# Quantum Mechanics and Neuroplasticity

## An Elementary Examination of the Interrelationship

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## Quantum Mechanics

Left unchallenged for over 200 years (Or, as some suggest, neglected. See Stapp, 2003a), classic or Newtonian physics continues to hold a revered place in scientific belief. This includes neuroscience. Many contemporary works in neuroscience and related fields ascribe to this traditional system, citing "ordinary laws of physics" (see general discussion Schwartz & Begley, 2002, pp. pp. 260-261), as that solely employed in brain processes (see Benson, 1998; Kalat, 1993; Kolb & Whishaw, 1996; Sonderegger, 1998). For example, these works do not broach the basic quantum principles underlying many of the fundamental brain processes of neuron activation or "firing" (Stapp, 2001a). Stapp[1] explains that "brain processes depend critically upon synaptic processes, which depend critically upon ionic processes that are highly dependent upon their quantum nature" (2001a). William James' late 19th century views on mind-brain interaction, consistent with contemporary interpretation of quantum theory, is "eerie" (Schwartz & Begley, 2002). Common descriptions of brain functions tend to be provided in traditional terms of mechanical determinism of particles[2] (*e.g.,* neurons release a chemical that either excites or inhibits the next neuron, action potentials reach the terminal button causing the release of neurotransmitter molecules, calcium channels are opened in the synaptic membrane when an action potential reaches the synapse).

Founder of our classic system of physics, Isaac Newton is, of course, venerated. Newton saw things that no other person had seen (Walker, 2000). Modern physics reached its culmination with Newton's 1687 book *Principia* which described, as Polkinghorne explains, "motions of particles in ways that were clean and deterministic" (2002, p. p. 1). His 17th century work was elevated to the position of an "imposing theoretical edifice" (Polkinghorne, 2002, p. p. 4). Today, with some humor and, one may assume, equal embarrassment with the voiced naiveté of the past, the scientific community recalls many early “celebrated assertions” attesting to this. By the end of the 18th century, there were reverent decrees that “a being, equipped with unlimited calculating powers and given complete knowledge of the disposition of all particles at some instant in time, could use Newton’s equations to predict the future, and to retrodict with equal certainty the past” (Polkinghorne, 2002, p. p. 1). By the end of the 19th century some believed that “all the big ideas of physics were now known and all that remained to do was tidy up the details with increased accuracy” (Polkinghorne, 2002, p. p. 4), left only to fill in the sixth decimal place (McEvoy & Zarate, 1996). And in the last half of the 20th many continued to believe that physics is a “science of experience” and “differs in no way from the classic physics which was… magnificently developed by Isaac Newton” (Fuchs, 1967, p. p. 94).

However, cracks started to appear in the edifice of Newtonian physics in the first quarter of the 20th century. It has widened into an irreconcilable chasm until, today, we have the classic view that *explains* everyday experiences and quantum mechanics that – with current knowledge – can only *describe* how the universe works. After all, “… nobody understands quantum mechanics” (Feynman, 2001, p. p. 129); quantum mechanics cannot be explained, only described (Feynman, 2001, p. p. 130; Polkinghorne, 2002, p. p. 22). There has evolved, then, a cataclysmic break from classic physics.

### *Break from Classic Physics*

Even in Newton’s time scientist recognized that he did not “embrace all aspects of the physical world that were then known” (Polkinghorne, 2002, p. p. 1). Issues left unaddressed included the nature of the universal inverse-square law of gravity. Issues which received only speculative conjecture from Newton included the particle nature of light (later discovered to exhibit wave properties, as well). These unsettled issues, even in the late 17th century , "threatened belief in the self-sufficiency of the Newtonian synthesis" (Polkinghorne, 2002, p. p. 1). While Newton's achievements were "imposing," they left unanswered questions and, more important, clearly indicated that his fundamental premise of the mechanical nature of reality was incorrect. This view simply did not allow for an understanding of conscious experience.

However, Newton was to rise to wide acceptance, heralded as "the greatest genius in the history of physics" (Fuchs, 1967, p. p. 191). No significant challenges to Newtonian physics occurred for nearly 200 years (from his 1687 publication of *Principia*). However, beginning in 1885, as can be seen in Table 2, there occurred in a 38-year period six major findings which questioned the foundational concepts of classical physics. Each drove a wedge deeper into the structure of this system. The continued findings which contradict Newton's early assumption include contemporary concepts subsumed under quantum theory.

One may ask, why was there such a long period of weak theoretical exploration and discovery? Coupled with the reverence in which Newton and his ideas were held, technology, or rather the lack of significant advances in it, had prohibited further theoretical exploration. As examples, Rutherford's 1907 work with radioactive alpha particles and his ultimate discovery of the atom's nucleus required a more sophisticated microscope than had previously been available. One of his students, Hans Geiger, would continue conducting theoretical research in radioactivity going on to develop the radiation detector that continues to bear his name.

As Table 1 illustrates, much of the physics work conducted in the later part of the 19th century fell on practical applications of physics especially involving mechanical work rather than a continued exploration of the theoretical underpinnings.

Table 1. Advances in Physics: Practical Applications

| Year | Researcher | Finding |
|---|---|---|
| 1750 | James Watt | Steam engine |
| 1840 | James Joule | Mechanical work |
| 1847 | Herman von Helmholtz | Conservation of energy |
| 1850 | Rudolf Clausius | Entropy |
| 1859 | J.C. Maxwell | Kinetic theory of gasses |
| 1870 | Ludwig Boltzman | Thermal equilibrium |

Table 2. Major Challenges to Newtonian Physics

| Year | Researcher | Finding | Brief Description |
|---|---|---|---|
| 1885 | Johann Jakob Balmer (1825-1896) | Spectra | The spectrum of hydrogen, different colors actually correspond to different frequencies (Polkinghorne, 2002). Balmer's sequences strongly suggested some kind of energy diagram as the emission/absorption of light from an atom must correspond to a decrease/increase in the atom's energy (McEvoy & Zarate, 1996). "… could not be explained by the classical physicists" (McEvoy & Zarate, 1996, p. p. 60). |
| 1900 | Lord Rayleigh | "Ultraviolet Catastrophe" | Rayleigh applied statistical physics to the problem of how energy is distributed among different frequencies… the straightforward application of the ideas of statistical physics led to disastrous results… infinite amount of energy concentrated in the very highest frequencies (Polkinghorne, 2002). This contradicted classic physics as explained by Ludwig Boltzman 1870s theory, "… energy will be shared equally among all degrees of freedom if the system reaches thermal equilibrium" (McEvoy & Zarate, 1996, p. p. 24). |
| 1905 | Albert Einstein (1879-1955) | Photoelectric effect | In classic physics electron ejection from metal when bombarded by "cathode rays" or electron beam is a function of the beam's *intensity*, while the results from experiments – in direct contradiction – indicated that electron ejection occurred as a function of the beam's *frequency*. The 19th-century insights into the wave nature of light could not be reconciled with the new ideas. |
| 1911 | Ernest Rutherford (1871-1937) | Nuclear atom | Rutherford discovered in 1907 the atom's nucleus thus dispelling the concept of atomic structure known by various names including "the plum pudding model" (Polkinghorne, 2002, p. p. 5), "Christmas Pudding Atom," and "Raisin in Cake Model of the Atom" (McEvoy & Zarate, 1996, p. p. 71) (*i.e.,* negative electrons evenly distributed within the positive charge of the atom), theorized in 1897 by J.J. Thomas and Lord Kelvin. As Polkinghorne describes, "the discovery of the nucleus plunged classical physics into its deepest crisis yet" (Polkinghorne, 2002, p. p. 11). The classical view demanded that an orbiting electron would emit radiation and, thereby, lose energy. This loss of energy would result in the electron collapsing into the nucleus, which it clearly did not. |
| 1913 | Niels Bohr (1886-1962) | The Bohr atom | Bohr applied to atoms Planck's principle of discrete energy exchanges (versus the classical view that energy continuously "oozes") where the electron's orbit about the nucleus assumed specific radii determined as a function of their energy. To move, therefore, to a lower orbit the electron first had to give up energy (radiated as a single photon) in a stepped, discrete manner. |
| 1923 | Arthur Compton (1892-1962) | Compton scattering | Compton's experimented with scattering x-rays by matter (photons and electrons) establishing that rays can behave as particles. His experiments helped prove the quantum theory. |

### *Discovery and Development*

The years 1925 and 1926 witnessed two major discoveries that started the “quantum revolution:” The German Werner Heisenberg (1901-1976) and his matrix mechanics and the Austrian Edwin Schrodinger and his wave mechanics. These two seeming dissimilar discoveries were later recognized as a “single theory” (Polkinghorne, 2002, p. p. 20) differing only in mathematical expressions.

Heisenberg’s discovery was made while continuing his work on atomic spectra and special mathematical entities called matrices[4]. The continued development of the quantum theory would benefit from Heisenberg’s “matrix mechanics” (the name derived from the underlying mathematical entities employed in his calculations). Heisenberg’s discovery relative to the mathematical properties of matrices, namely their violation of fundamental commutative law of multiplication or the critical nature of the order of multiplication of the numbers unlike simple numbers, would play a vital role in determining which quantities could be simultaneously measured in quantum mechanics.

Schrodinger continued the 1924 work of Prince Louis de Broglie[5] whom suggested that as with light waves manifesting particle-like properties, particles (*e.g.,* electrons) may manifest wave-like properties (Polkinghorne, 2002). Creating a “mini-dictionary” for translating between particles and waves, Broglie suggested that momentum was related to wavelength adding to previous work suggesting that particle energy was proportional to frequency (see Polkinghorne, 2002, pp. pp. 18-20). Schrodinger was able to further generalize de Broglie’s findings as to allow for interaction. He had found an equation[6] that was applicable to any physical system in which the mathematical form of the energy was known, one that bears his name today[7]. Polkinghorne asserts that the Schrodinger equation is recognized as the “fundamental dynamical equation of quantum theory" (2002, p. p. 20). It allows a mixing of states that would be mutually exclusive within classical physics.

The "revolution" that these two early 20th century physicists started continues today as theoretical physicists struggle with elemental behavior that is, as the 1965 Nobel Prize winner in Physics Richard Feynman explains, "like nothing you have seen before" (2001, p. p. 128). Both the Heisenberg and Schrodinger equations describe (in mathematical language) this behavior, but, as Feynman asks, "what can I call it?" (2001, p. p. 128). Electrons exhibit wave properties. Light *waves* exhibit particle-like properties. This dual behavior, repeatedly witnessed in experiments, is "simply different." This logic-defying behavior is quantum mechanics. While we can describe it, we continue to lack an understanding of it.

It is worth noting that quantum physics with all its "fuzziness" continues to lack reasonable incorporation into popular scientific thought. School children are typically not exposed to its wonders and mysteries. It is, rather, relegated in the minds of the average person – if thought of at all – to science fiction (*e.g.,* the recent movie and Michael Crichton book *Timeline,* the movie fully omitting basic descriptions of quantum theory provided in the book) (see Crichton, 1999, pp. pp. ix-xii). As late as 1967, quantum theory was not fully embraced in basic education (with theoretical physicists yes, but in the classroom no). Neils Bohr's laws, quantum laws of atomic structure which broke with Maxwell's electrodynamics and Newton's mechanics, were considered "arbitrarily constructed" (Fuchs, 1967, p. p. 107). Fuchs, in his 1967 entry level physics text broached the topic of the "frontiers of scientific research" (p. p. 339) addressing, in part, quantum mechanics. (It is interesting to note that Fuchs wrote his physics text in his native Germany, home of much of the world's physics discoveries. Originally published with the German title *Exakte Geheimnisse: Knaurs Buch Der Modernen Physik,* it was later translated for English speakers under the title Physics for the Modern Mind). Here he asserts that he “wants to take a look at some questions which *lie outside of the scope of physics*, but which are, nevertheless, related to it.” Fuchs goes on to contradictorily suggest that quantum theory’s entry into the realm of physics has improved its image. However, it is “far less important to the physicist than to the interested layman” (p. p. 340). Strongly exhibiting his belief in the mechanical view of physics, Fuchs goes on to assert that “to be operative… [one must] comprehend intellectually since observation fails deplorably. However, problems such as these fall well *within the realms of psychology and sociology*” (p. p. 341). One would doubt if many in the psychology community realize that those in the physics community have passed to them this responsibility to continue the exploration of the mysteries of quantum mechanics!

### *Fundamentals*

As stated earlier, the experimentally witnessed logic-defying dual-behavior of particles and waves is quantum mechanics. While we can describe it, we continue to lack understanding of it. Without having to resort to the mind-bending mathematical descriptions of quantum mechanics, one can easily describe the principles by providing an overview of the oft sited “double slits experiment” (Feynman, 2001, pp. 129-148; McEvoy & Zarate, 1996, p. p. 107; Polkinghorne, 2002, pp. pp. 22-25; Stapp, 2003a, pp. pp. 19-20).

As Feynman suggests, any situation in quantum mechanics can be explained by saying, “You remember the case of the experiment with the two holes? It’s the same thing” (2001, p. p. 120). Polkinghorne, referring to Feynman, offers the same advice. He suggests that Feynman believed that one had to “swallow quantum theory whole, without worrying about the taste or whether you could digest it” (Polkinghorne, 2002, p. p. 22). One has only to “gulp down” the double slits experiment. Polkinghorne offers Fenyman thoughts relative to this (2002, p. p. 22),

> In reality it [the double slit experiment] contains the only mystery. We cannot make the mystery go away by ‘explaining’ how it works. We will just tell you how it works. In telling you how it works we will have told you about the basic peculiarities of quantum mechanics.

The classic double slit experiment is simple enough to mentally arrange, to imagine (see Figure 1). The results of the experiment, however, defy common logic (and, similarly, what school children are taught in entry-level physics). The result is an exhibited “wave/particle duality.” To ensure understanding of the phenomenon we will need to review tenets of classic physics relative to such an experiment.

Classic physics dictates that, given the experimental arrangement of an electron gun firing at a screen containing two vertically-arranged slits (one above the other) which rests immediately before a detector screen, will yield a familiar bell-shaped distribution pattern. The electron gun, randomly firing, will propel electrons with trajectories that will have various angles of entry into and through the slits. It will, as well, provide trajectories that will propel electrons into the first screen, stopping the electron from continuing its journey beyond the first to be detected, as the others, on the second screen. Electrons passing through each of the slits will be collected on the second “detector” screen, leaving a mark (depositing their energy). Over time, these accumulated electrons will exhibit a typical statistical bell-shaped curve immediately past the points of entry.

Similarly imagined, our source of energy can be a wave that moves toward our first screen with the two slits. As basic physics suggests, the wave will develop corresponding wave action just past the slits (the openings through which the wave flows). These resultant waves on the backside of the first screen will continue to traverse toward the second detector screen widening, dispersing as they go. It is during their travel to the second screen that, as witnessed countless times on sea-side vacations, the waves will meet, interact, and disrupt the initial wave formation. They create an "interference" patter. The peaks of some of the waves will meet and combine creating a stronger, higher wave. Some, conversely, will be timed such that the troth of one will interact with that of another essentially eliminating the wave. There are, of course, a myriad of combinations between these two extremes. The energy waves will create an interference pattern as that depicted in Figure 1.

However, it is not what experiments of quantum elements reveal. Now imagine the electron gun, firing single electrons, timed as to allow each individual electron ample time to traverse the space between the electron gun and the double slit screen and, then, on to the detector screen where it departs its energy, its arrival recorded. Only upon detection of the arriving electron will the gun fire again, sending another single electron through the same exercise. What might one see at the end of the experiment? What might the detector pattern reveal?

Counter intuitively we would find at the end of the experiment that the independent electrons have imparted their energy on the detector screen in such a manner as to create an interference pattern. The electron *particles* created a *wave* pattern. Therefore, each electron must have acted in such as way as to produce it. But, how? We know that we fired the electron gun in such a manner as to disallow any opportunity for an electron to interfere with another. It was, simply, a single particle fired at a screen, one containing double slits through which the electron would pass. Its only "choice," one would well imagine, was through which slit it would travel. But it does not.

The debate continues. How does the electron act in this way? Does it somehow know beforehand where it should register its energy so to create an interference pattern? Did the detected electron somehow "communicate" with the next in line? Did it somehow miraculously interference with itself? Did the electron, similarly defying all known properties of physics, split immediately before the slits continuing on as fractions of its former self continuing its trek to the detector where it develops an interference pattern with characteristics of energy required of an intact, whole electron? Physicists simply do not know. What is clear, however, is that atomic level behavior is not that postulated by classic physics. These elements simply behave differently. This is of significant importance in neuroscience where, as Feynman suggests, the basic brain processes depended on quantum elements (*e.g.,* electrons, ions). This dependence is worthy of continued exploration.

Perhaps, it has been suggested, the resultant behavior is a manifestation of the observers interaction with the experiment. Somehow such intervention has caused the strange behavior. This has widened the quantum mechanics debate to the "measurement problem."

Most scholars of quantum theory admit to the ease of measurement in classic physics (example Polkinghorne, 2002, p. p. 44). As Polkinghorne (2002, p. p. 44) suggests, however,

> Measurement in conventional quantum theory is different because the superposition principle[8] holds together alternative, and eventually mutually exclusive, possibilities right

> until the last moment, when suddenly one of them alone surfaces as the realized actuality on this occasion.

Table 3 lists the most accepted theories of what causes this probability collapse onto a single actuality.

**Table 3. Quantum Measurement Theories**

| Name | Description |
|---|---|
| Irrelevance | With numerous variations, interpreters in the "irrelevance" camp suggest that science is about correlating phenomena (essentially, describing what happens) and not understanding the fundamental principles underlying the described event (essentially, explaining why it happens). |
| Large System | Introduction of the measuring device will have an influential effect which will determine the outcome. This theory discounts the quantum constituents of the measuring device and their corresponding reliance on quantum mechanics and, further, their impact to the witnessed outcome of the experiment. This is a strange position to take in that the discussion centers on effects of quantum elements (why consider such effects on the material of exploration and not that used in such measurement?). |
| New Physics | GRW theory – named for its founders Ghirardi, Rimmer, and Weber – suggests that there is a universal property of random wave function collapse which is a function of and depended on the amount of matter which is present. Most theoretical physicists believe that this theory is "too ad hoc" and essentially discount it. |
| Determinism | Established by David Bohm in 1954, this theory suggests that quantum mechanics is "fully deterministic." He separates, to make his theory work, wave and particles into independent yet interrelated phenomenon. The particle (the electron in our earlier description) acts fully in accordance with classic physics. Bohm suggests that, simultaneously, there appears a "guiding" wave capturing all information about the environment in which the particle resides. It also exhibits characteristics that are classical. Few physicists accept this theory believing it is a contrivance with the objective of producing empirically acceptable answers (*i.e.,* explaining away quantum mechanics). |
| Many Worlds | As Polkinghorne suggests, the Many Worlds theory seems to be a "metaphysical hammer brought in to crack a admittedly tough quantum nut" (2002, p. p. 53). The Many Worlds theory suggests that everything that can happen does happen. Every measurement forces into reality, albeit in different universes, each possible outcome. There is, as some illustrate in describing this theory, a universe where John Kennedy was shot and one where he was not. It is interesting to wonder at a veiled universe just beyond our consciousness where every alternative decision resides in fully developed reality. But, hard for most to understand or accept. It is noteworthy that many prominent theoretical physicists embrace this theory as one that may explain quantum theory. |
| Consciousness | While vigorously debated, many distinguished physicists embrace this theory. It suggests that the collapse of the probability waves in quantum experiments is the result of conscious thought. The measurement intervention, unlike the large system that itself depends upon quantum elements, is conscious thought. As Polkinghorne speculates, "Perhaps, then, it is the intervention of a conscious observer that determines the outcome of a measurement" (2002, p. p. 51). How this may happen, as with much in quantum mechanics, science simply does not understand. |

## *Implications*

Applied psychology depends to some degree on ones ability to change. Many worlds theory negates this need. Both psychological states would exist simultaneously. The question would be why work so diligently in this universe to effect a change if one knows that through this action he/she is only forcing into another universe the pre-changed psychological state. This has the feeling of passing ones problems on to another. In this case, a parallel self! The psychologist in this universe, while celebrating success with his patient, would have a counterpart in a parallel universe agonizing over his/her inability to help the patient.

Large systems theory, similarly, seems to pose a problem. As Polkinghorne suggests, the physicists subscribing to this notion have discounted that the measuring devices are equally comprised of atomic matter and, therefore, subject to quantum mechanics (2002, pp. pp. 48-49). Particularly for psychologists and psychiatrists it is an exceptionally troubling proposition. What "large system" is introduced into the brain of a patient undergoing psychotherapy? What exists beyond the doctor's voice (of ideas, concepts, reflection) and the patients reception, understanding, thoughts, and will? If a patient improves, by definition there has been change (Cozolino, 2002). If there has been change, at an atomic level quantum mechanics suggests that a probability wave has collapsed to effect brain changes, including new neural connections (Schwartz & Begley, 2002, p. p. 15), axon growth (Kolb & Whishaw, 1996, p. p. 69), increase of dendrite receptors via "second messengers" (Kolb & Whishaw, 1996, p. p. 89), increased synaptic efficacy and new anatomical connections (Tinazzi, Testoni, & Volpato, 1998), increased central benzodiazepine receptor densities in various subnuclei of the amygdala, and permanent increase in concentrations in concentrations of receptors for glucocorticoids in both the hippocampus and the PFC (Davidson, 2000). This theory, when considered within the context of psychology, does not seem satisfactory.

The "irrelevance" theory seems to be naïvely absurd. Those embracing this theory suggests that science is about correlating phenomena (essentially, describing what happens) and not understanding the fundamental principles underlying the described event. How can understanding the witnessed phenomenon be irrelevant when it is reveals the fundamental principle by which the universe operates and, therefore, events in our daily lives? As Polkinghorne suggests, those subscribing to this theory are attempting to "finesse" the quantum mechanics problem rather than aggressively addressing it (2002, p. p. 46).

As most physicists subscribe, the need for a "new physics" seems too ad hoc. Proponents of this theory suggests that there is a "universal property of random wave function collapse in space, but that the rate at which this happens depends on the amount of matter present" (Polkinghorne, 2002, p. p. 50). Again, as with large systems theory, these proponents propose that quantum elements are too small to effect probability wave collapse. However, they continue, with the introduction of a sufficient amount of matter (*e.g.,* measurement instrument) there would be a near-instantaneous wave collapse. One is left, then, as with the large system theory, with the question of what large system is introduced into the mind of a patient undergoing psychotherapy?

Determinism theory clutches, as a drowning man to a life ring, to the materialists notions of classic physics. It, too, seems inappropriate.

Where then does the experimenter turn? Where do *we* turn? What might have profound psychological consequences? How might the brain change, repair? The introduction of consciousness (mind) into the physics equation of matter (brain) seems to be the determinant of the experimental outcomes.

## Neuroplasticity

The traditional view in neuroscience has been that brain plasticity was limited to an early development window (Cozolino, 2002; Garlick, 2002). Restrictions to this period included neurogenesis (Cozolino, 2002; Gould, Reeves, Graziano, & Gross, 1999), synaptogenesis (Shrager & Johnson, 1995), and synaptic formation and remodeling (Gould et al., 1999; Manji, Quiroz, & Gould, 2003). This period was believed to comprise the last two months *in vitro* and several months following birth (Kolb & Whishaw, 1996). Some believe that this “exaggerated dogma” meant that the adult brain could not grow, the only change being the constant death of neurons (Julesz & Kovacs, 1995, p. p. xiii).

Recent research, however, suggests otherwise (see Department of Defense, 2003; United Cerebral Palsy Association, 1997). Current studies suggests that neural ontogeny is a continuous maturational process (Schuman, 1997). This section will explore current understanding of neuroplasticity, the brain’s ability to change.

### *Exploration, Definition*

Neuroplasticity is a fundamental property of neurons and the nervous system (Shaw & McEachern, 2001a). Researchers content that it is manifest in the ability of neurons to change the way they behave and relate to each other (Cozolino, 2002) and make new connections (Schwartz & Begley, 2002) including the process of dendritic arborization (Kolb, 1995, 2003; Kolb & Whishaw, 1996). Some researchers suggest that neuroplasticity includes synaptogenesis (Manji et al., 2003) and increased synaptic remodeling, efficacy and new synaptic connections (Manji et al., 2003; Tinazzi et al., 1998). Further, some believe that it includes an increase in the number of neural receptors and the activity of postsynaptic channels (Kolb, 2003), and enhanced long-term potentiation (LTP) (Manji et al., 2003). Neuroplasticity, then, as evidenced by contemporary research, means different things to different researchers (Shaw & McEachern, 2001c). It is for this reason that some find it difficult to provide an exact definition of neuroplasticity.

Being "vaguely defined," some find the term neuroplasticity nearly meaningless (Shaw & McEachern, 2001c, p. p. xv). Shaw and McEachern suggest that as "conceptual cliches" plasticity and neuroplasticity are general statements of beliefs expressed by many in neuroscience (2001c). A working definition or our continued exploration here, however, may be "the capacity for sensory and/or pharmacological manipulations to induce permanent (or long-term) changes stemming from mechanisms not present in the naïve animal" (E. Katz, Victor, & Purpura, 1995, p. p. 165). This allows for various mediating events, with numerous change mechanisms, producing different results to fall readily within the realm of neuroplasticity. As Shaw and McEachern sought, it allows for a synthesis of diverse ideas, concepts, and notions relative to neuroplasticity (2001c, p. p. xv)

## *Neurological Ontogeny*

### *Neuron*

Neurons, a nerve cell specialized to transmit nerve impulses in the form of action potentials (Dictionary, 2003), are the microscopic processing units comprising the building blocks of the nervous system (Cozolino, 2002; Kolb & Whishaw, 1996). Some suggest that these fundamentals elements are complicated and continue to lack understanding (Pinker, 1997). However, others provide detailed explanation of the neuron's structure and the mechanisms of and process for their operation (see Cozolino, 2002, p. p. 68; Kolb & Whishaw, 1996, pp. pp. 39-43). Others clearly have identified its function (Garlick, 2002). It is foundation for an exploration of neuroplasticity to understand basic neuron structure and operation.

Neurons, with estimates ranging from a low of 10 billion (Kolb, 1995), 12 billion (Cozolino, 2002), 15 billion (Benson, 1998), and 20 billion (Satinover, 2001) to as high as 80 billion (Kolb & Whishaw, 1996) and 100 billion (Kalat, 1993) in the human brain, are of three types: sensory (located in sense organs such as eye which receives information), motor (carries information from the nervous system to the body's organs, gland, and muscles), and interneurons (association neurons, connections between sensory and motor neurons) (Benson, 1998). They are extremely small, with cell bodies between 5 to 100 microns in diameter. The "simple neurons" consist of a cell body which contain the cell's nucleus – housing deoxyribonucleic acid or DNA – and diametrically positioned extensions from the cell's body called a dendrite and an axon (Kolb & Whishaw, 1996, p. p. 41). The dendrites (from the Greek "tree") are short, widely branching structures. The axon is a single, long, thin, straight fiber with branches (collaterals) near its tip (see Kalat, 1993, pp. pp. 86-88). These branches end in terminations called teleodendria or presynaptic endings which themselves end in terminal knobs (Kolb & Whishaw, 1996) or buttons (Kalat, 1993). It is a change in electrical potential at the terminal knob that causes the release of neurotransmitters (from its storage in synaptic vesicles) and allows "communication" between neurons.

Neurons normally exhibit a cross-membrane "resting potential" of approximately -70 millivolts (mV). This is maintained by an off-balanced distribution of sodium ions ($Na^+$) which concentrate on the outside of the axon's membrane. The axon's interior, therefore, produce the slightly negative charge. Other ionic elements present include the negatively charged organic ($An^-$) and chlorine ions ($Cl^-$) and positively charged potassium ($K^+$) and the aforementioned sodium ions ($Na^+$) (see Kolb & Whishaw, 1996, p. p. 71). The mechanism by which neurons work is via an electrochemical impulse called an "action potential" (Kalat, 1993) resulting from a cross-membrane ion exchange. Sodium ions enter through an ion channel which, at the narrowest point, is smaller than a nanometer in diameter (Stapp, 2001a). These ions move across the membrane (bringing their positive charge to the negatively charged interior). Subsequently potassium ions exit, restoring the negative charge across the membrane. These "nerve impulses" travel along the axon at between 1-100 meters per second (m/sec).

It is noteworthy here to repeat that theoretical quantum physicists believe that "brain processes depend critically upon synaptic processes, which depend critically upon ionic processes that are highly dependent upon their quantum nature" (Stapp, 2001a). In particular Stapp suggests that the smallness of these ion channels has "profound quantum mechanical importance" (2001a, p. p. 11).

### *Neural Network*

While neurons change their behavior with experience (*e.g.*, learn, remember, and forget) (see Kolb & Whishaw, 1996, p. p. 65), neurons alone cannot produce the brain processes manifest in such functions as memory, language, and sight. It has been proven that neurons must act in concert to produce such phenomenon (see for example Kolb, 2003; Milner, 2003). They produce idiosyncratic connections with the other neurons of the cortex (Garlick, 2002). And, as Canadian psychologist Peter Milner suggests, commonsense decrees that such coordinated action must be learned (2003). This understanding has its roots in 18th century philosophy.

In the 17th and 18th centuries philosophers linked sensations and ideas as central to thought processes (Kalat, 1993). Such notable British philosophers holding this idea were John Locke, David Hume, and David Hartley. These philosophers held that all concepts (or, as they referred, ideas) were the result of experience, a notion called "concept empiricism" (for expansion of this idea see Hospers, 1967, pp. pp. 101-113). Hartley, in 1746, suggested that an association between two or more concurrent events produced “neural vibrations.” Ideas, then, were the result of consequential “after-vibrations” (Milner, 2003).

Alexander Bain in his 1874 book *Mind and Body* argued that such association was the result of two or more things fixed together in memory. They could be separate impressions that are made together or occurring in close succession on one or repeated occasions. Bain was the first to propose that “nerve-current” resulting from these associations would strengthen the connection (Milner, 2003). This is an idea that would be explored and developed in the 20th century.

Expanding this work, researching how the external world is internally represented in the brain (Kolb, 2003), Donald Hebb theorized that the structural basis for memory is synaptic change (Kolb & Whishaw, 1996). There remains little direct evidence for this (Kolb, 1999); however, it remains a viable hypothesis on which research continues to rest. Hebb broke with early concepts of psychology arguing that psychology is really a biological science (Benson, 1998), employing a “reductionist approach” which held that all behavior is neuronal and biochemical in nature. Hebb’s 1949 book *The Organization of Behavior* clearly explained what was to be variously referenced as the Hebb’s postulate, Hebb Rule (Kolb, 2003; Milner, 2003), the Hebb Synapse (Kolb & Whishaw, 1996; Milner, 2003), and the Cell Assembly Theory (Benson, 1998). Milner’s “introductory essay” for Canadian Psychology (where he is tasked with presenting “what Hebb actually said”) (2003) references back to Hebb’s 1932 unpublished MA thesis to explain Hebb’s premise:

> An excited neuron tends to decrease its discharge to inactive neurons, and to increase this discharge to any active neuron, and therefore to form a route to it, whether there are intervening neurons between the two or not. With repetition this tendency is prepotent in the formation of neural routes.

Hebb had theorized the mechanism whereby associated events are represented in the brain. Neurons "organize" forming complex neural networks. The mechanism of learning is accomplished through a change to this network.

### *Emerging Understanding*

It is now accepted that the adult brain can change (Cozolino, 2002; Kolb, 1995; Satinover, 2001; Schwartz & Begley, 2002; Schwartz & Beyette, 1996; Stapp, 1993). There is amble evidence of such (Julesz & Kovacs, 1995) as seen in recent research (see for example Begley, 2000; Gould et al., 1999; E. Katz et al., 1995; Kolb, 1999; Manji et al., 2003; Schuman, 1997; Tinazzi et al., 1998). There is not, however, a synthesis of ideas relative to what constitutes a general theory of neuroplasticity. Some suggest that the poorly defined area makes a general definition almost impossible (Shaw & McEachern, 2001a). There are recent attempts to develop such synthesis, compiling and critiquing recent concepts (see Julesz & Kovacs, 1995; Shaw & McEachern, 2001a, 2001c). The area remains, however, as expressed by Shaw and McEachern, "paralyzed between poles: in need of a working definition and framework for the field as a whole, but too diverse for any but the most general ones to work" (2001c, p. p. xv). It is within this framework that neuroplasticity is explored below.

Many believe that changes to cognitive function is directly correlated to changes to the cortical structure (see for example Kolb, 1995; Kolb, 1999; Tinazzi et al., 1998), most specifically that of the synapse (Kolb, 1999; Kolb, Gibb, & Gonzalez, 2000). Kolb traces this notion back to the early 20th century Spanish anatomist Ramon y Cajal who proposed that learning produced "morphological changes in the efficiency of the synapse" (2000, p. p. 224). They report that neuroplasticity includes such structural neural changes as neurogenesis (Gould et al., 1999; Ormerod & Galea, 2000), increased synaptic efficacy and new anatomical connections (Tinazzi et al., 1998), enhanced activity of post-synaptic channels (Kolb, 2003), increased number of dendrite receptors (Kolb & Whishaw, 1996), and intracellular signaling cascades (Manji et al., 2003). These changes are largely attributed to experience-dependent activity (Shrager & Johnson, 1995) or sensory experience (see for example L. C. Katz & Schatz, 1996). The changes are mediated by alterations in the amount or pattering (or both) of neural activity (L. C. Katz & Schatz, 1996; Tinazzi et al., 1998). Some, however, argue a conflicting view.

While holding that the brain's adaptive ability resides in the plasticity of the neuron's synapse, Schuman argues that this faculty is a function of a "new class of modifiers" (Schuman, 1997). Adult brain synaptic changes may be based on the reuse of developmental growth molecules (*e.g.,* transforming growth factor-beta or TGF-beta). Schuman reports that recent research indicates that TGF-beta stimulates protein translation and, therefore, "promotes site-specific modification of synaptic function" (1997, p. p. 2). He further advances the notion that TGF-beta may act directly at the synapse by activating the receptor serine-threonine kinase. Other significant work centers on chemical-induced rather than activity-induced mediation of neuroplasticity (see for example Bailey & Chen, 1992; L. C. Katz & McAllister, 1999). The ongoing research, however, as suggested of many other synaptic signals, fails to reveal the underlying mechanism for changing synaptic transmission (see for example discussion in Kolb, 1995, p. p. 108).

Neuroplasticity has been researched in association with such varied areas as mood disorders (Manji et al., 2003), carpal tunnel syndrome (Tinazzi et al., 1998), intelligence (Garlick, 2002), post-injury recovery of brain function (E. Katz et al., 1995; Kolb, 1999; Robertson & Murre, 1999; United Cerebral Palsy Association, 1997), posttraumatic stress (Department of Defense, 2003), Alzheimer's disease (Neill, 2001), Obsessive-Compulsive Disorder (OCD) (Schwartz & Begley, 2002; Schwartz & Beyette, 1996), and general psychotherapy (Cozolino, 2002; Davidson, Jackson, & Kalin, 2000).

Neuroplasticity is being researched in marine mollusk (Schuman, 1997), rats (as Kolb asserts, more is know about plasticity and its factors in the rat than any other species) (Kolb, 1999; Kolb et al., 2000), lower vertebrates and primates (Gould et al., 1999; Schwartz & Begley, 2002) as well as human subjects (Tinazzi et al., 1998).

Neuroplasticity has been found throughout the cerebral cortex (Tinazzi et al., 1998). Current research suggests that there is no neuronal structures that are incapable of plasticity (see general discussion Shaw & McEachern, 2001c, p. p. 428). Brain research areas where neuroplasticity has been specifically evidenced include the somatosensory cortex, spinal dorsal horn, and brainstem (Tinazzi et al., 1998), olfactory bulb and hippocampus (Gould et al., 1999), and sensory motoneuron synapses (Schuman, 1997). Plasticity has been indicated in regions previously considered "hard-wired" and, therefore, incapable of change (*e.g.*, motor reflex arcs) (Shaw & McEachern, 2001b).

Neuroplasticity is reported to have various mediating sources. While such triggers of neuroplasticity remain poorly understood (Shaw & McEachern, 2001b) they include "molecules, manipulations, perturbations, and stressors" (Kolb et al., 2000, p. p. 428). Current research points to the plasticity mediators of moderate stress (Cozolino, 2002), psychopharmacological chemicals and neurotransmitters (*e.g.,* serotonin) (Bailey & Chen, 1992), experience-dependent activity (Begley, 2000, 2002; Shrager & Johnson, 1995) including the concept of enhancement via spaced activation protocol (Teskey, 2000), exercise-induced neurotrophins (*e.g.,* BDNF) (Gomez-Pinilla, Ying, Roy, Molteni, & Edgerton, 2002), neurotrophic factors (L. C. Katz & McAllister, 1999), electromygraphic (EMG) based therapy (Ruud, 1998), deep brain stimulation (Lozano, 2001), learning (Edeline, Pham, & Weinberger, 1993; Garlick, 2002; Kolb, 2003; Milner, 2003) and thought (Kolb, 1995).

It is apparent that neuroplasticity means different things to researchers in different fields. There is no commonly accepted definition or set of principles (see Shaw & McEachern, 2001a). As Julesz and Kovacs attest, neuroplasticity is "multifaceted" and a "quickly moving field" (1995). Perhaps the rapidity of exploration and discovery has precluded a pause whereby common aspects could emerge. Without the application of a foundational synthesis in diverse research fields may be the reason why the term is considered an "umbrella term" (Shaw & McEachern, 2001a). As generally used, the term neuroplasticity has been rendered meaningless (Shaw & McEachern, 2001c). While work continues to bring about a synthesis of ideas relative to neuroplasticity (Julesz & Kovacs, 1995; Kolb, 1995; Shaw & McEachern, 2001c), many in the field suggest that this continues to be a journey of exploration and discovery; the destination has not been reached (see discussion Shaw & McEachern, 2001b, pp. pp. 437-438). Others do not attempt a synthesis, rather vowing that given the "vast and novel" research available that trying to do so would "put it in a straightjacket" (Julesz & Kovacs, 1995, pp. p, xx). They leave such task to the reader. The following overview, therefore, must be viewed through a flexible lens on an evolving and diverse field.

### *General Theory: Mediation and Mechanism*

As Polkinghorne states relative to quantum theory, "the behavior one finds depends upon what one chooses to look for" (2002, p. p. 25). The questions posed to nature dictate nature's response. Referencing back to the quantum double-slit experiment, as an example, asking a particle-like question gives a particle-like answer; asking a wave-like question gives a wave-like answer. In this light, as can be seen in Table 4, it is interesting to note that different explorers pose different questions in their search for a general theory of neuroplasticity (Kolb, 1995; Shaw & McEachern, 2001b). The same author at different times may pose different questions (Kolb, 1995; Kolb et al., 2000). Shaw and McEachern foresaw this development. Recognizing that their assembled studies for *Toward a Theory of Neuroplasticity* covered "different species, development stages, and levels of neural organization from genetic through behavior" (2001b, p. p 428). They admit that other searches of the field may have produced different results based on differences of assembled and critiqued research. While speculative, research for this essay suggests that scientists working in this field, with passionate dedication, would be biased against compromising to a level necessary for a general theory framing their concentrated work. A second obstacle to the development of a general theory is the dynamic, evolutionary state of discovery in this field (Julesz & Kovacs, 1995). There remain significant knowledge gaps (Shaw & McEachern, 2001b). There is, then, not a theory of neuroplasticity as much as there is a set of guiding themes and principles for it (see Shaw & McEachern, 2001b, pp. pp. 428-435).

**Table 4. Questions Posed in the Search for a General Theory of Neuroplasticity**

| | **Toward a Theory of Neuroplasticity** (Shaw & McEachern, 2001a) | **Brain Plasticity and Behavior** (Kolb, 1995) | **Cortical Injury and Neuroplasticity During Brain Development** (Kolb et al., 2000) |
|---|---|---|---|
| 1 | How does the nervous system achieve flexibility, yet stability? | How is it that a changing brain can produce the same behavior at different times? | |
| 2 | Do neurons and neural circuits saturate their ability to be modified over time? | What are the constraints of neuroplasticity? | |
| 3 | What age-dependent changes are there in neuroplastic processes from young to old CNS? | What factors influence plasticity? | What factors influence plasticity? |
| 4 | What are the natural events that can induce neuroplasticity, and how to they differ from those employed in vitro? | | |
| 5 | How do various types of neuropathology arise and progress, and how are these changes similar to or different from the normal process of neuroplasticity? | | |
| 6 | | If the brain is plastic, what does this imply for the nature or cortical organization? | |
| 7 | | What are the limits to brain plasticity and what determines them? | How plastic is the developing brain? |
| 8 | | What are the nervous system properties which allow plasticity? | |
| 9 | | Are all regions of the brain equally plastic? | |
| 10 | | Can we gain control of plasticity? | |
| 11 | | | How do the plastic changes in the brain relate to function? |

The 26 studies incorporated into Shaw and McEachern's *Toward a Theory of Neuroplasticity* suggests that there are 11 fundamental themes and principles that are relative to any general theory of neuroplasticity (see discussion 2001b, pp. pp. 428-435). They are listed in Table 5. These non-definitive principles (*e.g.*, no cortical structure is precluded from plastic effects, no defined list of causes of plasticity exists, plasticity in one cortical region is not limited to that area but may effect neighboring regions) suggests a fundamental complication precluding the establishment of a general theory of neuroplasticity. Shaw and McEachern, while attesting to have done so, have failed to establish a general theory of neuroplasticity. With no identified family or set of causation, no accepted mechanism of effect, no accepted understanding of limits or constraints, no limited or defined region where plasticity exists, and necessarily influenced by the context in which plasticity occurs including all environmental and internal stimuli, Shaw and McEachern center their theory on cross-level cortical relationship. However, statement of “theory” presents a proposition as a conjectured explanation for an observed phenomenon (Dictionary, 2003). There remains “significant knowledge gaps” in their “incomplete and overly simplistic” theory (Shaw & McEachern, 2001b) that precludes a complete understanding and explanation for the diverse aspects of neuroplasticity.

**Table 5. Synthesis of Key Themes and General Principles of Neuroplasticity**
(adapted from discussion of Shaw & McEachern, 2001b, pp. pp. 428-435)

| | |
|---|---|
| Where plasticity is found | No distinct subset of neuronal structures or behaviors that is incapable of plasticity (see also Tinazzi et al., 1998). |
| What types of stimuli induces plasticity | Vast number of molecules, manipulations, perturbations, and stressors. Influencers may include intensity, duration, and temporal pattern of stimulus. |
| Progressive response potentiation | Progressive increase in neural response. |
| Cross-sensitization | Stimulus in one modality transfers to another modality. |
| Age-dependence | There are both quantitative and qualitative differences in the properties of the plasticity at different developmental stages. |
| Characteristics of activity-dependent change | |
| Stimulus pattern | Spaced activation is superior to massed activation for causing lasting increases in neural and behavioral function. |
| Context | Environmental and molecular context encoding is important. |
| Persistence | Longevity of neuroplastic alterations spans a range from very short to essentially permanent. |
| Memory code | An increase in the number of cells tuned to an important stimulus. |
| Assigning significance to stimuli | A crucial concept and general principle of neuroplasticity is tagging or assigning significance or importance to experience. |
| Cell birth and death | Recent rediscoveries of new cell proliferation is certain to revolutionize many areas of neuroplasticity (see also Gould et al., 1999). |
| Signaling mechanism in homeostasis and plasticity | Biochemical signaling mechanisms provide controlling homeostatic regulation (e.g., scaling up or down of synaptic strengths, ion conductance regulation). |
| Plasticity-pathology | Some stimuli can co-opt normal plasticity mechanisms inducing inappropriate or pathological alterations in brain function. |
| LTP- and LTP-like phenomenon | Putative model of memory and/or learning processes, with conflicting views:<br>No definitive conclusion whether LTP subserves any form of learning and memory (see Cain, 2001); LTP is generic mechanism for increasing synaptic gain (see Kolb, 1995, 1999; Malenka & Nicoll, 1999; Squire, Weinberger, Lynch, & McGaugh, 1991; Teyler, 2001) |

Establishing a general theory of neuroplasticity is further complicated by the fact that the 11 themes are, where appropriate, considered across the eight levels of neural organization[9]. It is, then, complex. Shaw and McEachern's "central idea" is that neural activity is not limited to one level of organization, but rather all eight (see discussion Shaw & McEachern, 2001b, pp. pp. 439-445). They provide their theory in three dimensions: Interdependence of cortical organizational levels[9], necessity of pertinent instruction, and drive for neural stability.

### *Interdependence of cortical organizational levels*

Each level of cortical organization exhibits "novel properties" (e.g., gene expression via DNA, cellular reactions via biochemical processes). Each level, however, is dependent upon those above and below. As an example, synaptic changes are influenced by genetically controlled protein expression. These changes, then, are "mutually reinforcing." Such reinforcing cross-level action forms a "trajectory" of changes across the neuronal organization.

### *Necessity of pertinent instruction*

Instruction, both external stimuli acting down through progressive levels of cortical organization or internal genetic signals expressed up, must be of sufficient strength. "Strength" is a function of the stimuli frequency, intensity, or relevance.

### *Drive for neural stability*

Each level of neuronal organization seeks stability. It is maintained through opposing negative feedback mechanisms. As an example, constraints to synaptic changes are produced via protein kinases and phosphatases. Final stabilization is achieved by cellular morphology.

# Quantum Brain: An Elementary Examination of the Interrelationship Between Quantum Mechanics and Neuroplasticity

## *Mind-Brain Separation: Artificial Division of Interrelated Action*

The force creating the near four century irreconcilable chasm between the mind and brain sprang from the contradictory 17th century views held by René Descartes and the church. Descartes argued that there were two parallel domains of, what became know as, the “Cartesian dualism” (Schwartz & Begley, 2002): 1) mind, whose essence is thought, where every event is *cogitatio*, or a content of experience (Chalmers, 1996) and 2) the material world. The church, perceiving a threat from scientific advances, orchestrated a division of the two (usually through threat of physical violence). Science readily ceded the soul and conscious mind to religion. This is understandable given Descartes argument that matter is subject to scientific inquiry while mind and consciousness are not. Science retained the material world (see general discussion Schwartz & Begley, 2002, pp. pp. 31-35). It is interesting to note that some believe that centuries after his assertions that Descartes became the “laughingstock of scientist” for his dualist views (Pinker, 1997). Dualism precluded a rigorous examination of the interrelationship of the two; the link between psychological mind and phenomenal mind continues to be ill understood (Chalmers, 1996).

While the intellectual tradition of Western science fosters a continued division between mind and matter, many have challenged its precepts (Schwartz & Begley, 2002). Julien Offray de la Mettrie (1709-1751), 18th century French physician, taught that the mind and brain are two aspects of the same physical reality. He based his research and ultimate conclusions on the mid-17th century advent of neuroscience and the early explorations of a mind-brain relationship.

William James (1842-1910) in the 19th century explored human consciousness and its influence on the physical world in a pragmatic exploration of a “jointless continuity of space” (James, 1997). His views are considered “thoroughly modern” (with their “eerie” parallel with contemporary understanding of quantum processes of the brain) (see discussion Schwartz & Begley, 2002, pp. pp. 260-261). Twentieth century challenges to dualism have been advanced by such scientific notables as Wilder Penfield, Charles Sherrington, and Sir John Eccles. Eccles, a Nobel Prize winner for his work in cross-synaptic communication, proposed a mind-brain theory that has some appeal to quantum mechanics (see comparison with Eccles. Stapp, 1993, p. p. 36). Quantum mechanics is believed to be the mechanism by which the mind acts back on the brain (Brown University, 2003) (see also Green, 2002; Satinover, 2001; Stapp, 1993, 2001a, 2001b, 2003b; Walker, 2000; Wolinsky, 1993).

## *The Quantum Brain: Mechanism of Action*

By the principles of classic physics and Descartes’ concept man is but a mechanical automaton (Stapp, 2001a). Rejected by many philosophers (Hospers, 1967; Stapp, 2003a), this notion is a logical extension of the classic view suggesting a purely material world. It holds that tiny “mindless” particles, acting much like billiard balls, react with each other void of man’s conscious intervention. Acts are, then, fixed by physically described conditions and controlled by mechanical laws. Western science has made “unbridgeable” the divide between the world of mind and that of matter. This includes the foundational building blocks of the brain (*e.g.*, ions) and, thus, the consequential processes of the brain (Stapp, 1993, 2001a, 2003b).

Quantum mechanics has, however, bridged this chasm. Quantum mechanics is a “pragmatic scientific solution” (Brown University, 2003) that allows mind the power to act back on the brain (see also Schwartz & Begley, 2002, p. p. 260). As William James said at the end of the 19th century, "volitional effort is effort of attention" (Stapp, 2003a, p. p. 28). James, physician and psychologist, believed that consciousness – and consequential purposeful attention – provides a means whereby brain processes gain force to develop at the exclusion of others. James did not, however, enjoy a supportive system of physics. He had no supportive epistemology of "how" this would happen. James ideas were not supported by tenets of classical physics and, therefore, failed to develop in mainstream science. Some suggest that the "very origin of the mind-brain problem lies in a physics that has been outdated for almost a century" (Schwartz & Begley, 2002, p. p. 261). Philosophers continued to explore the interrelationship of mind and body, consciousness and matter. They pose the question that if mind never affects body then would not the course of physical events in the physical world have been the same even if there had been no minds? (see discussion Hospers, 1967, p. p 397). Nobel physicist Eugene Wigner contends that "matter has become intrinsically connected to subjective [conscious] experience" (Schwartz & Begley, 2002, p. p. 283).

David Chalmers, Australian philosopher, holds that consciousness cannot be reduced to brain processes (Schwartz & Begley, 2002). He believes that consciousness cannot be reduce to anything more basic, regarding it, rather, as a "nonreductive primitive" (see philosophical discussion Schwartz & Begley, 2002, pp. pp. 46-53). Henry Stapp, physicist, holds much the same view. He contends that "In quantum theory, experience is the essential reality, and matter is viewed as a representation of the primary reality, which is [conscious] experience" (Schwartz & Begley, 2002, p. p. 278). The relationship between physical and mental is a basic law of nature, we can go no further (Hospers, 1967). It is "causally-efficacious reality that is connected to the physical brain processes in a non-local, non-reducible, non-redundant, non-illusionary, and non-trivial way" (Stapp, 2001a, p. p. 9).

A fundamental premise underlying an exploration of the interrelationship of quantum mechanics and brain changes assumes an acceptance that the brain is also comprised of quantum elements (see discussion Schwartz & Begley, 2002, pp. pp. 284-286) (also see elementary illustration of relationship in Figure 2). Most accept that this includes calcium ions (Stapp, 2001a, 2003a). The ionic role in brain processes is clear: Ion movements create electrical signals that determine the release of neurotransmitters. Quantum mechanics describes the mechanism by which these ions "move."

Consciousness – by various names: "Conscious mental field" (Schwartz & Begley, 2002), "mental force" (Schwartz & Begley, 2002; Schwartz & Beyette, 1996), quantum "operators" (Polkinghorne, 2002; Stapp, 1993), or von Neumanns' "Process I" actions (Barrett, 1997; Brown University, 2003; Stapp, 2003a) – plays a critical role in quantum theory. Unlike Process II, Process I action reflects those arbitrary changes resulting from "measurement" (the before mentioned intervention of an observer) (Barrett, 1997). Process I action is random, discontinuous, and nonlinear. Process II actions are deterministic, continuous, and linear reflecting the automatic changes that occur with the passage of time (Barrett, 1997). They are predictable stimulus-response actions that are void of conscious cognition (Cozolino, 2002).

Von Neumann extended the concept of quantum theory from that of atomic science to include neuroscience (Brown University, 2003). This allowed for the scientific exploration of quantum wave phase entanglement and probability wave collapse as underlying biological correlates of brain changes (Barrett, 1997). It is well documented that neuroplasticity, in part as evidenced in synaptic strengthening, results from increased "firings" (Cain, 2001; L. C. Katz & Schatz, 1996; Kolb, 1999; Schuman, 1997; Teyler, 2001) Ian Robertson, neuroscientist, contends that conscious attention can sculpt brain activity by turning up or down the rate of synaptic firing (Schwartz & Begley, 2002). It is proven that repeated synaptic firings causes them to strengthen (Kolb, 2003; Milner, 2003). In accordance with quantum theory, these firings are controlled by "consent" and thereby triggering Process I quantum mechanics. The "consent" can be increased through "mental effort" (Stapp, 2001a).

Contrary to classic physics, the quantum superposition principle permits mixing together states that would classically be immiscible (Polkinghorne, 2002). As example, given that an elementary brain state could be represented by "Yes = P" and "No = (I – P)," a Process I or conscious act on a brain system "S" would result in a new brain state S' as follows: $ConsciousAct \Rightarrow S \rightarrow S' = PSP + (I - P)S(I - P)$ (where I is the identity operator). The new state S' would represent a superposition of brain states including both "Yes" AND "No." Of course, the deterministic principles of classic physics suggest that the brain state, determined void of consciousness intervention and depending solely on material properties, would be in either a state of "Yes" OR "No." It is by the "purposeful actions" of the observer (Stapp, 2003a) through exerting "mental force" (Schwartz & Begley, 2002; Schwartz & Beyette, 1996) or willfully paying "attention" (James, 1997) that feedback of the brain state condition reflects "Yes" or "No." As Stapp suggests, mental choices can influence behavior (2003a).

Providing a mathematical structure of quantum mechanics from classic physics requires replacing numbers with actions, a procedure called "quantization" (Stapp, 2003a). In this transition, as suggested by Heisenberg's matrix mechanics, the order of action is important (see McEvoy & Zarate, 1996; Polkinghorne, 2002). Unlike the basic law of commutation where $(X \times P) = (P \times X)$, in quantum mechanics $(X \times P) \neq (P \times X)$. In fact, $(X \times P) - (P \times X) = (h \times i)$, where $h$ = Plank's constant (6.63 x $10^{-34}$ joule-seconds) and $i$ = an imaginary unit ($i$ x $i$ = -1). The order, then, of actions on brain processes is important. It will determine the feedback which conforms to various brain states. By classic physics, the numerous quantum elements that comprise the brain would be in neatly ordered, pre-specified locations. In accordance with the principles of quantum mechanics these elements are actually in harmonic oscillating states of macroscopic subsystems of the brain (Stapp, 2003a). These oscillating modes of the electromagnetic field act to integrate the contributions of billions of individual particles. Process I events, then, act to single out quasi-stable large-scale patterns of brain activity that are correlates of particular mental actions (see discussion Stapp, 2003a, p. p. 23). The three-step process, as explained of Stapp's interpretation in *The Mind and The Brain: Neuroplasticity and the Power of Mental Force* (Schwartz & Begley, 2002, p. p. 282) is:

1. The evolution of the wave equation (Schrodinger Equation);
2. Choice of which question to pose (Heisenberg Choice);
3. Nature's statistical choice of answer (Dirac Choice).

### *Implications*

The practical implications are staggering. “Directed neuroplasticity” (see Schwartz & Begley, 2002; Schwartz & Beyette, 1996) suggests:

$$(Mental\,Effort) \Rightarrow (Mental\,Force) \Rightarrow (Physical\,Effects)$$

As proven by Schwartz, such a mechanism has tangible benefits in relieving symptoms of Obsessive Compulsive Disorder (OCD) (Schwartz & Begley, 2002). He believes that his “Four-Step Self-Treatment Method” – 1. Relabel, 2. Reattribute, 3. Refocus, and 4. Revalue – provides a practical means to harness and channel the power of mental force. Cozolino suggests that all psychotherapy is therapist-facilitated focused mental effort bringing about brain changes and, thus, relief of psychological symptoms (Cozolino, 2002). It seems, then, that one practical implication for the interrelationship of quantum mechanics and neuroplasticity is within the field of mental health. Research is progressing is this area (see for example Bailey & Chen, 1992; Department of Defense, 2003; Manji et al., 2003; Ruud, 1998). However, the research centers primarily on neuroplasticity void of adequate attention to quantum theory and its power to induce the necessary physiological changes of the brain. Of course, continued research is necessary.

Recovery from brain injury is another important area where such a relationship should be explored. Foundational work in this area is being conducted (Bailey & Chen, 1992; E. Katz et al., 1995; Kolb et al., 2000; Robertson & Murre, 1999). Schwartz provides a powerful example of such work in the case of an individual suffering the debilitating effects of a brainstem stroke (Schwartz & Begley, 2002, pp. pp. 315-316). Unable to communicate bodily, with electrodes implanted into the motor cortex, the individual developed the capability to “will” a computer cursor to move. Further research incorporating mental efforts influence of brain changes is necessary here, as well.

Another significant area in which research is warranted is that of psychological role adaptation during the high-stress situation of large-scale organization change (McElroy, 1999). Leaders are tasked with "learning" new roles (*e.g.*, employee coach, guide, counselor) coincident with organization change. "… much of the contemporary change literature suggests that the leader will be ready for these new roles. It suggests that the leader is psychologically ready to engage in the organization change activities; the necessary foundational readiness for the leader is assumed" (McElroy, 1999, p. p. 3). As I stated in my Master's thesis relative to organization leaders,

> [Leaders]… will be susceptible and to experience emotional stresses associated with the large-scale change borne of industry deregulation (Armstrong-Strassen, 1998). Along with the added demands placed upon the leader (*e.g.,* new roles), the leader will also experience stress associated with the consequential surrender of psychological possessions such as status and power (Hurst, 1991). Experts assert that organizational change includes personal change. Edward Deming recognized this need when he espoused his belief that nothing happens without personal transformation (Senge, 1994). The leader, then, leads change by in-part experiencing personal change. This is a basic tenet of preparing for the new roles. Managers will experience apprehension about the psychological transition which they face. It is the fear of losing, of having to give up something and finding oneself in a situation full of new unknowns (Nortier, 1995).

Unlike post-traumatic stress disorder (PTSD) when therapeutic action is initiated following the stressful event, organization leaders enveloped within change is tasked with psychological adaptation while the inhibiting stressors are present. Moderate stress is suggested as a trigger to neuroplasticity, particularly the increased production of brain cells involved in learning (Cozolino, 2002). Elevated or chronic stress, however, precludes neuroplasticity (Manji et al., 2003). Future research should center on aiding the organization leader to psychologically adapt to new roles and responsibilities that are coincident with the high-stress situation of organizational change. This research should focus on self-directed learning (directed neuroplasticity) aided by the universal laws of quantum theory being harnessed by mental force.

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## Footnotes

1. Henry P. Stapp, theoretical physicists and scholar of quantum theory.
2. Most traditional work related to brain processes treat the subject on synaptic function in terms of classic physics. As an example, quantum mechanics experts in exploring brain functions explain it in terms of "quantum elements" (*e.g.,* electrons, ions) (Cozolino, 2002; Schwartz & Begley, 2002; Stapp, 2001a) and, therefore, explore the concepts underlying quantum functions in the brain.
3. Rev Dr. John Polkinghorne KBE FRS, Cambridge University, England, is a Fellow of the Royal Society, a Fellow (and former President) of Queens' College,Cambridge and a Canon Theologian of Liverpool Cathedral. He was born 16th Oct 1930 in Weston-super-Mare, England, and is married to Ruth. They have three children (Peter, Isobel and Michael). He was at school at Elmhurst Grammar School, Street, Somerset and his distinguished career as a Physicist began at Trinity College Cambridge where he studied under Dirac and others. He recieved his MA in 1956, was elected a Fellow in 1954, and gained his PhD in 1955. In 1956 he was appointed a Lecturer in Mathematical Physics at Edinburgh: returning to Cambridge as a Lecturer in 1958, promoted to Reader in 1965 and Professor in 1968. In 1974 he was elected FRS in and awarded an ScD by Cambridge. During this time he published many papers on theoretical elementary particle physics in learned journals, and 2 technical scientific books, *The Analytic S-Matrix* (CUP 1966, jointly with RJ Eden, PV Landshoff and DI Olive) and *Models of High Energy Processes* (CUP 1980). In 1979 he resigned his Professorship to train for the Anglican Priesthood, studying at Westcott House, He was ordained Deacon in 1981 and served as Curate in Cambridge (St Andrew's Chesterton 1981-82) and Bristol (St Michael and All Angels, Bedminster 1982-84) and was Vicar of Blean

(near Canterbury) from 1984-86. He was appointed an Honorary Professor of Physics at the University of Kent in 1984. In 1986 he was appointed Fellow, Dean and Chaplain Trinity Hall, Cambridge, and in 1989 ("you could have knocked me over with a feather" was his comment) he was appointed President of Queens' College, from which he retired in 1996. He was appointed KBE (Knight Commander of the order of the British Empire) in 1997. (http://www.polkinghorne.org/).

4. “Spectoscopy has played a very important role in the development of modern physics. One reason has been that experimental techniques for the measurement of the frequencies of spectral lines are capable of great refinement, so that they yield very accurate results that pose very precise problems for theorists to attack. Heisenberg was concerned with a much wider and more ambitious assault on special properties generally. [His] calculations looked pretty complicated but, when the mathematical dust settled, it became apparent that what had been involved was the manipulation of mathematical entities called matrices (arrays of numbers that multiply together in a particular way)… matrices differ from simple numbers in that, in general, they do not commute” (Polkinghorne, 2002, p. p. 17). “He… work[ed] out a code for connecting the quantum numbers and energy states in an atom with the experimentally determined frequencies and intensities (brightness) of the light spectra” (McEvoy & Zarate, 1996, p. p. 124).
5. Prince Louis de Brolie was awarded the Nobel Prize for physics in 1929 for his revolutionary discovery of the wave properties of particles.
6. $i\hbar \frac{\partial \Psi}{\partial t} = \left[ -\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2} + V(x) \right]\psi$ The solution to this equation is a wave that describes the quantum aspects of a system. However, physically interpreting the wave is one of the main

philosophical problems of quantum mechanics. The solution to the equation is based on the method of Eigen Values devised by Fourier. This is where any mathematical function is expressed as the sum of an infinite series of other periodic functions. The trick is to find the correct functions that have the right amplitudes so that when added together by superposition they give the desired solution. So, the solution to Schrondinger's equation, the wave function for the system, was replaced by the wave functions of the individual series, natural harmonics of each other, an infinite series. Shrodinger has discovered that the replacement waves described the individual states of the quantum system and their amplitudes gave the relative importance of that state to the whole system. Schrodinger's equation shows all of the wave like properties of matter and was one of greatest achievements of 20th century science. It is used in physics and most of chemistry to deal with problems about the atomic structure of matter. It is an extremely powerful mathematical tool and the whole basis of wave mechanics. (Simon Hooks, Physics A-Level Student, Gosport, UK. Retrieved on December 3, 2003 from http://www.physlink.com/Education/AskExperts/ae329.cfm).

7. At the beginning of the twentieth century, experimental evidence suggested that atomic particles were also wave-like in nature. For example, electrons were found to give diffraction patterns when passed through a double slit in a similar way to light waves. Therefore, it was reasonable to assume that a wave equation could explain the behavior of atomic particles. Schrodinger was the first person to write down such a wave equation. Much discussion then centered on what the equation meant. The eigenvalues of the wave equation were shown to be equal to the energy levels of the quantum mechanical system, and the best test of the equation was when it was used to solve for the energy levels of the Hydrogen atom, and the energy levels were found to be in accord with Rydberg's Law. It was initially much less

obvious what the wavefunction of the equation was. After much debate, the wavefunction is now accepted to be a probability distribution. The Schrodinger equation is used to find the allowed energy levels of quantum mechanical systems (such as atoms, or transistors). The associated wavefunction gives the probability of finding the particle at a certain position. (Ian Taylor, Ph.D., Theoretical Physics (Cambridge), UK. Retrieved on December 3, 2003 from http://www.physlink.com/Education/AskExperts/ae329.cfm).

8. Superposition principle: Quantum theory permits the mixing together of states that classically would be mutually exclusive of each other.
9. Shaw and McEachern (2001b, pp. pp. 437-439) describe interactive neural levels of cortical organization comprising a "neural web." They believe that a particular gap in current knowledge relative to neuroplasticity is the effect across these levels. Most research is "highly reductionist and/or focus at only one level" (Shaw & McEachern, 2001b, p. p. 435). These levels are:
    a. Gene- and Transcription-Level (acting via DNA, mRNA, and protein expression);
    b. Molecular-level (biochemical reactions occurring within the cell);
    c. Synaptic-level (structural changes to the synapse);
    d. Cellular (Neuronal)-level (cumulative effects of synapse on a neuron via ionic current flow);
    e. Circuit-level (interactions occur among cells in a neural circuit and involve the electrical, chemical, and other transduction pathways);
    f. System-level (coordination of excitation or inhibition among circuits of the same modality to produce a cohesive overall response which acts to synchronize or desynchronize the activity in the component circuit);

g. Whole CNS (coordination/integration of activity in various systems);

h. Behavior (response to external or internal stimuli).

# Figure Captions

*1. Double slit experiment*

*2. Quantum Dynamic*

Figure 1

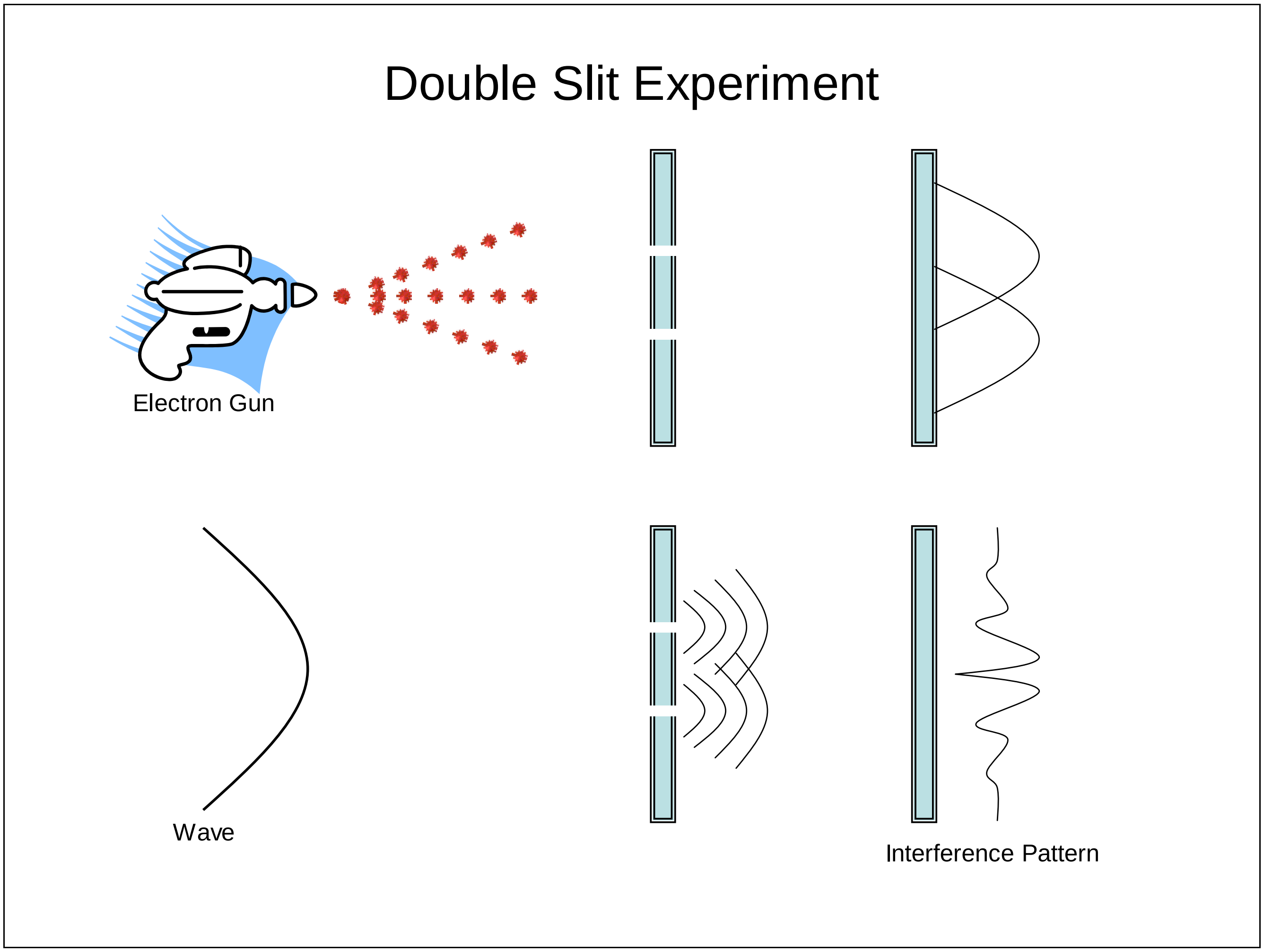
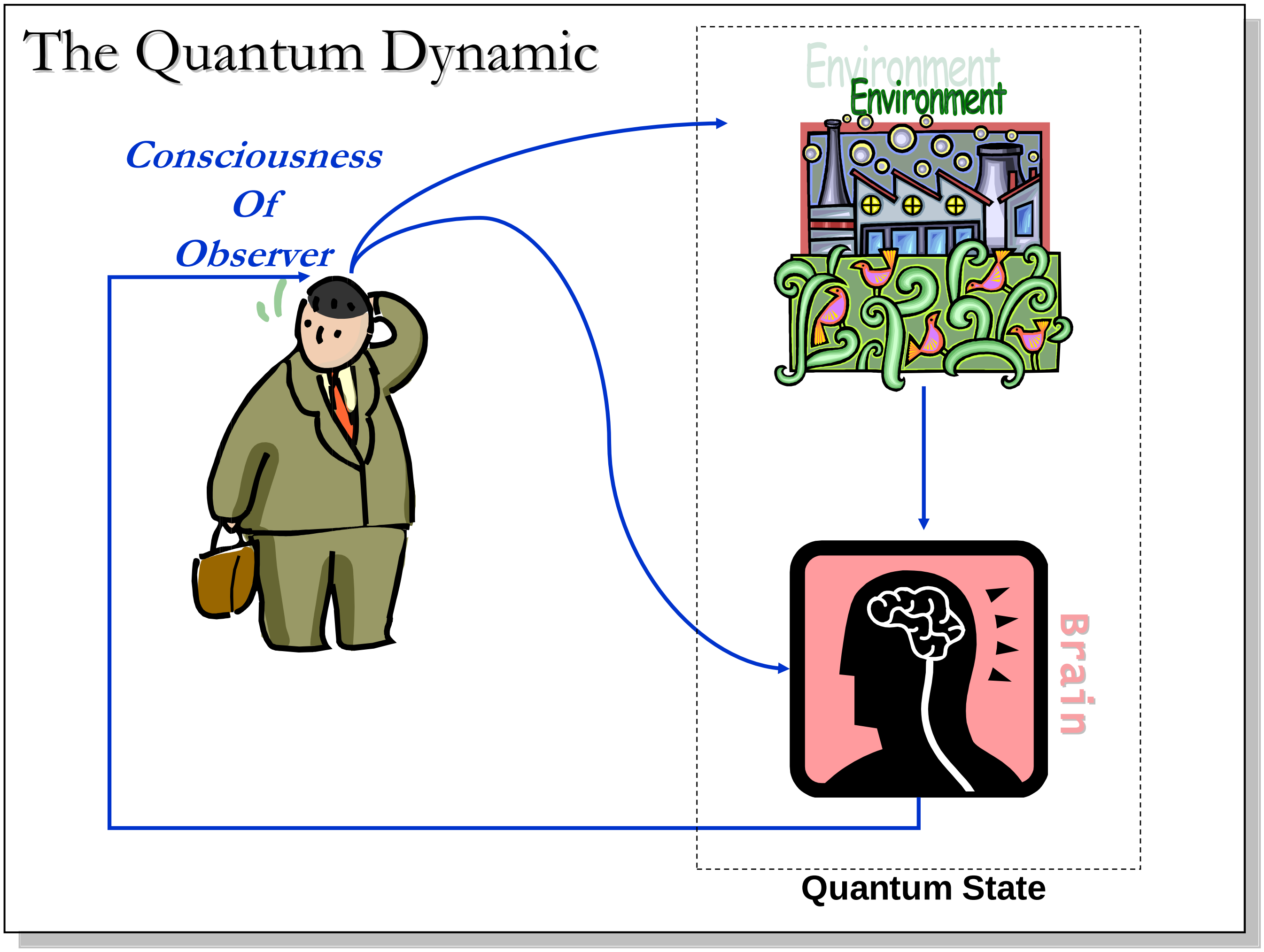

Double Slit Experiment
Electron Gun
Wave
Interference Pattern

Figure 2


The Quantum Dynamic
Consciousness Of Observer
Environment
Environment
Brain
Quantum State