tendency to see quantum theory merely as a mathematical tool to predict the results of measurement, but was always trying to develop models of quantum reality which do not presuppose the existence of a classical level or measuring apparatuses. This makes Bohm's various approaches particularly suitable for anyone who is concerned with finding the place of mind and conscious experience in nature. The conventional or "Copenhagen" interpretation of quantum theory gave up early the attempt to provide a model of quantum objects, and thus it has little to say about the nature of reality at the quantum level, and thus about how consciousness might relate to fundamental physical reality.

3 Bohm's discovery of a quantum ontology

In our research we have on the one hand explored Bohm's ontological (hidden variable, causal) interpretation of quantum theory, which he initially proposed in 1952 and developed further since the mid-1970s with one of us (Bohm 1952; Bohm and Hiley 1987, 1993). On the other hand we have explored a more general approach, a new "implicate order" framework in which one can begin to bring together quantum theory and relativity, which Bohm and Hiley began to develop in the early 1960s.

Is there anything in these approaches that might be relevant to tackling the hard problem of consciousness? We have suggested that there is. When Bohm and Hiley began to re-examine Bohm's 1952 interpretation in the mid-1970s, they soon came up with a radical proposal. As is well known, the Bohm interpretation postulates that a particle (say an electron) is not a particle OR a field (as in the conventional interpretation of quantum theory), but it is always a particle AND a field. The field guides the particle through a new potential, the quantum potential, and in this way one can give an intelligible explanation of many puzzling quantum phenomena, such as the two-slit experiment, tunnelling, the measurement problem etc. (see Bohm and Hiley 1987, 1993).

To understand why the Bohm interpretation is relevant to understanding the mind and even conscious experience, let us consider it in some detail (for more extensive presentations see Bohm and Hiley 1987, 1993 and for more recent work see Hiley and Callaghan 2012 and Hiley, Dennis and de Gosson 2021). Bohm had published in 1951 a text-book *Quantum theory*, in which one of his main aims was to provide a more physical interpretation of the conventional "Copenhagen" interpretation, to complement the mathematical formulation. Bohm's book contains many philosophically important ideas, for example the idea that a quantum object should be understood as consisting of mutually incompatible potentialities before interactions with systems such as measuring apparatuses. After completing the book Bohm still felt that something was incomplete or missing in the conventional interpretation, namely an account of what happens to quantum objects between measurements, an account of actual movement. Discussions with Einstein in Princeton further prompted him to seek a realistic and deterministic account of quantum reality.

When thinking about the problem Bohm considered the WKB approximation, which is used to show how quantum theory gives rise to classical mechanics. What happens in the WKB approximation is that one writes the wave function in polar form, substitutes this to the Schrödinger equation and obtains an equation that looks very much like a formulation of classical mechanics, the Hamilton-Jacobi equation, except that there appears an extra term which we denote by Q which looks like some form of potential energy.

To show how this works mathematically, we first express the wave function in polar form $\psi(\mathbf{r},t) = R(\mathbf{r},t)\exp[iS(\mathbf{r},t)/\hbar]$

Here R and S are two physically real fields that describe the time evolution of the energy that constitutes the particle. To see how this works we substitute this expression into the Schrödinger equation and then separating the real and imaginary parts of the resulting equation, we find that the real part gives

$$\frac{\partial S}{\partial t} + \frac{1}{2m}\nabla S^2 + V + Q = 0. \tag{1}$$

This equation, which is an expression for the conservation of energy, would be identical to the single classical particle Hamilton-Jacobi equation except that there is the extra term Q, which is a quantum energy term, taking the form

$$Q = -\frac{\hbar^2}{2m}\frac{\nabla^2 R}{R} \tag{2}$$

In the WKB approximation if one now assumes that this extra term goes to zero (e.g. by assuming counterfactually that h is zero), one gets classical mechanics out of quantum mechanics. In classical mechanics each particle has well defined position and momentum, so that we have a particle ontology. But, Bohm asked, what happens if we do not assume that Q is zero? After all, h is a constant so it cannot actually go to zero. Could we still have an ontology, albeit a different, quantum ontology? The answer is yes. Q has the dimensions of energy, so it is natural to interpret it as an additional potential acting on the particle, alongside the classical potential V.

Indeed, it is the term Q which produces a behaviour in the particle that distinguishes it from a classical particle. Those unfamiliar with the Hamilton-Jacobi theory will more easily recognise the following formula:

$$\frac{dp}{dt} = -\nabla[V + Q], \tag{3}$$

which is just Newton's equation of motion with an additional potential, Q, which is called the quantum potential.

It is well known that Newton's equation produces particle trajectories in the classical case as does the Hamilton-Jacobi equation. This implies that even in the quantum domain we can still regard every particle as having a well-defined position and momentum giving rise to a trajectory even though we are unable to measure position and momentum simultaneously. In order to produce the quantum behaviour the 'particle' must be accompanied by the R, S coupled field, $\psi(\mathbf{r}, t)$, which satisfies the Schrödinger equation. Thus Bohm's quantum ontology for non-relativistic particle quantum mechanics is not just a particle ontology, it is a particle AND field ontology; it is the field which gives rise to the quantum potential. Indeed quantum trajectories can be (and have been) calculated for many different situations, including the classic two-slit interference experiment (see Bohm and Hiley 1993 and Oriols and Mompart eds 2019 for more details).

Because of the uncertainty principle we cannot observe the trajectory of a single quantum object directly as long as we remain in the domain in which quantum mechanics is valid. So the idea that a single quantum object moves along a trajectory ought to be seen as a hypothesis which has not been empirically verified. However, by making use of measurements of weak values it is possible to measure average trajectories (see Flack and Hiley 2018).

Importantly, Bohm's interpretation also provides a way of thinking about when we should use quantum mechanics, and when classical mechanics is sufficient to provide a good approximate description. The quantum potential is negligibly small in conditions where Newtonian mechanics works for all practical purposes (see Bohm and Hiley 1993, ch8).

4 The quantum potential and active information

Now, in what sense might the Bohm interpretation be relevant to understanding the place of mind and even conscious experience in nature? One philosophically interesting point is that the quantum potential only depends on the *form* (second spatial derivative) of the quantum field, R, since

$$Q = -\frac{\hbar^2}{2m}\frac{\nabla^2 R}{R} \tag{4}$$

After reflecting upon and debating this feature, Bohm and Hiley (1987) proposed that what is going on is that the field enfolds *information* about the environment of the particle (e.g. the precise nature of the slits) and is organizing its behaviour by literally IN-FORMING or putting form into its movement, rather than pushing and pulling it mechanically, an example of 'formative' causation. This notion is reminiscent of Kant's discussion of phoronomy (see Stan 2021 for details), later taken up by Einstein (1924) in discussing the shift in the perihelion Mercury that has its explanation in general relativity, a shift that has the same origins as the more familiar Coriolis force.

An example of formative causation is the notion of "active information" - something that is operative in many other contexts. The basic idea of active information is that a form having very little energy enters into and directs a much greater energy. In this process the activity of the greater energy is given a form similar to that of the smaller energy.

We can give a useful analogy by recalling that in radio transmission the audio signal modulates the profile of the high frequency carrier wave. Here the audio energy can be quite small, but its form can be amplified to produce a large effect in the radio itself. By analogy the small energy in the quantum wave can be magnified by some as yet unknown internal process so as to produce a large effect on the particle.

As another example, think about a ship guided by radar waves which contain information about the environment of the ship (e.g. rocks at the bottom of the sea). The radar waves are not pushing and pulling the ship. They have a small energy that in-forms the greater energy of the ship.

The computer is another obvious example where we see information being active in this way. Here information is carried in the chip and all of this information is passive until the appropriate software activates some of the information. Thus when the computer is working, some of this 'passive' information becomes 'active', modifying the input by giving it new form. Hence in the computer there is a continual interplay between passive and active information.

It is interesting to note that Feynman once proposed that every point of space is like a computer processing incoming information and outputting new information (see Finkelstein 1969). For our approach to non-relativistic quantum mechanics, it is the particle that processes the information although in field theory (which we discuss later) our approach is very similar to the kind of structure Feynman had in mind. In the case of the computer, the significance of the information is decided by outside human activity both in terms of the software we use and the type of information that is stored in the chip.

Artificial neural networks provide another example. In this case the network learns how to function by receiving information from some external source and adjusting its weights e.g. as a result of backpropagation to produce a relevant output. Once that information has been stored in the net, it then remains passive until the net is activated. Neural nets do not need quantum mechanics in order to function, being essentially based on the Ising model. However this model is itself a classical approximation to a fully quantum version known as the Heisenberg model. It seems clear that the Heisenberg model will have properties that are different from those of the classical model, but what is not clear is whether the properties of the Heisenberg model will have features that will be of direct relevance to artificial neural networks.[4]

It would be more convincing to have an example where there is no direct human intervention, and here we have also used DNA as an analogy. In this case, the genetic code can be regarded as the passive information that has accumulated over the years through the process of evolution. It was not put there by human beings (although this need no longer be the case.) Parts of this code can be accessed by RNA which carries the information to the

[4]Pylkkänen (1992: 116) discusses briefly in a qualitative way how insight could be instantiated by a quantum neural network. For a discussion of learning in a quantum neurocomputer (including a critical discussion of the idea of active information) see Chrisley 1996.

appropriate part of the cell where the information can become active in the sense that the processes in the cell change to allow it to develop in a new and meaningful way. Here we see how passive information becomes active under appropriate conditions.

Connected to this, Anita Goel (2008) has studied molecular machines that read and write information into molecules of DNA. She writes:

> These nanomotors (matter) transduce chemical free energy into mechanical work as they copy biological information stored in a DNA molecule. These motors can be thought of as information processing machines that use information in their environment to evolve or adapt the way they read out DNA. In ways (as of yet unknown to us), information from their environment can couple into and modulate the dynamics of these nanomachines as they replicate or transcribe genetic information.

Indeed, she has suggested that quantum mechanics may play a role in influencing the motors as they read/write bits of DNA and suggested to us that it is worth exploring whether the notion of active information at the quantum level might be relevant here (private communication, January 2020).

While we have above emphasized that information is an objective commodity that exists and acts independently of the human mind, it is obvious that active information also plays a role in human subjective experience. For example, when reading a map, the information contained in the map typically gives rise to virtual activities (e.g. possible routes) in the mind, and one of these is typically realised as an actual movement in the territory, depending on where one wants to go.

5 The Quantum Potential as an Essential Feature of Kinematics

As the idea that the quantum potential contains active information is likely to meet with skepticism, let us look at it in more detail. Firstly, what exactly is the role played by the quantum potential Q that appears in equation (1)? A simple but naive way to think about this term is to regard it as generating a force in a similar way as the classical potential V generates forces. However there is a vital difference between the two potentials. V arises from some external field and can be considered as the effect of an external force driving the particle is some way. In contrast, the quantum potential has no external source, but is an internal feature of the kinematic process and so should not be regarded as a driving force. In this sense it can be regarded as a 'formative' cause.

To begin to understand the role of the quantum potential energy, it is important to think of it as a new quality of energy, which is not present in the classical domain. To see the reason for this, let us look at equation (1) written in words

$$\text{Kinetic energy} + \text{ quantum PE} + \text{classical PE} = \text{total energy.}$$

where PE stands for potential energy. Clearly this is simply a conservation of energy equation as we are considering a closed system. Since the total energy is fixed, any change in the motion of the particle comes from a re-distribution of energy between the kinetic energy, the quantum potential energy and the classical external energy. We can also think of this as involving a new process where there is a redistribution of internal energy between the kinetic energy and the quantum potential energy, a process that does not occur in classical mechanics.

In a situation where interference is involved, the kinetic energy of the particle gives up some of its energy to the quantum potential energy, the amount and form of which is conditioned by the experimental environment as Bohr 1961 insisted. This may seem a strange, new idea, but it emerges from the Schrödinger equation itself, with no new mathematical content added. The kinetic energy term in equation (1) uses the Bohm momentum which, as we have argued, is the weak value of the momentum. Thus the kinetic energy term must be the weak value of the kinetic energy (see Hiley 2012.) This redistribution can be regarded as a kind of self-organisation involving in the whole process.

The form dependence of the quantum potential energy also helps us to understand why this energy can produce significant effects over large distances. The quantum wave of a particle typically spreads out over a greater and greater distance, so that its amplitude decreases suggesting the energy becomes more spread out. Had the force depended on the amplitude, then it would necessarily decrease with distance, but since the mathematical form of the quantum potential shows that it does not depend on the amplitude, the resultant effect remains regardless of the distance. As we have already emphasized, it depends on the *form* of the quantum wave. This is yet another reason for asserting that it is not meaningful to talk about the quantum potential as generating a force. Thus it is possible to have very long range quantum effects and even non-local effects of the type required to account for the situation described by the Einstein-Podolsky-Rosen (1935) paradox. That gravitational energy is non-local, has long been known in general relativity, especially in gravitational waves (see Bondi, van der Burg and Metzner 1962 and Penrose and Rindler 1984).

We can take these arguments one stage further. If we consider the quantum potential in particular cases, for example, in the two-slit experiment, a detailed examination of the mathematical form of the quantum potential energy shows that it contains information about the momentum of the particle, the width of the slits and how far they are apart. That is, the energy carries information of the *whole experimental arrangement*. We can regard this information as being *active* in the sense that it modifies the behaviour of the particle. As we remarked above Bohr 1961 came to a similar conclusion, but from a very different point of view. He saw the necessity of talking about the *wholeness of the quantum phenomenon*. He writes:

> As a more appropriate way of expression I advocate the application of the word *phenomenon* exclusively to refer to the observations obtained under specified circumstances, including the *whole experimental arrangement*.

For Bohr such *wholeness* implied that the quantum process could not be analysed even in principle, but the Bohm interpretation shows that analysis is possible and by carrying out this analysis, we can provide a different way of understanding what is meant by *quantum wholeness* (for Bohr's view, see Bohm and Hiley 1993, ch 2.2; Pylkkänen 2015).

It was the above types of considerations that led us to the suggestion that the quantum potential should be considered as an *information potential*. Not only does the quantum potential carry information about the experimental set up, but, more importantly, it induces a change of form from within the system itself. It is in this more general sense that we can regard the quantum potential as an information potential. In making this suggestion, we were strongly influenced by the etymological roots of the word 'information'. In its simplest form to in-form literally means to form from within. As Miller (1987) writes:

> As with many words in the English language, the word "information" has both Greek and Latin roots. The Latin informatio bears direct and obvious structural similarities to our modern "information". The prefix (in) is equivalent to the English "in", "within", or "into"; the suffix (ito) denotes action or process and is used to construct nouns of action. The central stem (forma) carries the primary meaning of visible form, outward appearance, shape or outline. So informo (or informare) signifies the action of forming, fashioning or bringing a certain shape or order into something, and informatio is the noun from which signifies the "formation" thus arrived at.

In other words this information can be either active or passive. Interestingly, one of the most prominent contemporary theories of consciousness, Tononi et al.'s (2016) integrated information theory (IIT) similarly understand information as in-forming, albeit in a different sense. Quantum active information has holistic features which provide a new type of integration which may well be relevant to the kind of unity we find in conscious experience (see Pylkkänen 2016).[5]

[5]Both Tononi and Bohm use the concept of information in a way different than it is used in communication theory. For Tononi, information refers to how a system of mechanisms in a state, through its cause-effect power, gives rise to a form ("informs" a conceptual structure) in the space of possibilities. Such in-forming is needed to account for the fact that consciousness is specific: each experience is the particular way it is - it is composed of a specific set of specific phenomenological distinctions, thereby differing from other possible experiences (Tononi calls this differentiation). For Bohm active information refers to situations when a form (carrying a little energy) enters and literally in-forms a larger energy. He further says (modifying Bateson's definition) that information is a difference of form that makes a difference of content. We have above considered situations where information in-forms the motion of matter, but we can also apply this to perception. For example, when we are accounting for visual experiences, we can say that the form carried by light waves is taken up by the eye and the brain, and that this process involving differences of form results in rich differences of content in our phenomenal experience. Thus the specific structure of the content of our phenomenal visual experiences is partly informed by the form carried by the movement of the light waves that was the input. So active information plays a role in making each phenomenal experience into the specific experience that it is. There is thus an interesting similarity between our and Tononi's schemes,

6 Information and meaning

A concept closely associated with information is that of meaning. To connect these concepts in a novel way Bohm suggested that an important aspect of meaning is the activity, virtual or actual, that flows out of information. An example of "virtual activity" can be seen by considering a situation where we are reading a map, and all sorts of possible routes arise in our subjective experience of imagination. These are the virtual inward activities that the information contained in the map gives rise to in us. Depending on the context, one of these may be selected and becomes the actual external activity (see Bohm 1989). In this situation, the information in the map is information for us.

However, the information carried by the quantum field is clearly not information for us, it is information for the electron and as such is objective. If we assume that meaning is activity of information, then there is a sense in which meaning is involved, at least in an elementary sense, in the behaviour of a quantum particle:

> in the quantum theory, the quantum potential may ... be regarded as representing active information ... In accordance with the suggestion that meaning is the activity, virtual or actual, that flows out of such information, we are led to regard the movements of the self-active particles as the meaning of this information. (Bohm 1989: 58)

Since meaning is involved, we are not using the word "information" in the sense of Shannon 1948. According to Shannon, the information content for the word "coming" as calculated using the expression $H = \sum p_i \ln p_i$ is exactly the same as the word "gnmioc", but one is meaningful and the other is not. The quantum potential always has a kind of meaning for its particle, although it might not have meaning for other particles at the same location.

Floridi (2015) distinguishes between environmental and semantic information; and semantic information can be further distinguished into factual and instructional information. Environmental information is information as mere

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although there are subtle differences. We will discuss Bohm's notion of information in more detail later in sections 6 and 8.

correlation, e.g. the way tree rings carry information about age. The quantum active information can be seen as environmental in the sense that the form of the quantum field is correlated with the environment (e.g. whether or not two slits are open in a two-slit experiment). But we can also say that the quantum active information is *about* something (the environment, slits, etc.), it is *for* the particle and it helps to *bring about* something (a certain movement of the particle). This suggests that it is semantic and has both factual and instructional aspects (cf. Floridi 2015). We note here that Dretske (1981) and Barwise and Seligman (1997) have explored the possibility that information in the sense of factual semantic contents (i.e. information as meaningful data that represents facts correctly or incorrectly) can be grounded in environmental information (i.e. information as mere correlation, e.g. the way tree rings carry information about age).

7 The organic unity of the quantum many-body system

So far we have just considered the case of a single particle, but the notion of active information takes on a new and potentially more significant meaning in a many-body system. Consider a situation in which we have two sets of particles, A and B. Suppose system A is described by a non-product, or "entangled" wave function $\Psi_A(\boldsymbol{r}_1, \boldsymbol{r}_2, ...\boldsymbol{r}_n, t)$ which will produce a quantum potential $Q_A(\boldsymbol{r}_1, \boldsymbol{r}_2, ...\boldsymbol{r}_n, t)$ that couples all the particles of A into a coherent group, while the B group of particles are linked by a different quantum potential $Q_B(\boldsymbol{r}'_1, \boldsymbol{r}'_2, ...\boldsymbol{r}'_n, t)$ which arises from a different non-product wave function$\Psi_B(\boldsymbol{r}'_1, \boldsymbol{r}'_2, ...\boldsymbol{r}'_n, t)$. This implies that we have two independent groups of particles, each group being co-ordinated into some kind of coherent unit where each particle of the group responds *only* to the co-ordinated movement of the rest of the particles in its own group.

To help understand this co-ordinated movement we have likened the group behaviour to ballet dancers whose movements are co-ordinated, not by direct mechanical forces, but rather each individual is responding to a common theme. In the case of the ballet, each dancer responds to the musical score as it develops in time. Thus in the analogy the wave function provides the "score" to which the particles respond. The two independent wave functions correspond in the analogy to two sets of dancers following their own theme. Here the form of the movement in each group can be regarded as unfolding from within and the energy that is needed to bring about these changes is provided by the individuals themselves. Although the analogy has obvious weaknesses, it nevertheless highlights the radical difference between classical forces and the type of effect generated by the quantum potential.

One can see why attempts to continue to regard the quantum potential as producing another kind of mechanical force will fail by considering the two sets of particles discussed above. Members of the two groups can be in the same region of space and provided they have no classical forces between them, they will not experience the quantum potential of the other group. The quantum potential for each group is somehow a 'private' experience for only that group. There is no mechanical way of bringing about such behaviour.[6]

Since the group behaviour is something that is intrinsic to that particular group of particles and to no others, it seems, once again, as if there were some kind of self-organisation involved, but a self-organisation that is shaped by the environment and mediated by the quantum potential. Thus the system behaves as a *whole* or a *totality* in such a way that the particles appear to be nonlocally linked. This radical approach suggests that nature at its very fundamental level is more *organic* than expected. We will return discuss the connection between quantum mechanics and life further in section 12.

8 Meaning organizes matter

Traditional mechanistic materialism - which still prevails as the underlying paradigm of much of natural sciences and mind sciences alike - assumes that everything that exists can be reduced to basic material elements (particles and fields) and their mechanical interactions. By saying that information exists objectively (independently of the human mind) and plays an active organizing role at different levels of nature, we are proposing that we should radically change our world view. Instead of saying that everything is fundamentally matter and energy, we follow Bohm in suggesting that reality is one process which has two sides, a somatic, material/energetic side and a significant, meaningful side (Bohm called this idea the principle of soma-

[6]This example is related to the metaphysical question of whether quantum objects are individuals, see Pylkkänen, Hiley and Pättiniemi 2016.

significance). This implies we can treat any process either as somatic or as significant. So we are leaving traditional mechanistic materialism behind, and move toward a version of dual-aspect monism (see Atmanspacher 2014). Bohm (1986b: 38) describes this view succinctly in an interview with Renee Weber:

> A very elementary case is the printed paper: it's somatic in that it is just printed ink; and it also has significance. ... any part of the body or body processes is somatic, it's the nerves moving chemically and physically; and in addition it has a meaning which is active. The essential point about intelligence is the activity of significance, right? In computers, we have begun to imitate that to some extent. ...all of nature is organized according to the activity of significance. This, however, can be conceived somatically in a more subtle form of matter which, in turn is organized by a still more subtle form of significance. So in that way every level is both somatic and significant.

So for example, when reading a newspaper, light waves (which are somatic) carry the significance contained in the printed ink toward the reader. When the light hits the retina, the information is abstracted and carried by the more subtle somatic processes of the brain until the meaning of the information is apprehended at some even more subtle somatic level of the brain. This example illustrates the significance of the soma, the idea being that each somatic configuration has a meaning (at least potentially) and that it is such meaning that is grasped at more subtle levels of soma. Bohm calls this the soma-significant relation. But there is also an inverse, signa-somatic relation: "This is the other side of the same process in which every meaning at a given level is seen *actively* to affect the soma at a more manifest level" (Bohm 2003: 163). This needs some qualification, for if we consider the significance carried by printed ink, it does not directly affect the soma; it is only when the significance is interpreted by the more subtle levels in the reader that there may be a signa-somatic effect. While much of information is naturally active in the sense that the significance affects the soma (e.g. information in the DNA molecule), there exists also as a special case passive information (e.g. printed ink), which needs to be interpreted by a suitable system before its meaning becomes active.

The above can be clarified by further considering the notion of information. Gregory Bateson said that information is a difference that makes a difference. Bohm noted that this is too liberal because every difference makes a difference. To restrict the notion he proposed the following characterization: information is a difference of form that makes a difference of content (Bohm 1989). In this sense form and content are two interrelated aspects of one process. Information is thus not mere form.

The point here is similar to the one John Searle (1980) made with his famous Chinese room thought experiment, which can be described (in a simplified form) as follows. There is a monolingual English speaker in a room, and she is given batches of Chinese writing. She has a rule book written in English telling her that when a certain set of symbols comes in, she is to pass another set of of symbols out of the room. The differences in the forms she receives make no difference of content to her. In other words, she is producing answers by manipulating uninterpreted formal symbols. Searle's point was that such manipulation of forms without understanding what those forms mean does not constitute true understanding. As computers process forms in the same way as the person in the Chinese room, computers do not understand anything, although they appear to give meaningful responses.

Our radical hypothesis is that there exist some informational processes in nature taking place without human intervention, which involve both form and content (this is the basic idea of soma-significance). And not only that. The content is not merely an abstract, ethereal quality, it has causal powers in that it can act to organize material processes at lower levels. Or as we already mentioned above, meaning includes the activity - virtual or actual - which information gives rise to. The activity often unfolds or reveals the meaning, as in the case where something means "danger" and there is a signa-somatic response in the body. Our human experience of meaning is thus not unique, but a highly developed instance of a fundamental feature of the universe. The information in the quantum potential has a primitive content which is active, just as information in the DNA molecule has in suitable circumstances.

We underline the importance of the quantum information potential here. It suggests that at a very fundamental level of nature something at least analogous to meaning or content plays a causal, organizing role. The Bohmian electron where a field of information is guiding a particle-like entity can be seen as a *prototype model* which defines a whole class of similar systems, similarly to the way the Watt governor does for the dynamical systems theory (Pylkkänen 1999; cf. van Gelder 1997). We usually assume that meaning cannot play a genuine causal role, because we assume that physics is fundamental and there is no room for such a role of meaning in physics. However, the quantum potential, when seen as an information potential, is a counterexample to this assumption. If you like, this may be one of the best ways of seeing how quantum theory calls into question an entire world view, namely the mechanistic world view. This is why it is so important.

Bohm's favourite example to illustrate a signa-somatic effect was to consider a person who is walking in a park in a dark night, and has heard that a dangerous assailant may be moving about in the area. Suddenly, he sees a suspicious looking shadow. If he interprets that as "the assailant" this signifies "danger", which will typically give rise to a powerful somatic reaction in the body of the person (e.g. adrenalin will flow). If the person then realizes that he is seeing just a shadow of a tree, he will start to calm down. As another example, think of how you would react if someone comes into a room full of people shouting "fire" and you judge this to be correct. In these situations, significance or meaning is not merely an abstract, passive quality, it is fundamentally active in organizing more manifest material levels of the body. And Bohm's proposal is that all of nature is organized according to such activity of significance, from the way information in the DNA molecule organizes biological process, all the way down to the quantum level, where information contained in the quantum potential signa-somatically guides the activity of, say, an electron. This suggests a radical change in the way we are thinking about physical processes and their relation to information and meaning.

Now, to say that all of nature is organized according to the activity of significance, and that such active information applies even at the quantum level may be radical and interesting, but is it relevant to the hard problem of consciousness?

9 The mind-like quantum

Bohm sketched a new theory of mind and matter based on the notions of soma-significance and active information and discussed it extensively with one of us (PP) from the mid-1980s till the early 1990s (see Bohm and

Pylkkänen 1991). In the first formulation (1986a) he wrote "...in some sense, a rudimentary consciousness is present even at the level of particle physics." In a later version of the same article (1990) he qualified this by saying: "...the quantum theory, which is now basic, implies that the particles of physics have certain primitive mind-like qualities which are not possible in terms of Newtonian concepts (though, of course, they do not have consciousness)". To say that a rudimentary consciousness is present even at the level of particle physics is to endorse panpsychism. To say that particles of physics have certain primitive mind-like qualities but that they do not have consciousness is compatible with a weaker doctrine, panprotopsychism. As David Chalmers (2015: 259) puts it

> ...panprotopsychism is the view that fundamental physical entities are proto-conscious. In more detail, let us say that protophenomenal properties are special properties that are not phenomenal (there is nothing it is like to have a single protophenomenal property) but that can collectively constitute phenomenal properties, perhaps when arranged in the right structure. Panprotopsychism is then the view that some fundamental physical entities have protophenomenal properties.

While both panpsychism and panprotopsychism are likely to sound implausible, or even absurd in the context of the prevailing mechanistic materialism, the failure of mechanistic materialism to tackle the hard problem has led more and more researchers to consider pan(proto)psychism as one of the approaches worth pursuing if we are ever to solve the hard problem (see Seager 2020).

To connect our approach to panprotopsychism, we could say that active information at the quantum level has protophenomenal properties. There is nothing it is like to be a single electron; but when electrons and other elementary particles and fields are arranged in the right hierarchical structure (e.g. that of the human brain), phenomenal properties in a full sense emerge from the underlying protophenomenal ground (for discussions of the relation of panpsychism to active information at the quantum level, see Pylkkänen 1995, 2020; see also Skrbina 2005: 202-6.) This would be similar to David Chalmers's own very interesting attempt to solve the hard problem, namely his double-aspect theory of information which he summarizes as follows:

> ...information (or at least some information) has two basic aspects, a physical aspect and a phenomenal aspect. This has the status of a basic principle that might underlie and explain the emergence of experience from the physical. Experience arises by virtue of its status as one aspect of information, when the other aspect is found embodied in physical processing.

One trouble with Chalmers' proposal which he himself realized was that his double-aspect principle may be too liberal. There is information in a thermostat - is a thermostat therefore conscious? Many of us would say "obviously not", which undermines the plausibility of Chalmers' proposal. It is not likely that all information has a phenomenal aspect. As far as we know, only certain biological organisms are conscious and can be conscious of the world and their internal states. For those who are seeking a physicalist explanation of consciousness it is thus a reasonable hypothesis to make that some processes that (at least currently) only take place in living organisms are responsible for consciousness - both for the fact that the organism is conscious (rather than unconscious) and the fact that the organism is conscious of some information and not conscious of some other information.

We agree with Chalmers that it is a good intuition that information (and its meaning) is connected to consciousness. However, rather than saying that information has a phenomenal aspect, let us say that the meaning of information has the potentiality of becoming the content of the consciousness of a system. The hard problem then is to say what it is that makes such potentially conscious information into actually conscious information. And assuming that currently only living organisms are conscious, there then is something in living organisms (but not in other systems) which enables them to be conscious of information.

A further advantage of connecting our approach to Chalmers's double-aspect theory of information is that while Chalmers's theory suffers from epiphenomenalism, our scheme, when modified, opens up the possibility of a genuine causal efficacy of phenomenal properties upon the physical domain (see Pylkkänen 2007: 244-7; Pylkkänen 2017; see also Hiley and Pylkkänen 2005). Also, Chalmers himself has suggested that it is an interesting possibility that some sort of activity is required for experience, and that static information (e.g. information in a thermostat in a constant state) thus is not likely to have experience associated with it (1996: 298). If we say that (proto)phenomenal properties are always properties of some kind of active information, we could do justice to the intuition that activity is required for experience.

In the soma-significance scheme we sketched above, it is natural to say that consciousness comes in only at the more subtle soma-significant levels. It seems obvious that a typical soma-significant process (such as reading a newspaper) starts unconsciously, and consciousness only appears at some stage when the significance is consciously experienced, then perhaps giving rise to a signa-somatic response, depending on the meaning of the information (e.g., as we saw, if the meaning is "danger", this typically gives rise to a powerful signa-somatic response). But what is it that makes this non-conscious soma-significant process conscious? This is the hard problem in the scheme of soma-significance. What we have said thus far is that consciousness comes in at the more subtle levels of soma-significance - perhaps when a certain subtle level is related in a suitable way to a more manifest level (this would be a version of a higher-order theory of consciousness, see e.g. Rosenthal 1997 and Gennaro 2012).

But what do we mean by subtle? Quantum mechanics can here give some insight. As we proposed above, the Bohmian model of the electron can be seen as a prototype model of a coupling between a subtle aspect (the quantum field described by the wave function) and a more manifest aspect (the corpuscle or particle aspect of the electron). The subtle aspect enfolds information about the environment of the particle, and then signa-somatically organizes the movement of the particle. We are not saying that the electron is conscious, but we could say that conscious experience arises in a hierachical relationship between a more manifest and a more subtle level, which is analogous to the relation between the quantum field and the particle.

Indeed, it seems obvious that our conscious mental processes involve a hierarchy of levels of active information. We do not merely think about objects in the external world, but we can also become aware of our thinking. Bohm suggested that such meta-level awareness typically gives rise to a new, higher level of information. This higher level gathers information about the lower level. But because its essential nature is active information, it does not merely make a passive representation of the lower level. Rather, the higher level also acts to organize the lower level, a bit analogously to the way the active information in the quantum potential acts to organize the movement of the particle. And of course, we can become aware of this higher level of information from a yet higher level, and so on. So we have a hierarchy of levels of information in the mind. At some point in this hierarchy conscious experience appears. In the quantum model we have considered thus far there are just two levels, the particle and the field. To connect the mental hierarchy to the physical world, is there any way we could find a quantum model which also has a hierarchy of levels of information?

We have thus far discussed the quantum particle theory, but note that the Bohm model can easily be extended to fields (for more details see Bohm and Hiley (1993)). One important feature is that this field theory can be naturally extended into a hierarchy of levels, each containing active information. Let us thus next consider the Bohm model of the quantum field theory.

10 Extension to quantum field theory

The field, $\phi(\boldsymbol{r}, t)$, and its conjugate momentum, $\pi(\boldsymbol{r}, t)$, replace the position and momentum as beables. These field quantities would then be the appropriate variables that are to be identified with the relevant fields functioning in the brain. These fields would be organised by a generalisation of the wave function, namely, the wave functional of the field, $\Psi(\phi(\boldsymbol{r}, t))$, which we will call the superwave function. The time evolution of this superwave function is described by a super-Schrödinger wave equation

$$i\frac{\partial \Psi(\phi(\boldsymbol{r}, t))}{\partial t} = H(\phi(\boldsymbol{r}, t), \pi(\boldsymbol{r}, t))\Psi(\phi(\boldsymbol{r}, t)), \tag{5}$$

The correspondence between field theory and the particle theory is as follows:-

$$\boldsymbol{r} \longleftrightarrow \phi(\boldsymbol{r}, t) \qquad \boldsymbol{p} \longleftrightarrow \pi(\boldsymbol{r}, t) \qquad \left(= \frac{\delta L}{\delta \dot{\phi}}\right)$$

$$\psi(\boldsymbol{r}, t) \longleftrightarrow \Psi(\phi(\boldsymbol{r}, t))$$

$$\frac{\partial S}{\partial t} + \frac{(\nabla S)^2}{2m} + V + Q = 0 \longleftrightarrow \frac{\partial S}{\partial t} + \frac{1}{2}\int [(\frac{\delta S}{\delta \phi})^2 + (\nabla \phi)^2] d^3 r + SQ = 0$$

$$Q = -\frac{1}{2m}\frac{\nabla^2 S}{R} \longleftrightarrow SQ = -\frac{1}{2}\int \frac{\delta^2 R}{(\delta \phi)^2} d^3 r$$

Here we find there is a super-quantum potential, SQ, that organises the field through a Hamilton-Jacobi field equation.

Since these equations have the same form as those describing particles, all the qualitative ideas discussed above for the particle model apply equally to quantum fields. However this provides a much richer structure and is far more appropriate for discussing the mind/brain relationship.

One directly significant feature is the emergence of a hierarchy of levels. To motivate this discussion, it should be recalled that in field theory, these fields, $\phi(\boldsymbol{r}, t)$, in turn affect the particles (which are themselves manifestations of these fields) through the quantum potential so that we have two levels operating, one at the particle level and the other at the field level. As far as these ideas have been applied to physical processes to date, only two levels seem necessary. However our theory has within it the possibility of a third, fourth and yet higher levels, producing a rich hierarchy, each level generating subtle effects in the level below.

This structure frees us from all traces of the original mechanical starting point of the quantum particle theory. For example, the particles themselves are merely semi-autonomous manifestations of the fields which can be created and annihilated and are organised by a "pool of information" that is contained in the superwave function and mediated by the super-quantum potential. Thus even the particles themselves are but discrete manifestations of the quantum fields.

We have above suggested that mental processes typically involve a hierarchy, and we just saw that the Bohm model of quantum field theory can be naturally extended into a hierarchy of fields. How are these two hierarchies related? Bohm (1990) proposed that they are the same hierarchy, which provides us with one schematic way of understanding how mind and matter are related. "Matter" corresponds to the more manifest levels, while "mind" refers to the more subtle levels, but each level has both a somatic and a significant aspect.

11 Consciousness and the hierarchy of quantum fields of information

We can now make the following speculative hypothesis: conscious experience only arises in the context of a hierarchy of levels of information which involves the activity of quantum fields. This does not mean that all information in the brain would be carried by quantum fields. On the contrary, it is likely that a great deal of information in the brain is carried by more stable structures (e.g. neural activity patterns) that for all practical purposes can be described by classical physics. But, we are proposing, the conscious apprehension of the meaning of such "classical" information involves the operation of quantum fields. We are assuming that conscious experience is not possible in a situation where non-trivial quantum effects are negligible.

What is it that makes non-conscious information become conscious information in this scheme? We propose that the best possibility is to make use of some version of higher order theories of consciousness to explain why a given soma-significant level is conscious. For example, we could say that what makes information at a given level conscious is that it is the intentional target of (typically) unconscious information at a more subtle quantum mechanical or quantum-like level. It is important to assume that the information at a more subtle level can be unconscious, otherwise we get into an infinite regress (cf. Rosenthal 1997).

But there are other possible accounts for what makes non-conscious information conscious. We have already suggested that one way to tackle the hard problem in our scheme is to make use of Chalmers's idea that experience is an aspect of (some kind of) information; for example information that is held in suitably subtle somatic levels in the brains of some biological organisms, in conditions where subtle quantum effects can survive as it were (cf. Hameroff and Penrose 2014). Alternatively, we could apply some aspects of Tononi et al.'s (2016) integrated information theory of consciousness to Bohmian active information. Active information at the quantum level is holistic in the way that is likely to have a high value of phi which in Tononi's theory measures the degree of consciousness. Or finally, we could consider whether a Bohmian many-body quantum potential can be seen as a kind of global workspace in the spirit of Baars's (2017) global workspace theory of consciousness.

12 Life, consciousness and quantum mechanics

As we have already hinted above, one important aspect with conscious experience is that it seems to be intrinsically related to the living state of matter, for it is (thus far) only with certain biological organisms that we find conscious experience with some certainty. Creating various artificial information processing systems with our current technology does not seem to enable conscious experience to appear. But what is it about living (as opposed to non-living) systems that enables conscious experience?

We suggest that this has to do with quantum mechanics. We saw above that the many-body system in the ontological interpretation of quantum theory exhibits a kind of organic unity that is very reminiscent of the organic unity of living organisms. Taking a step toward quantum biology, could it be that a necessary condition for a material system to be a living system is that it has a non-negligible quantum potential (or some higher level quantum-like potential) operating within it, providing its organic unity? And could it be that (currently) only certain biological organisms provide the kinds of conditions in which the kind of hierarchy of levels involving quantum fields which according to our proposal enables conscious experience can arise? Quantum mechanics would thus play a crucial role in making both life and consciousness possible. To put it simply: where there are non-trivial quantum effects operative, there can be life, and where there is life, there can be consciousness.

Given that consciousness only appears in living organisms, when searching for the physical preconditions of consciousness it would then be interesting to find processes that only take place in the conditions of the living state of matter, but which disappear or become negligibly small in the non-living state (e.g. in physical systems, such as thermostats, that operate at the macroscopic domain of non-living matter that can be approximately described by Newtonian physics). So for our hypothesis it would be useful to find non-trivial quantum processes that only operate in those conditions where we find consciousness but become negligible in conditions where consciousness is not present.

What is extremely interesting in this context is that Bohm and Hiley's ontological interpretation of quantum theory provides us with a prototype model of quantum information which is active in some conditions but has a negligible effect in other conditions. We pointed out above that the quantum potential is negligibly small in the domain where classical physics provides a good approximation, but has a significant effect in the quantum domain. We can now proceed to make the following speculative hypothesis: consciousness in biological organisms has to do with the non-negligible, non-trivial operation of quantum active information in the brain. It is only when there exists such quantum information in a suitable biological environment that there can be conscious experience. This immediately restricts consciousness to biological organisms, at least as far as the present moment is concerned.

However, the hypothesis also opens up, in principle, the possibility of artificial consciousness. If we knew the relevant structures and processes in biological organisms which make possible for there to operate a non-negligible quantum potential, it is possible in principle that we could replicate them in an artificial system. But if life essentially involves the organic unity characteristic of the quantum potential, then such system might also be a genuinely living system, albeit artificially manufactured. In this hypothesis, the quantum potential accounts for both life and phenomenal properties.

Indeed, one of the advantages of the Bohm approach is precisely that it provides us with an elegant account of the relation between the quantum level and the classical level, which is notoriously difficult to deal with in the usual interpretation of quantum theory. So insofar as a thermostat operates at the classical level, the quantum potential (and the (proto)phenomenal properties) have a negligible effect, and we need not say that a thermostat has (proto)phenomenal properties or that it is conscious. There is information in the thermostat, but it is not the holistic active information that we meet at the quantum level, but rather a more mechanistic information at the classical level. So although such mechanistic information (e.g. printed ink) can carry significance, it is only in situations where the quantum potential plays a non-negligible role in biological organisms that such significance can be consciously experienced. In our approach thus not all information has protophenomenal properties.

In this paper our discussion has been largely at the general, philosophical level, and we have not considered in detail the possible "quantum sites" in the brain, where a non-neglibigle quantum potential (or a hierarchy of quantum fields) could play a non-negligible role. However, there are currently a number of more concrete proposals to which we can connect our approach, for example Vitiello and Freeman's work on quantum field theory of brain states, Beck and Eccles's work on quantum mechanics at the synaptic cleft and Penrose and Hameroff's work on quantum gravity and microtubuli (for a review and references, see Atmanspacher 2020). We propose that when these approaches are viewed from the perspective of our approach, they can become richer and more relevant to the mind-matter issue, because of the new possibilities opened up by the novel notions of levels of active information and quantum wholeness in our approach.

13 From panpsychism to cosmopsychism

The proposal that the particles of physics have certain primitive mind-like qualities may sound like a "quantized" version of traditional pan(proto)psychism However, quantum phenomena exhibit some holistic features which suggest a novel way to approach the combination problem of panpsychism, namely the problem of giving an account of how the primitive consciousness of the elements of a system could possibly combine into the full consciousness of the system. The combination problem presupposes what Atmanspacher (2014) calls a compositional approach, i.e., explaining the properties of the whole in terms of its parts. However, there are quite generally instances in quantum theory where the whole is prior to parts (cf. Schaffer 2010).

For example, in Bohm and Hiley's ontological interpretation of the many-body system, the behavior of individual particles cannot be understood in terms of their spatial relationships only, but we need to consider the quantum state of the whole system. So we do not explain the behavior of the whole in a bottom-up way in terms of the behavior of the parts, but we rather explain the behavior of the parts in a top-down way partly in terms of the properties of the whole (cf. Aharonov et al. 2018). More precisely, as we saw above, the particles in a Bohm-Hiley many-body quantum system are guided by a "common pool" of information enfolded in the many-body quantum potential that cannot be reduced to the "private pools" of individual particles. On the contrary, the whole is prior to the parts in the sense that these private pools arise from the common pool in certain circumstances through factorization. Thus, a key issue is to give an account how the whole decomposes into parts, as opposed to the parts combining to constitute the whole.

To summarize, our scheme has a panprotopsychist flavor in that we postulate that elementary particles have mind-like qualities, when the quantum potential for a particle is non-negligible. However, our emphasis on the priority of the whole goes against the spirit of the bottom-up way of explaining consciousness characteristic of traditional panpsychism.

Now consider the entire universe in the light of the Bohm-Hiley interpretation with its idea that active information (a proto-mental quality) is fundamental. It is suggested that the universe is a process which is in some sense simultaneously proto-mental and physical. This view would be called cosmoprotopsychism in the contemporary literature (cf. Chalmers 2020a). What about cosmopsychism? Is there any sense in which the universe as a whole with such dual aspect properties might be said to be conscious - or is conscious experience restricted to certain individual biological organisms, or at most collectives of them, as our folk psychology would have it? While most of us might take it to be obvious that the universe as a whole is not conscious, Bohm had a somewhat different view, as revealed in his discussion with the American philosopher Renee Weber (Weber ed. 1986: 95):

> Bohm: Hegel took the view that thought was fundamental and that nature was mind showing itself to itself. Marx turned that upside down and said matter is fundamental and consciousness is matter showing itself to itself. Or you could take the view that neither matter nor mind is fundamental, but something unknown, which you could call a deeper or implicate ground. It is this view which I'm inclined toward.
>
> Weber: Is that ground self-aware?
>
> Bohm: Yes. I would say, since it contains both matter and mind, it would have in some sense to be aware. Let's say it's in the direction of mind, but beyond it. It's not below it, but above it.

Of course, to say that the ground of the universe is "in some sense aware" is not yet to say that the ground is conscious; for example, it may be conscious only in virtue of containing or enfolding all the minds and conscious experiences of all mental systems, but does not have a separate consciousness of its own. Such idea of enfoldment leads us to briefly discuss the notion of implicate or enfolded order in the next section.

14 The Implicate Order and Consciousness

We have discussed above the new possibilities opened up by the Bohm and Hiley ontological interpretation of quantum theory, which develops Bohm's 1952 theory, generalising the original proposals so as to include spin and special relativity. This approach introduces some radically new ideas, such as the idea that material particles respond to information, and that the particles themselves are manifestations of a deeper structure. However, there is a sense in which traditional materialism is still retained. For example we assume an independently existent 3-dimensional space *containing* the material particles which constitute material objects, such as tables, chairs and brains. This framework leads us to treat space-time and the material particles and fields as separately existing fundamental entities, while mental states and conscious experience are features that need to be explained in terms of matter. Yet a deeper reflection of quantum and relativity physics suggests that perhaps we should not take space-time as fundamental but abstract its properties from some deeper structure process as suggested by Bohm (1965) and more recently by Penrose (1991).

In the early 1960s Bohm's attention shifted from the causal interpretation to a more general and fundamental approach in which one could bring together quantum theory and general relativity. This approach introduced the notion of structure process, which Bohm developed during a long correspondence with the American artist Charles Biederman and became known as the implicate order (see Pylkkänen ed. 1999). The implicate order involves a radical change in our entire concept of reality, which also has profound implications to our attempts to understand the place of mind and conscious experience in nature.

To begin to understand this radical outlook, Bohm noted that in physics the basic order has traditionally been that of the Cartesian rectilinear grid, a description that is suitable for the analysis of the world into separately existent parts (e.g. independent particles or fields in interaction). Indeed, such analysis has been the key aspect of science since the Newtonian revolution. Yet, Bohm realized that both relativity and quantum theory emphasized, not separately existent parts-in-interaction, but rather an undivided wholeness. This suggests that underlying our usual reality of objects in space-time (the Cartesian or "explicate" order) there exists a deeper reality (the holomovement) in which unbroken wholeness prevails (the "implicate" order).

The implicate order cannot reveal all aspects of reality simultaneously in one unique explicate order, rather specific partial orders can be revealed, for example in different experimental situations. These partial views reveal different complementary explicate orders so that complementarity becomes ontological, not epistemological. In this way the implicate order prevails in a whole range of phenomena, including biological and psychological phenomena.

The basic idea of the implicate order is that each region of space and time contains a total structure or total order *enfolded within it*. This is illustrated by the fact that the movement of light waves in a small region of a room contain information about the entire room; and more radically, when you look at the night sky, the movement of light waves in the region where your eye is placed contains information about structures covering immense stretches of space and time.

Such distinction between explicate and implicate is also crucial in our lives as human beings. Our body and brain live in the explicate order of space and time. But it is not so obvious that our mental and conscious processes can be thought of as existing *in* space and time. To be sure, many of our experiences, especially sensory experiences involve the explicate order. Even when we dream we can find ourselves in a 3-dimensional environment, so it is obvious that the brain can, as it were, simulate a 3-dimensional reality, a kind of virtual reality which we then consciously experience in our dreams. Many cognitive neuroscientists suggest that even when we are awake, the brain is constructing a simulation of virtual reality. But unlike during dreams, this awake virtual reality is driven by the senses, and we instinctively take it to be the real world.

The notion of implicate order is useful when trying to understand how the brain constructs this 3-dimensional virtual reality of consciousness. One useful analogy here is holography. Indeed, Karl Pribram suggested in 1971 that the brain stores information in a somewhat holographic fashion. Just as in holography we are able to produce 3-dimensional images from a complex interference pattern, Pribram thought that the brain reconstructs images through a mechanism that resembles holography (Pribram 1977:162) . Holography exemplifies the implicate order in the sense that each region of the holographic plate enfolds information about the whole illuminated object. In other words, in a hologram a total structure is enfolded in each region, which is a key feature of the implicate order. Bohm (1980: 160) described the change between an illuminated object and its hologram as a *metamorphosis* rather than as a transformation. Similarly, we can propose that the change between information as it is stored in the brain and the phenomenal experience that arises from the information is a kind of metamorphosis. It may well be worthwhile to try to describe this metamorphosis mathematically (as an example, see the mathematical description of metamorphosis connected to the hologram given by Bohm 1980:160). The challenge is to move from the implicate order of the information stored in the brain into the explicate order of our phenomenal experience which contains phenomenal objects with qualia (e.g. colours, sounds) situated in a spatio-temporal structure. In terms of our notion of information, we can say that the differences of form in the information stored in the brain make a difference of phenomenal content which we consciously experience.

There is, however, much in our conscious experience that is not obviously and fundamentally spatial. Think about your thoughts and emotions, the sense of flow in your stream of consciousness. Language clearly is an implicate order in the sense that the meanings of words enfold each other. Philosophers have emphasized that a kind of unity is a key characteristics of conscious experiences, so might there be an aspect of conscious experience that lives at the level of the implicate order rather than the explicate order? Bohm certainly thought so, and suggested that we can understand some key aspects of conscious experience (such as time consciousness e.g. when listening to music) in terms of the implicate order.

We will not describe this approach in detail here, but point out that our research programme does not take the existence of a physical world of particles and field elements in 3-dimensional space as fundamental, but rather sees these as manifestations from a deeper level of reality. This may obviously affect the way we understand and approach problems in philosophy of mind and consciousness studies. To understand these problems it may be necessary to take this deeper level of reality into account. Thus instead of asking how can the physical processes in 3D space possibly give rise to conscious experiences (the usual hard problem), we can ask whether conscious experiences arise in the broader context which takes into account the enfolded or implicate ground from which ordinary matter constantly unfolds (for further discussion see Pylkkänen 2007).

That the universe contains much more than known matter in space and time is also suggested by Bohm's discussion of zero point energy:

> "the mathematics of the ... quantum theory ... treats the particle as ... the quantized state of the field, that is, as a field spread over space but in some mysterious way with a quantum of energy. Now each wave in the field has a certain quantum of energy proportional to its frequency. And if you take the electromagnetic field, for example, in empty space, every wave has what is called a zero point energy below which it cannot go, even when there is no energy available. If you were to add up all the waves in any region of empty space you would find that they have an infinite amount of energy because an infinite number of waves are possible. However, you may have reason to suppose that the energy may not be infinite, that maybe you cannot keep on adding waves that are shorter and shorter, each contributing to the energy. There may be some shortest possible wave, and then the total number of waves would be finite and the energy would also be finite." (Bohm 1986:27)

Bohm then suggests that general relativity implies that the shortest possible wavelength is about 10^{-33} cm.

> "If you then compute the energy that would be in space, with that shortest possible wave length, then it turns out that the energy in one cubic centimeter would be immensely beyond the total energy of all the known matter in the universe". (Bohm 1986: 28)

This again implies that the world view of mechanistic materialism gives a very limited picture of the universe.

15 What is Quantum Mechanics?

We have above given a short summary of our previous work on the Bohm theory, active information and connections to the mind and conscious experience but what has this to do with quantum mechanics? In the last few years one of us (BJH) has been exploring a different mathematical approach to quantum phenomena (Hiley 2016) which does not depend on the Cartesian order; rather it emphasises the algebraic structures defined by the dynamical variables. It involves no wave functions as all the information normally contained in the wave function is already present in the algebra itself in certain of elements of the left ideals. Using these techniques we can arrive at the equations of the Bohm interpretation in a very different way so there is no need to start with the Schrödinger equation.

This suggests that we should *not* automatically give primary relevance to the Schrödinger picture with its emphasis on the wave function as many mathematically equivalent alternatives are possible. Indeed, as we have already pointed out above, the Stone-von Neumann theorem states that the Schrödinger approach is only one of many unitarily equivalent pictures. These alternatives give very different physical insights into the nature of quantum phenomena.

Our focus in the rest of the paper is to try to bring out this different approach to quantum phenomena in a way that we hope will be relevant to future efforts attempting to tackle the mind-matter problem.

We believe the obsession with the wave function by giving it ontological status has hindered the wider application of the deep and significant changes needed to think about reality. One should realise that von Neumann himself already noted the shortcomings of giving the wave function a primary role. In a letter to Birkhoff he writes (1935), "I would like to make a confession which may seem immoral: I do not believe absolutely in Hilbert space any more". Why? Because: "the vectors ought to represent the physical states, but they do it redundantly, up to a complex factor, only". But there is a further more fundamental reason in that there are situations where probability cannot be defined because the wave function cannot be defined (See Rédei 1996). In spite of this unease and the many resulting paradoxes that this assumption encounters, we have learnt to live with the ambiguity in the wave function and the problem of probability, but in building any ontology on such an assumption, one should proceed with caution.

Using the Schrödinger picture as described above tends to hide the subtle features of the underlying non-commutative algebraic structure. There is another picture that places the operators centre stage by making them time dependent; this is the Heisenberg picture. This picture has its use almost exclusively in high energy physics, a picture that is rarely raised in discussions on the foundations of quantum mechanics. Yet it is this non-commutative structure of the dynamical variables that should lie at the heart of any philosophical discussion of quantum phenomena.

This point was realised in the early days by people like Dirac, Jordan, Feynman and even Schrödinger who regarded the non-commutativity structure as basic. Instead of relying on continuity and the the continuity of derivatives, the essential point of non-commutativity implied that while we may well have continuous functions, but derivatives will not be continuous. (See Feynman 1948). This was a feature that was built into the sum over paths approach by Feynman. What this means is that we must introduce the notion of a 'backward' and 'forward derivatives' as Feynman makes clear in his 1948 paper.

Let us see how this distinction can arise. We can write

$$\frac{dA}{dx} = \lim_{\delta\to 0} \frac{A(x+\delta) - A(x)}{\delta} \quad \text{or} \quad \frac{dA}{dx} = \lim_{\delta\to 0} \frac{A(x) - A(x-\delta)}{\delta}$$

so that at the point x, we have the possibility of two 'derivatives' if the two expressions are not equal. Classical physics assumes that in the limit they become equal. However in Brownian motion they are not equal. There we have a "cause" for this inequality, a collision with another smaller particle. But what if Newton's first law is not valid at the quantum level? Assume at this level these two expressions are not in fact equal, then non-commutativity will be the consequence. To see this, first introduce the notation

$$\overrightarrow{D}A(x) = \lim_{\delta\to 0} \frac{A(x+\delta) - A(x)}{\delta} \quad \text{and} \quad A\overleftarrow{D}(x) = \lim_{\delta\to 0} \frac{A(x) - A(x-\delta)}{\delta}.$$

Now let us form

$$A\overleftarrow{D} - \overrightarrow{D}A \neq 0 \quad \text{and} \quad A\overleftarrow{D} + \overrightarrow{D}A \neq 0$$

Thus the commutator and anti-commutator need not vanish so that non-commutativity becomes a necessity in the quantum domain. Remember it is the failure of the operators of position and momentum to commute that gives rise to the uncertainty principle.

To quickly see how the Bohm equations emerge from non-commutativity, first note that the most general description of a state will now need a two point function $\rho(x', x, t)$, which is the analogue of the density matrix. The pure state emerges in the coincident limit, $x' \to x$, when $\rho(x, x, t)^2 = \rho(x, x, t)$. We can write our state function as $\rho(x', x) = |x'\rangle\langle x|$, so if $H(x', x)$ is the Hamiltonian operator, we can define two equations, one being

$$i\frac{\partial |x'\rangle}{\partial t}\langle x| = H(x', x)\rho(x', x)$$

and the other is

$$-i|x'\rangle\frac{\partial\langle x|}{\partial t}=\rho(x',x)H(x',x)$$

If we subtract these two equations we obtain

$$i\frac{\partial\rho}{\partial t}=[H,\rho]_- \tag{6}$$

which is just the quantum Liouville equation in the limit $x'\to x$. This accounts for the conservation of probability if $\rho^2(x,t)$ is taken to be the probability in the usual sense.

We form a second equation by adding the two equations and find

$$i\left[\left(\frac{\partial|\psi\rangle}{\partial t}\right)\langle\psi|-|\psi\rangle\left(\frac{\partial\langle\psi|}{\partial t}\right)\right]=\left(\overrightarrow{H}|\psi\rangle\right)\langle\psi|+|\psi\rangle\left(\langle\psi|\overleftarrow{H}\right)=[H,\rho]_+ \tag{7}$$

To connect up with the usual approach we now need to see how the wave function appears, so we can write $\psi(x,t)=\langle\psi|x,t\rangle$. If we polar decompose the wave function, we obtain from equation (6)

$$\frac{\partial P(x,t)}{\partial t}+\nabla\cdot\left(P(x,t)\frac{\nabla S(s,t)}{m}\right)=0 \tag{8}$$

where $P(x,t)$ is the probability of a particle being at (x,t). Equation (7) now becomes

$$\partial_t S(x,t)+\frac{1}{2m}[\partial_x S(x,t)]^2+Q(x,t)+V(x,t)=0 \tag{9}$$

Thus we have obtained the two defining equations of the Bohm approach directly from the non-commutative algebra of quantum operators showing that the quantum potential energy, Q, must take the form it does in order to conserve energy in the system.

In other work the operator algebra has been shown to be isomorphic with the Moyal algebra. (For details see von Neumann 1931 and Moyal 1949). Indeed the motivation of this approach to quantum phenomena emerged from a detailed study of the algebra of quantum operators as detailed in Dirac 1947. This algebra contains the Bohm equations (8) and (7) but appears from what at first sight seems an entirely different non-commutative structure, namely a structure of a non-commutative phase space (x, p) (See Hiley 2015). The non-commutativity arises from the introduction of a new product, the Weyl $\star$-product. This is defined through the relation

$$a(x,p) \star b(x,p) = a(x,p) \exp\left[i\hbar\left(\overleftarrow{\partial}_x \overrightarrow{\partial}_p - \overrightarrow{\partial}_x \overleftarrow{\partial}_p\right)/2\right] b(x,p)$$

It should be noted that this expression is just the exponentiation of the Poisson bracket. In this way one sees that classical mechanics appears in the first two terms of the expansion of the exponent. Thus we see that classical physics emerges as an approximation to the non-commutative quantum formalism. This is the origin of the approach to quantum mechanics known as deformation quantum mechanics. (See Hirshfeld and Henselder 2002 for a simple account of this approach).

This structure contains a density distribution function, $F(x, p)$, from which one constructs a marginal momentum through

$$\rho\bar{p}(x) = \int pF(x,p)dp$$

Here $\bar{p}(x)$ turns out to be identical to the Bohm momentum $p_B(x) = \nabla S(x)$ and the equation of transport of this momentum is just the equation (9) showing that the Bohm equations also arise from a very different structure than the one that depends on the *abstract* non-commutating operator formalism. (See Hiley 2015). What is common to both approaches is the non-commutative structure of the elements of the algebra.

But we have already shown in section 3 how the pair of equations that Bohm obtained follow directly from the Schrödinger equation so what have we gained? The approach we have outlined in this section is more general and can be applied to the Pauli and Dirac equations, equations necessary to account for spin and relativity. These equations are not discussed in the context of the Bohm approach because it is wrongly believed that that the approach cannot be applied in the relativistic domain. It can and has been applied to the relativistic domain. Here one cannot simply split the wave function into real and imaginary parts. One has to use the non-commutative algebra, indicating the essential need for non-commutative techniques. (For details of this approach see Hiley and Callaghan 2010a, 2010b, 2012).

To give the reader a feel of how the results emerge more generally, we will sketch some details of the results that arise when spin and relativity are included. The Pauli quantum Hamilton-Jacobi equation is

$$2mE(t) = P^2 + [2(\nabla W \cdot S) + W^2] \tag{10}$$

where the quantum potential is

$$Q = (\nabla W \cdot S)/m + W^2/2m. \tag{11}$$

We can express equation (11) purely in terms of P, ρ and the spin bivector S. After some straight forward but tedious work we find the quantum potential is now

$$Q = \{S^2[2\nabla^2 \ln \rho + (\nabla \ln \rho)^2] + S \cdot \nabla^2 S\}/2m = Q_1 + Q_2. \tag{12}$$

An expression for Q has been evaluated by Dewdney *et al.* (1986) in terms of Euler angles. Hiley and Callahan (2010a) show that

$$Q_1 = -\frac{1}{2m}\frac{\nabla^2 R}{R} \tag{13}$$

which is just the contribution of the Schrödinger particle to the quantum potential. However we now have a spin dependent part, Q_2 which takes the form

$$Q_2 = [(\nabla\theta)^2 + \sin^2\theta(\nabla\phi)^2]/8m. \tag{14}$$

Thus we can write the Pauli quantum Hamilton-Jacobi equation in the form

$$(\partial_t\psi + \cos\theta\partial_t\phi)/2 + P_B^2/2m + Q_1 + Q_2 = 0 \tag{15}$$

which, in this representation, agrees exactly with the expression given in Dewdney *et al.* (1986).

For the Dirac particle things are far more complicated but the principles are the same. After some work, the energy equation can be written in the form

$$P^2 + W^2 + [J\partial_\mu W^\mu + \partial_\mu W^\mu J] - m^2 = 0 \tag{16}$$

which is to be compared with the relativistic energy equation

$$p_\mu p^\mu - m^2 = 0.$$

Thus we see that the extra two terms must be related to the quantum potential in some way. After some detailed manipulation we find the quantum potential for the Dirac particle can be written in the form

$$Q_D = \Pi^2 + W^2 + [J\partial_\mu W^\mu + \partial_\mu W^\mu J]. \tag{17}$$

In the non-relativistic limit, $\Pi = 0$, and equation (17) reduces to the quantum potential for the Pauli particle. (See Hiley and Callaghan 2010).

$$Q_P = W^2 + [S(\nabla W) + (\nabla W)S] \tag{18}$$

where $2\rho S = \psi_L e_{12}\psi_R$ is the non-relativistic spin limit of J. W is the non-relativistic limit of W^μ. We have written the expressions for the quantum energy equations and the quantum potential in these two examples simply to show there is a lot more detail to be explored in this approach.

16 The $\star$-product and Classical Physics

We have seen one of the key steps to maintain a (q, p) phase space description in spite of the uncertainty principle was to replace the usual commutative scalar product $f(q, p) \circ g(q, p)$ by a non-commutative star-product, $f(q, p) \star g(q, p)$ for which $q \star p \neq p \star q$. It turns out that the star-product is the exponential of the classical Poisson bracket, once again showing how classical mechanics is related to the quantum formalism. Those familiar with group theory will recognise this procedure as 'lifting' the classical group structure on to the covering group. This suggests that it is the covering groups of the classical symmetry groups that provide the link between classical and quantum phenomena. This is the fact that Feynman exploited when he exponentiated the classical action to produce his "sum over paths" approach.

These results have led one of us (BJH) to reexamine the foundations of classical mechanics itself in this new light. Because Hamilton's equations of motion are a pair of first order differential equations, the significance of the Poisson brackets is often overlooked. To appreciate the significance of the Poisson bracket appearing in the exponential form of the $\star$-product, let us write this product in its original form:-

$$f(x, p) \star g(x, p) = \frac{1}{\hbar^2\pi^2}\int dp'dp''dx'dx'' f(x', p')\, g(x'', p'')$$

$$\times \exp\left(\frac{-2i}{\hbar}\left(p\left(x'-x''\right)+p'\left(x''-x\right)+p''\left(x-x'\right)\right)\right).$$

(See Groenewold 1946 and Baker 1958). The expression in the exponential is twice the area of a phase space triangle (mod $2i/\hbar$) formed by the three points (z'', z', z) where $z = (x, p)$

$$A\left(z'', z', z\right) = (\mathbf{z}' - \mathbf{z}) \wedge (\mathbf{z} - \mathbf{z}'') = \mathbf{z}'' \wedge \mathbf{z}' + \mathbf{z}' \wedge \mathbf{z} + \mathbf{z} \wedge \mathbf{z}''$$

This expression brings out another novel feature of the product, namely its non-local nature since we see the product involves *three points* in phase space. This gives rise to an invariant area of phase space which corresponds to the quantum invariant

$$\oint pdx = nh.$$

Since the $\star$-product can also be written as the exponentiation of the Poisson bracket then classical mechanics must contain some trace of this non-locality, suggesting that classical mechanics itself has some features that we have missed simply by using Newton's or even Hamilton's differential equations of motion.

Indeed the symplectic geometry upon which classical mechanics is based is a geometry that preserves (q, p) areas in phase space. The difference between classical and quantum mechanics lies in the nature of these *phase space areas*. In classical physics it is assumed these areas can be shrunk to a point, whereas in quantum mechanics they can only be shrunk to a cell of area of the order of $\hbar$ under a symplectomorphism. That is what the uncertainty principle is indicating in the operator language. Clearly the key to the difference between the classical and the quantum becomes geometric with the appearance of $\hbar$.

If we explore what happens mathematically as we let $\hbar \to 0$, we find the quantum structure remains right down to $\hbar = 0 + \epsilon$ no matter how small we make ϵ. If you make it zero, the whole structure literally "blows up" because an infinity appears (See Schempp 1984 for more details). Since, in the physical world, $\hbar$ is not zero it follows that classical physics cannot hold in the very small. But under the appropriate conditions we should expect the classical world to emerge from the quantum world.

This idea is very significant for biological phenomena. Already there is mounting evidence for quantum effects occurring in biological systems. For example, photosynthesis and avian magnetoreception have recently attracted much attention (for details, see Kolli et al. 2012; Klinman and Kohen 2013; Emlen et al. 1976.) This is not the place to discuss these proposal in detail but we feel it is essential to draw the reader's attention to this rapidly developing field which has been held back in the belief that "wave-decoherence" is the fatal factor that destroys quantum effects in living systems. This negative outlook traps us in a totally obscure notion of "wave-particle duality" and all the conflicting images that throws up. We should instead direct our attention towards a dynamical structure conditioned by non-commutative geometry. It is through these structures that quantum mechanics is beginning to play a role in biological systems and therefore could play a significant role in addressing the mind-matter question and perhaps even the hard problem of consciousness.

17 Concluding remarks

It has been fairly common for researchers to say that there is nothing quantum mechanical going on in the brain. However, without quantum mechanics there would be no brain. All molecular structures ultimately depend on quantum mechanics to account for their stability. One tends to think only of the more spectacular quantum effects such as interference or diffraction and, of course, here the phenomena are extremely susceptible to external disturbances. Great care has to be taken to protect these phenomenaagainst such disturbances and this is the source of the worries about the relevance of quantum mechanics in brain processes and the assumption that it is unlikely that effects like these will play any role in the brain.

However, in the brain we already have molecular structures which gain their stability from quantum processes. Recall that the covalent bond is one of the strongest chemical bonds and they are purely quantum mechanical. The brain contains many macromolecules making up the components of the neural network and its synaptic and dendritic interconnections and a lot more. Could there be some long range effect or global obstructions, common in non-commutative mathematical structures, which are not destroyed by temperature? The stability of long-chain molecules has already received some preliminary investigations by Salari et al. (2017) and Collini et al. (2010) and it is too soon to rule out all possibility of long-range quantum coherence processes. With our knowledge today we should not rule out the possibility of quantum effects in the brain based only on decoherence arguments. Perhaps the fragility of the entangled states raises further worries about stability but with the development of new mathematical techniques to investigate quantum effects we feel it is too early to definitely rule out such possibilities (for a recent review, see Adams and Petruccione 2020).

In this paper we have given a summary of our previous work on how the Bohm interpretation - and the notion of active information in particular - can help to approach the mind-matter problem in a new way. How do the discussions in the previous two sections affect our ideas about active information? If anything they have strengthened our case. By showing how the quantum potential can be generalised to include spin and relativity, we see that active information can appear in all domains.

We have naturally focused on the idea that the quantum potential is the source of the active information, but ultimately its source is a new quality of energy. It is neither classical kinetic energy, nor classical external potential energy. The appearance of an other quality of energy should not surprise us. In thermodynamics we have many notions of energy, internal energy, Helmholtz free energy, Gibbs free energy and even heat energy, all of which arise in general chemical processes, so why would they not appear in brain processes?

Finally, do these new ideas have any relevance to the mind-matter relation? The answer is absolutely everything. Remember Eccles (1986). His ideas were plagued with the horror of non-conservation of energy. The advantage with this new quality of energy is that it is "borrowed" from the kinetic energy to shape the overall process but in such a way that energy is always conserved. We never see anything like this at the classical level. If we assume that this new quality of energy is part of the essence of mental states, we obtain a much better way of understanding how mental states can influence physical processes. Thus active information is an extremely interesting novel concept in physics, relevant in a wide range of phenomena. As we have proposed, it could be an important way to begin to unite mind and matter and even move forward on the hard problem.

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