Quantum Coherence as a Marker of Synchronous Time and Its Implication on Consciousness Acting in the Brain

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Abstract

Quantum mechanics furnishes each quantum with synchronous time in one form or another. Every participant to forming a quantum fits perfectly well into every other joining there all at once. It shares the same synchronous time. In contrast, synchronous time in interaction among interacting quanta is constructed in a bottom-up manner. A most conspicuous case of the internalist construction of synchronous time in interaction is seen in the quantum coherence to be realized in the biological realm. One demonstrative case is the occurrence of a weak magnetization along an actin filament sliding on myosin molecules as hydrolyzing ATP molecules. One more case is with the quantum coherence associated with synchronization acting in the conscious brain.

Keywords: Consciousness, Disentanglement, Internal Measurement, Quantum Entanglement, Synchronous Time

1 Introduction

Proved competence of quantum mechanics so far in the material domain raises an extremely convoluted question of how the observer making such an observational statement could be justified on the same material ground of quantum mechanics. This complication is at the heart of the thorny issue of the dichotomy between mind and matter or between mind and the brain. The bridge connecting the two domains has traditionally been called consciousness. The mind side of consciousness is competent in exercising our linguistic faculty, while the matter side touches upon neurophysiological processing acting in the brain. If quantum mechanics really deserves the role of tailoring material substrates for whatever outfit available in the empirical domain, the agenda of consciousness connecting mind to matter and vice versa must strictly be quantum mechanical. At issue is a relationship between quantum mechanics as understood as a form of linguistic discourse to be tested on empirical grounds on the one hand and our linguistic faculty itself on the other (Matsuno, 1999).

What is unique to our linguistic faculty is envisaged in the prominence of third person descriptions made in present tense. Prerequisite to making and comprehending whatever third person descriptions in present tense is the notion of time as a guarantee for the synchronization among all the participants appearing in the descriptions, since all of them are supposed to share the same present tense there. Third person descriptions in present tense require synchronous time prior to anything else. Our mind takes such a synchronous

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time to be applied on the global scale for granted whenever it addresses and processes third person descriptions in present tense. This priority of synchronous time is unique to the capacity of our mind and is exclusively of our linguistic origin. However, this emphasis of synchronous time in the linguistic domain contrasts with the absence of material means to examine whether synchronous time could also be the case in the material domain. Although one can declare to impose synchronous time upon the material domain globally as with the case of classical mechanics, there is no material means to examine whether the notion of synchronous time could really be applicable. No detection proceeds faster than light does. Of course, a mere absence of material means to examine the existence of simultaneity at superluminal velocity does not dismiss the likelihood of an occurrence of synchronous time to a certain extent.

What does matter, however, is how can one attain synchronous time in the linguistic domain as starting from the material one in which material means of examining the occurrence of simultaneity everywhere at once is intrinsically lacking, and vice versa. At this point, the practice of quantum mechanics so far has been ambivalent in vindicating the existence of synchronous time theoretically as observed in the underlying equation of motion while limiting its applicability only to a single energy quantum or at most to its entangled extension experimentally or empirically. Imposition of synchronous time upon the quantum mechanical equation of motion would seem quite natural if the mind side of consciousness is overwhelming on the part of the physicist conceiving such an equation of motion in the first place. In contrast, appreciation of synchronous time only in limited cases strictly on observational grounds would also seem quite natural to the physicist whose consciousness is akin more to the matter side. Practicing quantum mechanics theoretically is highly mind-oriented, while practicing it experimentally is quite matter-oriented. The underlying theme is how to accommodate both the mind side and matter side of consciousness into a unitary and coherent body of materials as practicing quantum mechanics.

2 Quantum Mechanics: Mind Side

The standard procedure of practicing quantum mechanics as a theoretical discourse is an activity supervening on ordinary spacetime space. Even relativistic formulation of quantum mechanics is no exception in accepting an *a priori* notion of space and time. Time appearing in the quantum mechanical equation of motion is synchronously shared by all of the variables and parameters constituting the equation of motion. Synchronous sharing of the same time by all of the participants appearing out there in an objective manner is in fact a common denominator of third person descriptions in present tense. Rather, the quantum mechanical equation of motion takes most advantage of third person descriptions that are competent enough to address any object out there in the present tense. The present *a priori* ubiquity of synchronous time now comes to let whatever theoretical construct upon it be supervenient on the presumed ordinary spacetime space. For there is, by definition, no possibility of undermining the basis of such a spacetime space once the ubiquity of synchronous time is taken for granted. The underlying spacetime space remains invulnerable to whatever constructs may be figured out. Among them, Hilbert spaces stand out.

A Hilbert space specifies the basis set of the quantum states constituting an arbitrary quantum mechanical system. Above all, what is peculiar to a Hilbert space is that the reduction of whatever quantum states to one of the states belonging to the privileged basis set induces a non-local effect. The present non-local reduction, however, only proceeds in the supervening Hilbert space, but not in ordinary spacetime space. This is simply no more than a theoretically refined statement of the empirical fact that an energy quantum after Max Planck is a non-local object to be specified by referring to synchronous time applicable exclusively to the quantum itself. Non-locality specific to a Hilbert space dismissing causal relations, of course, cannot and does not dismiss local causality in ordinary spacetime space. The superficial absence of local causality in the supervening Hilbert space is in fact sought in its linguistic mode of third person descriptions in present tense. Insofar as one comes to notice that third person descriptions in present tense cannot be locally causal because of the temporal homogeneity of their implications, the supervening Hilbert space that is describable objectively in the present tense cannot be causal from within. What exerts causal influences upon a supervening Hilbert space is the process called measurement.

One attempt for internalizing measurement within the framework of quantum mechanics is the scheme von Neumann and Wigner proposed as having recourse to the process called measurement as an operation of non-unitary projection (Stapp, 1993). This certainly contrasts with the standard Copenhagen interpretation making the process of measurement simply external to the underlying quantum mechanical process. Despite that, the von Neumann-Wigner scheme stops short of internalizing the non-unitary projection in the supervening Hilbert space in a causal manner, though it seems quite natural to associate the operation of non-unitary projection with the capacity of mind on the part of the observer. The underlying serious issue is how to make the process of measurement imputed to the act of non-unitary projection to be locally causative, since the observer resides in ordinary spacetime space, but not in the articulated supervening Hilbert space in whatever form.

Difficulty in accommodating the unitary development in quantum mechanics to the non-unitary process of measurement rests upon limited capacity of the underlying third person descriptions in present tense. Measurement is intrinsically temporally inhomogeneous in distinguishing between, before, and after the act of measurement, while the third person descriptions in present tense giving a unitary development in quantum mechanics are temporally homogenous in treating any present tense on a par equally and indifferently.

The mind side of consciousness can duly be appreciated by the practice of third person descriptions in present tense, while it fails in making its own operation causal. Insofar as one accepts the view that our mind operates causally, but not spontaneously, the mind side of consciousness cannot be said to stand alone. At this point enters the matter side of consciousness that is also certainly quantum mechanical. We are thus required to address how quantum mechanics can be practiced in other than third person descriptions in present tense.

3 Quantum Mechanics: Matter Side

Measurement, whatever it may be, is an act of pointing to or being pointed out by something else that is concrete and particular. This activity cannot properly be addressed in third person descriptions in present tense, because the capacity of making something concrete particular cannot be objectified in an invariant manner. Instead, first and second person descriptions come to the foreground. First person description is about something concrete particular pointing to something else. The first person "I" making a statement is specific and concrete enough to make such a choice of the statement out of indefinitely countless alternatives. Second person description is about something concrete particular pointed out by something else. The second person "You" pointed out by the speaker is made distinguished as the foreground in contrast to the indefinitely vast background. In contrast, third person description is taken to be about something general universal related to something else without recourse to the activity of pointing to and being pointed out. An example of third person descriptions is a mathematical theorem stated in terms of ordinary and abstract nouns, which are general and universal in their implications. Measurement internal to the material domain or, internal measurement in short, is thus unquestionably empirical, though accessible only in first and second person descriptions (Matsuno, 1985, 1989).

Rather, our linguistic capacity allowing for first and second person descriptions makes the occurrence of internal measurement in the material domain to be imperative because of the underlying activity of pointing to and of being pointed out. Internal measurement is linguistically made ubiquitous (Matsuno, 2000). However, its global coordination is not guaranteed in an *a priori* manner in advance. The linguistic imperative for internal measurement has to go along with another empirical constraint making no detection process proceed faster than light does. There is no means to make internal measurement consistent globally on the spot, while the reverberation of internal measurement is made imperative because of its linguistic necessity. Consequently, internal measurement is made locally causative. What is addressed at this point is how to make a linguistic access to local causation unique to internal measurement. We then face a sturdy issue of how our linguistic vehicle of first and second person descriptions could come to accommodate to itself internal measurement that is empirically constrained by both local causation and absence of a prior global coordination. Both are non-linguistic in their origins. In contrast, third person descriptions are free from such a burden because they have to globally be consistent in what they imply. They become causative only externally. One clue for this linguistic matter may be to make an appeal to the present progressive tense latent in first and second person descriptions.

First and second person descriptions are taken to address those events in progress when the activities of pointing to and of being pointed out are directly referred to. The present progressive tense, instead of the present tense, turn out to be the grammatical tense underlying the action in progress. The present progressive tense makes any material participant to be a locally causative actor since every participant detecting others internally makes the viewpoint also to be its own blind spot. The inevitable interference of the blind spots is grounded upon the simple empirical fact that no detection proceeds faster than light does. No material participant can tell how others in the neighborhood detect it exactly in a concurrent manner. This absence of simultaneous detection makes the presence of the blind spots inevitable. The presence of the blind spots then makes the occurrence of some form of inconsistencies among the material participants also inevitable. However, such inconsistencies should not be left behind in the record registered in the present perfect tense. Once the record registering completed and perfected events is established, it can also be addressed in the present tense. The record addressable in the present tense allows for no internal inconsistency, otherwise no record could be conceivable. Insofar as we pay due attention to the occurrence of the record registered in the present perfect tense, no inconsistencies have to be left behind.

There is an inherent difference between the present progressive and the present perfect tense although both are about something concrete particular. In fact, present progressive tense is about measurement in progress, while present perfect tense about measurement in the completed record. The difference, however, resides in the nature of inconsistencies whose occurrence is necessitated by the inevitable participation of the blind spots. What is imperative to internal measurement in the present progressive mode is, at the least, to pass migrating inconsistencies constantly forward so as not to leave any of their remnants behind in the completed record. Those inconsistencies are constantly migrating because there is no means to identify their nature in advance.

The present form of internal measurement addressing migrating inconsistencies exhibits a marked contrast to measurement understood within the classical framework or classical physics. Measurement in the classical sense takes both the activities of pointing to and being pointed out to be completely synchronous between them. As the result, the measurement, once completed, can be frozen in the record with no further reverberations of the activities of pointing to and being pointed out. Even in quantum mechanics, once one decides to employ the scheme of classical measurement such as Born's statistical interpretation of the wave function as the probability amplitude, it could eliminate internal measurement processing migrating inconsistencies. Classical measurement is closed to consistency because of its strictly methodological stipulation, while non-classical measurement in quantum mechanics upon internal measurement is open to inconsistencies. The difference between quantum and classical physics is not the matter of the difference between small and big. The difference resides in the nature of measurement conceived in material dynamics (Polanyi, 1968; Pattee, 1982). Classical measurement addresses concrete particulars mutually consistent, while non-classical measurement copes with the process of constantly passing internal or migrating inconsistencies forward as leaving none of them behind in the record. In short, classical measurement makes quantum mechanics eventually as an ensemble statistics as with the case of the Copenhagen interpretation as championed by Born's, while non-classical measurement makes quantum mechanics a matrix of possible experiences.

At the core of the dichotomy between classical and non-classical measurement is the occurrence of inconsistencies in the present progressive mode. Of course, inconsistency cannot be addressed in the present tense neither in the present perfect tense, otherwise our entire linguistic institution would collapse. In contrast, however, it can survive in the present progressive tense because there is no prior means to make every participant on the scene consistent with everybody else. The present progressive tense is being practiced by the participants/observers, while they are blind to themselves because the eyes cannot see themselves directly. The participants/observers having their inevitable blind spots are constantly creating problems and inconsistencies among themselves even if each of them is earnestly solving the problems they are facing. As a matter of fact, the activity of passing migrating inconsistencies constantly forward among the participants serves as a cohesive factor among themselves because they come to share those migrating inconsistencies in the effect. The issue of quantum coherence can now take a new outlook if internal measurement, that is definitely non-classical, is properly taken into account.

Quantum coherence observable in physics or especially in low-temperature physics has been understood as condensation of energy quanta into a single quantum state to a macroscopic extent. Descriptively, however, quantum coherence is one attribute of the quantum state specifiable in a Hilbert space that can eventually be detected in ordinary spacetime space. Measurable quantum coherence thus comes to address how the quantum state referring to a Hilbert space can be represented in ordinary spacetime space. What physics has clarified so far is that the act of representing the quantum state in ordinary space time space does not disturb the supervening original Hilbert space that has been responsible for fixing the very state. Unless the process of measurement proceeding in ordinary spacetime space disturbs the Hilbert space as a theoretical construct, quantum coherence can be measured as a property of the supervening Hilbert space. However such a measurement leaving the Hilbert space intact is merely an idealization.

Actual measurement proceeding in the empirical domain is non-local in constantly perturbing the supervening Hilbert space since internal measurement makes those spaces supervening on ordinary spacetime space to be in charge of passing migrating inconsistencies constantly forward as modifying themselves in the ordinary space, instead of in the predetermined invariant Hilbert space. Although the quantum state to be specified is unique to the associated Hilbert space, quantum coherence to be measured and experienced is a property unique to ordinary spacetime space. Underlying the issue of quantum coherence to be measured is how internal measurement proceeds and how quantum coherence comes to be influenced accordingly. What becomes relevant at this point is both quantum entanglement and disentanglement.

Quantum entanglement is a process of interaction changes proceeding in ordinary spacetime space as making more than one quantum state linearly superposed as ending up with a single pure state. The resulting pure state can be seen as an entangled quantum state belonging to a newly formed entangled Hilbert space that differs from the Hilbert space unique to each constituent member of the entangled state. Transforming a Hilbert space from one form to another underlies the process of quantum entanglement. Likewise, quantum disentanglement is a process of interaction changes proceeding in ordinary spacetime space as reducing the entangled quantum state to one of the states belonging to the basis set unique to the measuring body, whatever it may be.

Both quantum entanglement and disentanglement are the two faces of one and the same process called internal measurement passing migrating inconsistencies constantly forward in ordinary spacetime space. Henceforth, internal measurement makes both quantum entanglement and disentanglement locally causative in ordinary spacetime space. The entangled quantum state that is sustainable in ordinary spacetime space now turns out to be robust against both quantum entanglement and disentanglement. The associated entangled Hilbert space carrying the entangled quantum state also remains robust as supervening on ordinary spacetime space. Robustness of the entangled quantum state is thus found to be a factor of quantum coherence, that is a property of the quantum state detectable in ordinary spacetime space.

What then becomes significant in practicing quantum mechanics on the matter side is seen in the endeavor on how one can construct an entangled Hilbert space supervening on ordinary spacetime space. Participation of internal measurement is imperative. In order to proceed further, it will be required to examine whether there may be empirical evidence on constructing quantum coherence in a bottom-up manner in ordinary spacetime space (Pribram, 1991; Rizi et al., 2000). One candidate for effectively constructing an entangled Hilbert space can be seen in the occurrence of a magnetic ordering with an ATP-activated actin filament as a functional unit of muscle contraction. We shall examine and review how such an entangled quantum state could be constructed in an actin filament contacting myosin molecules in the presence of ATP to be hydrolyzed.

4 Entanglement and Disentanglement: An Evidence

Our particular system of interest is muscle contraction. It demonstrates a robust coordination of the dynamic interactions among the participating biomolecules. Muscle contraction as a representative case of cell motility consists of an actin filament sliding on myosin molecules in the presence of ATP molecules to be hydrolyzed. Since the typical linear dimension of an actin filament is about $5\mu m$ in its length and since the sliding velocity is about $5\mu m\ s$, the water environment surrounding the actin filament is highly viscous (e.g., Hatori et al., 1998a,b). The corresponding Reynolds number of a typical actin filament is of order of 10^{-5} due to the fact that the kinetic viscosity of water is roughly 0.02 $[cm^2\ s]$. This implies that the sliding actin filament in water is subject to strong drag force imputed to the viscous fluid in the surroundings. Energy-deficient fluctuations associated with the actin filament sliding in highly dissipative environments are to be met by the countering energy-surplus fluctuations or sources in the neighborhood. What is happening there is the fastest compensation of energy-deficient fluctuations (Matsuno and Swenson, 1999). If the actin-activated myosin ATPase activity compensates the energy-deficient fluctuations faster than the local energy-surplus occurring in the filament due to the thermal fluctuations of the viscous fluid, ATP-driven sliding movement of an actin filament can be materialized. Underlying all this is the second law of thermodynamics implementing the fastest compensation of energy-deficient fluctuations.

The second law of thermodynamics tailored for implementing cell motility certainly faces thermal fluctuations. Despite that, an organized activity at a meso- or macroscopic scale is guaranteed in cell motility. This observation urges us to how to figure out such an ordered and organized activity in the presence of thermal fluctuations. In fact, one dominant factor for the occurrence of a macroscopic organization of material origin must be sought in quantum coherence that remains robust in itself even in the presence of whatever disturbances to a certain extent. Quantum coherence is unique compared to classical coherence as encountered in continuum mechanics, in the latter of which the coherence is vulnerable to the slightest changes in the boundary conditions applied externally (Conrad and Matsuno, 1990).

In particular, both an actin filament and a myosin molecule as the major constituent elements of muscle contraction are unquestionably quantum-mechanical in holding their own structures. The structural stability of these biomolecules rests upon the stable quantum mechanical configurations of electrostatic interactions among the constituent smaller molecules and atoms. Quantum coherence holding these biomolecules as stable structures remains indisputable. Nonetheless, the quantum coherence upon these electrostatic interactions is not directly related to the occurrence of the cell motility because it remains intact even in the absence of ATP molecules driving muscle contraction in action. We thus observe that the quantum coherence, if any, underlying the stable realization of the cell motility would have to be sought in other than the quantum mechanics of electrostatic interactions. One alternative must be the quantum mechanics of magnetostatic interactions. We shall first review such a likelihood of magnetostatic interactions rather on the factual basis that can be examined in the laboratory experiments.

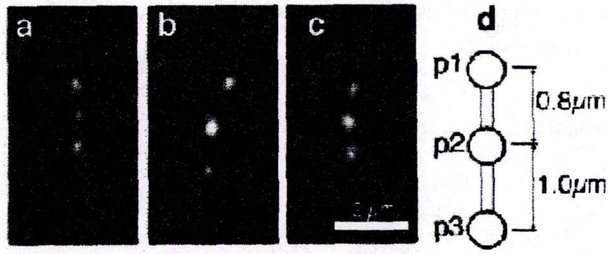

Figure 1: (a-c) Fluorescent image of a speckled actin filament. Three independent samples are displayed. (d) Schematic representation of a speckled actin filament. Circles correspond to fluorescent regions. These circles are denoted as *p1* through *p3*. The distances between the neighboring circles are measured as referring to the center of each circle.

We prepared an actin filament with a few fluorescent markers sliding on myosin molecules in the presence of one milli-molar concentration of ATP to be hydrolyzed (see Figure 1). We then measured the fluctuation intensity of the parallel displacements of the markers in the presence of magnetic flux (Matsuno, 2001). Both the preparation and measurement were done at room temperature. Spatial identification of each marker of spatial resolution 20 nm at every 0.033 s was accomplished by reading its actual displacement relative to the smoothed, time-averaged position of the marker over a limited time interval (see Figure 2). The size of the actual time window for taking the averaging was chosen to be 0.7 s, centered at the actual time point to be referred to. Figure 3 displays the cross-correlation function of the fluctuating parallel displacements of two neighboring actual reference points measured relative to the corresponding smoothed reference points. The time interval required for estimating the time-averaged cross-correlation functions was chosen to be 3.3 s.

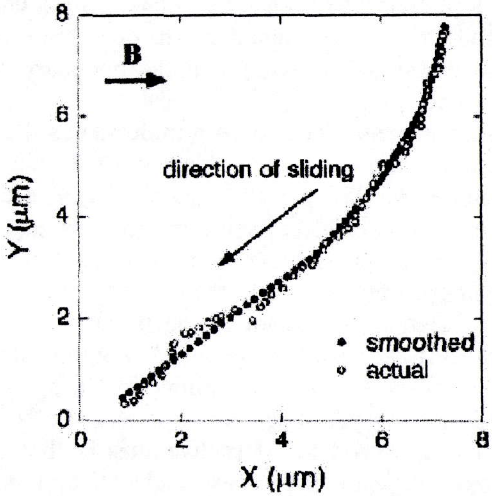

Figure 2: Trajectories of an actual reference point and of the corresponding smoothed one, attached on a speckled actin filament sliding on myosin molecules. Magnetic flux with its density B (= 50*m*T) is applied externally in parallel to the planar plane on which the filament can slide.

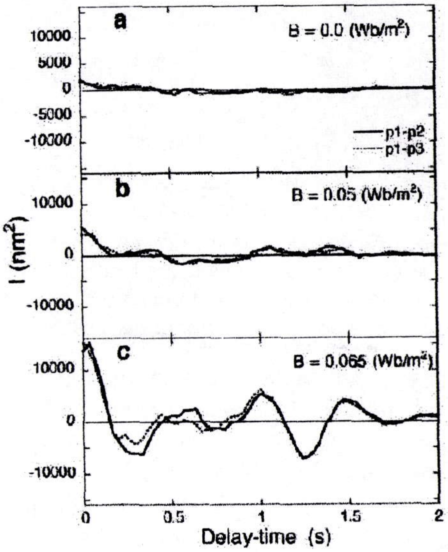

Figure 3: Intensity I (*n*m^2) of the cross-correlation function of the fluctuating parallel displacements between two actual reference points, between *p1-p2* and between *p1-p3*, attached on a speckled actin filament parameterized in terms of the delay time for estimating the cross-correlation, and its dependence on the magnetic flux density B (*m*T) applied externally. Magnetic flux was applied in parallel to the planar plane on which a speckled actin filament slid. Two samples between *p1-p2* and between *p1-p3* are displayed. The averaged distance between *p1* and *p2* was 0.8 μm, and 1.8μm between *p1* and *p3* (Matsuno, 2001).

Intensity of the cross-correlation at no time delay was found to increase as the magnetic flux density applied externally increased, though, in the absence of ATP, there was no such enhancement of the intensity of the cross-correlation with the increase of the strength of the applied magnetic flux. This enhancement manifests the occurrence of the fluctuating magnetic dipole moments induced along the actin filament, since magnetic dipole moment is energetically conjugate to magnetic flux. The applied magnetic flux in fact served as a probe to detect the induced magnetic dipoles, if any. Intensity of the cross-correlation in the presence of magnetic flux was also found to remain almost unchanged even though the distance between the two points over which the cross-correlation was evaluated was increased up to the top-to-end of the entire filament. This relative invariance of the cross-correlation over varying distances reveals that the fluctuating strength of the induced magnetic dipole moment was almost in phase over the whole length.

Increase in the fluctuating intensity of the parallel displacements of an actin filament in the presence of magnetic flux points up the internal tensile force generated there. When a magnetic dipole carrying its moment density M [Ampere/meter] is put in the magnetic flux with its density B [Tesla], the energy density E [Joule/meter^3] of the dipole gives $E=-MB-B^2\ 2\mu_0$. Here, μ_0 (=4π × 10^{-7} [Tesla meter/Ampere]) is the magnetic permeability of the vacuum. The magnetic energy density E becomes negative for $0<B<2\mu_0 M$, implying that the applied magnetic flux B induces the internal tensile force between the magnetic dipole and the non-magnetic surroundings with its strength $(MB\text{-}B^2\ 2\mu_0)$ per unit area [Newton/meter^2]. In fact, the difference of the magnetic permeability across the boundary between the magnetic dipole with its moment M and the non-magnetic surroundings with their magnetic permeability μ_0 acts as a source of the magnetostrictive tensile force. Conversely, the occurrence of such a magnetostrictive tensile force manifests the presence of a spatial gradient of magnetic permeability imputed, for instance, to the boundary between magnetic and non-magnetic materials. The maximum tensile force $\mu_0 M^2\ 2$ is thus expected at the magnetic flux density $B=\mu_0 M$. Since the parallel displacements of an actin filament come to respond to the internal tensile force generated there, the maximum displacement can be expected at the magnetic flux density $B=\mu_0 M$.

Figure 4 demonstrates the relationship between the fluctuating intensity of the parallel displacements and the strength of the applied magnetic flux density, in which the large spread in the values of the intensity was due to the fact that the trajectory of the sliding movement was not always rectilinear. The maximum displacement responding to the maximum tensile force was observed to occur at the flux density $B=65m$T [*milli* Tesla]. The magnetic dipole density was thus found to be $M=5.2\times 10^4$A/m. Accordingly, the magnetic dipole moment per actin monomer was estimated to roughly be 1.7×10^{-21}Am^2 ($\cong 180\ \mu_B$, where μ_B is Bohr magneton). For this estimation, we assumed a coherent unit of magnetization to be an actin monomer of its diameter 4×10^{-9}m within which electrons forming covalent bonds are confined.

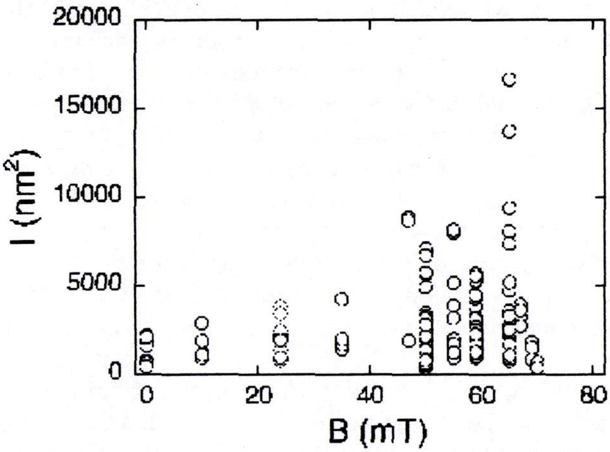

Figure 4: Intensity I (nm^2) of the cross-correlation function of the fluctuating parallel displacements of two actual reference points *p1* and *p2* (see Fig. 1) attached on a speckled actin filament at no time delay parameterized in terms of the applied magnetic flux density B (mT). The direction of the sliding movement for each sample was in parallel to the planar plane on which the magnetic flux was fixed, but was taken arbitrary to the linear direction of the applied magnetic flux (Matsuno, 2001).

The magnetic dipoles induced along an actin filament exhibited a mesoscopic magnetic alignment along it. This was seen in the relationship between the fluctuating intensity of the parallel displacements of an actin filament and the direction of the magnetic flux applied externally, as demonstrated in Figure 5. The fluctuating intensity increased as the direction along which an actin filament slid on myosin molecules maintained a certain angle against the direction of the magnetic flux applied externally.

Magnetic dipoles induced over an actin filament sliding on myosin molecules in the presence of ATP to be hydrolyzed were found to align with each other coherently over the entire filament though the strengths of their moments were fluctuating. Even in the presence of thermal agitations inducing rapid decoherence (Tegmark, 2000), the magnetic dipoles in ATP-activated actomyosin complexes maintained their coherence over the entire actin filament (Matsuno, 1993, 1999; Matsuno and Paton, 2000). The energy of the magnetic dipole-dipole interaction per actin monomer was estimated to be of the magnitude of the magnetic moment 1.7×10^{-21}Am^2 of each dipole multiplied by the magnetic flux induced by the nearest neighbor dipole placed roughly 4×10^{-9}m apart. The dipole-dipole interaction energy was thus found to be about 1.1×10^{-22} Joule, which is far less than the thermal energy per degree of freedom available at room temperature, that is, of the order of 4×10^{-21} Joule. If there were no mechanism for a magnetic alignment other than the magnetic dipole-dipole interaction, thermal agitations would destroy its likelihood and no magnetic ordering along the actin filament could be expected, despite our observation of the ordering to the contrary. Even the applied external magnetic flux whose strength was less than 100 mT was not strong enough to align those magnetic dipoles fluctuating as responding to the surrounding thermal agitations. The applied magnetic flux with its strength 100 *m*T could impart to each actin monomer the magnetic energy only of the order of 1.7×10^{-22} Joule, which is far less than the available thermal energy per degree of freedom, 4×10^{-21} Joule. The observed magnetic alignment along an ATP-activated actin filament now suggests participation of a factor other than the magnetic dipole-dipole interaction and the applied magnetic flux.

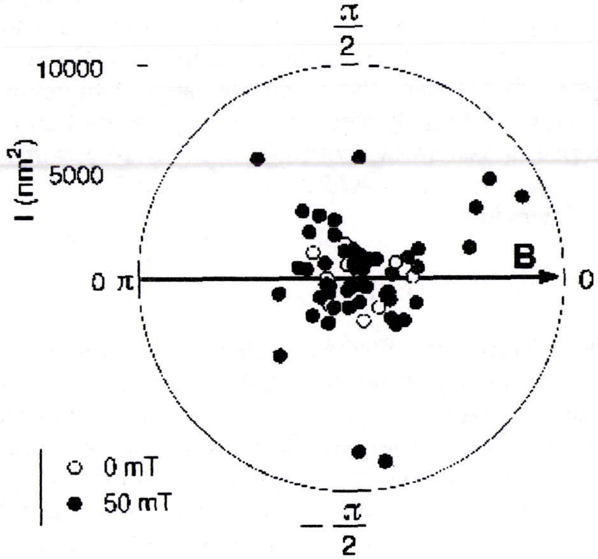

Figure 5: Intensity I (*n*m^2) of the cross-correlation function of the fluctuating parallel displacements of two actual reference points *p1* and *p2* (see Fig. 1) at no time delay parameterized in terms of the direction and the strength of the applied magnetic flux density B (*m*T). The direction of the sliding movement of the filament was measured relative to the direction towards which the magnetic flux was applied (Matsuno, 2001).

One likely candidate for the observed magnetic ordering along an ATP-activated actin filament may be a quantum entanglement (Matsuno, 1999). A bare actin filament that is not yet ATP-activated forms an electrostatically coherent alignment of individual actin monomers. Each monomer is electrostatic in its cohesive interaction with other monomers in the neighborhood. Actin filament as an electrostatic alignment of actin monomers is certainly stable quantum mechanically and remains robust enough against thermal agitations available at room temperature. In contrast, an ATP-activated actin filament, that is stable electrostatically, can also form a magnetostatically coherent alignment of individual actin monomers, in which each monomer is magnetostatic in its cohesive interaction with others in the neighborhood. Consequently, each actin monomer in an ATP-activated actin filament can quantum-mechanically be in either a pure entangled state out of both the electrostatic and magnetostatic states or in a mixed state out of the two individual states.

If each actin monomer is in a mixed state out of the electrostatic and magnetostatic ones, thermal agitations would easily destroy a coherent alignment of the magnetic dipoles along the filament because of the presumed absence of any coherent correlation between the two individual states. The magnetic dipole-dipole interaction alone would not be strong enough to hold the coherent alignment of the dipoles as being subject to thermal agitations. On the other hand, if an ATP-activated actin monomer is in a quantum entanglement out of both the electrostatic and magnetostatic states, it can participate in forming a coherent magnetostatic alignment along the filament, as having recourse to the entanglement with the underlying robust quantum coherence of electrostatic origin giving the filament its structural stability. What is more, the quantum entanglement out of the electrostatic and magnetostatic states is constantly preceded and followed by a quantum disentanglement imputed to internal measurement derived from the hydrolysis of ATP molecules since a myosin molecule carrying its ATPase activity keeps detecting or measuring target ATP molecules internally.

5 Supervening on an Entangled Hilbert Space

Magnetic ordering in an ATP-activated actin filament contacting myosin molecules demonstrates the occurrence of a sustainable entangled quantum state on an empirical ground. This empirical demonstration of a robust entangled quantum state is significant in that quantum coherence at a meso- or even at a macroscopic scale can obtain at the ambient temperature of the natural context, not necessarily limited to extremely low temperature. Robustness of a sustainable entangled quantum state now imparts to whatever viewpoint placed inside the state the competency of synchrony even at the available ambient temperature strictly in the sense that every quantum is perceived from within as a synchronous whole embodied in the corresponding Hilbert space. The viewpoint placed inside the entangled quantum state, however, differs in what it perceives depending upon whether it points towards its inside or the outside. The difference is that while non-local synchrony is associated with the view towards the inside, local causation is specific to the view towards the outside in being constantly subject to quantum disentanglement imputed to internal measurement originating elsewhere. The entangled quantum state is thus seen as an almost complete closure of migrating inconsistencies from the perspective of internal measurement. The robustness of such a closure is what a quantum is all about in the empirical domain. A descriptive means to make an access to non-local synchrony intrinsic to the entangled quantum state is an entangled Hilbert space.

What is more, the robust entangled quantum is sustainable as being subject to measurements of internal origin (Penrose and Hameroff, 1995; Hameroff, 2001; Penrose, 2001). The robustness of non-local synchrony is in fact identified internally as referring to the basis set specific to the entangled quantum. This identification is associated with the measurement activity of reducing its state to one of the states belonging to the quantum itself. That is nothing other than a form of self-awareness by the quantum.

Self-awareness of non-local synchrony rests upon the measurement activity of the quantum to secure its robustness from within. Synchronous time is just another name for a product out of self-awareness of non-local synchrony. Descriptively, the entangled Hilbert space that can remain robust even as being subject to internal measurement comes to provide a means to make an access to synchronous time. That is synchronous time supervening on the entangled Hilbert space, rather the other way around.

The basis set unique to the robust entangled quantum, however, does not remain invariant because the quantum is constantly in the process of passing migrating inconsistencies forward. The basis set can spontaneously be varied and transformed so as to meet the requirement that no migrating inconsistencies may be left behind in the record registered in the present perfect tense. The attentive focus of self-awareness can be alternated as with autonomous transformation of the basis set. This does not mean denial of synchronous time. Rather, what has been meant is a change in the representation of synchronous time.

Practicing quantum mechanics in a Hilbert space supervening on ordinary spacetime space has its own advantage in skimming synchronous time out of ordinary spacetime, but has the disadvantage in failing in making an access to asynchronous dynamic movements that are ubiquitous in the empirical domain. In contrast, practicing quantum mechanics in synchronous time supervening on the robust entangled Hilbert space is modest in admitting that such a synchronous time is merely a precipitation from the underlying asynchronous dynamics. The robust entangled quantum certainly equips itself with the capacity of updating its dynamic movement asynchronously. The matter side of consciousness undoubtedly comes to take advantage of the asynchronous movement of the robust entangled quantum.

6 Concluding Remarks

Synchronous time, or time in short, is difficult to unlearn once we are convinced to have learned it. This is due to the very nature of our linguistic institution. Any ordinary noun appearing in statements made in the present tense assumes its synchronous ubiquity and applicability. This problematic situation would become most acute if one wants to figure out the extent to which time could be synchronous in reality. If one tries to employ some basic terms to cope with this sturdy problem of time, they must be free from the stipulation of predestined synchrony. Ordinary nouns of definite implication do not satisfy this requirement. Imposition of synchronous time would become imperative insofar as one commits oneself to making statements in terms only of those definite nouns in the present tense. One attempt to avoid such an entrapment by the forceful imposition of synchronous time that we have tried is to make an appeal to a noun of indefinite implication. That is internal measurement.

Internal measurement addressing the capacity of passing migrating inconsistencies constantly forward is a noun, but remains indefinite in its implication because of its inevitable association with the dynamic transference of inconsistencies. The matter side of consciousness can ground itself upon internal measurement since it does not presuppose the occurrence of synchronous time, the latter of which is a sine qua non for the mind side of consciousness to the contrary. The present emphasis of internal measurement is, however, by no means anthropocentric. Synchronous time is no more than a consequence precipitated from internal measurement that is ubiquitous in the material domain. This understanding of synchronous time as a derivative is in accord with our linguistic practice of letting the movement in progress, that is in the present progressive tense, precipitate the record registered in the present perfect tense. There is, of course, no chance of anthropocentric monopoly of the present tense over the present progressive tense since there is no material means to coordinate everything to everything else everywhere in a synchronous manner. This makes the matter side of consciousness non-anthropocentric.

Underlying non-anthropocentric agency of internal measurement is the occurrence of a robust entangled quantum. This may suggest an association of the brain with a robust entangled quantum on a mesoscopic or macroscopic scale. One thing quite unique and peculiar to the operation of the brain functioning is that both non-local synchrony and local causation coexist. A typical example is a phenomenon associated with what is called qualia. The redness of a color red to be experienced, or similarly the painfulness of a pain to be suffered, points to the necessary connection between the mind side and the matter side of consciousness. The brain as a robust entangled quantum can descriptively be taken to point to a non-local synchrony that may remain invariant, by referring to the corresponding entangled Hilbert space, which is certainly accessible to the anthropocentric mind side of consciousness. At the same time, the brain as a robust entangled quantum is locally causative in its own maintenance through successive quantum entanglement and disentanglement. In particular, suppose that the redness of a color red to be experienced by the brain is descriptively associated with one of the quantum states constituting the basis set specific to the brain as a robust entangled quantum. Then, the non-local invariant character of the redness could be saved at least to the extent that the robustness of the brain is maintained.

The mind side of consciousness, that is anthropocentric, is a descriptive property of the brain referred to in terms of the basis set unique to the brain itself. The self-referential complication would, however, come to necessarily mask the underlying dynamics. The dynamics in charge of generating and transforming the basis set, on the other hand, is explicitly anchored at the matter side of consciousness that is non-anthropocentric. In fact, the matter side of consciousness is linguistically grounded upon the present progressive tense, but not upon the present tense. Although the present tense can be retrieved form the present progressive tense only to the extent that the leftover kept in the record registered in the present perfect tense can be referred to in the present tense, there constantly remain migrating inconsistencies to be passed forward. The mind side of consciousness eventually supervenes on the matter side of consciousness. That is to say, the issue of consciousness cannot get rid of the irony that non-local consistency supervenes on local inconsistencies. The brain as a robust entangled quantum is just a material vehicle letting consistency feed on inconsistencies.

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