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Scientific Explanations and Consciousness

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I see, I hear, I smell, I think, I exercise my will, I enjoy, I suffer, I imagine, I remember, I am aware of myself, I am aware of my dreams and my sleep. Whatever is responsible in the final essence for these acts of mine, I regard as my consciousness. One strong reason for saying so is that I can do none of these when I am unconscious.

What is consciousness? Is it a thing? Is it a force? Is it a process? Where is consciousness located? Where is the action leading to consciousness taking place? What or who is this "I" and what precisely is the connection between consciousness and the "I". These are the questions that have been deliberated upon by intellectuals of different disciplines for centuries, perhaps for several millenia.

For a long time it was thought that consciousness was the business of this intangible "I" and is a subjective phenomenon and therefore not amenable for scientific investigation. This wrong view has rightly changed. Even though each individual experiences his consciousness as a subjective phenomenon,

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he also recognises that a similar, though may not be identical, experience is present in every individual around him. Therefore it is an objective phenomenon as well and must be capable of being analysed just like any other objective phenomenon. In fact there is the added advantage that there is a similarity to one's own direct experience.

When one tries to analyse in the objective mode one recognises immediately that one is part of the earth, which in turn is part of the universe and in the scheme of the vast mighty universe, the earth itself is a tiny little speck and oneself infinitely less significant. Yet the power of the mind, especially the collective power of the minds of the scientists is such that it has been possible to figure out to a great extent the intricate workings of the vast universe with myriads of vastly different constituents and processes resulting in a rich variety of phenomena one encounters. As Einstein put it "What is incomprehensible is that the universe is comprehensible".

In this continuing endeavour of comprehending the universe, perhaps the most challenging and perhaps the last frontier is the understanding of the origin and modalities of functioning of consciousness. As we shall see, this endeavour involves a highly multidisciplinary approach not only of sciences but also of the other avenues of knowledge acquisition. The real complication is, as Max Planck has put it "We ourselves are part of the mystery we are trying to solve".

1. The Scientific Methodology

To understand the kind of approach that science can adopt in tackling the complex problem of consciousness it is necessary to familiarize ourselves with some aspects of the methodology of science that has evolved over the past several hundred years. In science too there are various levels at which scientific explanations are sought depending on the purpose and the level of understanding of the enquirer. With the advancement of science leading to a cumulative acquisition of knowledge and technology making available more and more sophisticated instruments, it has become feasible to go to deeper and more fundamental levels of explanation. This has enabled the scientist to move from qualitative explanations of physical phenomena to quantitative explanations and make predictions that can be verified by further specifically designed observations and experimentations. In this, mathematical formulations have played a very significant role. However precise evaluations of the 'constants of nature' that enter into the equations have become crucial for quantitative predictions.

Let us consider a few examples from the field of physical sciences to illustrate this methodology of science and also consider what kind of limitations set in at the various levels.

If a small length of a cotton wick is wrapped round a piece of wire, dipped in a solution of common salt (sodium chloride)

and inserted inside the flame of a burner, it is seen that the flame acquires a brilliant yellow colour for a little while. What is the explanation for this observation? The flame excites the sodium atoms and lifts them to higher energy levels. These return to their normal levels by emitting, what have been designated as sodium D_1 and D_2 . When looked through a spectroscope the sharp lines stand out in contrast to the background light of the flame.

The observation is simple. – the flame turning yellow. The explanation involves many concepts – atoms, energy levels of the atoms, transition from one energy level to another, emission of the energy difference in the form of light, the relation between the frequency of light “ f ” and the energy difference, ($E_1 - E_2 = \hbar\nu$) and the Planck’s constant and the value of it. The calculations of the energy levels require further the values of the charge and mass of the electron and of the Sodium nucleus etc. What is however intriguing and unsatisfactory is that finally the yellow “colour sensation” that we see is something that cannot be explained on the basis of these ideas. All that can be said is that there is a strict correlation between the emitted frequencies and the yellow colour observed. The physicist leaves it to the biologist to account for the yellow sensation in terms of happenings inside the body of the viewer. He stops at the retina where images of the lines are formed by the action of the eye lenses.

Let us consider another simple phenomenon. If a stone is dropped from a height, it falls to the ground. Why? Newton gave the answer four hundred years ago. The stone falls because of the “gravitational force” between the stone and the

earth. He gave the famous equation $F = G \cdot \frac{m_s \cdot m_E}{r_{SE}^2}$ where F is the gravitational force, m_s and m_E are masses of the stone and the earth r_{SE} and r_{SE} is the distance between the centre of the stone and that of the earth and G is the gravitational constant. Using this equation Newton derived the orbits of the various planets and accounted for the laws of planetary motion.

However, there is an important question, which Newton was well aware of and could not answer. How is the gravitational force transmitted across the space ? How does the action at a distance take place ? Newton is reported to have said “God only knows” !

Space, time, causality, force, mass, motion etc are concepts which we become familiar on the basis of our everyday experience. Requirement of precedence in time and strict contiguity in space as essential factors in cause-effect relations is again a consequence of personal experiences like lifting of a stone or pushing a cart or hitting a ball with a bat.. etc. The three dimensionality of space, the uniformity and unidirectionality and the universality of time are again concepts which we acquire from extensions and rationalizations of our everyday experiences. The evolutionary biologists (see Max

Delbruck¹) attribute the acquisition of these concepts by man to a phylogenetic learning process that has gone on in the struggle for survival and attempts at adaptation to environment by the various species that preceded the descent of man. This evolutionary angle to the acquisition of concepts like space and time is a little difficult to understand in the framework of classical ideas. There is no material content associated with space and time in classical physics. If evolution has played a role then it has to be through its indirect action on mind. In the context of modern physics, however, space, time, causality, mind, matter have connotations which are quite different from classical ideas and from everyday experience. We will come to this aspect later.

2. Mathematics and Physical Explanation

Newton was the first to introduce mathematical equations in connection with the solution of physical problems. Since then mathematics has become an important tool in the hands of the physicist, and has contributed very significantly to the development of science. The use of highly sophisticated mathematics has become necessary with all the new knowledge that has been acquired especially in the domain of fundamental particles and their interactions, explored with cosmic rays and particle beams at high energy accelerators; and also for understanding the exotic happenings in the environments of stars, neutron stars, black holes, quasars, etc information

regarding which is pouring in from the investigations in the field of astronomy. There is a thought provoking article by Eugene Wigner² entitled “the unreasonable effectiveness of mathematics in natural sciences”. If mathematics is just a consistent formulation of the human brain based on its own logic, then how is it that nature in all its happenings is seen to conform so closely to mathematical laws? What precisely is the mechanism that guides this conformity in actual action? Or is mathematics a ploy that has been cleverly superposed on nature to bring about an understanding of its working by the limited and conditioned brain of the scientist? The relation of mathematics to nature is an issue that goes back to the time of Plato himself. Very recently the famous mathematician Alain Connes³ in conversation with the molecular biologist Jean/Pierre Changeux, has taken the stand that mathematical reality is at par with physical reality. He even goes to the extent of asserting that mathematical reality could be the cause of physical reality. (see also the article of N. Mukunda⁴ in this proceedings.)

3. Further implications of a falling stone – role of vacuum

Let us get back to the case of the “falling stone” since it can tell us many other aspects of recent developments that have a relevance to the issues on consciousness. – of course in the final analysis. It is known that the stone is a composite object made essentially of silicon, oxygen and impurities like iron,

sulphur, carbon etc. So a chemist would say that when the stone is falling it is really these molecules held together by molecular forces that are falling. The molecular forces are essentially the electromagnetic forces of the ions and the electrons. Further the molecules are made of atoms and the atoms of protons, neutrons and electrons. Here one more force, the nuclear force, holding the protons and neutrons comes into play. The protons and neutrons themselves are made of quarks which are held together by gluons, the mediators of quark-quark forces. In a sense, when a stone is falling it is the cluster of quarks, gluons and electrons held together in various configurations (nuclei, atoms, molecules, ... stone) that is falling. In the same strain we have to consider that the earth itself which is bringing the stone down, is a big cluster of quarks, gluons and electrons. The gravitational force is acting between the quarks, gluons and electrons of the stone with those of the earth.

This way of looking at the falling of stone in terms of the microstructures at deeper and deeper levels brings out the many intricate happenings that necessarily take place in what in the first instance appears to be a gross phenomenon. Though to begin with our focus was on the gravitational force and we glibly described that the fall is due to this force, when we go into the microstructural details, there are many other forces also operating to keep the stone a stone while falling. There is another very vital aspect that is generally ignored and not

given its due importance – that is the nature and properties of the empty space in which the stone is falling.

In each one of the various structures that we have considered above, there is surprisingly more empty space than what is occupied by material contents. In effect the stone is 99.99..% empty space. The atom is orders of magnitude smaller than the molecule and the nucleus is orders of magnitude smaller than the atom. This persistent feature brings us back to the old problem, how do these forces, the electromagnetic, the nuclear, the quark-quark operate over such empty spaces in between? – the action at a distance problem repeatedly revisited.

It is in this context that the concept of the ‘field ’introduced by Faraday, Coulomb and Maxwell becomes relevant. When they proposed the field theory, the concept of a stationary “ether” which had the properties to sustain the magnetic, electric or electromagnetic fields and transmit the action due to the forces was implicit. The stationary ether would also be an absolute frame of reference. Einstein demolished the idea of stationary ether with his theory of relativity and replaced it with a new concept, the four dimensional space-time continuum., and endowed this continuum with physical properties. The various fields, the gravitational field, the electromagnetic field, the weak field... became the attributes of the empty space (vacuum). In short, the fields became the primary realities and not the consequences of other realities.

Even a gross property like “elasticity” regarded as a mechanical property of matter turns out to be a consequence of the electromagnetic interactions of the particles.

Similar ideas on the privileged role of vacuum started flowing from the direction of quantum theory when attempts were made to bring relativity and quantum mechanics together by Paul Dirac. Surprisingly, the solution to the relativistic wave equation for the electron formulated by Dirac gave both positive and negative energy values. The negative energy values were not ignored by Dirac as physically meaningless, but were interpreted by him as corresponding to anti-particles of electrons. For this interpretation Dirac had to make an extremely bold and rather wild assumption that at every point of space all the negative energy states of the electrons are completely filled normally and whenever a ‘hole’ is created in this Dirac sea of negative energy electron states, the ‘hole’ manifests itself as a positively charged electron. The theory got a boost when just such a particle, the ‘positron’ was discovered in cosmic rays. As time passed more and more anti-particles – the antiproton, and antineutron, etc were discovered at accelerators. In fact a symbiotic relation between particles and antiparticles during production and annihilation of these was established.

These developments gave yet another twist to the concept of empty space or vacuum. It became in the true sense the

universal material background – the repository of all particles discovered and those not discovered yet in completely filled negative energy states – some prefer the later description that vacuum is the repository of all the ‘fields’, the field ‘quanta’ corresponding to all the particles.

Vacuum, from something which could never be changed to anything under any circumstances, became ‘the source’ of all particles and antiparticles, with many interesting consequences. Spontaneous fluctuations leading to the emergence of particle-antiparticle pairs became a distinct possibility. What is most exciting and a triumph for the theories in this field is the recognition that these spontaneous emissions are subject to the restrictions of the Heisenberg’s principle of uncertainty – deviation from the conservation of energy (ΔE) is permitted in a time interval (Δt defined by $\Delta E \cdot \Delta t \sim \hbar$). Where \hbar is the planck constant divided by 2π) – Because of their extremely short duration and low range, these particles cannot be experimentally observed. They are therefore called ‘virtual particles’. However their creation and annihilation have been established by indirect experiments and observations. Apart from spontaneous creation, the virtual particles are also created in the interactions between particles and in the interactions between the particles and the vacuum itself. Such interactions lead to a very strange situation that there is an on going continuous transformation of particles into other permitted channels of particles which in turn can get converted to yet

another system of particles and soon and after many such transformations get back to their original state. All this happens in extremely short intervals of time. For example a proton could get transformed into a proton and a neutral pion and the pion into a proton and anti proton and the proton into a neutron and positive pion which can transform into an antineutron and a proton and so on. So if one is able to look at the reality in those very short time intervals, it will be very different compared to observation in longer time intervals. These transformations are however not chaotic and they conform to the conservation of certain laws like conservation of charge, spin etc. even when they are violating the conservation of energy within the limitations of the uncertainty principle. What is most important to recognize in all this is that the interactions between the particles are executed by the exchange of these virtual particles which are part of the vacuum. The phenomena like the spontaneous decay of particles, radioactivity, creation and annihilation of particles are all due to the very subtle happenings in the vacuum. For this, it is essential as emphasised earlier, that vacuum has to be endowed with very specific and special properties.

As Heinz Pagels⁵ states in his popular book “The cosmic code”: Instead of “Nature abhors vacuum”, the view of the new physics suggests “vacuum is all of physics”. Everything that ever existed or can exist is already potentially there in the nothingness of space. Physicist came to this remarkable view

of vacuum by way of a deeper understanding of Heisenberg's principle of uncertainty and the existence of anti-particles". This view can be buttressed by the statements of the masters themselves behind this revolution:

Einstein: "Matter when we perceive is merely nothing but a great concentration of energy in very small regions. We may therefore regard matter as being constituted of space in which the field is extremely intense ... Field is the only reality."

Dirac: "All matter is created out of some imperceptible substratum ... Nothingness....unimaginable and undetectable. But it is a peculiar form of nothingness out of which all matter is created".

Steven Weinberg :

At the present level of understanding they seem to be all elementary quantum fields. They are highly simple because they are governed by symmetries. These are not objects with which we are familiar. In fact our ordinary intuitive notions of space, time, causation substance and so on really lose meaning on that scale".

4. Neurons and consciousness

What is the relevance of all this physics for an explanation of consciousness?

If we want to maintain, as practically all scientists would like to, that consciousness cannot be anything outside the domain of matter and forces, then in the final analysis it also has to have its origin in some manifestation of vacuum just as everything else, as seen above, is ultimately traced to this source. There is just nothing else available to the scientist. All physical, chemical, material, engineering and medicinal properties are traced to different level configurations like crystals, molecules, atoms, nuclei etc of the same substratum (vacuum) and its activities. In the light of the tremendous success of the double helix molecule DNA as the agent for all the chemical activities in the diverse cells of the organisms – amoeba to man, naturally the very justifiable confidence exists among the molecular biologists that even life and consciousness will be accounted for in terms of activities at the molecular level and it may not be necessary to go to deeper levels. The biologists' approach to the problem of consciousness is based on the belief that it is a consequence of the physico-chemical processes going on in the brain and the associated complex nervous system comprising hundreds of billions of neurons. The sense organs, the eyes, the ears, the skin, etc. respond to the radiations like light, sound, heat etc. by producing action

potentials or electrical signals in the associated neurons which carry the signals to the various cortices in the brain like the visual, audio, somatosensory etc. The information to be conveyed is coded in terms of spacing between signals, bursting character of the signals, simultaneous response of several parallel neurons etc. Each neuron has to pass through on the average a thousand synapses in which the signal is not electrical but is chemical – release and transmission of special neurotransmitter chemicals. These synapses can also inhibit further transmission of the signals depending on the input from the associated dendrites connected to neighbouring, sometimes even distant neurons. There is lot of systematics about the connections of neurons – for example, particular layers of the retina are connected to layers of the visual cortex. Such intricate connections have a bearing on colour vision, angle definitions etc. The general approach is to establish the neuronal correlates to specific details of events and responses. In achieving this, the role of the modern imaging techniques – the positron emission topography PET, the functional magnetic resonance imaging fMRI, the laser beam modulation techniques as well as the relatively older electroencephalography EEG, microelectrode recordings, observation during open brain surgery have been very valuable (some of the detailed aspects have been discussed in this proceedings – see Shobini Rao⁽⁶⁾).

What has been the net result of these efforts ?

The Nobel Laureate Francis Crick⁽⁷⁾ has dealt with this question in his book “The Astonishing Hypothesis”.

Crick starts out with the rather bold hypothesis:

“Your joys, your sorrows, your memories and your ambitions, your sense of personal identity, your free will are in fact no more than the behaviour of a vast assembly of nerve cells and their associated molecules”.

He expounds in a masterly fashion the recent developments that have taken place in the field of neurosciences including some of his own contributions on visual awareness. However at the end of 262 pages of the book, he comes to rather surprising conclusion :

“The astonishing hypothesis may be proved correct. Alternatively some views close to religious one may become more plausible. There is always a third possibility that the facts support a new way of looking at the mind-brain problem that is significantly different from the rather crude materialistic view many neuroscientist hold today and also from the religious point of view. Only time and much further scientific work, will enable us to decide:

Then naturally as a scientist he goes on to defend the scientific approach in contrast to others by saying “Whatever the answer, the only sensible way to arrive at it is through detailed scientific research. All the other approaches are little more than whistling to keep our courage up. Man is endowed with a relentless curiosity about the world. We cannot be satisfied for ever by the guesses of yesterday, however much the charms of the tradition and ritual may, for a time, lull our doubts about their validity. We must hammer away until we have forged a clear and valid picture not only fo this vast universe in which we live but also of ourselves”.

What follows from the above assessment is that

- (i) The problem of consciousness is not solved yet with the molecular approaches that have been attempted so far and other approaches may be required even at this level
or
- (ii) The consciousness problem has to be tackled at a much deeper level.

It is worthwhile remembering that the simple sodium D line emission that we considered earlier could be answered only at the atomic level and radio-activity could be accounted for only at the much deeper nuclear and particle physics level. A simple question like how is it that my finger which is 99.99% empty space cannot pass through the top of the wooden table which is also 99.99% empty space requires the quantum mechanical Pauli’s exclusion principle for a proper answer.

An aspect that needs to be considered at this stage is the phenomenon of 'emergence' which is essentially the manifestation of a new feature (new property) that is not present in the constituents as individuals, but is discernible in large assemblies of these constituents. Typical examples in the domain of physical sciences are the laser beams and the super conducting currents. These are long range quantum coherence phenomena in which phase connections are correlated, naturally through the action that take place in the intervening vacuum. This kind of phenomenon has been termed 'downward' causation – essentially the group dictating the behaviour of the individuals rather than the opposite which is the more common and more easily understood modality of the reductionistic method of explanation. Hameroff⁽⁸⁾ has suggested "that consciousness may emerge as a macroscopic quantumstate from a critical level of coherence of quantum level events in and around a specific class of neurobiological microstructure: cytoskeletal microtubules within neurons throughout the brain". The work of Jibu⁽⁹⁾ et al point to the production of coherent photons (super-radiance) that penetrate without dissipation the microtubule cores of the neurons.

Both the subtle and the dominating role of empty space – the quantum mechanical vacuum – in all the processes in the universe is gradually unfolding. While the Dirac Vacuum when he proposed the positron theory comprised only the then known particles – the electrons, photons, neutrons, protons

and neutrinos and the anti-particles of all these, this number increased enormously with the discovery of many more particles belonging to the meson and baryon categories, all the strange particles and their antipartners. It is important to note that not all these particles have been recorded directly with visual detectors like cloud chambers, bubble chambers, spark chambers and photographic emulsions. Many of them are definitively established by considerations of balance of energy, momentum, spin etc in specific events in which they are produced. Some of them are so short lived they can never be seen as individual particles. But they control extremely important phenomena. Some of them were first theoretically postulated and then discovered experimentally. The discovery of the intermediate vector bosons that mediate weak interactions and are responsible for spontaneous decay of particles and of radioactivity in general, required the construction of special accelerators costing hundreds of millions of dollars. What the international physics community has done over the past 50 years is to ferret out one by one these hidden aspects of vacuum. It has costed billions of dollars. The expectation is that there are still many more particles to be discovered... the Higgs particle that is envisaged to give masses to particles, the super-symmetric partners of all the known fermions and bosons, the X_0 particles that could make the Proton decay and so on.

Vacuum which is the source of all that constitutes the physical universe and is responsible for all its activity should certainly have the potential in some as yet undiscovered and unferreted out fashion to give rise to both life and consciousness. How does one proceed to explore this possibility?

In all physical and chemical processes where the role of the substratum, vacuum, becomes crucial and dominant, inevitably relativistic and quantum mechanical considerations step in bringing in both the advantages and disadvantages in explanation. The chief disadvantage is that the everyday and common sense notions of concepts like space, time, causality are no longer valid and consequently "picturisation" of the sequence of events is no longer feasible. The advantages are many – the probabilistic interpretation, indeterminacy, duality, non-locality, coherence, etc. Though these features have made the interpretation of quantum mechanics itself difficult everyone agrees that much of the advances in physical sciences is due to the applications of quantum mechanics. Some of the technological advances in electronics, communications and computers are traced to realization of processes predicted by quantum mechanical theories.

One of the standard problems that one becomes familiar in the study of consciousness and its relation to brain functions is the Binding problem. Any event in the external world is represented by the firings of different sets of neurons in the

different cortices of the brain, the visual, the auditory, somatosensory etc. To interpret the event, the mind whatever it is, has to collate the information available at widely different locations and also draw upon the memories wherever they are located. By their very diverse and transitory nature, such bindings cannot arise out of any permanent neuronal interconnections in the network of neurons. An important observation has been the occurrence of correlated oscillations (~ 40 HZ) between sets of neurons in different locations of the brain, the correlations persisting for hundreds of milliseconds.

In a general discussion on consciousness, what gets highlighted is the distinction between the experiencer, the experienced and the experience. If, as per dictates of modern physics, we have to account for everything in the universe in terms of the manifestation of just one substratum, the quantum mechanical vacuum or the four dimensional space time continuum, then the distinction between the above three reduces to different physical states of the substratum. Physically these could be at the level of clusters of molecules or the molecules or at deeper levels or in the form of oscillations in specific regions. The neuroscientists are delineating these. However there could be two types of limitations. One associated with the spatio-temporal resolution of the scan instruments and the other more intrinsic to the process itself. In the physical example of radioactivity we have discussed above, even with the higher resolution instruments we cannot trace trajectory of the particle

right back to the nucleus. There is no definition of the trajectory in the quantum tunneling process by which the particle emerges out of the nuclear barrier. Also the production of the intermediate vector boson and its decay cannot be recorded at all. The essential point to note is that even physical processes for which a chain of explanations is established, not all the intermediate processes can be recorded visually by even the most sophisticated instruments. To complete the explanation one has to make use of (i) whatever is observed experimentally (ii) the theory behind the explanation (iii) the predictions of the theory that have been verified experimentally, may be in some other context as well.

To sum up, even in physical phenomena where one recognizes the sole dominant role of vacuum, there are limitations to the recording of all the processes at the different levels and the mechanisms that operate at various levels. Theoretical insights have played a major role in filling these gaps and in opening new avenues of experimental investigation. By attributing a possible similar role to the same physical vacuum in the explanation of consciousness, may be in the molecular processes or at deeper levels inside the neurons and synapses, the need for a through examination and vigilance to the existence/manifestation of subtler processes is indicated. The altered or higher states of consciousness achieved by meditation, medication, zen, yoga etc may show some of these departures in the physico-chemical processes more

effectively, since the sensory influences are partially or totally eliminated. The fact is that the universal substratum – the quantum mechanical vacuum, the four dimensional space continuum is involved in many subtle and sensitive ways in determining the physico-chemical properties of everything around us and in differentiating their properties too; For example the differences in the properties of say hydrogen, oxygen and water despite all of these having the same constituents - differing numbers of protons, neutrons and electrons, the differences in the properties arise out of differences in the shapes and structures of the neighbouring molecules – “the patterns” configured by the action of the electromagnets forces between the electrons and the ions and the polarization of the vacuum in their neighbourhood. The long term stability of these dynamical systems is maintained through adherence to conservation laws. Small impurities can disturb these patterns, giving rise to radically different properties in some of the substances, strength, colour, brittleness, conducting properties. The whole of chemistry and physics of materials rest on these structures and patterns at the molecular levels. Chemical affinities, bondings, explosive characteristics all depend on these pattern and structures. It is well known that in the case of ‘living systems’ the chemistry that goes on inside each cell – the role of enzymes, proteins depend on the three dimensional configurations of the chains of molecules and molecular complexes. A protein molecule is useless unless it folds itself into a particular three dimensional

configuration. In all this, what is generally ignored is the recognition of the supreme role of the vacuum processes that really are responsible for all the action.

As already emphasised, if all that is associated with consciousness has to be explained within the framework of the natural sciences, the possible role of vacuum has to be figured out. Involving vacuum naturally involves quantum processes and interpreting everything in terms of inter-actions – essentially one part of the vacuum interacting with another part.

While all this points to the ultimate essence of the physical activities associated with consciousness and can be classified as necessary it is by no means sufficient to assert that it provides any answer to the distinctive aspects of consciousness such as – why music delights us or why and how certain incidents move us into tears. Referring to such experiences Erwin Schwdinger⁽¹⁰⁾ says “ Science we believe, can, in principle describe in full detail all that happens in the latter case in our sensorium and motorium from the moment the waves of compression and dilation reach our ear to the moment when certain glands secrete a salty fluid that emerges from our eyes. But of the feelings of delight and sorrow that accompany the process, science is ignorant and therefore reticent”. Crick⁽⁷⁾ tried to break this reticence, but not successfully yet as he himself concludes in his book.

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