# The duality of psycho-physics

Stanley A. Klein

School of Optometry, University of California
Berkeley, CA 94720, USA

This is another paper on the mind-body problem and on the question of whether computers can ever become conscious and have feelings. Dozens of papers and books are written on this topic every year. The great philosophers from Plato through Descartes and Kant wrote and worried on it. So why another paper? Four reasons:

1. This conference on visual perception is in the land of Rene Descartes, who gave the first clear statement of the mind-body problem, and of Alain Aspect, the physicist whose recent experiments (to be discussed) cast doubt on an objective world that exists without being observed. It seems entirely appropriate to honor and connect the contributions of these two Frenchmen.
2. This particular session of the conference is about tacit assumptions in our models of vision. We should ask what assumptions about consciousness and the homunculus we need for our models. Is it possible to truncate the infinite regress associated with the homunculus? How are our subjective impressions linked to our objective button pushes? It is good to get the tacit assumptions out on the table.
3. The name of our field, "psychophysics", entitles us to be the "chosen field" to worry about the connection between psyche and physics.
4. Last, but not least, I have a novel situation for the mind-body or the subjective-objective duality, related to a little-known aspect of quantum mechanics.

Section 1 of the paper attempts to show that there is a problem worth worrying about. Section 2 introduces the laws of quantum mechanics. Section 3 provides a solution to the mind-body problem based on a little-known quirk of quantum mechanics.

**Section 1. Is there a problem?** Most scientists, being materialists, would say that there is no mind-body problem; they would say that the mind is reducible to the operations of the brain. So the first task of this essay is to convince the reader that there is a mind-body problem. I will begin with definitions of what I mean by the mind and body. Then a brief history of the mind-body problem is presented to help us understand how this state of affairs came about. Part of this history is an examination of how the success of reductionism tempts one to believe that the mind can be understood in terms of the brain. Finally I will present arguments for why my mind is not reducible to the physical operations of my brain. Once we have established the non-equivalence of mind and brain we are back to the classical problem of how the mind and brain interrelate. It is to this question that I offer a novel answer in Section 3.

This morning as I was writing this paper I asked my wife whether she thought a robot could ever have feelings or be conscious. She thought is a dumb question because without the slightest doubt she answered, "NO!" She feels there is something very special about our emotions and thoughts that will always be missing from robots. Those readers who agree with my wife can skip Section 1 and proceed with Section 2 on quantum mechanics. Section 1 is for those people whose scientific training has given them too great faith in reductionism, and for those whose science fiction reading (Hofstadter & Dennett, 1981) convinced them that it is no big deal for robots to have humor, emotions and self-consciousness.

A hint that the mind might cause trouble for reductionists is that so many respectable scientists and philosophers are still writing and arguing about it. The same issue is found under many guises: Will computers ever gain consciousness? Can algorithmic machines solve nonalgorithmic problems? What is the substrate for human consciousness? Can one have free will in a deterministic body? How does one identify a thought such as "I am happy" with brain mechanisms? The surprising point of this essay is that these questions might have answers.

**1a. Definition of body.** By "body" I mean the brain as a machine. The essential property of a machine is that its operations can be understood in terms of the presently known laws of physics, chemistry and biology, similar to how the eye is understood (or is expected to be understood).

It is possible to define body differently. Recently Searle (1980, 1990) and Penrose (1989) made a distinction between a machine that is equivalent to an algorithm (a universal Turing machine) and a machine with "meat" (as allowed in our definition) in which the processing is hardware dependent. The definition of body as algorithm is associated with what Searle calls the Strong AI position. Searle believes Strong AI to be wrong and Section 1d offers a suggestion on how Strong AI can be modified to appease him. Another view of body is proposed by Penrose who believes that changes in the laws of physics are needed to account for brain operation. Section 1e will examine Penrose's unique view of the brain's machinery. I will argue, however, that these different definitions of what is meant by "body" are irrelevant to the mind-body problem.

Definition of mind. The aspect of mind to be considered in this paper is subjective <u>feelings</u>. By feelings I mean the type of feelings I feel when I feel strong feelings. The point of this circular definition is that subjective states don't like to be reduced to words. Haugeland (1985) does an excellent job of classifying feelings and pondering what it would mean for a computer to have feelings. I focus on feelings rather than thoughts and awareness (consciousness) since feeling a sharp pain is clear and vivid. Defining mind in terms of thoughts and awareness would have led us astray into abstract philosophical discussions of intentionality. There is nothing abstract about a strong feeling. We all know the feeling of pain. Subjective feelings are sufficient to produce a mind not reducible to a brain, which is all that is needed for this essay. In a strict sense I am the only entity with feelings, but as shall be discussed in connection with Turing's "imitation game", there are circumstances in which, through empathy, I might become convinced that another entity also has subjective feelings. Since this definition of mind focuses on subjectivity, the mind-body problem is one version of the subjective-objective problem: How can we reconcile the observer's subjective world with the objective world of the observed? Those who have studied quantum mechanics will notice a familiar ring to this way of stating the problem.

Section 3 will discuss the important distinction between the mind as a carrier of feelings vs. mind as observer.

**1b. A statement of the mind-body problem.** Science seeks to understand *you* as a machine, to explain *your* every action, including why *you* scream when badly hurt, squirm when tickled and why *you* say *you* feel happy (or frustrated) when *you* contemplate philosophy. On the other hand, as pointed out by philosophers of mind, *my* subjective feelings while in pain or being tickled, or while contemplating philosophy, are not equivalent to the associated neural impulses. The mind-body problem arises because of the paradox of being able to totally reduce *your* (observed) brain to neural events, while not being able to do the same reduction to *my* (observer's) brain. Quantum mechanics, with its sophisticated duality, provides a novel solution to this dilemma.

**1c. History of mind-body problem.** Galileo (1564-1642), the father of modern science, is a good starting point. H e showed that combining reason with experiments produced a powerful tool for learning about nature. However, he got into trouble with the church because, by not explicitly removing the mind from his domain of study he was encroaching on the province of the church. The first to make a clear separation of mind from nature was Descartes (1596-1650), the first modern philosopher and the first modern mathematician. Cartesian duality is usually discussed in the context of how nasty it is because of the difficulty in figuring out how the physical and the mental halves of the duality interact. An excellent analysis of Cartesianism is given by Lockwood (1989). What is often forgotten in discussions of Descartes' contribution is that his duality provided the underpinning for the scientific revolution that was to follow. By getting the mind out of the operation of the physical world, Descartes' metaphysics paved the way for Newton and followers to develop a purely mechanistic universe with minimal complaints from the church. It was Newton (1642-1727) who had the greatest impact on removing mind and magic from the operation of nature (although Newton himself did believe in magic). Before Newton, the heavens were still assumed to operate according to aesthetic principles, such as Kepler's (1571-1630) proposal that the planets move according to "musical harmonies." After Newton, the motions of all bodies, both heavenly and earthly, moved in straight lines unless affected by simple forces such as gravity. A mind wasn't needed to keep the system running, and it would keep running even if no minds observed it. The success of this mechanical reductionist approach to explaining nature is well known to us.

**Reductionism.** The materialist worldview is that everything in nature can be understood in terms of the physical world. Complicated phenomena can be explained in terms of simpler underlying mechanisms. The scientific explorations of 300 years following Newton have produced a worldview in which the realm of the physical has been constantly expanding. The success of the reductionist program has left little room for mind. It is sometimes claimed that quantum mechanics has drastically changed the materialist worldview. Not so. The world of quantum mechanics still operates by precisely stated principles and forces and there is no room for influences outside its narrow framework. Quantum mechanics does not, for example, tolerate a "mind-force" working outside the physical realm that is nevertheless able to influence the probabilities of events.

It may surprise some people that even though reductionism places limits on possible explanations of events, it is not opposed to duality, but is in fact one half of a duality. To make this point I reprint the last paragraph of Descartes' "Treatise of Man" (Descartes, 1664):

> "I desire you to consider, further, that all the functions that I have attributed to this machine, such as … waking and sleeping; the reception by the external sense organs of light, sounds, smells, tastes, heat, and all other such qualities; the imprinting of the ideas of these qualities in the organ of common sense and imagination; the retention or imprint of these ideas in the memory; the internal movements of appetites and passions; and finally, the external movements of all the members that so properly follow both the actions of objects presented to the senses and the passions and impressions which are entailed in the possible and that they follow naturally in this machine entirely from the disposition of the organs—no more nor less than do the movements of a clock of other automaton, from the arrangement of its counterweights and wheels."

This dramatic affirmation of reductionism by the father if duality emphasizes that a person can believe in both duality and reductionism.

Less than 100 years ago there was still a belief that the reductionist program might be halted. It was thought that there might be something special about life that couldn't be reduced to chemistry. Biologists and physicists were searching for a new fundamental force that they thought was needed to explain life. However, within the past 50 years it has become clear that the life-force can be understood in terms of DNA and proteins, using the same laws of chemistry that govern inanimate matter. It has been found that biology can be reduced to chemistry, which can be reduced to physics and quantum mechanics.

When it comes to explaining consciousness of mind, there is again the possibility that the reductionist program will fail. This time the possibility of failure is greater than ever before for one paramount reason. The reductionist program has collapsed in another arena: quantum mechanics. Since, as I will argue, the quantum duality is split along a similar subjective-objective cut as the mind-body problem (remember our definition of mind as subjectivity) it is possible that it is the same duality (the theme of this essay). Possibly the clever way in which the quantum duality both is and is not reductionistic might apply to the mind-body duality.

In order to clarify my views of the mind-body problem it is useful to compare them to alternative viewpoints. Sections 1d and 1e will examine the points of view of Searle (1980, 1990) and Penrose (1989). Both of these authors have generated a good deal of discussion recently.

**1d. Strong AI: an aside on Turing's imitation game.** Strong AI believes that both mind and body will some day be understood in terms of a complex algorithm, independent of the hardware implementing the algorithm. Searle (1980, 1990), however, argues that algorithms can not be minds. He makes the analogy to how a person doesn't understand Chinese if all he knows is how to follow an algorithm written in English that specifies how to respond with Chinese letters to a question given in Chinese letters. That is, minds can understand, algorithms can't.

The Strong AI program seeks to convince us that a sufficiently clever algorithm can have feelings by playing Turing's imitation game. However, I now will argue that the usual version of the imitation game would not work for me.

The way a robot would go about convincing me about its feelings it that we would spend a few days living together. I am a skeptical person, but I am open-minded and might be convinced. I do, for example, believe that dogs have feelings. I have seen the looks on their faces and their wagging tails. I know that if I felt happy and excited and had a tail I would wag it just as a dog does. Most important for me is that I know that dogs are made of the same kind of stuff as I am. A robot on the other hand, would have great trouble convincing me that it had feelings. I can easily imagine a futuristic robot with a modulated voice (such as HAL in the movie 2001 or C3PO in Star Wars) that could evoke my empathy even better than could a dog. However, I don't think that HAL of C3PO would convince me that they truly had feelings. I'd be skeptical and worry that they were just programmed to imitate feelings and to respond as would a feeling person. I, in agreement with Searle, will never be convinced that an algorithm can have feelings.

Does this mean that no robot could convince me that it has feelings? No. Here's what a robot could do to convince me. After conversing for a few days and getting angry with each other, I would finally realize that one of the reasons that I doubted its feelings if that for me feelings involve sensations in my stomach, muscles and nerve endings throughout my body. At this point, the robot, would hand me a screwdriver and allow me to inspect some of its innards. It would show me the flask in its chemistry panel where dozens of chemicals were being mixed. It would point out that its many internal sensors were "feeling" a large excess of hydrochloric acid that had recently been added because of its aggravation with me. A few more conversations like this and I might become convinced that the computer algorithm plus the hardware were close enough to what was going on inside me that this creature actually had feelings. This conclusion is the same as Searle's point that thinking and understanding is tied to the brain's *hardware*.

The argument above indicated that for a robot to convince me it had feelings it had to show me specific hardware and plumbing as well as being a sophisticated conversationalist with a sense of self. An electronic stimulation of the "stomach" would definitely not convince me because a real feeling needs real hardware. Since I am the only creature that I really know has feelings I attribute feelings and subjective awareness to others only to the degree that their innards are like mine. The word "feeling" thus has a strong anthropomorphic connotation. I suspect that the simple "stomach" flask described above was too simple to convince me. In addition to seeing the stomach and sensors I would need to see that the robot's brain was organized like my brain before I could ever accept that it had feelings. The brain is more important than the stomach since one doesn't need a stomach to have feelings. A futuristic live head, severed from the body, would be expected to have feelings when electrical stimuli are applied to the nerves that came from the stomach. See Dennett (1978) for a wonderfully humorous discussion of these issues.

I should point out that although the above discussion might seem to be an exercise in how I gain knowledge (epistemology) it is really an exercise in the true nature of the robot (ontology). What convinces me about the robot's ability to feel is seeing of what "stuff" the robot is built. When I see it has "nerves", "juices" and cortical activity like mine then I might be swayed about whether I think it has feelings.

The usual assumption about the relationship between Strong AI and dualism is that Strong AI is not dualistic since it claims to produce a mind out of an algorithm. Searle (1990), however, offers the following twist on this subject:

> The polemical literature in AI usually contains attacks on something the authors call dualism, but what they fail to see is that they themselves display dualism in a strong form, for unless one accepts the idea that the mind is completely independent of the brain or of any other physically specific system, one could not possibly hope to create minds just by designing programs.

From the point of view of this essay, Searle's indictment that Strong AI is dualistic might turn out to be a compliment rather than an indictment since we will be showing that duality is an attractive ontology that has proven to be successful in its quantum embodiment.

**1e. The Weak AI version of the mind-body problem.** Weak AI is based on the assumption that the brain is not algorithmic, but has some special hardware that can do the "feeling." This is exactly the point of adding the chemical flask plus sensors to the robot to act as a "feeling stomach" in Section 1d. A much more sophisticated hardware addition is advocated by Roger Penrose (1989). Penrose argues that a brain can do things that algorithms can't do. The crucial step is his argument concerns Godel's theorem which shows that within any algorithmic system there are theorems that can't be proven true or false from within the system, but which mathematicians can show to be true. Penrose, however, is on shaky ground since it should be possible for the computer to do just as well as the mathematician by expanding the computer's axiomatic base. Penrose argues that brains need something beyond algorithmic computation in order to function. He then goes out on a most fascinating limb, further than he needs to, with a speculation that quantum mechanics must be changed because of gravitational effects. He uses these gravitational effects, together with speculation on how present quantum theory is inadequate in his story of how consciousness might operate. Most neuroscientists, on the other hand, believe that someday we will have a reductionist explanation of consciousness and feelings (Crick & Koch 1990a, b; Freeman, 1990) without needing to change the present quantum laws.

There is indeed the possibility of a new theory coming along and radically changing our views of brain mechanisms (and possibly quantum mechanics). As Delbruck (1986) points out, the situation may be similar to what DNA did for biology:

> It might be said that Watson and Crick's discovery of the DNA double helix in 1953 did for biology what many physicists had hoped in vain could be done for atomic physics: it solved all the mysteries in term of classical models and theories, without forcing us to abandon our intuitive notions about truth and reality. Upon the discovery of the DNA double helix, the mystery of gene replication was revealed as a ludicrously simple trick. In people who had expected a deep solution to the deep problem of how in the living world like begets like it raised a feeling similar to the embarrassment one feels when shown a simple solution to a chess problem with which one has struggled in vain for a long time.

What kind of hardware might be required by a Weak AI understanding of consciousness? Descartes wondered how our conscious awareness is unitary even though our brain is split into two hemispheres. He speculated that the unitary mind is centered in the Pineal gland, one of the few brain structures that are unitary rather than paired. More recently there have been several proposals, with preliminary data to back them up, on how distant parts of the brain might be coupled together to act as a single entity. Consciousness might be based on something like the proposal of Crick & Koch (1990 a,b) that the 50 Hz signals found by Freeman (1985), Gray et al. (1989) and Eckhorn, et al. (1988) or the synchronous firing proposed by von der Malsburg & Schneider (1986) binds together all regions of the brain that are attended to at that moment (see Science (1990), **249** p. 856-858 for a summary). My point in mentioning the 1990 theories of awareness is to indicate that brain researchers are actively looking for the substrate of consciousness and intentionality. They may well find a relatively simple feedback process or neural structure that is straightforward to implement in a robot and to stimulate with an algorithm. Crick & Koch (1990 a,b) outline a host of specific experiments that must be done before the "DNA" of consciousness can be expected to be revealed. However, it is most important to point out that any future reductionist theory of consciousness would not change the dualistic nature of the mind-body interrelationship. The reductionist story is just one half of the duality.

**1f. The ethical distinction between mind and machine.** Barlow (1990) has recently written about an *ethical* reason for making a distinction between mind and brain. He sees a danger in treating people as machines because we are amoral in our use of machines. Barlow fears that moral structures (Thou shalt not kill) would be undermined if minds were reduced to machines. I disagree and believe that the opposite will happen. Rather than humans being ethically reduced to machines, I expect that the feeling and thinking robots of the future will be accorded rights similar to humans. In order to become ethical entities with rights and responsibilities, these future robots must exhibit intentionality (a technical philosophical term related to the robot's understanding and meaning of the symbols it uses), free will (an ability to make decisions independent of its programmer and its environment), a self awareness, and an awareness of the implications of its decisions. How a robot might be given these qualities and capabilities will not be discussed here. Many defenders of Weak AI would be delighted to invent scenarios on how computers of the future could obtain these qualities and capabilities (including their careful definitions).

**1g. Why mind is not reducible to body.** Suppose some wonderful theory comes along that explains consciousness to the satisfaction of all concerned scientists. Suppose even, that our understanding of the brain has advanced to the point such that by monitoring the voltages in a small subset of neurons we are able to reliably predict what the person is feeling and thinking. Would this understanding of the mind imply the end of the dualistic mind-body problem? I say no!

a. The original problem that Descartes first faced is that the subjective mind and the objective body are operating on entirely different levels. We still have the problem discussed above that my own *subjective feelings* are qualitatively different from what produced the feelings. Even though one might have an excellent explanation of why I am feeling a certain way, that is quite different from the subjective feel of the feelings. Einstein agreed and supposedly said: "Science can't tell you the taste of chicken soup". This is the subject of many philosophical analyses of mind (Hofstadter & Dennett, 1981; Kolak & Martin, 1990). The philosophers then get stumped because they do not know what to do with the resulting dualistic theory. They are fearful of wholeheartedly embracing the duality. One exception is the philosophical analysis by Lockwood (1989) who provides a thoughtful reexamination of Descartes' duality in light of modern knowledge.

b. There are pragmatic and religious reasons to maintain the mind-body split. Suppose your belief that you are a machine has made you start acting like a machine and you would like to change that behavior. Suppose you would like to have a conversation with God to put some extra meaning in your life, but your materialist worldview makes it difficult. The duality theory to be discussed in Section 3 makes it legitimate to be a materialist at one moment and a God fearer (or God himself or herself) the next moment.

   Many religions (Judeo-Christian, New Age, humanism) say that strong beliefs can create realities. For example, my belief that people around me are nice can make people around me nice. My belief that I can solve a problem can help me solve the problem. A person's belief in God or extraterrestrial "guides" (Lilly, 1972; Jeffrey & Lilly, 1990) who give advice and companionship can provide courage to get through difficult challenges and losses. The religious worldview allowed by a dualistic system seems to enable some people to cope with our complex world.

The split between mind and body is equivalent to the split between religion and science. If it were not for this split, scientists might still be persecuted like Galileo, and religionists would be intimidated by the constant expansion of science. The split allows friendly relationships between people with very different worldviews. The democratic nature of a dualistic metaphysics is one of the most important outcomes of the point of view that I will be advocating at the end of this essay.

**1h. Further reading.** The goal of Section 1 was to provide background on the mind-body problem and in particular to argue that there is a problem. Further information can be found in the many books published every year on this topic. Recent books that I have found most useful are Churchland's "Matter and Consciousness" (1988), Penrose's "The Emperor's New Mind" (1989) and Gregory's "The Oxford Companion to The Mind" (1987). In addition, the Artificial Intelligence debate between Searle and the Churchlands in the January 1990 Scientific American is required (and fun) reading. John Lilly's biography (Jeffrey & Lilly, 1990) provides a unique perspective of the power of the mind and of the lives of some of its explorers. The entertaining collection of articles in Hofstadter & Dennett (1981) and Kolak & Martin (1990) discuss both sides of our central question concerning how to connect the first person and third person experiences. My only criticism of these books and articles is that they do not appreciate that the two halves of a duality can fit together in a beautifully elegant and precise manner. That is the topic of Section 3 of this essay.

**Section 2. Quantum Mechanics.** This is not the place for a detailed introduction to quantum mechanics. Herbert's excellent book "Quantum Reality" (1985) does a superb job of examining quantum mechanics and its implications. Feynman's Lectures (1965) and his book "QED" (1985) give the master's view not only of quantum mechanics but also of the forces governing atomic structure. The present summary is limited to those points needed for the discussion of duality.

Quantum Mechanic, developed in 1926-1927 by Heisenberg and Schroedinger, is the theory that underlies all of physics and chemistry. It has been unbelievably successful, with no known violations and with some calculations (energy levels of hydrogen and magnetic moment of the electron) accurate to more than 10 decimal places. The most interesting feature of quantum mechanics for us is that it is a dualistic theory. The thousands of years of human thinkers from Plato to Kant couldn't put together a pretty mind-body duality. Nature, being cleverer than her humans, did figure out how to arrange a pretty duality with a remarkable way of connecting the two halves of the split.

Quantum mechanics is dualistic. The generally accepted interpretation of quantum mechanic, the Copenhagen Interpretation, was put forth by Bohr who insisted on its dualistic nature. This interpretation of the meaning of quantum mechanics was an outcome of the historic debates between Bohr and Einstein that have been eloquently written up by Bohr (1949). Einstein never accepted the probabilistic nature of quantum mechanics. Stapp (1972) provides a clear discussion of the Copenhagen Interpretation. Alternative interpretations of quantum mechanics will be shown in Section 3 to actually be consistent with the Copenhagen view. The Copenhagen Interpretation says that the universe must be split into two parts with very different laws governing the two halves. Above the split is the real world with which we are familiar. Observations are made, feelings are felt, experiments are described classically. The world looks almost like the classical world of Newton in which matter exists as particles with definite locations. Below the split the laws are very different. No observations are allowed. Contrary to some interpretations of the uncertainty principle, there is no uncertainty about the laws of nature of the state of the system beneath the split. The state of the system is represented by a set of complex numbers, called amplitudes or wave functions. Feynman (1948, 1985) proposed a set of algorithmic rules, compatible with relativity, for calculating the amplitude for the state of the system to propagate from one time to a future time. The connection between the two sides of the duality is surprising, but simple. The probability for an event to occur in the world above the split is equal to the magnitude squared of the amplitude for that event below that split. This connection does not violate the essential nature of a true duality which is that the properties above the split cannot be reduced to the laws below the split. Of importance for the present essay is the question of where the split should be placed, to be considered in Section 3.

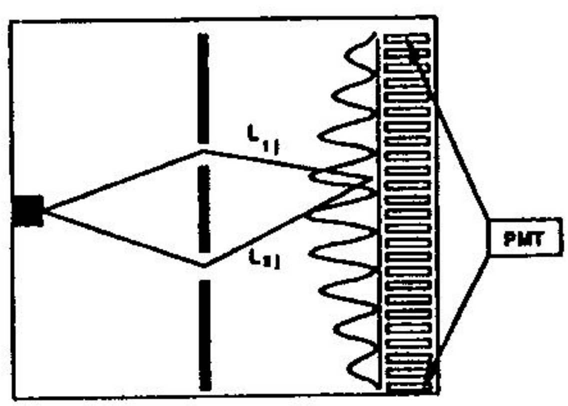


Fig. 1.

**Double slit experiment.** It is useful to describe a concrete example: the double slit experiment shown in Fig. 1. A source of photons is directed at a metal plate with two closely spaced slits. At the back of the box are hundreds of photomultiplier tubes (PMT) which detect individual photons. In such a situation the split is usually placed so that the photon source and the detectors are above the split and the metal plate with the slits is below the split. Thus each photon is prepared classically and is detected classically. The photomultiplier tubes are acting as the observers. Every time a photomultiplier clicks, a photon is being observed. Between the entrance hole and the detectors, no observations are made. Thus it is not possible to tell through which slit the photon went. Quantum mechanics as formulated by Feynman (1948) says that the amplitude to get from the entrance hole to one of the Geiger counters is the sum of the amplitudes for each path the electron could take. Feynman showed that all possible curved paths should be included, but for the simple double slit experiment the answer is the same as if one only considers 2 straight-line paths, one through each slit. The amplitude to go through the *i*th slit to the *j*th counter is given by the complex number $E_j \exp(i\phi)$. The phase, $\phi$, equals $2\pi L_{ij}/\lambda$, where $\lambda$ is the wavelength of the photon and $L_{ij}$ is the distance from the *i*th slit to the *j*th detector. The exponential is simply a mathematical notation that allows one to keep track of the phase of the wave. The Gaussian-like envelope function $E_j$ is present to normalize to unity the probability of finding the photon somewhere. For simplicity we neglect the slight dependence of the envelope on the slit number. The photon's wavelength was determined by the experimenter who sent the photon through the hole. By combining all I have said so far, the amplitude of finding the photon in the jth counter is approximately:

$$A_j = E_j \left[\exp(i2\pi L_{1j}/\lambda) + \exp(i2\pi L_{2j}/\lambda)\right]. \qquad (1)$$

We now want to connect the world below the split to the physical world above the split. As stated earlier, the connection between the two is that the probability for an event to take place is given by the magnitude of the amplitude squared:

$$\text{Prob}_j = 2\, E_j^2 \left[1 + \cos(2\pi\,(L_{1j} - L_{2j})/\lambda)\right]. \qquad (2)$$

We have now completed a full quantum mechanical calculation. The cosine term in Eq. 2 is due to the photon's wave nature of being able to sample both slits, resulting in a sinusoidal probability of landing in a given photomultiplier counter, as shown in Fig. 1.

When the multiplier slit experiment was actually carried out for photons, the characteristic interference pattern was found. The situation makes no sense to classical ways of thinking because it means that when nobody was looking the single photon sampled both slit 1 **AND** slit 2. According to classical thinking the photon would have gone through slit 1 **OR** slit 2. Many physicists have tried to reduce or modify the **AND** logic or quantum mechanics to the **OR** logic of classical mechanics. They have not succeeded. Photons and all other matter behave as waves when not observed and as particles when an observation is made. This behavior is called the wave-particle duality. Physics offers no reductionist help in showing how the localized particles can be obtained from the spread-out wave.

**Schroedinger's Cat.** Although the double-slit experiment with its wave-particle duality violates one's sensibilities most physicists accept it when it involves low mass particles such as photons, electrons or atoms because quantum mechanics does so well in correctly predicting their behavior. However, quantum mechanics know no boundaries and when applied to macroscopic phenomena we begin to feel queasy. The physicists created a theory that was more successful than they may have wanted. To illustrate the macroscopic implications Schroedinger (1935) developed the parable, now called the Schroedinger's Cat paradox, in which a cat is coupled to a quantum mechanical process, like the double slit setup, except that a trigger is pulled to kill the cat if the photon went in the upper slit. If the cat is not observed then it is in a superposition of states just as the photon was in a superposition of states in going through both slits. Before being observed the cat is both alive and dead rather than the classical notion of being alive or dead. In principle an interference experiment could be carried out between the alive and dead states just as was done for the photon going through the upper and lower slit. The cat parable points out the unusual nature of quantum mechanics. When the system is not observed it is in a state that does not correspond to out usual notions of reality. Most physicists are not bothered by this situation; in fact, they never even think about it. There are also physicists, however, who are deeply disturbed by the implications that unobserved states do not have properties. It is our goal to show that even though quantum reality might be a bit disturbing it is also quite beautiful.

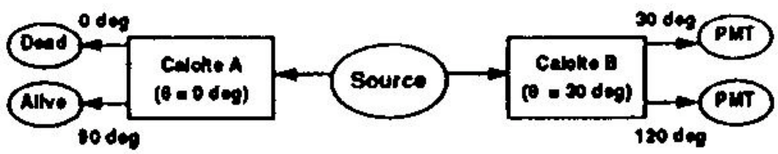


Fig. 2. The source in the center emits two photons. The calcite crystals split the beam according to the photon's polarization. The photomultiplier tubes (PMT) detect photon B. Photon A determines whether the cat is dead or alive.

The gedanken experiment shown in Fig. 2 adds further insight both for the Schroedinger Cat and also for the forthcoming discussion of Bell's theorem. The photons now come from the radioactive decay of positronium. This decay has the property that two photons, A and B, are always emitted in opposite directions and they always have the same angle of polarization. The photons then pass through calcite crystals as shown. Calcite has the property that an incoming photon whose polarization is aligned with the crystal will go through the calcite undeviated whereas for the perpendicular polarization it will be given a small displacement. The advantage of calcite over a simple polarizer is that calcite analyzes the state of polarization without absorbing any photons. Suppose in our experiment the crystals A and B are oriented at 0° and 30° respectively. Calcite B will direct photon B into the upper or lower beam depending on whether its polarization is 30° or 120° (polarization at any other angle can be expressed as a superposition of 30° and 120° polarizations). The polarization of photon B is determined by placing a pair of photon detectors (photomultiplier tubes) at the two exit positions of the 30° calcite. Since the polarization of photon A is the same as that of photon B (due to the properties of positronium decay) the polarization of photon A is known without measuring it (since we measured photon A that has the identical polarization). With this setup we know the exact timing of each individual photon A, and we know its polarization (either 30° or 120°) before it enters calcite A.

We now use the upper beam (vertical polarization) to trigger the machine that kills Schroedinger's Cat. According to quantum mechanics the state of the cat is: cos(q)|alive> + sin(q)|dead> where q is the angle between the polarization of photons A and B and the notation | > is used to specify the state of the system. If photon B is in the upper beam (q = 30°) then the cat wave function is: .866|alive> + .5|dead>. The cat has a 75% chance of being alive and a 25% chance of being dead (the probability is the amplitude squared, i.e. $\cos^2$(q) ). If photon B is in the lower beam (q = 120°) then the cat wave function is: -.5|alive> + .866|dead>. This exotic version of the Shroedinger Cat paradox shows that the relative sign between the live and the dead cat depends on whether photon B was polarized at 30° or 120°. Since quantum mechanics applies to large as well as small objects, one could in principle extract this sign, so in some sense the cat is both alive and dead when not being observed. This refined representation of the Shroedinger Cat paradox was given to strengthen the case that the cat is actually in a superposition of states.

**Bell's Theorem.** John Bell (1965) noticed an important property of the gedanken experiment with the calcite. He wondered what would happen if, after the positronium decay, the orientation of the calcite A had been switched from 0° to -30° or if calcite B had been switched from 30° to 0° (I am changing the details of Bell's experiment to simplify the discussion). The experiment with the fast switchers is shown in Fig. 3.

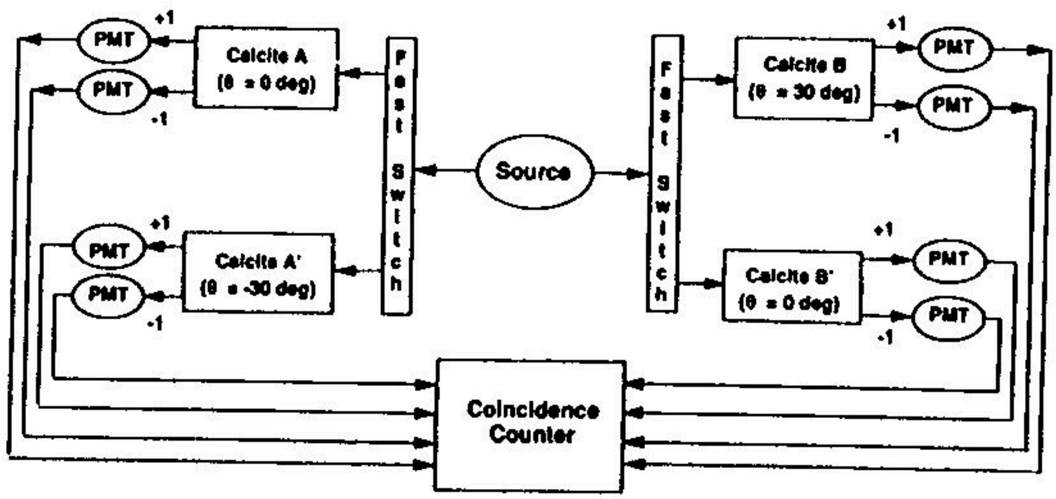


Fig. 3. The source in the center emits two photons. The fast switches direct each beam into one of two calcite crystals, which then splits the beam according to the photon's polarization. The photomultiplier tubes (PMT) detect the photons and send the detection information to coincidence circuitry to calculate the correlations.

One can make the following table enumerating all possible outcomes of the 4 possible experiments.

| Decay | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A (at 0°) | **+1** | –1 | –1 | +1 | **+1** | +1 | –1 | **–1** | **+1** | **+1** | –1 |
| A' (at -30°) | –1 | **–1** | **+1** | **+1** | –1 | **+1** | **+1** | +1 | +1 | –1 | **–1** |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B (at 30°) | **+1** | **+1** | –1 | **+1** | –1 | +1 | +1 | –1 | **–1** | **+1** | **+1** |
| B’ (at 0°) | +1 | –1 | **–1** | +1 | **+1** | **+1** | **–1** | **–1** | +1 | +1 | –1 |
| Correl.(AB’+AB+A’B’-A’B) | +2 | +2 | +2 | +2 | –2 | +2 | –2 | +2 | +2 | +2 | +2 |

There are 4 possible experiments (AB, AB’, A’B, A’B’) since each crystal could have two orientations as shown in the column at the left. The top row counts the decays of positronium. The next 4 rows list possible outcomes of whether the photon goes into the top (+1) or bottom (-1) path of the calcite. The numbers were chosen randomly except that when both calcite crystals are oriented at 0° the photons are perfectly correlated. If photon A goes up then so does photon B. The bottom row is a curious sum and difference of products of pairs of rows devised by Bell. Notice that the sum is either +2 or –2. Then Bell took the average of these products, which turns out to be less than 2. Now comes the problem. Alain Aspect did this experiment, in Paris, and found that the final average was significantly greater than 2! Quantum mechanics predicts that the average of each product is given by $\cos^2(q)$ where q is the relative angle between the two calcite crystals. This $\cos^2$ law, commonly known as the Law of Malus, predicts a Bell sum of: Sum = $1 + 2\ \cos^2(q) - \cos^2(2q) = 1 + 2 \times \_ - \_ = 2.25$ since q=30° for the above arrangement. Aspect’s experiment was in agreement with the quantum mechanical prediction and in disagreement with the logic we used above to give Sum □ 2.

The Copenhagen Interpretation of quantum mechanics has no problem with Bell’s Theorem since calcite A could not be oriented at both 0° and 30° for a particular decay. The bold numbers in Table 1 indicate the actual orientations for each decay. One should not ask what would have happened on that trial had the calcite been rotated, since that experiment was not done. The only experimental results that can be considered are experiments actually performed. The conclusion to be drawn from the violation of Bell’s Theorem is that the photons were not real before they were observed. By real, one means each photon had properties, such as polarization, before it was observed. If photon A had been real before it was observed then it would have made sense to ask about its properties as seen by an analyzer at an arbitrary angle. Aspect’s experiment rules out the possibility that the photon had properties before it was observed. An alternate interpretation of the violation of Bell’s inequality is that the photon does have properties such as polarization before it is observed, but there is a nonlocal interaction such that photon B “knows” the outcome of the experiment on photon A. In this case, Table 1 is invalid because whether photon B decides to go into the +1 or the –1 beam depends on the orientation of calcite A. Aspect’s experiment was designed so that the orientation of the polarizer was switched while the two photons were in flight so that information about the orientation of polarizer A would have to go faster that the speed of light to reach photon B in time to affect whether it goes into the +1 or –1 beam.

Aspect’s experiment together with Bell’s theorem imply that the world is either nonlocal or not real. Typically, authors who discuss these issues choose whether they prefer locality or reality to be violated. The dualistic nature of quantum mechanics allow both interpretations of the violation depending upon which half of the split is being considered. The rules of the real world above the split are nonlocal. The rules of the unobserved world below the split are local but not real (a particle can simultaneously have conflicting properties). Stapp (1990b) recently relaxed the reality assumption that was needed to derive Bell’s theorem. He derives Bell’s inequality from the simple assumption that any observation results in a unique answer (ruling out the "many worlds" interpretation).

Bell's theorem and Aspect's experiment imply that our world is very different from the classical world of Newton. The failure of many attempts to reduce classical mechanics to quantum mechanics is what qualifies the laws of quantum mechanics to be a true duality. Having an example of a true duality is a breakthrough for philosophers who have been fiddling with past dualities. The duality of quantum mechanics is much more explicit than previous dualities such as Descartes' mind-body duality and the yin-yang dualities of Eastern religions. These old dualities were fuzzy in that the worldview on each side of the split and the connection between the two sides weren't precisely specified. For quantum mechanic duality, on the other hand, algorithms are available for how to do computations on both sides of the split. In addition, the quantum mechanical duality solves the split placement problem in a most elegant manner as will be considered next.

**Summary.** The characteristics above and below the split are summarized in this Table.

| <u>Below split</u> | <u>Above split</u> |
|---|---|
| to be observed | observer |
| deterministic laws | probabilistic laws |
| Feynman rules | Classical rules (almost) |
| behaves like waves | behaves like particles |
| local interactions | some nonlocality |
| objective | subjective |
| body | mind |
| "dead" <u>and</u> "alive" | "dead" <u>or</u> "alive" |

**Section 3. Von Neumann's insight that the split is moveable.** In 1932 von Neumann published a most influential book: "The Foundations of Quantum Mechanics" (von Neumann, 1932). It is remarkable that so soon after quantum mechanics began, von Neumann wrote the book that still provides the mathematical foundation for the subject. To me the most interesting feature of quantum mechanics for the present discussion is a point, derived by von Neumann, which has received little notice. Von Neumann showed that the laws on both sides of the split are so cleverly constrained that the precise location of the split is not critical. **The split can be moved.** I will argue that the moveable split feature of quantum mechanics is exactly what is needed for overcoming the stickiest aspects of the mind-body problem.

**3a. Schroedinger's cat again.** Schroedinger's cat is useful for illustrating von Neumann's insight as shown in the following sequence of panels. The split is shown by the dotted line. The leftmost panel gives the standard Schroedinger cat story. There is a single observer, to be called O1, outside the box. Before O1 opens the window to look, the cat is in a superposition of being both alive <u>and</u> dead. By opening the window and looking, O1 "collapses the wave-packet" so that the cat is now in a unique state of being alive <u>or</u> dead. The story gets more interesting if we place O1 in a second box as shown in the second panel. If I, the second observer, am not looking, then O1 is in a superposition of states seeing an alive cat <u>and</u> seeing a dead cat. Once I make an observation, O1 collapses to one state or the other. The third panel removes the split even further, placing it in my brain.

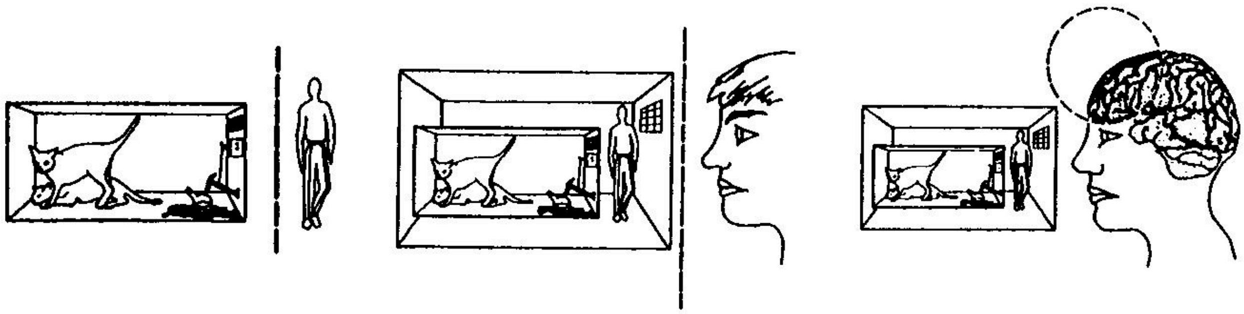

Fig. 4. Three placements of the quantum split are indicated by the dotted line. The left panel shows Schroedinger's Cat with observer O1. The middle panel has O1 inside a second box. I am the second observer (shown by the face). In the right panel a portion of my brain has been separated out as mind, with the rest of my brain as body.

**3b. Interpretations of different placements of the split.** The following placements are in ascending order.

**Bohm's real world of hidden variables.** David Bohm (1952) proposed a quantum formalism in which there was no split. All nature was on the same side as the observer. In terms of the moveable split, Bohm's formalism is equivalent to a placement of the split at the very bottom (see the last paragraph of this section for further discussion of whether this is a legitimate placement). We end up with a real world in which real particles are guided by an invisible "pilot wave" that is very similar to what had previously been the full quantum mechanical wave function. As pointed out in the previous section in connection with Bell's theorem, it is a world with nonlocal, complex interactions. It should be emphasized that the nonlocal interactions must be consistent with other placements of the split, so faster than light communications are ruled out. Proponents of "New Age" and Eastern religion seem to like the nonlocal aspects of the interactions. This placement of the split has the advantage that the split is invisible so that it looks like a unitary rather than a dualistic theory. This formalism, lacks elegance because unnecessary aspects of the wave function are carried along. Higher placements of the split, to be discussed next, seem cleaner because one only needs to deal with measured qualities and after a measurement the "non-actualized" outcomes are discarded. Stapp (1990b) raises a concern that Bohm's formalism includes predestination, the same as classical mechanics, that makes some people uncomfortable (rather than making me uncomfortable it makes me smile).

**The physicist's placement.** A physicist would say that the photon was detected (observed) by the photomultiplier tube that was used to trigger the device used to kill the cat. In this view the wave packet collapsed at an early stage so the cat was never in a superposition of states. The same outcome would be obtained if the cat were the observer. Although the physicist may want to keep the split below the photomultiplier tubes, he must tremble at the monster he created. Quantum mechanics that was invented to explain atoms, should also explain groups of atoms, like photomultiplier tubes and cats. The formalism of quantum mechanics does not stop when many atoms are interacting. A few physicists such as Penrose are attempting to modify quantum mechanics so that it fails for large objects, but these modifications have not yet been developed into a consistent theory. There is thus no way at present to stop the split from being placed above the cat!

**Placement in front of the first human.** The left panel of Fig. 4 shows the cat enclosed in a box with the split between the box and the human observer. If no information about the cat's state leaves the box then the cat is in a superposition of states and the collapse occurs when O1 peeks into the box. O1 could peek weeks after the photon was emitted. When O1 looks, he will either see a live cat or a cat that had been dead for weeks. Before he looked, in principle the alive-dead state could be time-reversed and an interference experiment could be done on the combined state to determine the relative phase between the alive and the dead components. This placement of the split, above the cat, corresponds to the theology of the bible in which humans have minds and souls and cats and other animals don't (like machines).

**Placement between other humans and me.** The middle panel of Fig. 4 places O1 plus the cat box in a larger box, with me being the observer. In the middle panel, I am represented by the face. With this placement of the split, other living creatures including humans are below the split, implying that everything about the operation of other humans must be reducible to the deterministic wave equation laws governing all matter. The total behavior of other humans must therefore be reducible to the laws of biology, chemistry, and physics. This is the placement that should please biologists and psychologists whose research careers are devoted to explaining human behavior.

**Placement between all minds and their bodies.** This is a favorite placement for people who write about quantum mechanics and consciousness. The idea is to place all minds above the split and all the rest of nature below. An exceptionally lucid discussion of this placement is given by Wignor (1961) whose article is of special interest to visual psychophysicists since he uses a visual detection task as his gedanken experiment. A similar placement is advocated by Stapp (1990a). We will come back to this placement in Section 3c.

**Placement just below my mind.** The righthand panel of Fig. 4 places the split somewhere in my brain. This placement is similar to a solipsist version of the world where I exist and the rest of the universe is a figment of my imagination. It is, of course, quite different from Berkeley's solipsism since the "imagined" world is operating according to a very precise and deterministic wave equation. This split placement where only one's mind is real and the outside world is an illusion is reminiscent of how Descartes (1641) begins his beautifully written "Meditations." His starting point of "I think; therefore, I am" was based on his analysis that his knowledge of the outside world could be illusory.

In placing the split with my consciousness on one side and the rest of my brain on the other I do not have in mind a spatial placement but something more like a linguistic placement. Consciousness involves the same neurons that are involved in nonconscious activity so it is not possible to separate particular neurons to be on one side and others to be on the other side. One might wonder whether it is legal to place the split between different modes of activity of the *same* atoms. It is gratifying to know that it is very common for physicists to place the split not between different objects but rather between modes of oscillation of a single object. Consider, for example, a measuring device in which the output is a pointer on a meter. Physicists commonly separate out the center of mass mode of motion of the pointer as the only aspect of the needle to be quantized to act as the "observer". The other modes of motion of the needle would be left "unobserved" below the split.

The placement of the split between my mind and my body provides an opportune occasion to comment on free will. The probabilistic nature of the world above the split allows my mind to be "free" to choose what to observe, thereby allowing a bit of free will. It should be pointed out that as the word "free will" is commonly used (especially by social rather than physical scientists), we have much more free will than the tiny bit allowed by quantum mechanics above the split. Free will also operates below the split since a significant percentage of a person's synapses have developed by internal influences in addition to being influenced by outside factors such as the environment and heredity. It is common to refer to behavior caused by this internally developed (although deterministic) aspect of the synapses as "free will." An alternative, less serious, view of free will, obtained by giving the split a microscopic thickness, was suggested by Pirsig (1974).

**Placing the split above me.** It is difficult for me to place the split above my awareness. The state of enlightenment that is the goal of some forms of Eastern meditation may be an attempt to place the split above one's consciousness. The meditation is supposed to stop me from being an observer and to become "at one with the world." The placements of the split discussed earlier involve different linguistic structures. Placing the split above me involves eliminating language and thought.

An alternative ontology with the split above me is the "Many Worlds" approach of Everett (1957). In this view, the wave function never collapses, but all possible outcomes of measurements do occur. The world with a live cat and the world with the dead cat both exist. I am only aware of one world. Other versions of me are aware of the other worlds. For this reason Stapp (1990b) calls it the "many minds" theory. Stapp has done the most creative work in making this view palatable. I believe that the "many minds" view is not opposed to the other views, as is commonly assumed. Rather it may simply correspond to a particular placement of von Neumann's split. The richness in the multiple interpretations is the great beauty of the quantum duality.

**A full circle?** The Bohm and the Many Worlds approach are quite similar. In both there was a question of whether a split was actually present since in neither approach is the split visible. I placed them into the formalism of the moveable split by placing the split at the extreme lower and upper ends respectively. Both the Bohm and the Many Worlds approach are based on the time evolution of the full wave function of the universe. In the Bohm case the wave function is used to guide the particles of the world and in the Many Worlds case the wave function is used to guide my mind. It pleases me (a lover of Klein bottles) to see that the two opposite placements of the split are not that different.

**3c. Implications of the moveable and relativistic split.** This section offers further views on how the split can be placed to help deal with the mind-body problem that started this essay.

**The homunculus.** In our psychophysics models, we invent mechanisms that process filtered versions of the image. The output of these mechanisms activate neural structures that produce motor output such as finger motions in pushing a response button or lip and tongue motions for a verbal response. We sometimes encapsulate the decision process, referring to it as a homunculus. The homunculus is a neural structure (involving motor cortex) that views the outputs of the mechanisms and makes the decision. Some scientists and philosophers are bothered by the homunculus concept since they worry that there must be a second homunculus viewing the first, etc., and an infinite regress results. For those who are worried about the infinite regress the quantum mechanical dualistic scheme discussed above should solve the problem. By placing the split between the sensory mechanisms and the motor output, a single homunculus is to be found above the split. The single split avoids an infinite regress.

The self-referential aspect of the homunculus brings up the image of bootstrapping (being able to fly by pulling up on one's bootstraps). As put by Delbruck (1986):

> We start with the naïve question: How can mind emerge from dead matter as the result of purely physical processes? Mind then looks back on itself and says, "Aha, this is how I came about." (Like Baron Munchhausen, pulling himself by his hair out of the mud.)

One of the important contributions of the duality approach is that the *single* split of quantum mechanics avoids the problems associated with self-reference. By clever placement of the split one can have one brain structure observe another brain structure. There is no self-reference since in quantum mechanics the observer does not observe himself.

The homunculus is commonly called "I". After exploring the central role of subjectivity it is amusing to note the foresight of the inventors of the English language for making the personal pronoun "I" so special. It is the only non-proper name that is always capitalized. The word "I" is also special because its shape reminds one of its meaning. It is a single vertical slash, reminding us of the quantum split. Quantum mechanics has come to the rescue of philosophy and has provided the necessary formalism establishing a unique place for "I", the observer, in the scheme of things.

**Relativism and Human Values.** The flexible placement of the split legitimizes many different worldviews. It is possible to believe that "I am God" by having me the only entity above the split. A similar placement of the split can lead to an Eastern theology in which the physical world is illusion. On the other hand, it is possible to have all humans above the split, with animals and inanimate nature being "machines" under our dominion, similar to the version of the Old Testament. The many conflicting worldviews can be brought into harmony since the democratic nature of quantum duality says that they all correspond to legitimate different placements of the split.

The extreme relativism of the quantum duality makes it difficult to derive absolute values from science. The difference between the quantum and classical worldviews does, however, radically change man's place in the universe. Whereas in classical mechanics there was no need for an observer, in quantum mechanics the observer is essential. Quantum mechanics brings the Copernican revolution full circle and restores the observer to be at the "center of the universe." As Stapp (1989) points out:

> The quantum conception gives an enlarged sense of self as architect of the universe. From such a self-image must flow lofty values that extend far beyond the confines of narrow personal self interest. With the diffusion of this quantum conception of man science will have fulfilled itself by adding to the material benefits it has already provided to man a philosophical insight of perhaps even greater value.

**Back to the mind-body problem.** In order to bring further clarity to the mind-body problem we must be careful about our definitions of mind and body. One might be tempted to define mind as the observer and body as the observed. According to this definition, *any* placement of the split is possible. The right panel of Fig. 4 has my consciousness as the observer and my body as the observed. The physicist's normal placement would have the photomultipliers as the observers and the photons as the observed. In this sense the photomultipliers would be considered as part of the mind. Since most of us are not comfortable with a photomultiplier having a mind the definition of "mind as observer" is not satisfactory. We would like a definition closer to that given in Section 1, where mind was associated with subjective feeling. There is general agreement that higher mammals have feelings. I discussed earlier why I believe dogs have feelings. I am told by people I trust that cats and dolphins also have feelings. I am undecided about ants and other tiny creatures. Some of my colleagues are sure ants have feelings and others are sure they do not. I suspect we would have to define the word "feelings" more carefully to be able to get agreement on where to draw the line. Somewhere among the lower animals, a split can be drawn with all creatures with feelings above the split and the non-feeling creatures and inanimate objects below. This placement of the split allows each creature with feelings to have its own mind and subjectivity that are not reducible to the underlying laws. Placing the split above the creature allows one to explain it's consciousness in terms of neurophysiology (Crick & Koch, 1990a,b; Freeman, 1990).

The precise placement of the split depends upon which aspect of subjectivity one wants to isolate. To keep my feelings subjective rather than objective I would place much of the activity of my brain's limbic system above the split. If I choose to focus on my self-awareness or thinking rather than on my feelings then the appropriate split placement would shift to a different brain structure or brain activation. It is nice that the quantum mechanical split has the flexibility to accommodate different nuances in what we mean by our words.

Bohr's viewpoint on the connection between quantum mechanics and the mind-body problem, as clearly spelled out by Delbruck (1986), is different from the view expressed here. Bohr believed that by analogy the dualistic notion of complementarity found in quantum mechanics could be applied to other domains such as life-not life and mind-body. My view is stronger. I believe that the mind-body duality is not *analogous* to the wave-particle duality; rather it is the *same* duality, just with a different placement of the quantum split.

Constraints. The moveability of the split was not easy to achieve. The laws on both sides of the split must be tightly constrained. The power of constraints recalls the bootstrap approach to theoretical particle physics advocated by Geoffrey Chew (1968) for the past 30 years. For about 10 years it was the dominant framework for particle theorists. It is based on the belief that quantum mechanics and relativity have so many consistency constraints that the theories are unique. It may well be the approach that will provide answers to the most fundamental questions. Capra's warm book (Capra, 1988) includes the following statement from Chew about the ambitions of the bootstrap program: "My feeling is that the bootstrap approach is going to eventually give us simultaneous explanations for space-time, quantum mechanics, and the meaning of Cartesian reality." As part of this marriage of quantum mechanics and relativity I expect the bootstrap will, in addition, produce a relativity in the placement of the split, which is the theme of this essay.

The constraints above and below the split are needed to produce a consistent theory. Below the split are the Feynman rules (Feynman, 1985), similar to wave equations. All interactions are local (the recent superstring theories allow a limited amount of nonlocality in a manner that doesn't violate relativity or causality, and which seems to include the effects of gravity). Below the split, particles follow all possible paths. Above the split is the "real" observed world. There are limitations about how accurately positions and velocities can be jointly specified (the uncertainty relationships). There is also a need to introduce long range correlations that go beyond what is expected classically. Finally the connection between the two halves of the duality is clearly specified whereby the probability of an observation event above the split is equal to the square of the amplitude of the event below the split. In addition to all these constraints there may be an additional need for the system to be dualistic and to have a moveable split in order to guarantee self-consistency.

**The end of ontology?** Many physicists and philosophers are unhappy with the moveable split associated with the dualistic nature of the present quantum theory. They would prefer a world in which the "collapse of the wave function" occurred at a unique place (such as at $10^{-5}$ grams in Penrose's speculation). Their problem with a moveable split is that one is not left with a firm ontology. They want an ontology that gives a *unique answer* to what is out there. The present quantum mechanics gives such a slippery ontology that maybe we shouldn't even use that word. It is often acknowledged that the Copenhagen Interpretation upon which this essay was based provides an epistemology rather than an ontology. However, it is also acknowledged that the extreme split placements of Bohm (1952) and Everett (1957) are ontologies. I am asserting that the intermediate split placements which are trimmed of unnecessary baggage should also be acceptable ontologies.

It is always possible that the present quantum theory will be found to disagree with experiment and a new theory without a moveable split will be found to better describe Nature. I, however, would be saddened if the physics of the future abandons the moveable split. The ability of the subjective-objective split to be placed *anywhere* is to me the most beautiful concept in modern science. There is something elegant about the leanness of present quantum mechanics that tells us to talk only about observed quantities. In a world without the moveable split, in order to relate subjective feelings to nerve impulses my descendents would have to say the connection between mind and body is *analogous* to the split present in 20th century quantum mechanics. It will feel so much better to reside in the 21st century and be able to say that the mind-body connection *is* the split.

**Acknowledgements.** I thank Alain Aspect, John Searle, Henry Stapp, Erich Sutter and Christopher Tyler for useful discussions. The material in Section 3 was originally presented at the 1976 Esalen Conference on Quantum Mechanics and Consciousness and I thank the Esalen Center for its support. This work was also supported by NIH grant EY04776 and NSF grant BNS-8820229.

**References.**

Aspect, A., Dalibard, J., & Roger, G. (1982): Experimental test of Bell's inequalities using time-varying analyzers. *Phys. Rev. Lett.* **49**, 1804 – 1807.

Barlow, H. (1990): The mechanical mind, *Annu. Rev. Neurosci.* **13**, 15-24.

Bell, J.S. (1965): On the Einstein, Podolsky, Rosen Paradox, *Physics* **1**, 195-200, reprinted in Quantum Theory and Measurement. Ed. J.A. Wheeler and W.H. Zurek, Princeton University Press, Princeton, (1983).

Bohm, D. (1952): A suggested interpretation of the quantum theory in terms of 'hidden' variables, I and II. *Phys. Rev.*, **85**, 166-193, reprinted in Quantum Theory and Measurement. Ed. J.A. Wheeler and W.H. Zurek, Princeton University Press, Princeton, (1983).

Bohr, N. (1949): Discussion with Einstein on epistemological problems in atomic physics. In *Albert Einstein: Philosopher-Scientist*, ed. P.A. Schlipp, The Library of Living Philosophers, Evanston. Reprinted in Quantum Theory and Measurement. Ed. J.A. Wheeler and W.H. Zurek, Princeton University Press, Princeton, (1983).

Capra, F. (1988): Uncommon Wisdom, Conversations with Remarkable People. Simon & Schuster.

Chew, G.F. (1968): "Bootstrap": A scientific idea? *Science*, **161**, 762-765.

Churchland, P.M. (1988): Matter and Consciousness, A Contemporary Introduction to the Philosophy of Mind. MIT Press, Cambridge, Mass.

Churchland, P.M. & Churchland, P.S. (1990): Could a machine think? *Scientific American*, January, 1990, **262**, 32-37.

Crick, F.H.C. & Koch, C. (1990a): Towards a neurobiological theory of consciousness. To appear in: *Seminars in the Neurosciences*. vol. **2**.

Crick, F.H.C. & Koch, C. (1990b): Some reflections on visual awareness. To appear in: *Symposia on Quantitative Biology*, vol. **55**, Cold Spring Harbor Press, 1990.

Delbruck, M. (1986): Mind from Matter? Blackwell Scientific Publishing, Oxford.

Dennett, D.C. (1978): Where am I? Excerpt from Brainstorms: Philosophical Essays on Mind and Psychology. Bradford Books, Cambridge, Mass. Reprinted in The Mind's I: Fantasies and Reflections on Self and Soul. Eds. Hofstadter, D.R. & Dennett, D.C., Bantam Books, New York (1981). Also reprinted in Experience of Philosophy. Wadsworth Pub. Eds. Kolak D. & Martin R. (1990).

Descartes, R. (1641): Meditations. Bobbs-Merrill Co. New York, (1960).

Descartes, R. (1664): Treatise of Man. Harvard Univ. Press. Cambridge, Mass. (1972).

Eckhorn, R., Bauer, R., Jordan, W., Brosch, M., Kruse, W., Munk, M., & Reitboeck, H.J. (1988): Coherent Oscillations: A mechanism of feature linking in the visual cortex? *Biological Cybernetics*, **60**, 121-130.

Everett, H. (1957): "Relative State" formulation of quantum mechanics. *Rev. Mod. Phys.* **29**, 454-462. Reprinted in Quantum Theory and Measurement. Ed. J.A. Wheeler and W.H. Zurek, Princeton University Press, Princeton, (1983).

Feynman, R.P. (1948): A relativistic cut-off for classical electrodynamics. *Phys Rev.* **74**, 939.

Feynman, R.P., Leighton, R.B., Sands, M. (1965): The Feynman Lectures on Physics: Volume III. Addison-Wesley, Reading, Mass.

Feynman, R.P. (1985): QED—The Strange Theory of Light and Matter. Princeton University Press, Princeton, NJ.

Freeman, W.J. & Skarda, C.A. (1985): Spatial EEG patterns, non-linear dynamics and perception: the Neo-Sherringtonian view. *Brain Res. Rev.* **10**, 147-175.

Freeman, W.J. (1990): On the fallacy of assigning an origin to consciousness. In Machinery of the Mind. Ed. E.R. John, Birkhauser, Cambridge, Mass.

Gray, C.M., Konig, P., Engel, A.K., & Singer, W. (1989): Oscillatory responses in cat visual cortex exhibit inter-columnar synchronization which reflects global stimulus properties. *Nature*, **338**, 334-337.

Gregory, R.L. (1987): The Oxford Companion to The Mind. Oxford University Press, Oxford, England.

Haugeland, J. (1985): Artificial Intelligence, The Very Idea. MIT Press, Cambridge, Mass.

Herbert, N. (1985): Quantum Reality. Anchor/Doubleday, New York.

Hofstadter, D.R. & Dennett, D.C. (1981): The Mind's I: Fantasies and Reflections on Self and Soul. Bantam Books, New York.

Jeffrey, F. and Lilly, J.C. (1990): John Lilly, so far… Jeremy Thatcher, Inc. Los Angeles.

Kolak D. & Martin R. (1990): Experience of Philosophy. Wadsworth Pub.

Lilly, J. (1972): The Center of the Cyclone. Julian Press, New York.

Lockwood, M. (1989): Mind, Brain and the Quantum, *The Compound I*. Basil Blackwell Ltd. Oxford, England.

Penrose, R. (1989): The Emperor's New Mind. Oxford University Press, Oxford, England.

Persig, R.M. (1974): Zen and the Art of Motorcycle Maintenance: An inquiry into values. Morrow, New York.

Schroedinger, E. (1935): The present situation in quantum mechanics: A translation of Schrodinger's "Cat paradox" paper. *Die Naturwissenschaften* **23**, 807-812; 823-828; 844-849. Reprinted in Quantum Theory and Measurement. Ed. J.A. Wheeler and W.H. Zurek, Princeton University Press, Princeton, (1983).

Searle, J.R. (1980): Minds, brains and programs with open peer commentaries. *The Behavioral and Brain Sciences*, **3**, 417-457. Reprinted with a provocative commentary by Hofstadter in The Mind's I, eds. Hofstadter, D.R. & Dennett, D.C., Bantam Books, New York (1981).

Searle, J.R. (1990): Is the brain's mind a computer program? *Scientific American*, January, 1990, **262**, 26-31.

Stapp, H.P. (1972): The Copenhagen Interpretation. *Am. J. Phys*. **40**, 1098-1116.

Stapp, H.P. (1989): Quantum physics and human values. Lawrence Berkeley Lab. report *LBL-27738.*

Stapp, H.P. (1990a): A quantum theory of the mind-brain interference. Lawrence Berkeley Lab. report *LBL-28574.*

Stapp, H.P. (1990b): Quantum measurement and the mind-brain connection. Lawrence Berkeley Lab. report *LBL-29594.*

Von der Malsburg, C. (1983): How are nervous structures organized? In Synergetics of the brain. Eds. E. Basar, H. Flohr, H. Haken, A.J. Mandell. Springer, Berlin, 238-249.

Von der Malsburg, C. & Schneider, W. (1986): A neural cocktail-party processor. *Biol. Cybern.* **54**, 29-40.

Von Neumann, J. (1932): Mathematische Grundlagen der Quantenmechanik. Springer-Verlag. English translation reprinted in Quantum Theory and Measurement. Ed. J.A. Wheeler and W.H. Zurek, Princeton University Press, Princeton, (1983).

Wignor, E.P. (1961): Remarks on the Mind-Body question, in *The Scientist Speculates*. Ed. I.J. Good, Heinemann, London. Reprinted in Quantum Theory and Measurement. Ed. J.A. Wheeler and W.H. Zurek, Princeton University Press, Princeton, (1983).