Perspective

Consciousness, Quantum Mechanics, Duality, Monism and Vedanta: Speculations and Facts

Sarma N. Gullapalli*

Abstract

Wave-particle duality, inseparability of the observed from the observer, and the role of observation in Niels Bohr's complementarity principle, have been central to most discussions in the quantum mechanical context of consciousness and monistic *Advaita Vedanta* philosophy. With regard to wave-particle duality and complementarity, recently it has been shown that *the physical particle always remains particle and the mathematical wave function associated with it always remains a wave defining probabilities*. This impacts viewpoints not only of wave-particle duality, but also of wave function collapse, entanglement, action-at-a-distance and others, often cited in context of consciousness. We discuss these new developments, improve objective clarity and reduce subjective vagueness regarding quantum mechanical phenomena. Additionally, we show that when probability is quantified, claims made about consciousness influencing physical outcomes through observation have such low probability ($< 10^{-10}$) that for *all practical purposes* they can be regarded as speculations.

Keywords: Consciousness, quantum mechanics, duality, monism, observer, observed, Vedanta.

Introduction

We first elaborate and discuss some important terms. Wherever possible the source is indicated, such as (oxford) for Oxford Languages.

Consciousness (oxford) "The awareness or perception of something by a person. The fact of awareness by the mind of itself and the world". Swami Chinmayananda (1969 Kindle Life, p58) "The core of the human personality is the Consciousness, which is the 'Life Center' around which all the activities of the body, mind and intellect revolve". Niels Bohr (1961 Atomic Physics and Human Knowledge, 92-93) "In the account of psychical experiences, we meet conditions of observation and corresponding means of expression still further removed from the terminology of physics. Quite apart from the extent to which the use of words like instinct and reason in the description of animal behavior is necessary and justifiable, the word *consciousness*, applied to oneself as well as to others, is indispensable when describing human situation … In deeds the use of words like thought and feeling does not refer to a firmly connected causal chain, but to experiences which exclude each other because of different distinctions between the *conscious content* and the *background* which we loosely term ourselves".

*Correspondence: Sarma N. Gullapalli, Independent Researcher. Email: sngullapalli@hotmail.com

Von Neumann (1955 Mathematical Foundations of Quantum Mechanics, Chapter IV) *proves* that the quantum mechanical measurement (when an observer is involved in the measurement) must include the observer's eyes, optic nerves ending in an area of brain - which we may call consciousness. Extensions of this by Stapp (1993) include 'feeling', and by Wigner (1967) include the reverse process, the impact of consciousness on the physical state of the measured system.

Consciousness, regarded as associated with brain which is fundamentally made up of particles of matter and energy which is the domain of quantum mechanics, can therefore be investigated in terms of quantum mechanics, a field of active research by neuroscientists, biologists and others. Early on, Niels Bohr (1934, cited by Bohm 1951 p170) "had suggested that thought involves such small amounts of energy that quantum theoretical limitations play an essential role in determining its character" in the functioning of the brain". But did not mention consciousness.

A comprehensive review of research on quantum physical functioning of the brain can be found in Betony Adams and Francesco Petuccione (2020) which briefly touches upon consciousness also. A detailed review of quantum approaches to consciousness can be found in H. Atmanspacher (2020) which discusses three main approaches: "(1) consciousness is a manifestation of quantum processes in the brain (2) quantum concepts are used to understand consciousness without referring to brain activity, and (3) matter and consciousness are regarded as dual aspects of one underlying reality". The first approach is closest to quantum physical reality with its wave functions defining probabilities in the physical brain, the second one is a model fashioned on the lines of quantum physics but is not quantum physics, and the third can be entertained without any reference to quantum physics, as a general philosophy that has been around for centuries long before quantum physics. We are primarily concerned with approach (1) which is based physical quantum mechanics, while commenting on meta-physical (2) and (3) also.

In contrast to these efforts to *explain consciousness in terms of quantum mechanics*, there have also been efforts to *explain quantum mechanics in terms of consciousness*. For example Manousakis (2006 'Founding quantum theory on the basis of consciousness'), Goswami (1993 'The Self-Aware Universe, how consciousness creates the material world') along the lines of Vedantic spiritual philosophy.

From the above, we can regard consciousness, which is essentially subjective, in two fundamentally different perspectives: (a) *physical consciousness* as pertaining to a zone of physical brain along with its electromagnetic signals that may extend into space outside the brain, and (b) *meta-physical consciousness* as pertaining to strictly non-physical meta-physical projections of the brain that may extend into the realm of spirituality.

Objective (oxford) "Not influenced by personal feelings or opinions in considering and representing facts".

Subjective (oxford) "Based on or influenced by personal feelings, tastes, or opinions". Heisenberg (1958 Physics and Philosophy pp 44 - 58) regards subjectivity as pertaining to the *statistical variation from person to person* in the matter of how the experiment is set up and how the results are observed, similar to the statistical errors inherent in the measuring equipment, all of which can be made practically small, limited only by the uncertainty principle, which limit in most cases is exceedingly small : "The probability function combines objective and subjective elements … In the ideal case the subjective element may be practically zero". He does not mention consciousness.

Observer (oxford) "A person who watches or notices something".

Observation (oxford) "The action or process of observing something or someone carefully or in order to gain information".

Epistemology (oxford) "The theory of knowledge, especially with regard to its methods, validity, and scope. Epistemology is the investigation of what distinguishes justified belief from opinion". Scientists justify their belief in quantum mechanics based on evidence of experiments which can be verified by others within the margins of (sufficiently small) instrument errors and (sufficiently small) errors in observation of instrument readings by persons conducting the experiments, and so such evidence-based belief is essentially objective. In contrast, opinions are weak in evidence and are mostly subjective. Niels Bohr (1984) 'Discussion with Einstein on epistemological problem in atomic physics' is informative about his views which are essentially objective and not subjective, observation essentially meaning measurement using instruments.

Quantum Mechanics: Oxford: "The branch of mechanics that deals with the mathematical description of the motion and interaction of subatomic particles, incorporating the concepts of quantization of energy, wave-particle duality, the uncertainty principle, and the correspondence principle". We emphasize the basis on *physical particles of matter and energy*, not merely a mathematical edifice.

For example, in Schrodinger's wave equation $(i \cdot \hbar)(\partial\psi/\partial t) = H\psi$ defining the wave function ψ, Hamiltonian function H is physical energy, involving physical parameters of the particle such as mass and momentum. Physical parameters result in finite velocity of propagation of wave function, less than speed of light for mass particles such as electron, and equal to speed of light for energy particles such as photon. Schrodinger's wave equation is grounded in physical reality, is not merely a mathematical construct.

Probability is not unique to quantum mechanics, was extensively used in classical physics long before quantum mechanics (Goodman 2000 Statistical Optics; Statistical Mechanics; Boltzmann's statistical formulation of effects of temperature foundational to thermodynamics). But what is unique in quantum mechanics is that probability, a non-negative quantity, is expressed as magnitude squared of *probability amplitude function* (the wave function) *which is sinusoidal* with both positive and negative excursions that is characteristic of wave propagation (non-negative classical probability does not result in wave propagation – herein lies the genius of Schrodinger).

The occurrence of "imaginary" number i (= $\sqrt{(-1)}$) in Schrodinger's wave equation (and also elsewhere in quantum mechanics) has evoked the view of unreality in quantum mechanics. But there is nothing "imaginary" (an unfortunate misleading terminology used in mathematics) about $\sqrt{(-1)}$. The algebra of complex numbers $(x + iy)$ where x and y are real numbers, can be just as rigorously developed without i, by using *pair of real numbers* (x, y), defined as follows: addition: $(x1, y1) + (x2, y2) = (x1 + x2, y1 + y2)$; multiplication: $(x1, y1)\cdot(x2, y2) = (x1\cdot x2 – y1\cdot y2, x1\cdot y1 + x2\cdot y2)$. It is readily verified that $(0, 1)\cdot(0, 1) = (-1, 0)$, that is, $(0, 1) = \sqrt{(-1, 0)}$, which is i. In this formulation, both x and y axes are real, y is not "imaginary". But this algebra is messy to keep track of, while $(x + iy)$ permits the use of ordinary algebra which is very convenient. Complex algebra is widely used in classical physics also, for convenience, especially in the analyses of wave propagation, and classical physics is all about real physical quantities. There is nothing unreal about quantum mechanics.

A fundamental postulate of quantum mechanics is Heisenberg's uncertainly principle (which can be derived from the Fourier transform relationship between conjugate pair of variables such as position p and momentum q, see Papoulis 1962, p 62-63) says that for a complementary pair of physical quantities, such as position p and momentum q of a particle, if Δp is uncertainty in p and Δq is uncertainty in q, then $\Delta p \cdot \Delta q \geq h/4\pi$ where h is Planck's constant ($6.63 \cdot 10^{-34}$ $kg \cdot m^2/s$). That is, both cannot be simultaneously defined to arbitrarily high accuracy. In classical mechanics there is no such limit. Some scholars cite this to claim that everything in the world is uncertain, "Maya", illusory. Note that h is an extremely small quantity, and so in the macro world, like a stone, pot or our body, Δp and Δq can be *practically extremely small* and still satisfy the uncertainty constraint. Errors in our yard sticks, speedometers and even laser gages are orders of magnitude higher. World is not illusory.

Application of the mathematical framework of quantum mechanics to meta-physics can lead to unnecessary difficulties due to *the finite velocity of propagation of wave function as defined by Schrodinger's wave equation*, whereas meta-physical thought processes and meta-physical consciousness can instantly reach the far corners of the universe.

Telepathy (oxford) "The supposed communication of thoughts or ideas by means other than the known senses".

Fact (oxford) "A thing that is known or proved to be true".

Speculation (oxford) "The forming of a theory or conjecture without firm evidence".

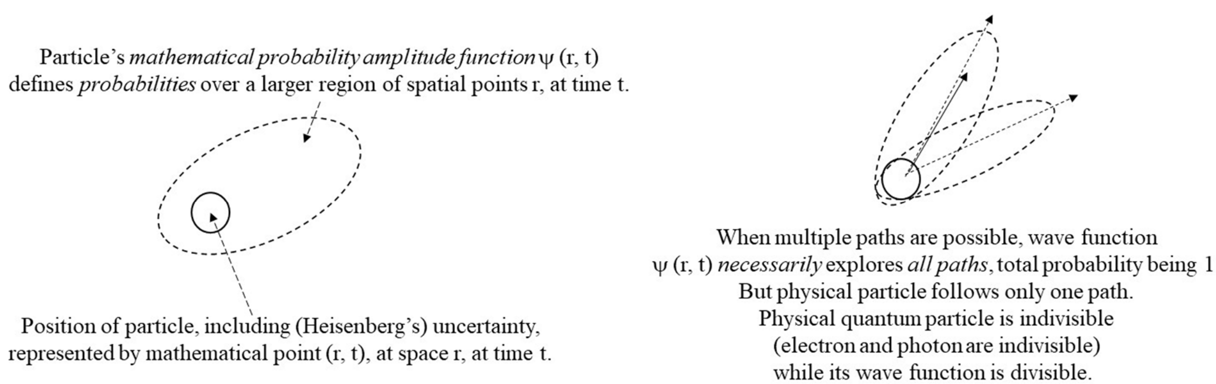
In the context of quantum mechanics which is fundamentally probabilistic, wherein, to quote a leading physicist in a TV documentary (NOVA, Einstein's Quantum Riddle), "*everything is possible*", how does one separate fact from speculation? The answer lies in "*with what probability?*" In the range of all possible *potentialities* with total probability of 1, an event with probability of 10^{-10} may be regarded as lacking evidence and hence speculative as compared to an event with probability of 0.99 which may be regarded as fact. Brian Greene (2020, p 297-299) estimates that long after our world, solar system and all galaxies have dissipated into swarms of wandering particles, there is a non-zero probability that a subset of them would coalesce into what constitutes a human brain (called Boltzmann brain, named after the scientist who first studied molecular random motions in the context of thermodynamics), *if we wait for* 10000000000^{68} (*that is 1 followed by 680000000000 zeros*) *years*! Without doubt, we can call occurrence of such an event speculation. Moreover, such a Boltzmann brain will exist only for a fleeting moment before dispersing, a dead brain without blood circulation even for a fleeting moment. This goes to show to what unrealistic lengths probability theory can be stretched. Quantum mechanical "*everything is possible*" is highly misleading if the associated probability is not quantified.

Part 1. Quantum Mechanics

We begin with a summary of a recent key new development (--- 2018, 2019) that is foundational to what follows, which explains wave-particle duality, which Richard Feynman (1965 Lectures on Physics volume 3 p 1-1) had called “the only mystery of quantum mechanics”, without Bohr’s complementarity principle that has been like a doorway through which have passed many a claim that consciousness influences the duality experiments.

1.1 **Wave-particle duality: Particle *always* remains particle, wave *always* remains wave.**

Particle such as an electron or a photon occupies non-zero volume in space, both due to inherent physical nature, and also due to (Heisenberg’s) uncertainty principle. Wave function $\psi(r, t)$ associated with the particle is a *mathematical probability amplitude* complex number that defines the *probability* $|\psi(r, t)|^2$ of the particle being *at spatial point r,* at time t, symbol $|\cdot|$ denoting the magnitude of complex number. Thus we need to *represent* the physical particle by a mathematical point. Without loss of generality we can choose the centroid (similar to center of gravity) of the blob that is the physical particle *including (Heisenberg’s) uncertainty spread*, as shown in Figure 1 (a). In general, $|\psi(r, t)|^2$ can be non-zero over a region of space larger than the particle, because the particle can possibly be at any one of the many points over the larger region. When the particle is in motion, and there are multiple possible paths, such as a photon hitting a beam splitter with two possible paths: reflected and transmitted, or a photon reaching the two slits in Young’s double slit experiment (discussed later) with two possible paths, one through each slit, then its wave function *necessarily* explores all paths and define corresponding probabilities, *total probability always being equal to 1*, as the particle is there somewhere in space.



(a) Mathematical wave function spans larger volume than physical particle

(b) Divisible wave function explores multiple paths while indivisible particle follows only one path

Figure 1. Particle always remains particle and its wave function always remains wave

This means that, as shown in Figure 1 (b), the *mathematical* wave function *is divisible* among the multiple paths, while the *physical* particle (quantum – electron or photon) *is indivisible* by definition of “quantum” in quantum mechanics. Thus, based on the very fundamental precepts of quantum mechanics, namely that (a) the particle's divisible wave function defines the mathematical probability of its position (it also defines other physical aspects of the particle, but that is beyond the scope of our discussion) along multiple paths and (b) the physical particle is indivisible, we see that *(a) the indivisible particle always remains particle, and (b) its divisible wave function always remains wave*. As we shall see, this dispels most misconceptions about quantum mechanics and replaces subjective vagueness with objective clarity. The prevailing view of wave-particle duality, namely that the particle *somehow changes* to wave, or wave *somehow changes* to particle, has a history, a short review of which helps dispel this misconception.

Early on, pondering about the wave function of a photon, Albert Einstein had suggested *interpreting* the electromagnetic wave (which in classical physics is a physical entity) as the *probability amplitude* (wave function) for the photon. Max Born then generalized this to apply to any particle such as an electron (Max Born, Nobel Lecture 1954 "The statistical interpretation of quantum mechanics"); the wave nature of electron was also experimentally confirmed. Classical electromagnetic wave being a physical wave, and electron being a physical particle, it was initially (wrongly) thought that the associated wave function is also a physical wave. Because wave function spatially covers a much larger space than the particle at any given time, it was initially (wrongly) thought that a particle could be at more than one place at the same time.

The fallacy here is that the wave function is not a physical entity. Probability amplitude is purely a mathematical construct, nothing physical. When we draw a graph of a probability density function (a bar graph or bell shaped graph) there is no physical entity with that shape. This fact is now recognized by most quantum physicists, but the old notion of wave function as a physical aspect of the particle still persists among some scientists. According to quantum mechanics, the physical particle can be *observed* to be at only one place at any given time. As an analogy, consider a fugitive escaped from prison, and is expected to be in one of ten neighboring towns T1 to T10, for which we assign probabilities P1 to P10, total being 1. This does not mean that the fugitive is in all ten towns at the same time. At any given time, there is *probability* that he is in respective towns.

1.2 **Niels Bohr's complementarity principle, and consciousness**

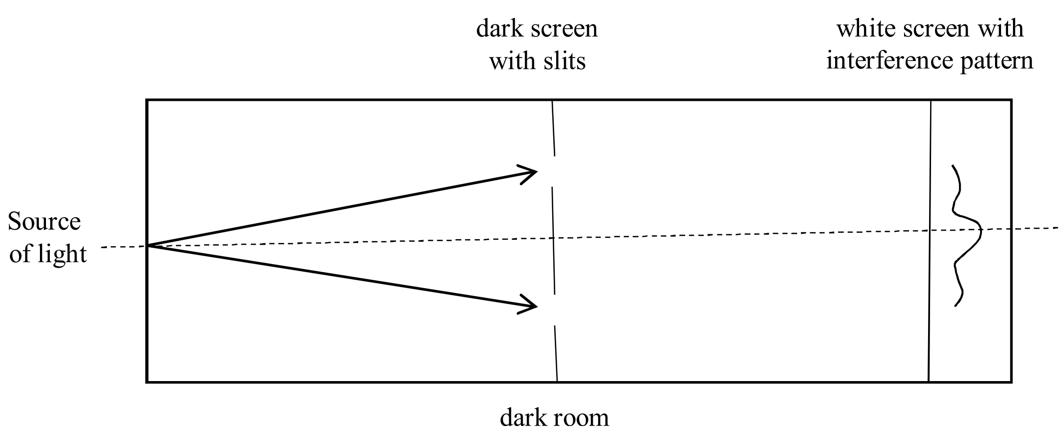


Figure 2. Young's double slit experiment

In 1803 Thomas Young demonstrated the wave nature of light by performing an elegant simple experiment shown in Figure 2.

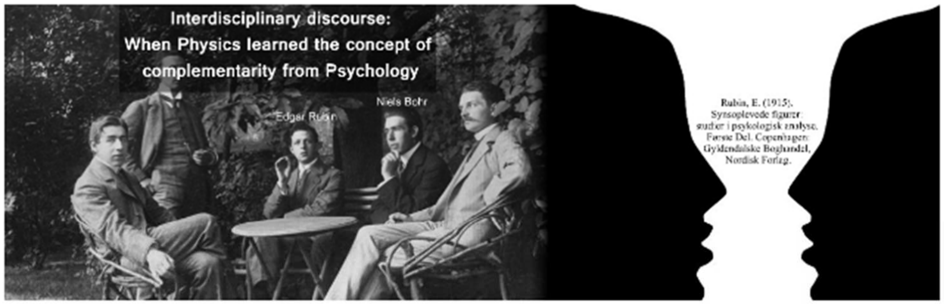
In a dark room, on one side of a dark screen is a point source of light, and on the other side is a white screen. In the dark screen there are two narrow parallel slits close together. On the white screen, instead of just two adjacent bright patches of light with darkness between the two on the center line as would be expected if light rays were made up of particles, one sees several alternating bright and dark bands of light with the main bright band peaking on the center line where it should have been dark. The only way this can happen is if light behaves like a wave. The two wavelets, one from each slit, reinforce each other (in phase) on the center line, and cancel each other (out of phase) at the dark bands, forming an *interference pattern*, like waves on water passing through two narrow nearby gaps.

In 1864, based on equations developed by himself, James Clerk Maxwell predicted electromagnetic wave propagation *exactly at the speed of light,* suggesting that light is an electromagnetic wave. During 1880s Heinrich Hertz experimentally generated electromagnetic radio waves, confirming Maxwell's predictions. Thus, by the end of 19th century the wave nature of light was firmly established. Then, when particle nature of light was required by quantum mechanics, Young's double slit experiment took center stage for re-examination. A particle of light (photon) can go through one or the other slit, not both. But observed interference pattern requires that the photon go through both slits like a wave!

Albert Einstein and Niels Bohr discussed this at great length (J.A. Wheeler and W.H. Zurek, 1984, pp 9-31; Niels Bohr, 1984 'Discussion with Einstein on epistemological problem in atomic physics'), with Young's experimental set up visualized with hypothetical modifications to detect particle nature of light at the slits by cooking up elaborate schemes, and came to the conclusion that if particle nature is detected, then the interference pattern must disappear (decades later, experiments with single photon detectors at the slits confirmed this). *Whether light behaves like a particle or wave depends on experimental setup!* How is this possible?

To answer this, Bohr postulated *Complementarity Principle* that almost begs the question: If experimental set up is to *observe* particle nature of light, then light will behave like a particle; if experimental set up is to *observe* wave nature of light, then light will behave like a wave. It appears that Bohr got his idea of complementarity during discussions with psychologist Edgar Rubin about *bi-stable human perception* of an object, such as the shape in Figure 3 which is seen either as a vase or human face but not both at the same time. This has induced some scholars to include the experimenter's subjective perception, consciousness, in Bohr's complementarity principle.

But in all his papers on complementarity Bohr makes it clear that by observation he means the experimental setup, and makes no reference to consciousness (Bohr 1949 'Discussions with Einstein on Epistemological Problems in Atomic Physics'; Holton, 1970. The Roots of Complementarity; Pauli 1948 Dialectica special issue).



Photograph of Niels Bohr and Edgar Rubin as members of the club "Ekliptika" (Royal Library of Denmark).

Figure 3. Edgar Rubin's bi-stable perception: vase or human face, not both at same time (source: https://qbism.art)

Albert Einstein vehemently disagreed, in effect saying *how can an inanimate particle know what the experimental set up is about?* Decades later, when fast single photon detectors became available, highly sophisticated experiments were conducted, which confirmed Bohr's complementarity principle (Kim *et al*, 2000; Jaques et al, 2006). The implications of Bohr's complementarity principle are huge for most technologies that rely on quantum mechanical behavior of single photons, such as quantum communications and quantum computers, where beam splitters and beam combiners are used in various interferometric configurations (the basic principle is same as Young's double slit experiment), wherein any *knowledge* of "which way" the particle went, in effect detecting particle nature, *would destroy the crucial interference phenomenon!* This "*which way*" criterion has been widely applied in designing and analyzing quantum systems, with rapidly increasing difficulty as the complexity of systems increases. Here again, *experimental knowledge of which way* has been extended by some scholars to include the consciousness of the experimenter.

Recently it has been shown (Sarma 2018, 2019) that the results of the highly sophisticated experiments that confirmed Bohr's complementarity principle can all be explained on the basis of *coherence and alignment considerations of the (mathematical) wave functions which depend only on the experimental setup, without using Bohr's Complementary Principle*, which, though true, *is thus redundant*. That is, the role of *observation* in particle or wave behavior of photon can be *entirely dispensed with*, and consequently, the inclusion of consciousness in Bohr's complementarity (he did not mention it) is not justified. This redeems Albert Einstein's view that the inanimate photon does not know that it is being observed.

1.3 **Joint wave function of measurement and consciousness:**

As proved by von Neumann, in quantum measurement all components (the measured object, the measuring instrument, eyes of the observer reading the instrument, his or her brain, and a terminating area of brain called consciousness) must be included in a *joint wave function*, and not independently. The state of a component is a projection of the joint state for that component. This is illustrated in Figure 4 for the case of Young's double slit experiment discussed earlier, with detectors at the slits to detect (*observe*) particle nature, extending observation to consciousness.

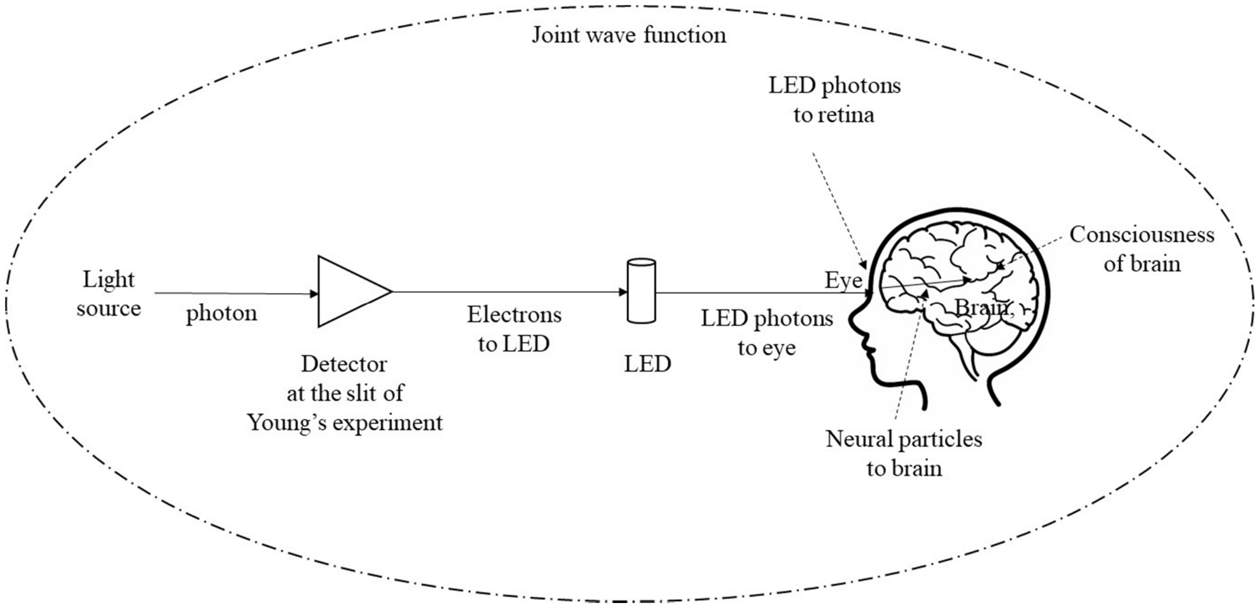


Figure 4. Joint wave function of measurement system from light source to consciousness

Scholars who claim that consciousness influences the experiment point to the joint wave function as the link through which this effect takes place. What they omit is the crucial *with what probability*, especially as probability is fundamental to quantum mechanics. We shall show that the probability of consciousness influencing the experiment is *practically* zero, and so the claim is not true *for all practical purposes*.

For clarity of discussion, let us simplify by first considering the joint wave function of orbital electron in the atom of light source and orbital electron of the atom in detector, say 0.3 meter from the light source, as shown in Figure 5. The amplitude of wave function of source orbital electron decreases exponentially with distance r as $e^{-r/(n \cdot a0)}$ (see Zweibach MIT Open Courseware) where n is the orbital number (less than 6 for most atoms) and a0 is first Bohr radius which is 0.053 nanometer (1 nanometer is one-billionth of a meter). At a distance of just 6 nanometers the amplitude is $2 \cdot 10^{-9}$ and probability is $4 \cdot 10^{-18}$, an extremely small number, practically zero. At t = 0 the source orbital electron drops to a lower energy level and emits a photon, whose wave function, traveling at speed of light, reaches the detector atom in 1 nanosecond (not instantaneously), where it interacts with the detector orbital electron, imparting to it energy which releases it to be amplified by the detector's amplifier circuitry.

The amplitude of the wave function (wave packet) of a photon of wavelength say 800 nanometers (visible light) is localized to within about 600 femtosecond duration (Brian J. Smith Figure 1) which at the speed of light is 180 microns, less than two tenths of a millimeter Experimentally, single photon detectors time stamp detection to this level of resolution, which shows the highly localized nature of photon. The small size of photon's wave packet should not be confused with its coherence length, which is the space-time distance over which *phase* of the wave packet remains stable with respect to another (earlier) space-time point, and it *depends on the source*, and can be very large for lasers due to the nature of laser source.

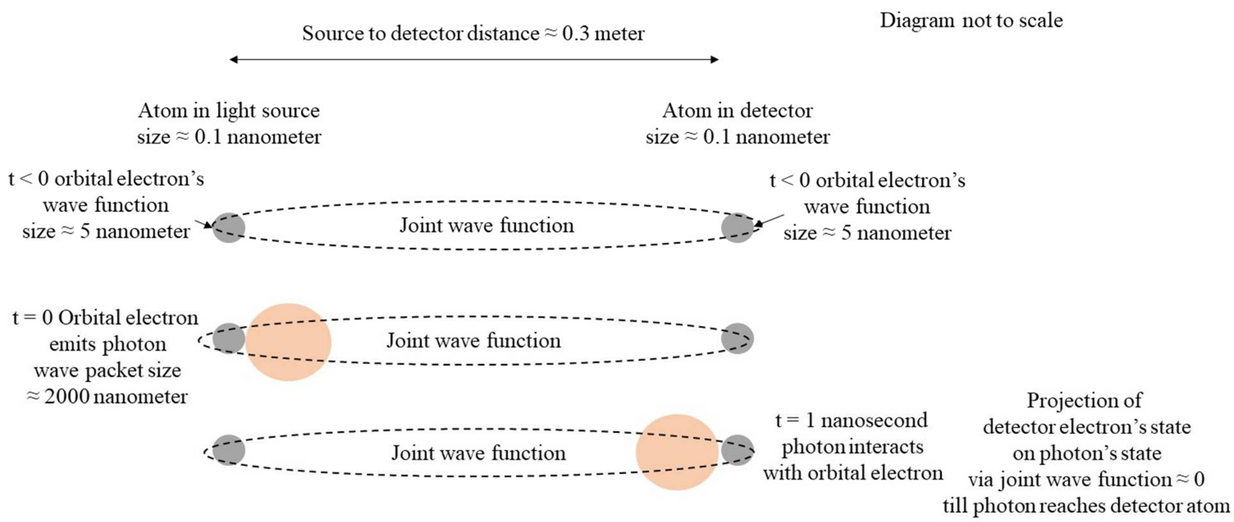


Figure 5. Joint wave function of source orbital electron, photon and detector orbital electron

Thus, until the photon is in the *atomic neighborhood* of the detector orbital electron, the projection of its state on the state of orbital electron via the joint wave function is *practically* zero, though *theoretically* non-zero. The point of this discussion is that until the time of detection there is *practically* no influence of detector orbital electron on the photon, which in turn has *practically* no influence on the source orbital electron after the photon leaves the atomic neighborhood of source orbital electron. Thus, the *theoretical* influence of detector atom on the source atom via photon in joint wave function has *practically zero probability*. Extending this reasoning to LED, eyes, retina, brain and the consciousness point in the brain, we conclude that effect of brain's consciousness on the source or detector in the experiment *by observation route* via joint wave function has *practically zero probability*. In contrast, an action by the observer *through his or her limbs* such as hand controlling the experiment will have a significant probability.

In the above scenario, the involvement of the observer's consciousness is through photons reaching the retina of the eye. If, however, we consider a scenario involving not light photons (whose wavelength and hence wave packet is extremely small), but microwave and radio wave photons which have much longer wavelength and wave packets (microwave ~ a few centimeters; radio waves ~ tens of meters, longer all the way down to electrostatics) in which case there can be non-trivial interaction between the source and detector, and, *if the observer's brain has the ability to interact directly with such longer wavelength electromagnetic waves or electrostatics* (not through the eyes), then one can make the case for brain / consciousness interacting with the experiment. This falls under telepathy and telekinesis, a nebulous subject that has been around for a long time. If confirmed through repeatable predictable experiments, it will be a major advancement for neuroscience. Some scholars (Goswami) have tried to explain some reported telepathy experimental results on the basis of quantum mechanical non-local-action-at-a-distance. We shall show later (in the section on non-local-action-at-a-distance) that this is not quite true.

1.4 **Wave function collapse**:

At the instant a particle is detected (*observed* in a detector), its wave function instantly vanishes everywhere else, localizing it (collapsing it) to just the detector. For example, when a photon interacts with an electron in the detector, the electron gains energy and (its wave packet) moves to the amplifier, while the photon (and its wave packet) disappears. This is called wave function collapse. This apparent violation of physical laws (instantly vanishing everywhere, faster than relativistic limit of speed of light) has been cited by some scholars to regard wave function as supernatural. But the wave function is non-physical mathematical probability amplitude, and so it can vanish instantly everywhere without violating any physical laws. In the earlier analogy of a fugitive on the run, when he is captured in a particular town, probabilities for all other towns instantly drop to zero. There is nothing supernatural in this. Sometimes particle is not absorbed, and continues on with modified energy or momentum. Then a *correspondingly modified* wave function defines its probabilities from that point on. In the analogy of fugitive on the run, if he is spotted in a town but not captured, the probabilities for the other towns get redefined, and some new towns may enter the picture with their own probabilities.

1.5 **Observation in quantum mechanics**:

Given a cause – effect relationship of an event, wherein the cause can have one of several values, in an ensemble of random probabilistic cause (at time t1) – effect (at time t2 > t1) events, in classical physics the randomness is resolved (which is the actual event out of the many probable events) at time t1, the effect of which is observed at time t2. In sharp contrast, in quantum mechanics the randomness is resolved *only at the time of observation*, till which time it all remains probabilistic. To the question "What is the *actual* event before the time of observation?" the quantum mechanical answer is "The question is ill-posed, we can talk *only* about probabilities till the time of observation".

One can argue that it makes no difference because for each observed effect there is a corresponding value of cause, in a one-to-one cause-effect relationship. But it makes a huge difference when two or more *entangled* particles are involved, which we shall discuss shortly in the context of non-local action at a distance, for which there is no parallel in classical physics.

Thus, in quantum mechanics *observation* plays a fundamental role, and opens the door to involving consciousness. An example is Schrodinger's cat.

1.6 **Superposition of states and Schrodinger's cat**:

Depending on the system, Schrodinger's wave equation can have multiple solutions (like the many modes of acoustic vibration of a string), each defining a distinct probability profile in space-time, the sum total of all probabilities must always equal 1 because the particle exists somewhere there in space-time. Each such probabilistic profile is called a quantum mechanical "state" of the system, and as each is a valid solution to Schrodinger's wave equation (which is a mathematically linear partial differential equation), a linear combination (a weighted sum) of these states is also a solution to Schrodinger's equation, and so is a valid (generalized) state. This is called *superposition of states*. All are still only probabilities. Clearly, this does not mean that the particle exists in all the states at the same time. While all states remain probabilistic until observation, the *observed* particle is only in one state. For someone rooted in classical mechanics this answer may not be convincing, and so the incorrect notion evolved that "the particle is in all states at the same time until the time of observation" which should actually read "the particle is *probabilistically* in all states at any given time until the time of observation".

To explain the fundamental role of observation in quantum mechanics, Schrodinger visualized the following hypothetical experiment: A cat is placed in a box, along with a mechanism that can release poisonous gas at some random instant of time in future, and the lid is closed. The question at some time in future is: *Is the cat dead or alive*? We will not know the answer to this question until we open the box and *observe* the cat, till which time the state of the cat is a superposition of two *probabilistic* states (dead, alive). Note that it is *not* actually being alive and dead at the same time. Some scholars include the consciousness of the observer in the observation, claiming to influence whether the cat is dead or alive. A test to verify this claim is to have the observer consciously decide whether the cat is dead or alive *before opening the box* and record the decision, and *then open the box*. Repeating this experiment many times, one would find that there is no correlation between conscious decision and the outcome. Furthermore, if no observation is ever made, after a long time, say a century, the cat would be definitely dead, no question of still being both alive and dead.

Note that observation defines a particular state of the object out of many potential states, but *does not create the object*. The object is in existence throughout, only its state is unknown till observation. It is wrong to say that observation creates the object.

Material universe functions even if no intellect ever observes it, as it has done for more than 14 billion years, even if no human beings ever existed to formulate the Big Bang theory. In nature, "observation" = inter-particle interaction.

1.7 **Entanglement, non-local action at a distance and the EPR Paradox**:

"Action at a distance" means cause and effect are separated by empty space. Examples are gravitational, electric and magnetic fields which act on a body at a distance across empty space, well known in classical physics. These fields propagate in free space at the speed of light which is about $3 \cdot 10^8$ meters per second. According to Einstein's special theory of relativity, nothing can travel faster than speed of light. That is, effect at time t1 of a cause at time t0 cannot happen at a place farther than $c \cdot (t1 - t0)$ where c is speed of light in free space. If the effect happens at a distance greater than this, it is called *non-local action at a distance*, "locality" being $c \cdot (t1 - t0)$.

Photons have the property of polarization, with two components: horizontal and vertical (familiar example is Polaroid eye glass which cuts off glare which is horizontal polarization component in scattered light). Sometimes when two photons are *created together* at the same space-time point, their polarizations can become *correlated* (for electron pair it is spin, plus or minus). That is, the state of one has a *fixed* relationship to the state of the other, the two states are not independent. Then the two particles are said to be *entangled*. The state can be random, but with a *given fixed relationship between the two*. In the classical picture, the actual value of random state is defined at the time of creation of the pair. In quantum mechanics where probability is fundamental, *only the joint probability of the pair is defined at the time of creation,* and (as Schrodinger pointed out in his cat experiment) *the actual state is known only at the time of observation (measurement).* This makes a huge difference.

Albert Einstein, who was uncomfortable with the fundamentally probabilistic nature of quantum mechanics (famously saying "God does not play dice", but, nevertheless, as a true objective scientist accepted all objective evidence that led to quantum mechanics, he himself being one of its founding fathers) set out to cook up a thought experiment that he hoped would show the inadequacy of quantum mechanics, described in a paper with co-authors Podolsky and Rosen titled "Is quantum mechanics complete?" (1935 Physics Review 47) – The now famous "EPR Paradox". In this thought experiment, a pair of entangled particles are created and sent along in opposite directions in space. When the spatial separation of the two is significant, the state of one particle is measured, at which time the state of the other particle, *which until that instant remained probabilistic according to quantum mechanics*, must be fixed instantly, thus acting at a distance instantly, violating the relativistic speed limit of velocity of light! Therefore, quantum mechanics must be missing something! Schrodinger immediately responded (1935 Mathematical Proceedings of Cambridge Philosophical Society 31-4) saying that this prediction of quantum mechanics is correct, and coined the term *entanglement* for this incredible classically unbelievable phenomenon.

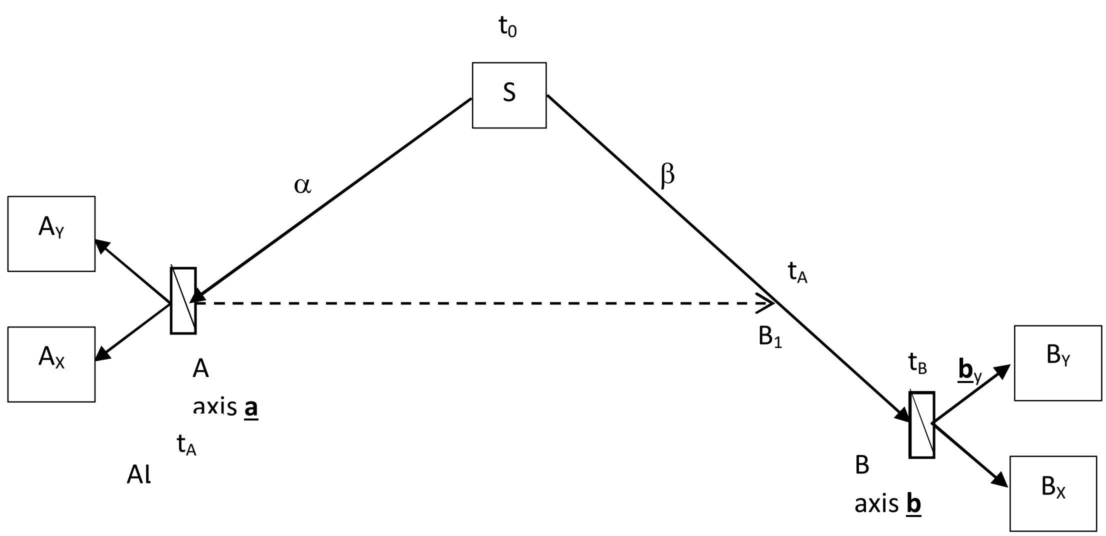


Figure 6. Experiment with polarization-entangled photons proving non-local-action-at-a-distance

Decades later, when technology was available for sending single photons uncorrupted over sufficiently long distances (fiber optics) and fast single photon detectors became available to detect/timestamp for determining correlation between the entangled photons with sufficient resolution and accuracy, *non-local action at a distance has been confirmed*, through numerous ingenious experiments, pioneering proposal by Aspect (1976) followed by many, including a notable one by Zeilinger (2015) over distance of kilometers. A typical setup is shown in Figure 6. Source S at time t0 emits a pair of polarization entangled photons, α to station Alice where its polarization state is measured at time t_A and β to station Bob where its polarization is measured at time $t_B = t_A + \Delta t$ (distance between Alice and Bob being greater than $c \cdot \Delta t$, and so non-local) and found to be correlated to that of α.

Does this mean there is something supernatural going on? No. Because what we are measuring for the entangled pair is *the correlation of their states and not individual states,* the measurement (observation) *is not complete* until both are measured. It is a question of *correlation* of the two, not a question of one being the cause and the other being the effect. In fact, if Bob's measurement at t_B is taken to be the cause (until which time we would not know there is correlation), the effect at t_A happens earlier than the cause, "*retro-causality*"! But the *divisible joint wave function* of the two travels from S along respective paths at a speed less than or equal to speed of light in free space. It can be argued that *if the act of entanglement at S is taken to be the cause*, as it should be, there is truly no non-local action at a distance, correlation requiring *both* measurements, not one cause and the other effect. This does not, however, diminish the astonishing nature of this phenomenon, so accurately predicted by Schrodinger and verified decades later – objectively, no subjective mysticism.

It may be noted that it is a challenge to measure the correlation, because (a) not all particles created are entangled, and not all particles received are entangled, constituting a noise background and (b) a particle must be correlated to *its* companion particle, not to a particle of another pair, which requires extremely high temporal resolution of the detections, requiring single photon (one photon at a time) regime of operation. It is a testament to the experimental genius and perseverance of the researchers.

In quantum physical reality (fact, not fiction or speculation), cause-effect relationships are thus far more complicated, *fundamentally probabilistic even in plurality of particles through joint probabilities*, than the simple minded one cause - one effect relationships lined up neatly along the arrow of time from past to future, foundational in classical mechanics, and also in religious concepts tracing back to God as the unique original cause without a cause.

1.8 **Quantum jump**:

In the quantum mechanical model of the atom, orbital electrons surrounding the nucleus are in different discrete levels of energy. When the energy of a photon is absorbed by an orbital electron, the electron "jumps" to a state of correspondingly higher energy. Likewise, when an orbital electron drops from a higher energy level to a lower energy level, a photon is emitted with the difference energy. These jumps are called *quantum jumps*. Believing the jump to be instantaneous, some scholars say that *at the instant* of the jump the electron exists in both orbits at the same time, being at two places at the same time, discussed and dismissed earlier in the context of wave function of the particle. It is worth noting that the jump is not instantaneous, and has been measured recently, Max Planck Institute (2016), to be about a hundred attoseconds (1 attosecond = 10^{-18} second). Even for an instant the orbital electron is not at two different energy levels. Nothing supernatural.

1.9 **Uncertainty principle**:

Heisenberg's uncertainly principle says that for a complementary pair of physical quantities, such as position p and momentum q of a particle, if Δp is uncertainty in p and Δq is uncertainty in q, then $\Delta p \cdot \Delta q \geq h/4\pi$ where h is Planck's constant ($6.63 \cdot 10^{-34}$ kg·m^2/s). That is, both cannot be defined to arbitrarily high accuracy. In classical mechanics there is no such limit. Some scholars cite this to claim that everything in the world is uncertain, an illusory perception by one's consciousness. Note that *h* is an extremely small quantity, and so in the macro world, for a stone, pot or our body, Δp and Δq can be *practically extremely small* and still satisfy the uncertainty constraint. Errors in our yard sticks, speedometers and even laser gages are orders of magnitude higher. World is not illusory, not a figment of imagination by one's consciousness.

1.10 **Telepathy**:

Reported experiments involving telepathy (*assuming that they have been conducted scientifically and repeatability verified by others*) involve a person communicating with another person across space, with *no electromagnetic neuro signals detected.* Scholars who suggest explaining such a phenomenon of telepathy as quantum mechanical non-local action at a distance (Goswamy 1993 p 130-133) overlook a key fact: In the time interval between cause (sending person initiating signal transmission) and effect (receiving person receiving the transmission) the distance covered at speed of light far exceeds the distance between sender and receiver, so it cannot be non-local. If neuro electromagnetic signals are not involved, as claimed, this would open up a new fertile ground for further research *in physical sciences, to send and receive non-neural telepathic signals*.

Part 2. Vedantic Consciousness and Quantum Mechanics

Quantum mechanics, in which wave function defines all probable *(not yet realized)* outcomes for physical event, out of which one is *observed (realized)* at the time of measurement, has naturally invited philosophical comparisons of quantum mechanics with Vedanta which says that the physical universe is *unreal* and that the *only Reality* is *Paramatma* the omnipresent highest level of consciousness (*Parama*: highest, *Atma*: consciousness) that also resides in all living beings at a lower level as *Jivatma* (*Jiva*: living being, *Atma*: consciousness) through which instantiations of physical objects are *observed (as if real)*. Such philosophical discussions are indeed very enlightening in the search for some underlying common truth. There are strong arguments both for and against similarities between quantum mechanics and Vedanta. To cite a few, review paper by Jonathan Duquette (2011) 'Quantum Physics and Vedanta: A perspective from Bernard d'Espagnat's Scientific Realism'; Goswami (1995) 'The Self-Aware Universe, how consciousness creates the material world'. Krishnamoorthy (2017) 'Quantum Physics came from Vedas: Schrodinger and Einstein read Vedas'; ISKCON (2009) 'Vedic Knowledge and Quantum Mechanics'.

But, certain important fundamental aspects must be considered, for completeness in such comparisons: (1) Quantum mechanics quantizes energy, which is also conserved. In Vedanta, the energy behind physical universe is *Paramatma*, any attempt at quantization of which is not only meaningless, it would degrade the very concept of *Paramatma*. Moreover, energy of *Paramatma* is limitless, so conservation of energy is meaningless. (2) Quantum mechanics deals *entirely* with physical reality, nothing unreal. All objects exist in physical reality at all times, only their *state* (out of all possible states) is undefined till measurement (observation). In Vedanta, physical existence itself is regarded as unreal, the *only Reality* is meta-physical *Paramatma*. (3) Applying physical quantum mechanics to meta-physical Vedanta invites the problem of finiteness of velocity of propagation of wave function as defined by Schrodinger's wave equation which includes physical parameters such as mass and momentum, whereas meta-physical consciousness can span the entire universe in an instant.

Until now, all scholarly discussions of quantum mechanics and Vedanta have been based on the prevailing view of wave-particle duality, namely that depending on observation the particle somehow mysteriously changes to wave or from wave to particle. New development discussed in Part 1 resolves this mystery and adds much desired clarity: Physical particle always remains particle and mathematical wave always remains wave, there is no role of consciousness. Other aspects of wave function such as wave function collapse, superposition of states, non-local action at a distance and quantum jump have also been shown not to involve consciousness or meta-physical mysticism. For example, with reference to Goswamy (1995), the following statements, which may be valid per prevailing view, are not true per the new development: p45 "in order to understand the behavior of quantum mechanics, however, we seem to need to inject consciousness – our ability to choose – according to the complementarity principle and subject – object mixing"; p48 "The antithesis of material realism is monistic idealism. In this philosophy, consciousness, not matter, is fundamental"; p85 "As soon as a conscious being observes, the material reality becomes manifest in a unique state"; p107 "The idealist resolution of the Schrodinger's cat demands that the consciousness of observing subject choose one facet from the multifaceted dead-and-alive coherent superposition of the cat and thus seal its fate. The subject is the chooser".

The claim that the material world is created by one's *conscious observation*, is not justified either by quantum mechanics (as shown in part 1), or by Vedanta:

Jivatma is same as *Paramatma (Self)*, but diluted by ignorance. (Swami Chinmayananda Self-Unfoldment p 41 "An individual is the Self as though degraded by ignorance, which finds expression in the world as thoughts and actions"). *Paramatma* does not directly interact with one's senses (Radhakrishnan p 581-4 Kena Upanishad verses 1.2 to 1.9). That interaction occurs through *Jivatma.* Thus*, Jivatma does not create the physical objects in the world through observation*.

Furthermore, Vedanta talks about *cyclical nature of creation*, *without a beginning or an end*, not a particular time in the distant past when the universe was "created". In the *Creation Hymn* (Rg Veda hymn 10-129), Vedic sages pose to themselves difficult questions about how the universe came to be, followed by suggestive answers, followed finally by honest "who knows?", *kindling* further inquiry, *guiding* one towards the truth. This hymn hints at *nothingness*, neither existence nor non-existence, neither air nor space, neither death nor immortality, neither darkness nor light, then the ONE enclosed in nothing *breathed*, the *calmness* of nothingness perturbed by ripples leading to the universe we see. Nothingness without beginning or end, cyclical creation is but like ripples disturbing the eternal nothingness. Such deeply inquiring knowledge was transmitted from teacher (*guru*) to student (*sishya*) in a strictly oral tradition over thousands of years, to this very day, long after writing, books and notebooks became available.

The import of this is that *Vedanta is all in the mind*, *the field of thoughts, requiring mental discipline and memory power*, *the central role of consciousness*. This remarkable oral tradition that has survived to this day has been studied and documented by Professor David M. Knipe (2015 Vedic Voices – Intimate Narratives of a Living Andhra Tradition) who spent thirty years with Vedic families in the Godavari river delta region of Andhra Pradesh, India.

To summarize, the essence of Vedanta is illustrated in Figure 7, which for completeness includes also the Hindu concept of cycle of rebirths before (by doing good and not evil) *Jivatma* merges with *Paramatma* which is salvation terminating the cycle of rebirths.

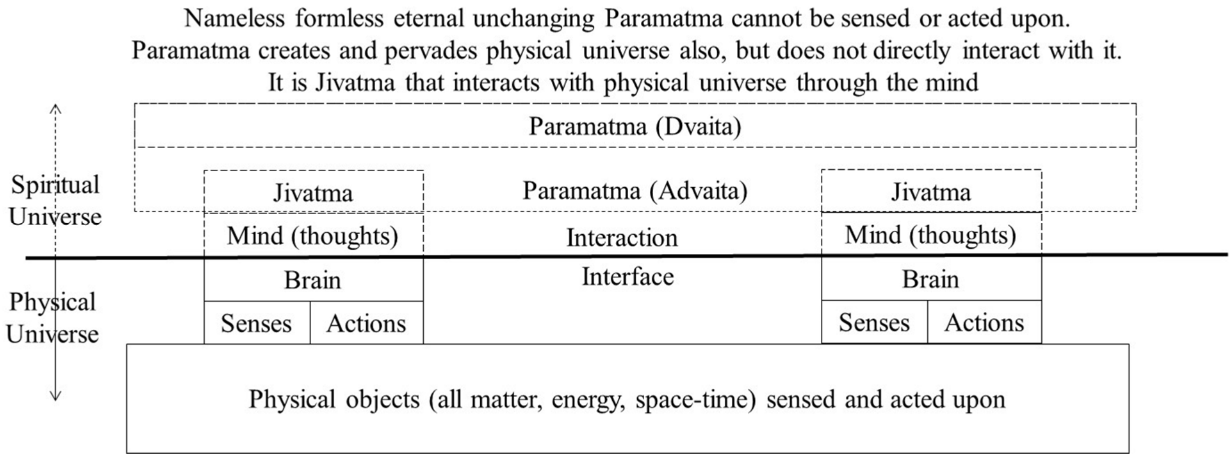


Figure 7. Vedanta Consciousness: Higher *Paramatma* and Lower *Jivatma*

Also shown is the distinction between monist (*Advaita*) and dualist (*Dvaita*) interpretations of Vedanta. Note that in Vedanta, consciousness is *entirely meta-physical*, as compared with physical treatments of consciousness as a zone in the brain.

Scholars who claim that the concepts of quantum mechanics came from Vedanta (Krishnamurthy, ISKCON) base their claims in part on the high praise for Vedanta by some founding fathers of quantum mechanics like Erwin Schrodinger (wave equation), Werner Heisenberg (uncertainty principle), Niels Bohr (quantized atomic structure) and Von Neumann (mathematical frame work), and also Robert Oppenheimer (atomic bomb). This, naturally demands clarification.

None of the scientists Erwin Schrodinger, Werner Heisenberg, Niels Bohr, Von Neumann and Robert Oppenheimer based their scientific work on Vedanta. Their high praise for Vedanta was strictly their *subjective philosophical opinions*. Their *objective scientific work* was entirely based on hard experimental evidence verifiable by any scientist, nothing subjective. Rooted in classical physics which had explained by late nineteenth century most of what physicists had thought was to be known, by the dawn of twentieth century they were confronted with formidable fundamental discrepancies (anomalies) which classical physics just could not explain. It is a testament to their collective genius that they, along with other eminent scientists like Max Planck, Albert Einstein, Max Born and Paul Dirac, painstakingly came up with quantum physics which resolved the anomalies. But, unlike classical mechanics which made intuitive sense, quantum mechanics is totally counter-intuitive and weird, which puzzled them and troubled them. It was in this context, namely that what is true at atomic level (quantum mechanics) was not what seemed to be true at macro level (classical mechanics) - for example a particle can also behave like a wave – that Erwin Schrodinger, Werner Heisenberg, Niels Bohr, Von Neumann and Robert Oppenheimer found comfort in Vedanta which teaches that the world we observe is not what it seems to be, the truth that drives the world is far more subtle.

Erwin Schrodinger (1944 'What is Life?'): "*From the early great Upanishads the recognition Atman = Brahman (the personal self equals the omnipresent, all-comprehending eternal self) was in Indian thought considered, far from being blasphemous, to represent the quintessence of deepest insight into the happenings of the world. The striving of all the scholars of Vedanta was, after having learnt to pronounce with their lips, really to assimilate in their minds this grandest of all thoughts.*" This shows his high regard for Vedantic philosophy. His remark "*The unity and continuity of Vedanta are reflected in the unity and continuity of wave mechanics. This is entirely consistent with the Vedanta concept of All in One*" shows how he felt comfort in the unifying wisdom of Vedanta in the context of his wave equation that unified the particle and wave nature of light. But his development of quantum mechanical wave equation in 1925 was *entirely and strictly based on objective facts of physical experimental evidence and related theories, not Vedanta*. The fact that Schrodinger read Vedas does not mean he based his wave equation on Vedas, to which he makes no reference in postulating his wave equation.

When Robert Oppenheimer saw the explosion of his prototype atomic bomb at White Sands test range in 1945, he was reminded of Lord Krishna's revelation of *Vishwarupam* described in Bhagavat Gita verse 9-12: *If the radiance of a thousand suns were to burst at once into the sky, that would be like the splendor of the mighty one*. It is said that he later recounted that another Bhagavat Gita verse 11-32 had also entered his mind at that time: *"kālo'smi lokakṣayakṛtpravṛddho lokānsamāhartumiha pravṛttaḥ" ("I am become Death, the destroyer of worlds")*. Because of this we cannot claim that Oppenheimer based his design of atom bomb on Bhagavat Gita. He based it entirely on objective experimental facts and theories of atomic physics.

Note that the other founding fathers of quantum mechanics like Max Planck, Albert Einstein, Max Born and Paul Dirac had not sought Vedanta for comfort. In fact, Paul Dirac was atheist. Scientists are also human beings, and they are entitled to their own subjective personal opinions about religions and spirituality. But their scientific work was never based on religion or spirituality. To say so would be unfair to them. Isaac Newton believed in the Biblical notion of the Last Day when the world would end, and he even predicted the date of the Last Day (that date passed without the world ending) but he never based his scientific work on his religious beliefs. In fact, Newton's laws of motion and his law of gravitation explained and supported Kepler's heliocentric model of planetary motions which was at that time vehemently opposed by the Church which believed in geocentric model (a short time before Newton, natural philosopher Bruno Giordano was brutally burnt alive at the stake by the Church for his belief in Kepler's heliocentric model, and seventy year old Galileo had barely escaped death by recanting his belief in heliocentric model on his knees before the Church). When science and religion are mixed, terrible things can happen: religion can lose its spirituality, and science can lose its objectivity.

Discussion

We have presented the implications of a new development in quantum mechanics that clears the century old mystery of wave-particle duality and other aspects of wave function, with particular reference to consciousness. We have shown that consciousness plays no statistically significant role in influencing the objective world through observation; it influences only through one's limbs or robot hooked up to one's brain. The notion that the essentially objective physical quantum mechanics implies a subjective role of physical (brain) or meta-physical (non-brain) consciousness in physicality has led to speculations that belie the facts.

Properly understood, there is nothing vague, mysterious or mystic about quantum mechanics, the most accurate physical science to date whose predictions have all been verified to be true. The fact that its predictions have been revolutionary compared to prior views of physical universe is no different from the fact that Newton's laws and his law of gravitation were revolutionary compared to prior views in explaining the "mystery" of motions of heavenly bodies. Both are accepted *only because their predictions are found to be true,* Newton's in the macroscopic world, and quantum mechanics in the atomic world. Once we accept the (more general than deterministic) fundamental probability amplitude wave function concept of quantum mechanics, everything, including the non-local action at a distance correlations of entangled particles, all make perfect sense. No ambiguity, mystery or mysticism whatsoever. It is really a case of mindset.

The magnificent edifice of Vedanta, rationally and logically inquiring into the nature of the universe, both physical and meta-physical, the genius of Vedic sages who were so humbled by the knowledge they uncovered that they did not claim authorship, saying it must be of divine origin, the knowledge that has survived intact for thousands of years entirely through oral tradition passed from generation to generation of gurus and students to this day, stands to lose its greatness through infusing of quantum mechanical concepts of today that will certainly be replaced in future by other scientific theories. Vedanta should not be diluted by quantum mechanics or any other physical science, all of which are transients compared to the permanence of Vedic knowledge.

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