Popper on the Mind-Brain Relation

Peter Århem

1 Introduction

This chapter examines the view of Popper on the mind-brain relation in the light of neuroscience. It is based on two interviews that Ingemar Lindahl and I made with him 1992 and 1994. In these interviews Popper presents an extension of his interactionist view, taking his point of departure from the observation that mind has many similarities with forces. The chapter is organized in three parts. The first discusses Popper's interactionism and competing views. His argument for an interactionist solution of the mind-brain question based on the theory of evolution is addressed, as is his view that biology is not reducible to physics. His interactionism is put into the context of the philosophical landscape of today, which is dominated by parallelist positions. His critical view on these positions are discussed, as well as his responses to the arguments against an interactionist position.

In the second part of the chapter his new view on mind is addressed. An interpretation suggesting that electromagnetic fields of the brain are an intermediate link between the conscious mind and the neuronal activity is presented. It is pointed out that the introduction of such an intermediate link that have properties in common both with conscious mind and with the spatio-temporal pattern of nerve impulses, may make it easier to conceive of an interaction between mind and brain. The chapter also addresses Popper's view that the relative autonomy of forces may be a relevant factor in the attempts to better understand the mind-brain issue. Further it discusses Popper's suggestion that the all-or-nothing principle of neurophysiology may be relevant for understanding how microscopic effects on the brain are amplified.

P. Århem (✉)
Department of Neuroscience and Department of Clinical Neuroscience, Karolinska Institutet, Stockholm, Sweden
e-mail: peter.arhem@ki.se

Z. Parusniková and D. Merritt (eds.), *Karl Popper's Science and Philosophy*,
https://doi.org/10.1007/978-3-030-67036-8_15

The final part of the chapter explores the idea that mind affects quantum mechanical probability fields. Two hypotheses are discussed. One is the microsite hypothesis of Beck and Eccles, assuming that the critical targets are cortical synapses. The other assumes that the targets are ion channels of cortical nerve cells. In both cases quantum tunneling is assumed to be involved. Quantitative estimations suggest that quantum mechanical principles may indeed play a role at a macroscopic level of cortical action. This is discussed with reference to Popper's view that a mechanism based on quantum principles is only one of many possible mechanisms to explain the mind-brain interaction.

2 Background

Popper had a long-standing interest in the mind-brain relation (Popper 1953, 1955, 1972, chapter 6, 1973, 1976, 1977, 1978, 1994; Popper and Eccles 1977). His most thoroughly discussed presentation is in "The Self and its Brain" from 1977, written together with the neurophysiologist John Eccles. In all his publications about this issue he argued for an interactionist solution of the problem, criticizing the dominant materialistic positions. Already from the beginning this was a controversial standpoint, and still is.

In my eyes his most convincing argument is based on the theory of evolution. It states that mind is a result of evolution, a result of biology, and not of physics. And biology is not reducible to physics. This is another controversial standpoint of Popper, epitomized in his dictum that biochemistry is not reducible to chemistry; a statement made in the debate with the chemist Max Perutz after his delivery of the Medawar Lecture in 1986 on active versus passive Darwinism (Niemann 2014). This of course entails that biophysics is not reducible to physics. In all areas of biology, aims and intentions are involved—and these are not used or needed in physics and chemistry.

> I do think mind is a result of biological evolution. It is something very special to biology.... and not to physics alone. Biology is something absolutely marvellous. Who, who saw the world before life arose in the world, who would have dreamt of all these marvellous … I think life is certainly the great turning point in the evolution of the world. We must admit that we know extremely little, and that materialism, I think, is just a word. And it really is refuted at every minute and every day of our lives. (Popper et al. 1994)

3 The Philosophical Landscape

Interactionism is a rather small, but not insignificant, stream in the contemporary philosophical landscape of today. There are other streams of thought that are more popular, at least in academia. The terrain can be mapped as follows:

1. a radical immaterialism, which denies that a material reality exists,

2. a radical materialism, which denies that consciousness exists,
3. a psychophysical interactionism, which assumes that conscious processes and neuronal processes interact and
4. a psychophysical parallelism, which assumes that conscious processes and neuronal processes are parallel, but do not but not interact. To this we can add
5. epiphenomenalism, which forms a hybrid between parallelism and interactionism, and which assumes that the brain unilaterally produces consciousness.

The two radical positions (1) and (2) are rather uninteresting from a neuroscientific perspective, as well as from Popper's perspective. The radical immaterialism simply assumes that material reality is merely a mental construction based on sense impressions. This was Berkeley's and Mach's solution of the consciousness problem. Radical materialism assumes that mental reality is merely behavior (Dennett 1991). The quality of consciousness does not exist. This position seems in a neuroscience perspective even less fertile than radical immaterialism.

The three other positions seem more fruitful. Psychophysical interactionism assumes that mental and neural processes in some sense interact. This was Descartes' classical solution and it is the common-sense solution in the light of the evolutionary theory, also adopted by Popper (Popper and Eccles 1977).

Psychophysical interactionism has a long history. It was not invented by René Descartes, as many mind-brain theorists would like us to believe (e.g. Ryle 1949). Interactionism can be found in prehistoric cultures (Solecki 1971) and it is a common view among present-day indigenous populations (see Bloch 2013; Descola 2013). Popper even asserted that all major thinkers before Descartes, and of course Descartes himself, were dualist interactionists in some form or another (Popper and Eccles 1977, 152). For Descartes the essence of matter was extension and for mind it was non-extension. The contact between the two was assumed to be found in the pineal gland, a rather reasonable idea since nerve activity was assumed to be hydrodynamic waves in fluids in hollow nerves and the fluid reservoirs in the brain are found in the system of ventricles in close contact with the pineal gland. Thus Descartes suggested that a system of valves in the pineal gland could be regulated by mind processes, under the precondition that the momentum of the fluid was preserved.

Psychophysical parallelism assumes that mental and neural processes perfectly follow each other, in a perfect 1 to 1 mapping. It was such an idea that was suggested by Leibniz and by Spinoza as a solution to the contradictions found in Descartes' interactionist theory. It is variants of this position, perhaps mainly the identity theory, which today dominates the philosophical landscape (Feigl 1967; Edelman 1992; Crick and Koch 1990; Searle 2004). It should be pointed out here, that Descartes view was based on rather detailed biological ideas about the anatomy of the brain, while Leibniz thinking was much more abstract. I think this is an observation of some interest here, related to discussion of instrumentalism by Popper in "Conjectures and Refutations" (1963). He there severely criticized instrumentalist attitudes, using as example the trial of Galilei and the conflict between the successful realistic ideas of Galilei and the unsuccessful instrumentalism of Roberto Bellarmino.

Both Spinoza and Leibniz advocated a specific form of parallelism with ancient roots, panpsychism; a theory assuming that everything materially also has a mental "inside" or internal aspect. This view has recently appeared in new shapes and seem to have gathered new adherents among neuroscientists (Smith 2008; Koch 2019). But still it seems as if the dominant parallelist positions today are different versions of the identity theory, assuming that conscious processes are in some sense (but not logically) identical, and thus in some sense (though not mathematically) completely parallel, with certain neural processes in certain parts of the brain.

The hybrid position of epiphenomenalism was originally presented by Thomas Huxley, one of Darwin's friends and the first public defender of his evolution theory. This approach assumes that consciousness is a byproduct, a surface phenomenon, of the activity of the brain.

Different approaches have different advantages and disadvantages. Psychophysical interactionism has to give a reasonable answer to the crucial question "How?". How can we explain that the non-physical consciousness affects and is influenced by physical processes? Psychophysical parallelism has to give a reasonable answer to the crucial question "Why?". Why do we have consciousness when it does not matter to our lives or to evolution? Panpsychism has a special position among the parallelist theories in that it is possibly evades these questions. I will come back to this problem later. Epiphenomenalism has to give a reasonable answer to both "Why?" and "How?". Why do we have consciousness if it does not matter in evolution? And how can physical processes affect the non-physical consciousness?

4 The Evolution Argument

As mentioned above, an important argument for Popper's position is the evolution argument. An interactionist solution answers the question "Why?". It is reasonable (but not necessary) to assume that consciousness has emerged during evolution and that organisms with consciousness had survival advantages over organisms without. This requires that conscious processes affect physical brain processes and vice versa.

Parallelist or epiphenomenalist solutions do not answer this question. In a parallelist theory, a description of consciousness is not required for a complete description of the world including humans and their actions; it seems that it is in principle possible to describe a person and her actions completely without assuming that she can experience anything, that she is conscious. But we know we are conscious and our consciousness is something extremely important for us! This is an old argument but it still weighs heavily. William James wrote in 1879:

> Consciousness is a manifested property of higher organisms, most evident in man; like all such characteristics it must have evolved; and it may only have been developed through natural selection; but if developed through natural selection it must have a use; and if it has a use it cannot be causally ineffective. (James 1879)

Popper also presented other arguments for an interactionist solution of the mind-brain problem. One refers to his three-world view on the universe. Since a world of objective theories, his World 3, exist and since we can use theories to modify the physical world, World 1, there must be a world that allows us to grip these World 3 elements. This is the world of subjective consciousness, World 2. And since we can work in world 1, the three worlds must be open to each other, i.e. interaction must be possible. Popper presented a number of arguments against parallelist theories beside the ones briefly mentioned above. Since I here focus on arguments related to the theory of evolution, I will highlight some of Popper's arguments against panpsychism, the parallelist theory that seems to be immune to evolution arguments.

5 Popper's Argument Against Panpsychism

Another reason for discussing panpsychism is that the interest in this theory has increased markedly in recent years (Smith 2008; Koch 2019). Originally the idea was introduced to eliminate the problem of how novelties emerge.

But Popper's point is that novelties do emerge. Solid ice becomes liquid water when temperature increases. It does not help us to understand the phase transition by introducing a concept of proto-liquidity in solid ice. It does not help us to understand the origin of consciousness to assume proto-consciousness in pre-biotic matter. Panpsychism seems to lack explanatory power. And even if stones would have some sort of proto-consciousness, we have to admit that animal consciousness seems so much richer than proto-consciousness of a stone that the difference between them becomes so great that in practice it would be difficult to distinguish a panpsychist explanation from explanations that assume that consciousness emerges during evolution.

Popper raised another argument against panpsychism that I find especially interesting (Popper and Eccles 1977, 69–71). It relates to quantum physics and concerns the question whether atoms and elementary particles have some form of memory. There are many reasons to assume that consciousness involves some form—albeit short-lived—of memory mechanism. It is hard to imagine conscious experience that does not include some kind of continuity over time. Popper makes a *Gedanken*-experiment to prove his point; atoms and elementary particles should, according to panpsychism, have memory-like properties. But many contemporary physicists emphatically stress that atoms and elementary particles lack memory. Two radioactive atoms of the same isotope have the same propensity for decay irrespective of their history. However, this might not be entirely uncontroversial. It has also been argued that quantum physics is compatible with a metaphysics of individual objects, but that such objects are indistinguishable in a sense, which leads to the violation of Leibniz's famous Principle of the Identity of Indiscernibles. In summary, the prevailing view today is that fundamental particles of physics cannot be regarded as individual objects, thus making panpsychism an unlikely solution of the consciousness problem.

6 Problems with the Interactionist Position

The main problem with the interactionist view is that it seems incompatible with the conservation laws of physics (Wilson 1999; Clarke 2014). Popper responded repeatedly and specifically to these arguments. But in general, he did not seem especially worried about this criticism. This was of course due to his hypothesis of a three-world universe and his central thesis that present-day physics is fundamentally incomplete; that the universe is open. Nevertheless, he gave specified arguments to his critics. His most often repeated argument was that the first law may only be statistically valid (Popper and Eccles 1977, dialogues X and XII). This is an idea first suggested by Schrödinger (1952).

> One possibility that would suit us extremely well would be that the law of the conservation of energy would turn out to be valid only statistically. If this is the case, it might be that we have to wait for a physical fluctuation of energy before world 2 can act on world 1, and the time-span in which we prepare for the "free-will movement of the finger" may easily be long enough to allow for such fluctuations to occur.

Another argument was that there might exist 'purely mental forms of energy, convertible into electrochemical forms' (Popper 1984, 21).

A further argument was that, according to some interpretations of de Broglie's particle-wave theory, 'there seem to be empty pilot waves that can interfere with non-empty (energy-piloting particles an energy-carrying) waves', and this would suggest 'the possibility of non-energetic influences upon energetic processes' (Popper 1984, 21–22).

7 Popper's New Theory of Mind

As mentioned above, Ingemar Lindahl and I had the opportunity on two occasions to interview Popper about what he called his new theory of mind (Popper et al. 1993, 1994, 2010). In these he pointed to the similarity between mind and forces, by characterizing mind as being: (i) located (ii) unextended (iii) incorporeal (iv) capable of acting on bodies (v) dependent upon body (vi) capable of being influenced by bodies (vii) intensities, and (viii) extended through a span of time.

> Most people would say, I think, if one tells them that something with all these properties exists, that it cannot be true. Especially, most materialists would say so, and most physicalists. Now, I say things of this kind <u>do</u> exist, and we all know it. So, what are these things? These things are forces. For example, electrical forces. Electrical and magnetic forces have all these properties. (Popper et al. 1993)

This similarity between mind and forces is not a new discovery. As Popper pointed out in "The Self and its Brain" (1977), the analogy between mind and forces has been used before. Hobbes and Leibniz identified a certain part of mind with a physical force. Gilbert in <u>De Magnete</u> "had compared the interaction between magnetic force and a loadstone to that between soul and body". Both Thomas Reid and Maine de

Biran emphasized our experience of the mind (the will) acting on our body and producing effects in the material world as the source of our universal notion of force. But Popper went further. He specified the type of force field he was thinking of, an electromagnetic field:

> I wish to propose here as a hypothesis that the complicated electro–magnetic wave fields which, as we know, are part of the physiology of our brains, represent the unconscious parts of our minds, and that the conscious mind — our conscious mental intensities, our conscious experiences — are capable of interacting with these unconscious physical force fields, especially when problems need to be solved that need what we call 'attention'". This admittedly vague working hypothesis seems to me as a small yet significant progress within a so far hopelessly difficult part of physiology. (Popper et al. 1993)

Popper seemed to view the "unconscious parts of our minds" as synonymous with "physical force fields". And he seemed to view the electromagnetic field (the unconscious) as an intermediate link between the conscious mind and the neuronal activity. This is perhaps the most central thesis in his new hypothesis of mind and I will come back to it below. But first I will mention another thought-provoking observation Popper took up in the interview, the relative autonomy of forces.

8 The Autonomy of Forces

> To what extent, if any, can a concept of physical force account for the apparent autonomy of mind? … We tend to think of forces as something attached to bodies, and not as something that can obtain autonomy…. The fundamental question is: "How can these forces, which are set up in the brain, continue themselves, so to speak, and continue to have a kind of identity which is even able to initiate in its turn biochemical processes in the brain?" (Popper et al. 1993)

Popper seemed to think that very few physicists had seen this autonomy of forces as a problem. One of the few was the Swedish physicist Hannes Alfvén (Nobel laureate 1970).

> In Alfvén's cosmology, forces, mainly electrical forces, but of great complexity, are living in the cosmos everywhere. Like the forces which creates the northern lights. To put it in another way, apart from the stars, which, of course, he admits exist, there exists a semi-matter, like electrons, without density of distribution, but with forces holding them together; electrical forces. The forces are partly the effect of the electrons. This phenomenon is as, let us say, weeds drifting in the sea. One does not know exactly why the electrons are together. They are not attracting each other. Somehow the electrons modify the situation.
>
> I mean, electrons, in any case, are not what we usually call matter. The electrons held together, forming curtains, like the real curtain-like arrangement of the northern lights are here repeated all through the cosmos.
>
> I do not think that Alfvén would claim to know all about forces. But he would say, yes forces are, in a sense, almost independent. Nothing is independent, but the forces are as independent as matter, in our space. That is roughly the situation. (Popper et al. 1994)

9 An Interpretation of Popper's Theory

In 1994 Ingemar Lindahl and I published an interpretation of Popper's new theory of mind. We took as point of departure his identification of unconscious mind with certain electromagnetic fields, and suggested a three-level scheme, depicted in Fig. 1 below (Lindahl and Århem 1994). It shows the relation between consciousness, or the conscious part of mind, the electromagnetic fields of the brain and what we called the action potential pattern of the brain. Perhaps a better label of the lowest level would have been electric current patterns of the brain; this perhaps would be more in line with at least one strand of Popper's realistic interpretation of the physical world (Popper 1982a); a world containing particles and fields (currents are moving electrons). The figure also shows the relations between worlds 1 and 2 as well as the relation between mind and brain.

According to this interpretation, there are two levels of interaction: the first between the currents associated with certain spatio-temporal patterns of action potentials and specific electromagnetic fields (the relations 1 and 2); the other between the electromagnetic fields/the unconscious, and the conscious mind (the relations 3 and 4).

The introduction of an intermediate link, the electromagnetic field/the unconscious, that have properties in common both with conscious mind (the eight properties) and with the spatio-temporal pattern of action potentials (the membership of world 1), may make it somewhat easier to conceive of an interaction between consciousness and the brain, two very different entities in themselves.

Relation 2 appears to be the least problematic of the four in the figure. This relation may in principle be studied within classical electrodynamics.

Relation 1 may seem more difficult to accept. In order to excite a resting, inactive neuron, it is necessary to change the membrane potential by 20 mV (Hille 2001). Simple calculations show that under the most favourable conditions an electric field of at least 0.5 V/cm would be necessary. However, the electric field around a nerve cell, induced by a normal impulse activity, is many times weaker due to the low resistance of the extracellular part of the local circuit. Thus, under these circumstances, an electromagnetic field effect on the brain seems highly unlikely. However, according to Popper (Popper and Eccles 1977, dialogue X), the electromagnetic field is not

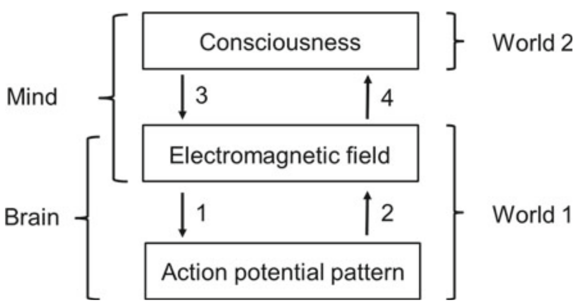

Fig. 1 (After Lindahl and Århem 1994)

expected to trigger inactive neurons, but to sculpture ongoing neuronal activity; to affect neurons in constant spontaneous activity.

> Thus, what I am here suggesting is that we might conceive of the openness of World 1 to World 2 somewhat on the lines of the impact of selection pressures on mutations. The mutations themselves can be considered as quantum effects; as fluctuations. Such fluctuations may occur, for example, in the brain. In the brain there may at first arise purely probabilistic or chaotic changes, and some of these fluctu-ations may be purposefully selected in the light of World 3 in a way similar to that in which natural selection quasi-purposefully selects mutations. […]. (Popper and Eccles 1977, 540)

In a next step, Popper even suggested that the so called all-or-nothing principle of nerve cell firing may be the mechanism of allowing microscopic effects to be macroscopic:

> The all–or–nothing principle of the firing of nerves may indeed be interpreted as a mechanism which would allow arbitrarily small fluctua-tions to have macroscopic effects…. The action of the mind on the brain may consist in allowing certain fluctuations to lead to the firing of neurones while others would merely lead to a slight rise in the temperature of the brain. (Popper and Eccles 1977, 541)

In referring to “quantum effects” Popper seemed to refer to truly random (i.e. not only in practice difficult to predict) neuronal activity. That can mean either indeterminate quantum effects, described by the Heisenberg principle in some form, or it can mean, more controversially, macroscopic indeterminate effects, described by Popper’s propensity theory (Popper 1982a, 1990).

Thus, according to Popper’s new theory of mind in our interpretation, it is mind effects on the electro-magnetic field that modulate the nerve cell firing. It is not direct effects on critical nerve cell structures that modulates their firing. These structures are the ion channels, membrane proteins that selectively allows metal ions to flow through the membrane. Ion channels will be discussed in more detail Sect. 12.

Two observations in my own lab may have some bearing on this issue. One was that opening of a single channel may cause certain neurons to fire action potentials (Johansson and Århem 1994). Normally thousands of channels are necessary for a neuron to fire an action potential. For a single channel current to induce a sufficient potential change, either the current or the membrane resistance must be unusually large (due to Ohm’s law). We succeeded to demonstrate such an effect in certain brain cells. These studies thus suggest that an extremely small effect may be amplified to trigger all-or-nothing action potentials in cells of the brain, and consequently to trigger activity in circuits and larger brain networks.

The second observation was that there seem to be “real” thresholds and “pseudo”-thresholds for triggering action potentials in neurons. A mathematical analysis of the excitability of different neuron models showed that some had a discontinuous current voltage-relation (a real threshold), and some had a continuous, albeit very steep current-voltage relation (a pseudo-threshold) (Århem and Blomberg 2007; Zeberg et al. 2010, 2015). The reason could be traced back to different bifurcation properties (Izhikevich 2007). This means that there may be neurons that are easier triggered than others, in theory by an infinitely small voltage change.

Popper's hypothesis is of course highly speculative. But such speculations seem necessary in order to get us somewhere in coping with this extreme problem. Popper's attempt to correlate mental processes with electromagnetic fields is an attempt to formulate a realistic hypothesis. Of course, Popper is not alone in discussing consciousness in field terms (for a summary, see Jones 2013). Benjamin Libet even offered an idea that is experimentally testable (Libet 1994, 1997). As stated previously:

> Our main conclusion is that Popper's hypothesis of consciousness interacting with neural activity through an electromagnetic field is a thought-provoking suggestion worth closer examination; and that his theory of mind as a whole is possibly the most promising proposal yet made for a future explanation of the survival and development of consciousness. (Lindahl and Århem 1994)

10 Beck's Interpretation of Popper's Theory

Friedrich Beck (1996) commented on our interpretation above (Lindahl and Århem 1994). His main criticism was that the direct relation between consciousness and the electromagnetic fields is in conflict with the conservation law of energy. To avoid this he suggested a direct relation between consciousness and probability fields of quantum mechanics, as depicted in Fig. 2 below.

The suggestion shows clear similarities with Popper's hypothesis. It also uses the argument of a family resemblance between fields and consciousness. The physicist Henry Margenau has previously discussed the resemblance between consciousness and quantum probability fields:

> The mind may be regarded as a field in the accepted physical sense of the term, but it is a non-material field, its closest analogue is perhaps a probability field …. nor is it required to contain energy in order to account for all the known phenomena in which mind interacts with the brain. (Margenau 1984).

But does this suggestion by Beck evade conflicts with other principles of physics? I do not think so. Quantum probability fields are stochastic and do not allow modulation outside the fixed values of the statistical parameters in present-day physics. So the

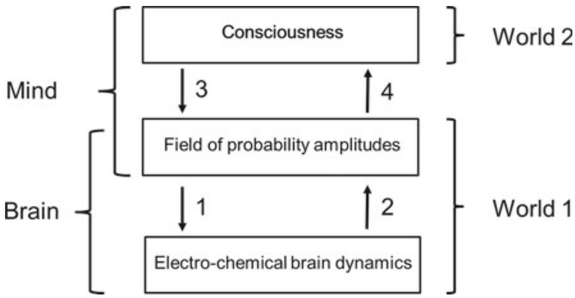

Fig. 2 (After Beck 1996)

question is how much more reasonable the probability field solution is than the electromagnetic field solution. This will be discussed in the next section.

11 Mind Affecting Probability Fields: The Microsite Hypothesis

The proposal by Beck above draws on quantum mechanical principles. He and Eccles have developed a hypothesis assuming that mental effects modifies quantum mechanical probability fields involved in synaptic transmission. They called this hypothesis the microsite hypothesis. Given Popper's long-standing interest in quantum mechanics (Popper 1982a) and his close friendship with Eccles, it may seem remarkable that he did not comment more on this hypothesis. Rather, in Ingemar Lindahl's and my discussion with him (Popper et al. 1994), he seemed rather uninterested in the quantum mechanical aspects of the mind-brain problem, illustrated by his remark "It is one of the hundred ways".

This seeming lack of interest may be related to his well-known criticism of the mainstream interpretations of quantum mechanics, as developed in "Quantum Theory and the Schism in Physics" (1982a). But again, considering his three-world view with its interacting worlds, it does not seem necessary to evade conservation laws of present-day physics with present-day physical principles. As stated in "The Open Universe", the universe is fundamentally open (Popper 1982b).

As mentioned above, Beck and Eccles developed the microsite hypothesis in 1992. Eccles had searched for quantum mechanical solutions for a long time (Eccles 1987, 1992), but did not find them successful until he established the collaboration with Beck. In his early attempts he assumed that mental events directly affected the vesicles containing neurotransmitters. With Beck, however, he assumed that the specific target was presynaptic grids (a structure within the synaptic bouton attached to apical dendrites of pyramidal cells, first described by (Akert et al. 1975)). By these quantum mechanical assumptions they hoped to avoid breaking the first law of thermodynamics. A reason, as mentioned above, not important for Popper.

The microsite hypothesis of Beck and Eccles assumes the existence of critical quasiparticles, the mass of which being in the range of hydrogen atoms, and therefore within the quantum mechanical regime, rather than in the classical thermodynamic regime. Mind is assumed to affect these quasiparticles located in the presynaptic grid by modifying their probability fields. This triggers a release of transmitter by movement of the quasiparticle through an energy barrier via the process of quantum tunneling, meaning that for a particle of a certain energy there is a finite probability of penetration through a barrier even when the particle energy is less than the barrier energy, something that is impossible in the thermodynamic regime. The probability of a particle penetrating the barrier is given by the transmission coefficient, which is a function of the shape and amplitude of the energy barrier, the mass of the particle and other factors. Beck and Eccles estimated the transmission coefficient to be between

0.4 and 4%, meaning that the probability of a synapse releasing transmitter substance at a nerve impulse is 25%. (The figures will be used in an illustration below).

The microsite hypothesis was not received uncritically by the neuroscience community, nor by the philosophy-of-mind community (see Wilson 1999; Clarke 2014). The main problem is of course that even if the conservation of energy is preserved in the hypothesis, it introduces an effect (mind modifying quantum probability fields) not belonging to present-day physics. Furthermore, the understanding of the process of synaptic release has evolved since the publication of the microsite hypothesis and seems not to support the processes Beck and Eccles assumed to be at hand.

An experimental finding seemingly incompatible with the hypothesis is the fact that processes in the quantum regime should be temperature independent, but transmitter release is temperature dependent. Such problems can be accounted for by making ad hoc assumptions, but this, of course, does not strengthen the hypothesis. In summary, the microsite hypothesis in its present form seems unlikely as explanation of the interaction between mind and brain.

12 Mind Affecting Probability Fields: The Ion Channel Hypothesis

Popper's new hypothesis assumed that consciousness interacts with brain activity via an intermediate level, the electromagnetic field level. Beck suggested interaction via quantum probability fields. Both hypotheses use the family resemblance argument. Let us explore the idea that consciousness interacts with the electric activity of nerve cells via modifying quantum probability fields associated with critical structures of ion channels. The impulse initiation in nerve cells seems today better understood in terms of molecular details than synaptic impulse transmission, which forms the basis of the microsite hypothesis. This gives us possibility to explore the role of quantum mechanics in brain function in more detail than when studying corresponding problem in synaptic processes.

Since the studies by Erwin Neher and Bert Sakmann in the early 80's, we know that the current through the membranes pass through pores of special proteins, called ion channels. With extremely sensitive technology, we can now directly study the activity of single ion channel molecules in real time. Through such studies in combination with molecular biology, we now know a lot about these ion channels (see Hille 2001). There are a wide variety of different types (143 species in the class of voltage-gated channels in humans forming the human channelome); there are channels selectively permeant to sodium, potassium and calcium ions; there are channels activated by the electrical voltage across the membrane and there are channels that are activated by specific molecules. Each nerve cell has its particular palette of ion channels depending on its function. For the passage of the nerve impulse along the nerve fibers, voltage-activated sodium and potassium channels play a major role.

The ion channels have a long evolutionary history. The same voltage-activated potassium channels that contribute to the nerve impulses in humans are found in some single-celled organisms that are present some 1400 million years ago. Sodium channels that play the leading role in human impulse conduction are found in the evolutionary early cnidarians (i.e. jellyfish, hydras and corals), perhaps 700 million years ago (Hille 2001). Consciousness apparently does not depend on specific molecules, specifically human consciousness does not depend on specific human molecules. There does not seem to be any specific human ion channels. The same molecules are found far down the phylogenetic chain.

For similar reasons, there does not seem to be specific neurons in species that can be assumed to be conscious. There are no specific human nerve cells. It seems likely that the emergence of a consciousness has to do with the organization and the processes of the nervous system, and that the emergence of a specific human consciousness has to do with the specific organization of the human brain.

Ion channels are membrane-bound proteins with a central ion-permeant pore. The voltage-sensitive component of voltage gated channels is an electrically charged helical structure, called the S4 segment. The details in the opening sequence are still debated, but a widely accepted idea is that the S4 moves outwards in a screw-like fashion, initiating a sequence of events that open the pore.

The mathematics of nerve excitability and the functioning of ion channels is relatively well developed. It is based on the ideas presented Allan Hodgkin and Andrew Huxley in 1952, extended with new mathematical tools such as bifurcation theory (Izhikevich 2007), explaining the firing patterns of different types of neurons, and the transition state theory of Henry Eyring and Michael Polanyi, explaining the rate of opening.

Let us assume mental events modify quantum probability field associated with the S4 segment. The S4 segment has a 200-fold higher mass than the quasiparticle postulated by Beck and Eccles in their microsite hypothesis, suggesting that in the channel opening case we are operating in the borderland between a quantum regime and a thermodynamic regime. What does this mean for the opening of the channel? Are quantum mechanical principles irrelevant for describing nerve firing? Probably not.

According to the transition rate theory, the rate constant for the opening is a complex function of the tunneling probability (i.e. the transmission coefficient), which in turn is a function of the mass of the critical structure and the barrier height. The barrier height depends on the membrane voltage and consequently on the specific spatial and temporal conditions for the neuron studied. To analyze this thoroughly we need massive computer power. However, for the present purpose we can use a simpler approach.

It does not seem unreasonable to assume that the transmission coefficient in some situations is within the range of the transmission coefficient estimated by Beck and Eccles, i.e. between 0.4 and 4%. Thus, assuming a transmission coefficient of 0.4%, conventional computer simulations of nerve cell activity using the Hodgkin-Huxley formalism show that the firing frequency differs measurably between that of a nerve cell model assuming tunneling and a nerve cell model without such an assumption, suggesting that quantum mechanical principles may play a role at a macroscopic level.

However, it does not show that mind acts in this way. Such a theory must explain how the suggested marginal effect is filtered out from thermodynamically initiated firing, how the thousands of channels are coordinated, and why certain cortical cells are affected. A plethora of biophysical, systems-biological and evolutionary questions remain to be answered.

From a Popperian point of view, I do not think performing detailed quantum mechanical calculations is the way to go. The main reason for this approach was the wish to evade the energy conservation laws. And as mentioned above, this was not an important issue for Popper.

13 Concluding Remark

In conclusion, no solution of the mind-brain problem seems to be in sight, not within present-day science boundaries. Nevertheless, the hypothesis discussed in the present chapter seems to offer some hope. In Popper's words (Popper et al. 1994):

> This admittedly vague working hypothesis seems to me as a small yet significant progress within a so far hopelessly difficult part of physiology.

Our interpretation of this hypothesis assumes an intermediate level between conscious mind and brain, and that this mediating stratum consists of specific electromagnetic fields in the brain.

It should be noted that mind-brain theories assuming a role of electromagnetic fields are not new. However, these theories often identify mind with an electromagnetic field (see Jones 2013; McFadden 2013). Consequently, they belong to the parallelist camp and can be criticized accordingly. In addition, they seem to fall prey to Leibnitz' law of the identity of indiscernibles.

As a final remark, I would like to comment on Popper's criticism of instrumentalist attitudes (Popper 1963). Many areas remain to be explored to get us closer to an understanding of the mind-brain relation. Specific questions related to Popper's hypothesis are: Which brain cells or groups of brain cells are selected by mind, what physical criteria characterize these cells, and why are they selected? How are the microscopic events amplified to macroscopic events? How are the induced microscopic fluctuations isolated and shielded from thermodynamic noise?

These questions are mainly neuroscience questions. But to understand mind-brain issues it is imperative to understand underlying neuroscience issues. And to do that, Popper's realist, anti-instrumentalist approach seems essential (Popper 1963); it inspires us to transform suggestions into realistic hypotheses that can be experimentally tested. All ways to approach the mind-brain problem must be continually confronted with neurophysiological findings. This is not always done. Instrumentalist black-box attitudes are unfortunately not uncommon in large areas of mind-brain studies; e.g. in studies based on computational or cognitive neuroscience. I am afraid such attitudes may hamper our attempts to make any progress within, to use the words of Popper again (Popper et al. 1993), "a so far hopelessly difficult part of physiology".

References

Akert, K., Peper, K., Sandri, C.: Structural organisation of motor end plate and central synapses. In: Waser, P.G. (ed.) Cholinergic Mechanisms, pp. 43–57. Raven, New York (1975)

Århem, P., Blomberg, C.: Ion channel density and threshold dynamics of repetitive firing in a cortical neuron model. Biosystems **89**(1–3), 117–125 (2007)

Beck, F.: Mind-brain interaction: comments on an article by B. I. B. Lindahl & P. Arhem. J. theor. Biol. **180**, 87–89 (1996)

Beck, F., Eccles, J.C.: Quantum aspects of brain activity and the role of consciousness. Proc. Natl. Acad. Sci. **89**, 11357–11361 (1992)

Bloch, M.: In and out of each other's bodies: theories of mind, evolution, truth, and the nature of the social. Paradigm, Boulder (2013)

Clarke, P.G.H.: Neuroscience, quantum indeterminism and the Cartesian soul. Brain Cogn. **84**(1), 109–117 (2014)

Crick, F., Koch, C.: Towards a neurobiological theory of consciousness. Semin. Neurosci. **2**, 263–275 (1990)

Dennett, D.C.: Consciousness explained. Little, Brown and Company, Boston (1991)

Descola, P.: Beyond nature and culture. University of Chicago Press, Chicago (2013)

Eccles, J.C.: Do mental events cause neural events analogously to the probability fields of quantum mechanics? Proc. R. Soc. Lond. B **227**, 411–428 (1987)

Eccles, J.C.: The evolution of consciousness. Proc. Natl. Acad. Sci. **8**, 7320–7324 (1992)

Edelman, G.M.: Bright air, brilliant fire: on the matter of the mind. Allen Lane the Penguin Press, Harmonsworth (1992)

Feigl, H.: The "mental" and the "physical". University of Minnesota, Minneapolis (1967)

Hille, B.: Ionic channels of excitable membranes, 3rd edn. Sinauer Associates Inc, Sunderland (2001)

Izhikevich, E.M.: Dynamical systems in neuroscience: the geometry of excitability and bursting. MIT Press, Cambridge (2007)

James, W.: Are we automata? Mind **4**, 1–22 (1879)

Johansson, S., Århem, P.: Single-channel currents trigger action potentials in small cultured hippocampal neurons. Proc. Natl. Acad. Sci. **91**, 1761–1765 (1994)

Jones, M.W.: Electromagnetic-field theories of mind. J. Conscious. Stud. **20**(11–12), 124–149 (2013)

Koch, C.: The feeling of life itself—why consciousness is widespread but can't be computed. The MIT Press, Cambridge (2019)

Libet, B.: A testable field theory of mind–brain interaction. J. Conscious. Stud. **1**, 119–126 (1994)

Libet, B.: Conscious mind as a force field: a reply to Lindahl & Århem. J. Theor. Biol. **185**, 137–138 (1997)

Lindahl, B.I.B., Århem, P.: Mind as a force field: comments on a new interactionistic hypothesis. J. Theor. Biol. **171**, 111–122 (1994)

Margenau, H.: The miracle of existence. Ox Bow Press, Woodbridge (1984)

McFadden, J.: The CEMI field theory: closing the loop. J. Conscious. Stud. **20**(1–2), 153–168 (2013)

Niemann, H.-J.: Karl Popper and the two new secrets of life. Mohr Siebeck, Tübingen (2014)

Popper, K.R.: Language and the body–mind problem: a restatement of interactionism. In: Proceedings of the XIth International Congress of Philosophy, vol. 7, 101–107. North-Holland, Amsterdam (1953)
Popper, K.R.: A note on the body–mind problem. Analysis **15**, 131–135 (1955)
Popper, K.R.: Conjectures and refutations: the growth of scientific knowledge. Routledge & Kegan Paul, London (1963)
Popper, K.R.: Objective knowledge: an evolutionary approach. Clarendon, Oxford (1972)
Popper, K.R.: Indeterminism is not enough. Encounter **40**, 20–26 (1973)
Popper, K.R.: Unended quest: an intellectual autobiography. Fontana/Collins, London (1976)
Popper, K.R.: Some remarks on panpsychism and epiphenomenalism. Dialectica **31**(1–2), 177–186 (1977)
Popper, K.R.: Natural selection and the emergence of mind. Dialectica **32**, 339–355 (1978)
Popper, K.R.: Quantum theory and the schism in physics. Unwin Hyman, London (1982a)
Popper, K.R.: The open universe: an argument for indeterminism. Hutchinson, London (1982b)
Popper, K.R.: Critical remarks on the knowledge of lower and higher organisms the so-called sensory motor systems. In: Creutzfeldt, O., Schmidt, R.F., Willis, W.O. (eds.) Sensory-Motor Integration in the Nervous System, pp. 19–31. Springer-Verlag, Berlin (1984)
Popper, K.R.: A world of propensities. Thoemmes, Bristol (1990)
Popper, P.R.: Knowledge and the body-mind problem. Routledge, London (1994)
Popper, K.R., Eccles, J.C.: The self and its brain: an argument for interactionism. Springer-Verlag, Berlin (1977)
Popper, K.R., Lindahl, B.I.B., Århem, P.: A discussion of the mind–brain problem. Theor. Med. **14**, 167–180 (1993)
Popper, K.R., Lindahl, B.I.B., Århem, P.: A discussion of the mind–brain problem. (Manuscript) (1994)
Popper, K.R., Lindahl, B.I.B., Århem, P.: Die Beziehung zwischen Bewusstsein und Gehirn: Disskussion einer interaktionistischen Hypothese. Aufklärung und Kritik **4**, 9–21 (2010)
Ryle, G.: The concept of mind. Hutchinson, London (1949)
Searle, J.R.: Mind: a brief introduction. Oxford University Press, New York (2004)
Schrödinger, E.: Are there quantum jumps? Part I-II. Br. J. Philos. Sci. **3**(109–123), 233–242 (1952)
Smith, C.U.M.: Synapses, quantum theory and panpsychism. NeuroQuantology **6**(2), 164–174 (2008)
Solecki, R.S.: Shanidar. Knopf, New York (1971)
Wilson, D.L.: Mind-brain interaction and violation of physical laws. J. Conscious. Stud. **6**(8–9), 185–200 (1999)
Zeberg, H., Blomberg, C., Århem, P.: Ion channel density regulates switches between regular and fast spiking in soma but not in axons. PLoS. Comput. Biol. **6**(4), 22 (2010)
Zeberg, H., Robinson, H.P., Århem, P.: Density of voltage-gated potassium channels is a bifurcation parameter in pyramidal neurons. J. Neurophysiol. **113**(2), 537–549 (2015)

Peter Århem is professor in neurophysiology at Karolinska Institutet, Stockholm, Sweden. He is studying the function of nerve cells and related mathematical and philosophical issues. He has contributed as author/editor to several books such as "Matter Matters" (1997) and "Consciousness Transitions" (2008). Together with Ingemar Lindahl, he has published two interviews with Karl Popper on the mind-brain problem. E-mail: peter.arhem@ki.se