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ON THE BOUNDARY BETWEEN QUANTUM AND CLASSICAL BEHAVIOUR IN NANOTECHNOLOGY

Alex Hankey, PhD*

Consultant Professor of Physical Science, Swami Vivekananda Yoga Anusandana Samsthana (SVYASA), Jigani, Bangalore

ABSTRACT

How quantum states merge into classical, as microscopic is expanded to macroscopic, has been the subject of debate over the entire 20th century. The issue is essential to understanding nanotechnology fully, because small nanoparticles lie on the boundary between 'quantum' and 'classical' behaviour. This article discusses the said boundary in light of a new scale constructed between the two: the 'Degree of Manifestation'. The possibility of connecting quantum and classical by such a scale was a much dreamed of, but elusive, possibility, until the proof by D'Espagnat that we do not live in an Objective Reality. The Vedic concepts of Vyakta and Avyakta, manifest and unmanifest, lead to a new approach to interpreting quantum theory in which decoherence, (essentially a process of equilibriation of system and environment), is supplemented by the idea of 'manifestation due to information production'. Here, lack of thermodynamic equilibrium, inherent in any directed energy exchange between any open system (including quantum systems) and its environment, has to supplement decoherence. This leads to new insights into information generation in nanotech systems on the boundary between quantum and classical physics. It also offers a new point of departure for the quantum theory of observation.

Key Words: *Quantum Information, Entropy-Information Principle, Wave Function Collapse, Classical Limit, Manifest Reality,*

I INTRODUCTION

Nanotechnology is increasingly important in the microminiaturization of things like computer components [1] , and also because science is more and more interested in phenomena such as the activities of single molecules in biology [2] , and the indeterminacies and fluctuations, to which phenomena at such size scale are subject [3] . Obviously, at small scales, thermal fluctuations become increasingly important. As scale decreases, the size of mean thermal energy, (1/2)k**T**, becomes increasingly significant. At the same time, as size narrows down to that of single molecules, and even single atoms, quantum effects become more and more possible. The question of when either or both have to be taken into account is an important one, with many implications for nano-scale engineering. In fact, thermal limitations are already a limiting factor mitigating against further miniaturization of nano-scale computer components. When junction size reduces differences in state energy to the order of a mere thermal fluctuation, thermal noise creates high error levels in system function; system reliability becomes intolerably low.

Interactions between these two possible sources of error, quantum on the one hand and thermal on the other, are thought to be understood, but this is probably not the case because of the poor level of understanding of what quantum theory means about the structure of reality. Traditional formulations of quantum theory [4,5] are made in terms of the mechanics of matter, energy and fields of force. Quantum mechanics and quantum field theory are well defined [6], as are the ways in which quantum particles interact with a thermal environment, in say, the physics of condensed matter [7] and quantum cosmology [8]. The problem is that developments over the past thirty years have brought the nature of the

*alexhankey@gmail.com

reality in which we live into question. Leading physicists such as John A. Wheeler at Princton [9], and Anton Zeilinger at Vienna [10] , famous for his work on phenomena like entanglement and quantum teleportation, seriously suggest that information may be more fundamental than energy.

The possibility of information being fundamental has been much vaunted, but little has so far been published. Historically, science has been so much attached to being objective in all its deliberations, that the only kind of reality permitted in scientific debate has been the naïve objective reality forming the metaphysics behind classical physics. The idea that information could be fundamental in a new, deeper way than matter-energy, so beautifully connected by Einstein's $\mathbf{E = M c^2}$ in special relativity, comes as a rude surprise. What would happen to 'objective reality', if information turned out to be the primary concept?

The surprising fact is that quantum theory itself brings 'objective reality' into question, and it does so decisively [11] – embarrassingly so, from some perspectives. That is the subject of the next section. That shows how the introduction of a simple concept derived from Indian philosophy, that of the 'manifest', can circumvent many of the problems associated with understanding quantum theory; it introduces information as primary; and does so maintaining the deep spirit of quantum theory.

Information, however, is known to be intimately linked to thermodynamics. Central to the link is Brillouin's famous Entropy Principle of Information [12] , which sets the second law of thermodynamics in an information theoretic context. If information is primary to quantum reality, then thermodynamics must enter the theory in a more fundamental way than has yet been assumed. That means that the thermal limitations on nanotechnology, and its quantum limit, must be more intimately connected than has hitherto been conceived to be the case.

This paper considers the connection between thermodynamics and quantum theory that arises when information is taken as primary, and the theory of 'manifestation' is applied to nanoscale phenomena; in particular, as the realm to which quantum theory applies gives way to manifest, classical appearance. The next section concerns reality in quantum theory, summarizing why 'manifest reality' is necessary. It shows how it unifies quantum theory with special relativity, and the microscopic quantum realm with the macroscopic 'classical world' in an entirely new way. The third section shows that manifestation implies that the universe is a 'quantum virtual reality', and considers for such a reality, what limitation the processes of manifestation imply on the structure of classical physics. The fourth section treats the connection between thermodynamics and information, deriving the energy information theorem, and suggesting reasons why it should hold at the quantum level. The fifth section shows that a primary role for information implies a new and deeper role for thermodynamics at the quantum level, and explores its implications for the manifestation process. This is turn allows us to explore interactions between thermodynamic and quantum phenomena at nanoscales, where thermodynamically driven processes of manifestation occur.

II WHAT QUANTUM THEORY TELLS US ABOUT REALITY

Quantum systems and the theories describing them have long presented a challenge to philosophers of science seeking to understand what they imply about the nature of reality. The field's originators, Neils Bohr and Albert Einstein, engaged in a long series of debates in which both argued the other to a standstill, the former invoking logical positivism in his famous 'Copenhagen Interpretation' [13] , while the latter fumed about the intrusion of probabilities into a world that he saw as perfect, and under the guidance of a divine intelligence, who, as he put it, 'did not play dice (with his creation)'. It may be that, during their life times, Einstein had the last word, for he pointed out that quantum theory predicted that under certain circumstances, quantum correlations would exist between widely separated systems at the classical level [1] [14], and that, he pointed out, led to such counter intuitive effects, as to be seemingly impossible.

Quantum correlations had long been recognized essential to its descriptions of identical particles, multiparticle systems, and things like the atomic bond [15] , where they create the energy gap stabilizing molecular structures. They make laser-light possible, so we make daily use of them in laser driven bar code readers at every supermarket counter, and on every airline boarding pass. They are a common part of modern technology.

Einstein and his colleagues, however, pointed out that correlations between different systems implied informational connections between systems separated by large, macroscopic distances, over which the finite velocity of light in special relativity denied the possibility of communication. When observations were made on two such systems, and one quantum system was forced to make a particular choice, how could the correlated, but distantly separated system possibly know which choice to make, so that the two systems agreed correctly, and macroscopic laws of physics were obeyed?

The presumed structure of physical science was called into question. If we live in a real world, with real laws that can be experimentally determined, and found to be correct, how could they be violated in such an outrageous way? Many attempts were made to side-step these problems, but the decisive next steps were taken by three physicists, two theoretical and one experimental.

First, John Bell at CERN, the European Nuclear Research Centre in Geneva, derived the famous result now known as Bell's theorem [16] which can be summarized as: When two quanta such as electrons with well correlated spin directions are measured with a small angle between the measuring apparatuses, the laws of quantum theory make completely different predictions from the result of making three apparently very simple and sensible assumptions about the nature of reality: (1) that reality is objective in the materialist sense, (2) Einstein separability, and (3) Logic.

Second, the French physicist Bernard D'Espagnat showed that the quantum correlations responsible for Bell's theorem specifically mean that objective reality is violated on both the microscopic quantum level, and also on the macroscopic classical level [11]. The idea that quanta are objectively real was also shown to be in error by D'Espagnat's Swiss colleague Josef Maria Jauch in his witty Dialogue, 'Are Quanta Real?', styled on Galileo's discussions of the laws of mechanics between Salvatio, Sagredo and Simplicio [17] .

Third, the French physicist, Alain Aspect, showed conclusively that, when experimental situations to which Bell's theorem applies are tested, quantum mechanics rather than the other possibility turns out to be correct [18,19]. At least one of the three assumptions must therefore be in error.

Combining all three physicists contributions, it is clear quantum theory is giving us a strong message: the world in which we live does not constitute a naïve objective reality. Sense phenomena are not caused by objects, which exist in and of themselves, without reference to anything else in the world around them. Since the time of Newton, scientists have assumed this to be the case, since it constitutes the metaphysics of the laws of mechanics and gravity, which Newton considered universal, absolute truths [20] . Many have assumed that for science to remain objective, the reality it describes must, in this sense, be objective as well. It is not an assumption which science can drop either easily or willingly. How else can agreement between different observers be guaranteed? What would it mean for an object-of-sense not to have an 'objective existence'? How could the implied concept of subjectivity be introduced into the world of science? What would it imply for the structure of physical law? Faced with the difficulty of answering these and other questions, few scientists have been willing to systematically explore the alternative to 'objective reality'.

Four who have done so include John A. Wheeler [9], Anton Zeilinger [10] and Amit Goswami [21] , and myself. All of us have begun to explore this unusual perspective on reality. My own ideas date from a 1986 research memorandum [22] concerning a new way of describing reality based on the concept of 'manifest' from the Vedic sciences of India, as a philosophically valid description of the status of the world of sense. An updated version of this paper[1] has recently been published [13] accepted for publication [23]. The principal idea behind 'manifest' is that it can be defined as 'available to sense perception'. The processes by which this occurs consist of information production events, initiated at the quantum level.

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[1] The original was part of a successful application for funding to the Leverhulme Foundation

Application of positivist thought indicates that any 'event' must be associated with information production: can you imagine an event, which took place, but which resulted in no information being produced? This contradiction in terms means that information producing 'events' are the basis for manifestation, and can be equated with wave packet reduction. This links quantum theory in a new and satisfying metaphysical way with special relativity, which also regards 'events' as a primary concept. A major secondary idea is that quantum correlations are necessary in order to guarantee agreement between different observers and different channels of sense, a fact first demonstrated by Hugh Everett III in his Relative State Interpretation of Quantum Theory [24] . Far from being problematic, quantum correlations now play central roles in generating an acceptable picture of the world around us.

Manifest reality is therefore in agreement with Wheeler's idea that 'ITs' arise from 'BITs', i.e. that the concept of an 'object' arises from a sequence of sensorily perceived information processes, onto which objectivity is projected by the subjective observer. In this sense it agrees with Zeilinger [10], that 'information is primary' and that the more 'objective' concepts of matter and energy arise from it. Goswami [21] presupposes that consciousness interacts with the physical world, but does not propose how this occurs. He solves the Many Worlds problem [5] by proposing that consciousness produces information making the choice between different possible alternative futures, at each step of the world process, so reducing the 'Many Worlds' to our single experience. This advance is also a feature of 'manifest reality'. Goswami also invokes Vedic concepts, which he refers to as 'Idealism'. However, without specifying a physical means by which consciousness can couple to the world, his important contribution lacks conviction. A recently proposed solution to this problem [25] may add to its acceptance.

A key attraction of the concept of 'manifest reality' is that it facilitates a major advance first suggested by Jauch [17], namely that it should be possible to connect the classical and quantum worlds by an experimentally defined scale, with the quantum at one end, and the classical at the other. It is easy to show that, because the process of manifestation is one of information production, and because this takes place as wave packets are reduced ('wave function collapse'), every manifest quantum particle or larger entity, is made manifest by its quantum interactions with its environment. A charged particle in a bubble chamber leaves behind a series of 'interaction events', which the bubble chamber transforms into a line of visible bubbles; an oil droplet in Millikan's experiment is made manifest by its scattering of light photons into the microscopie of the experimenter etc. In each case, there is a sequence of interactions, in which information is made available to the observer. The same is true of everything which is observably manifest in the macroscopic world. Manifest reality accounts for the world of sense in purely quantum terms. Most importantly, it defines a 'Degree of Manifestation' **d** of each entity as *the fraction of time spent in information producing collisions*. If each different interaction type i has a collision time t_i with the entity being considered, which can participate in any number n_i of simultaneous collisions of type i, then its **d** is given by:

$$\mathbf{d} = (1 - \mathrm{Exp}\{- \textstyle\sum_i n_i t_i\})$$

Clearly, non-interacting systems have all n_i zero, so at **d** = 0: the entity is'unmanifest'. Frequently interacting systems have **d** ~ 1: they are made 'manifest' by their interactions. Defining **d** this way connects quantum and classical worlds by a scale with the quantum at **d** = 0, and classical at **d** = 1. Of particular importance is that **d** = 0 allows superposition to occur, while **d** > 0 tends to deny it. Quantum and classical are unified, yet remain distinct in a way that agrees with known experimental behaviour.

THERMODYNAMICS IN MANIFEST REALITY

The key idea in this 'manifest ontology' hypothesis is that: information production through wave packet reduction causes manifestation of otherwise unmanifest entities. The macroscopic world is thus 'manifestly real', rather than 'objectively real'. The classical realm i.e. objective reality is eliminated. The hypothesis has two corollaries:

1. No manifestion without interaction.
2. No manifestation without lack of thermodynamic equilibrium.

The first corollary is illustrated by the definition of **d**; the second holds because the entropy principle of information requires that if information is produced in an isolated set of physical systems, there must also be an overall increase in entropy in those systems greater than or equal to the information produced; no increase in entropy can take place without there being a lack of equilibrium. Integrating thermodynamics into the 'manifest ontology' of quantum theory this way has new repercussions for the physics of nanosystems. The quantum limit and thermal noise can both be present to interfere with signal analysis, but have to be correctly combined according to the theory's requirements.

Previously in quantum theory, the distinction between classical and quantum worlds required treating the distinct laws obeyed by each kind of system simultaneously. In the manifest interpretation, the world of sense is quantum in essence, and only distinguished from the quantum world by interactions causing it to manifest, **interactions which are themselves between essentially quantum components; i.e. they are quantum in nature**. For this reason, in 'manifest reality', the laws of thermodynamics, including the Entropy Principle of Information, all have to originate at the quantum level.

DECOHERENCE IN MANIFEST REALITY

These insights distinguish the concept of a 'manifest reality' from the 'decoherence' account of the distinction between classical and quantum worlds [26] . Decoherence is a process by which a quantum entity equilibrates with its surroundings: its interactions cause loss of defining information about the system and this is called decoherence – in quantum systems, correlations produce information, so decoherence represents a loss of defining information. When decoherence takes place active information production processes need not occur.

The distinction between the processes of 'manifestation' and decoherence is best illustrated by the quantum mechanics of an oil drop suspended in a gas, its position observed through a microscope, and recorded by a human operator or a camera. When the light is switched off, there is nothing, strictly speaking, to make the oil drop manifest. Information about its initial position at the time of the light being switched off is slowly lost as the oil drop mechanically equilibrates with the surrounding gas, <u>with which it is already in thermal equilibrium</u>: one might say that 'decoherence takes place, so information is lost'. Strictly speaking, <u>this process is one of quantum diffusion</u>, in which the combined system of oil drop + gas co-evolve, and the interactions between droplet and gas result in a diffusion process. The density matrix of the combined systems will contain a superposition of all possible time evolutions, <u>because thermodynamic equilibrium means no choice has to be made at intermediate times</u>. The actual position of the oil droplet is neither known nor knowable however. (Being a distinct entity, its own internal structure is maintained, and in itself it does not become diffuse.) Its actual position is not 'manifest' until the light is switched on again. Then, <u>the far-from-equilibrium thermal distribution of light radiation can generate the information needed to reduce the gas-oil droplet wave packet, and 'manifest' a definite position for the oil droplet</u>. In this way, the concept of 'manifest reality' subsumes the idea of decoherence within itself, yet any 'process of manifestation' depends on a lack of thermodynamic equilibrium being present.

III VEDIC APPROACH TO QUANTUM THEORY: THE WORLD AS A VIRTUAL QUANTUM REALITY

'Manifest reality' is not so much an interpretation of quantum theory, as an interpretation of classical physics, from which it declares the simple derived metaphysics of objective reality to be in error. By itself, it does not qualify as a new interpretation of quantum theory, *it merely interprets what quantum theory seems to be telling us about the world in the simplest possible way*.

Positing 'manifest reality' means accepting quantum theory's messages about itself and classical physics at face value, and not protesting. What it emphasizes is that quantum theory's well known laws are capable of generating the *appearance* of an objective world, but not a naïvely objective world. In this it is parallel to the central dictum of the Vedic sciences of ancient India. The Vedic civilisation held that to posit the world of sense constituted a 'self-existing reality' was a fundamental delusion; the real nature of our universe is hidden from us by a veil, known as Maya, which can be systematically penetrated by developing one's conscious creative intelligence until the delusion's nature obvious.

Many sages from different civilisations have practised similar techniques to achieve this kind of highly illumined status. They number some of the greatest names in the history of human thought, including (among many others), Brahmarishi Vasishtha, Krishna, Adhi Shankara, Ramana Maharishi, and Maharishi Mahesh Yogi in the Indian subcontinent, Lao-Tse, Chuang-Tse and Buddhism's 7th Patriarch in China and Japan, Islam's Rumi, Plato, Kant and Traherne in Europe, and Deganawida, Ralph Waldo Emerson and Alfred Merrill-Wolff in North America. Shear [27] has put forward persuasive reasons to accept the trans-cultural nature of this fundamental phenomenon. It requires penetrating the simplest state of human consciousness, having rid oneself of repressed emotions and other deluding influences, which might disturb delicate levels of awareness and their subtley refined understanding. We can accept that this is universal knowledge, not specific to any culture, or India in particular.

Positing a full 'Vedic Interpretation of Quantum Theory' depends on two points: first that quantum theory is able to describe the information processing required for conscious experience to take place, and secondly that it can offer a reasonable account of the connection between mind and matter. The author's proposed solutions to these two problems [25, 28] therefore constitute an integral part of the Interpretation. The first is covered by the observation that quantum theory includes processes of information generation (in wave packet reduction), information transmission (in quanta propagation), and information storage (in bound states etc. of condensed matter). Quantum theory thus accounts for basic *information processing* by conscious minds. The second is far more subtle, and, since it depends on extreme complexity [25], is beyond the scope of the present article.

It then follows that processes of manifestation imply that the universe is a 'quantum virtual reality'. One advantage of this concept is that it immediately resolves the EPR paradox. Space-time, as much as matter and energy, are virtual realities, and constructs of information production manifestation processes. It follows that EPR's distantly separated, correlated processes of wave-packet reduction only happen to support a second level of the illusion of an objective reality. They imply a deeper level of description of the laws of physics, and do not present an in-principle problem the way EPR supposed. The Vedic Interpretation considers the limitations such a reality may impose on the structure of classical physics. If the classical world is the result of correlated information production processes, this must surely impose some limitations on the possible physics that could emerge at the macroscopic level. That is the subject of the next section.

SCIENCE FROM FISHER INFORMATION: SUPPORT FROM PHYSICS' LAGRANGIAN STRUCTURE

The Cambridge mathematician, R.A. Fisher, laid the foundation for modern statistics. In his studies of general forms of information obtained from scientific experiment and observation, particularly genetics[29], he developed the subject of statistical inference. Such data with a well defined distribution, usually the Normal Distribution, is known as 'Fisher Information'. As part of his approach, Fisher was able to derive a minimum principle, and show that the equations obeyed by the distributions could be derived from a minimum principle. Fisher's minimum principle is analogous to the minimum principles used to express the laws of physics in ways first discovered by the French Mathematician Lagrange. Interestingly, Lagrange's minimum principle, in the form of the Principle of Least Action, applies as much to quantum physics as it does to classical physics. All fundamental equations of physics, quantum and classical, can be formulated in terms of Lagrangians.

It is intriguing that the process of manifestation used to generate a 'manifest reality' in the Vedic Interpretation of Quantum Theory, makes everything manifest by means of information production, and that the information is produced by the same process as that occurring in experiments: it is that used in the quantum theory of observation. It is therefore identical to that treated by Fisher. This means that Fisher's minimum principle should apply to the information produced in the physical world.

But this is already a well-known fact: in his books, 'Physics from Fisher Information' [30] , and 'Science from Fisher Information' [31] , Roy Frieden shows that the forms taken by all the Lagrangians in classical and quantum physics have a very simple interpretation: their physics results from 'Fisher Information'. More precisely, etc. Frieden has shown that all known Lagrangians, quantum as well as classical, being second order in the canonical momenta, are of the general form derived by Fisher. While, from what we said, this should not appear surprising, it has a monumental consequence: the entire structure of physics, classical as well as quantum, seems to confirm the concept of a manifest reality: the physical properties of everything we can know about both microscopic and macroscopic worlds, results from information production, of the kind used in quantum data collection.

The Vedic Interpretation of Quantum Theory points out that quantum processes generate this information production, for both classical and quantum systems. This is significant: one might expect that, since quantum systems require to be observed using quantum processes, they should obey the structure of Fisher Information. That the classical world obeys it as well, points to its not being an objective reality, obeying arbitrary laws, but an appearance generated by the same quantum processes: a quantum virtual reality, generated by correlated quantum processes, the self-consistency of which convince its observers and experiencers of its apparently objective nature.

IV INFORMATION, THERMODYNAMICS AND THE ENERGY PRINCIPLE OF INFORMATION

To those introduced to physics in the traditional way via the equations of mechanics, gravitation, and classical physics in general, it may seem strange that even the classical world is merely a product of information generation. It need not seem so, the intimate relationship between information theory and thermodynamics, one of the most profound discoveries of 20th century science, implies it. That is because thermodynamics is a universal aspect of all physical systems. No macroscopic system exists that does not have thermodynamic properties – though one may regard such properties as inessential when considering particular aspects of their mechanical properties, and so justify neglecting them. This led to thinking of classical systems' mechanical properties as their essential characteristic, and their thermodynamic properties as an addition, or a luxury.

From another perspective, it is the other way round. To consider a macroscopic system as mechanical, purely, is only possible when one ignores its thermodynamic/information properties. This is a luxury in which one indulges in peril of loosing perspective on the real nature of physical systems. It has to be done with great care, and with the willingness to retrace one's steps. The fact that mechanics was discovered first, and later gave rise to statistical physics and thermodynamics is neither here nor there. The entropy / information principle and the entropy principle of information are primary facts of life, even in a mechanical universe, simply because a mechanical universe is macroscopic.

The entropy principle of information can be used to connect mechanical properties and information. In the same way that heat energy and entropy are equivalent, because of the equation $d\mathbf{S} = (dq/T)$, the principle implies that mechanical energy and information are equivalent, and connected by $d\mathbf{I} = (d\mathbf{E}/\mathbf{T})$. According to this prescription, every unit of mechanical energy can carry information, just as every bit of information can direct arbitrarily large amounts of mechanical energy.

This is intuitively obvious. Any flow matter or energy can be a carrier of information, and conversely any information, being abstract, can be encoded in the flow of matter or energy of any kind. Flows of matter and energy are orderly, which is why precise equations can be written for them. Flows of heat are disorderly, which is why they require the equations of thermodynamics, which are of a different kind, and do not obey the same kind of Lagrangian principles as the laws of mechanics. It is thus easy to grasp the close relationship existing between mechanics and information theory. This relationship makes it less surprising that, somehow, on a microscopic level, all that information has been generated out of thermodynamic processes in the world of matter and energy.

From this perspective, when macroscopic bodys of matter are generated in the early universe, it is only because the orderliness they embody was precipitated out of the disorderly background by a combination of the laws of thermodynamics, and mechanical laws like electromagnetism and gravity. As the temperatures in the Big Bang decreased far enough, the laws of electromagnetism (and quantum theory) permitted neutral atoms and molecules to form, and radiate the entropy to compensate for the increased orderliness this brought in the form of the spectral lines of electro-magnetic radiation, characteristic of the energy levels of their bound states. Then neutral matter was able to condense further, under the influence of its gravitational fields, into macroscopic forms of matter such as planetary nebulae and stellar systems, obeying mechanical laws. Such macroscopic condensations are also only formed at a thermodynamic price: a greater amount of entropy has to be radiated away from the system in the form of heat generated by lost gravitational potential energy and mechanical kinetic energy, when the system condensed **-** in accordance with the entropy principle of information.

When we look at any piece of condensed matter, apparently obeying mechanical laws, it has only been made possible by the laws of information/ thermodynamics referred to above, which have allowed the requisite amount of information to be generated so as to define each piece of matter concerned, including such mechanical properties as its velocity and angular momentum.

V THERMODYNAMICS IN THE MANIFEST ONTOLOGY

Although the laws for each area of physics involved in the generation of macroscopic pieces of matter, electromagnetism, light, gravity, and thermodynamics, were all first discovered in classical form, their quantum forms are all now known, and considered more fundamental that their originals. The whole story can and must be told at a quantum level. The same principle holds: no orderliness on either microscopic or macroscopic levels can be generated without the accompanying production of a larger amount of entropy. As the size of microscopic, quantum particles grows to be macroscopic and ‘manifest’, an amount of entropy must be generated to compensate for the orderliness created as each particle of condensed matter grows in size, and its ‘degree of manifestation’ increases.

In this way, when macroscopic (even nanoscopic) particles are created with a degree of manifestation, **d** ~ 1, an amount of entropy has been generated to compensate for the amount of information implied by the fact of their existence.

These considerations imply that there is a **primary** role for information / entropy at the quantum level, more than simply being written into the theory by hand, as is currently done. This primary role for order and disorder implies a similar new and deeper role for thermodynamics, it effects on, and its implications for, the manifestation process.

Where would such new interactions between thermodynamic and quantum phenomena become most important? The answer is at nanoscales, where thermodynamically driven processes of manifestation are occurring., and where the ‘classical’ limit of manifestation, **d** = 1, is beginning to breakdown. While it is common sense to say that thermodynamics does not respect the **d** = 1 limit, and must still apply as strongly as ever for d < 1, and 0 < d <<1, (it has to, since microscopic, quantum, processes are occurring all the time, and if they did not obey thermodynamic principles,thermodynamics would not be a universal law) it does not follow from the way quantum theory was formulated.

In the Bohr-Heisenberg formulation, quantum theory is divided into two processes:

Process I comprises all processes where wave-functions collapse, or wave packets are reduced, with a resultant generation of information for the observer;

Process II comprises all processes involving the equations of quantum theory describing the free propagation and bound states of different kinds of quanta (elementary particles in empty space and quantum cosmology, and quantized normal modes and their condensations in macroscopic matter).

Quantum theory was thus formulated as a theory of mechanics with no thermodynamic content, and is not designed to generate thermodynamic laws at a microscopic level. Although the manifestation process must obey the laws of thermodynamics, in particular, the entropy principle of information, *it requires a new formulation of quantum theory to encompass such things. To treat the required new formulation is beyond the scope of the present paper. It will be presented in a future article.*

VI SUMMARY

The Vedic interpretation of quantum theory incorporates two different, interwoven components, and its weft the idea information is primary (so that information dynamics both creates the impression of a self-consistent world of sense perception, and accounts for all information processing by consciousness). Its warp is the idea that the reality of sensory experience is not an objective reality, but a manifest reality, where classical 'objects' are represented as sequences of information production events. This kind of classical limit is truer to what happens in real systems than Bohr's correspondence principle, and allows decoherence to be included, in addition to far-from-equilibrium quantum information generation processes. In this approach: the concept of an 'event' as a point/region of information generation sets quantum theory and special relativity on a common basis for the first time; quantum correlations find a natural place, being necessary to guarantee the self-consistency of perceptions of the world by different observers; further insight is gained into the EPR paradox, and Consciousness assumes its natural, fundamental place in the world of sensory phenomena.

The Vedic interpretation works because it extends in a simple way the idea that wave functions refer to our knowledge of a quantum system; and because it uses quantum accounts of information processes to describe information processing aspects of conscious experience, and provide a description of the universe as a quantum virtual reality. By generating information from the quantum level, the universe generates coherent knowledge of events and macroscopic manifestations. These, subjective experiencers interpret according to their own preferences and predilection. The processes of quantum information production proposed here are exactly of this kind, scientific observation one among them.

Frieden's work could have been motivated by any perceptive student of classical physics and quantum field theory, who might well ask: "If the form of principles of least action allow the Lagrangians to take arbitrary and general forms, why are the actual physical Lagrangians we know so well in physics all second order in their canonical momenta, thus possessing such a uniformly simple structure?" Frieden's work provides the key insight. Their required form, second order in their canonical momenta, means 'Fisher information production' underlies each and every law of both quantum and classical physics: *all their physics can be derived from Fisher information*. As a result, the Principles of Least Action governing all dynamic laws of physics can be expressed as Fisher minimum principles. This implies that information generation is somehow at the root of all physical processes. It does not, however, specify particular *physical* sources of information production. That is provided by the Vedic interpretation: the universal physical source of information is quantum information production, a source of Fisher information, responsible for creating the 'virtual reality', which we call the universe. The Vedic interpretation's proposal that the universe is a 'virtual quantum reality' adds considerably to Frieden's picture, which in turn implies that all of physics confirms the Vedic interpretation.

Nanotechnology's limiting accuracies are governed by a combination of the quantum and thermodynamic limits. Their meeting point is best understood in light of the Vedic interpretation, which specifically suggests a simultaneous treatment of quantum theory and the thermodynamics of irreversible, far-from-equilibrium processes involved in information production. The entropy principle of information provides a further perspective, from which to study information production in quantum systems, how information is part of the world of mechanics, and their simple connections to Fisher Information and the laws of mechanics. The conclusion is that to study this exciting field in full detail requires a full account of irreversible thermodynamics at the microscopic level. Only such a theory can unfold every aspect of how the universe narrates its own story, manifesting information about its state and how it is continuously unfolding, under the influence of far-from-equilibrium thermodynamic conditions. Such a theory will be the subject of a future publication.

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