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Chapter 1

THE PHYSICS BEHIND VISION AND CONSCIOUSNESS

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ABSTRACT

Hyperacute vision experiments based on the eye of a house fly use solid state electronics to obtain a 10 fold improvement over digital camera technology. This contradicts neuroscience models of hyperacuity based on cortical processing because the house fly does not have a cortex. These experiments along with considerations from thermodynamics due to the laws of energy conservation and energy equipartition provide strong physical evidence that vision initiates in the retina in the form of a wave and propagates continuously along the optic nerve to the brain. The waves are conducted by nerve conduction currents due to sequentially activated action potentials and supported by metabolic energy that is uniformly distributed throughout the organism.

In quantum physics the de Broglie wave relation is used to describe the wave properties of matter. When it is applied to the matter waves traveling along the optic nerve a value for the wavelength is obtained that corresponds closely with functional and anatomical evidence in the eye, the optic nerve, the primary visual cortex, and throughout the brain. The evidence indicates that waves generated in the retina produce standing waves upon arriving in the visual cortex and throughout cortical surfaces. The waves provide a continuous medium for neural communication along horizontal pathways that is necessary for consciousness, memory, and other global characteristics such as personality and behavior. The global properties of the standing waves are compared with and found to share many of the characteristics of wave functions describing atomic structure. Global properties are also evident in the earth's oldest preserved visual system, the eyes of trilobites, and they are discussed as an alternative to the genetic theory of evolutionary progress.

1. Introduction

The visual cortex is the most powerful area of the brain. It is also the most intricate. Together the visual system and the body constitute the most complex material system known, perhaps in existence overall. Despite the seemingly overwhelming complexity of the subject matter it is a point of contention in the natural sciences whether to treat the organism as a summation of parts or as an undivided whole. It is argued on the one hand that because the same matter is found present in living organisms as in the non-living world, and the laws of nature apply universally and are not specific to certain locations or situations; we should be able to reduce the phenomena of life to the laws of physics and chemistry. The opposing view stresses the importance of the complexity, interdependence of biological processes, the global properties of life forms such as consciousness, and the failings of the hard sciences to account for life. Nevertheless attempts to explain life in the complete absence of the laws of physics is to create an even greater enigma. How does one account for the origins of life when no other logical explanation is apparent? Of all the processes of life, vision is especially dependent upon the natural laws because it concerns the conversion of electromagnetic radiation, whose microscopic properties at the atomic level are given by Maxwell's laws and are well-understood, into biological phenomena that respond to light at cell level. Visual experiences may seem ordinary to us, but the transition from electromagnetic radiation to an optical signal from the retina is not. There are 100 trillion atoms in a cell so if vision is viewed as a sum of parts the level of complexity needed to explain it is far beyond the capabilities of even the most powerful of computers.

In physics material systems consisting of atoms and molecules are typically interpreted using the conjugate variables position and momentum; variables that are hard to define in life processes because they have minimal influence and are present both externally and internally. However, an equivalent picture is available that complies with the idea of reductionism and is less ambiguous when applied to the study of complex systems; the use of the conjugate variables energy and time. Two laws in particular come to mind, the laws of energy conservation and energy equipartition. Both laws are reductionist, acting at a local level, but they also act in material systems at a global level. The law of energy equipartition, for example, predicts the average energy of monatomic atoms in a container of gas (temperature), a microscopic property, but it also predicts the total energy of the gas (heat capacity), a macroscopic property. Because they are universal laws they are necessarily present in the visual system and in life processes in general, but to be understood within that context their influence needs to be properly recognized and identified. Although no violations have ever been detected down to and including the molecular and atomic levels, the difficulty with using energy as a variable to describe life phenomena is that it is difficult to measure and quantify because it comes in many different forms; metabolism, action potentials, heat energy, sound energy, and motion to name a few. Rather than measure the energy in life processes and try to use the data to describe life we shall look at its properties in non-living matter, as defined by the laws of thermodynamics, and compare them to the properties of organisms.

The cell is the functional unit of study for life forms and has been since its introduction in 1839, while the neuron has been the basis for nervous system and brain function since 1891. This makes cell-based theories of life forms arguably the longest continuously conducted investigative efforts in all of science. It is also the least imaginative. Although the cell is the smallest unit of structure of an organism it does not exhibit any of the qualities that we think of when we describe life; motion, consciousness, or competitive behavior. Nevertheless the preferred method for analyzing life processes is to look at individual cell function at a local level, and then combine them in ever larger networks until an entire structure such as the brain is encompassed. This is evident in the premise of the international collaboration *BRAIN initiative* which states, “Researchers will be able to produce a revolutionary new dynamic picture of the brain that, for the first time, shows how individual cells and complex neural circuits interact in both time and space.” (https://braininitiative.nih.gov/) In other words, the brain is to be treated as a “sum of parts” synchronized in space and time. Attempts to describe brain function in “time and space” necessarily ignore the need to include processes such as consciousness, personality, and memory that encompass the *whole*, the entire brain structure which constitutes the individual. The European effort *Human Brain Project*; which is designed to accomplish brain modeling at several separate organizational levels ranging from the molecular though the subcellular to cellular and up to the whole organ; has similar goals. “At the microscopic level and below, the signaling between neurons is the focus.” (https://www.humanbrainproject.eu/en/) Both models effectively rule out the laws of physics for studies of brain function because they begin analysis at the level of the neuron, which is an extremely coarse level of measurement. Cell-level switching mechanisms such as the interconnectivity of neurons by synaptic transmission are used to model brain function, thereby setting the standard for all future models of visual systems. As a result the peripherals of mental processes are discussed rather than its foundations, and research is conducted that is more appropriate for applications in artificial intelligence and robots.

Vision is the most powerful of all areas of the brain devoted to the senses. In cases of blindness visual structures are immediately assumed by the other senses which in turn become much more acute themselves. Major advances in experimental techniques and instrumentation within the life sciences have not resulted in changes in the fundamentals of its approach despite significant advances elsewhere in the physical sciences, notably quantum physics in 1926. An example of the over dependence on cell-based models can now be found in new research on hyperacute vision which demands a physical explanation that does not rely on the properties of cells. Vision involves the transformation of electromagnetic waves, whose physical properties are well understood, into nerve impulses in the eye and their subsequent transition into the physiological phenomena of consciousness and awareness that are activated when we experience sight. The function of the visual system during an image's path from eye to brain cannot be analyzed with the traditional particle view of reductionism using the conjugate variables position and momentum due to its complexity, so the conjugate variables energy and time will be used instead; variables which are often described in classical physics by a wave representation. We begin with early vision and the laws of optics.

2. Hyperacute Vision

Extremely precise hyperacute vision in humans can resolve detail to less than a tenth the radius of a single photoreceptor cell and it is thought in neuroscience to evolve in the visual cortex by means of neural processing [1]. However, visual discrimination is much finer than can be predicted by interpolating data between photosensors. Furthermore, there are many organisms without a cortex that have hyperacute vision. Studies of housefly vision indicate that hyperacuity is due to the overlapping of signals in each of its approximately 3000 compound eyes. Researchers were able to show that speed and accuracy are a function of a small number of neurons near the surface of the eye rather than the deeper level main processing units by duplicating cell response to a visual stimulus with an electronic sensor [2]. If hyperacuity were a result of neural processing in the visual cortex large numbers of neurons would be necessary causing a slower response than what is actually observed in housefly behavior.

Hyperacute vision in life forms is treated as a paradox, consequently it is scarcely mentioned in neuroscience journals; however, biomedical engineering laboratories have obtained promising results by applying the laws of optics in an empirical setting. Researchers have carried out a detailed analysis of house fly retinas and the early layers of the fly's visual system in order to develop sensors that can duplicate hyperacute vision electronically [3]. The microlenses of the artificial compound eye have large fields of view so that each one projects an image onto many adjacent pixels of a sensor array. In this way high resolution information can be extracted with a coarse matrix of photoreceptors. Early success in creating a miniaturized optical detection system has also led to interest and funding from the military. The two studies of vision, engineering and physiology, act as if the other discipline did not even exist.

When hyperacuity is incorporated into a functioning prototype a 10 fold increase in resolution is achieved as compared to digital camera technology. An ordinary digital camera captures images with an array of pixels that are isolated from each other, have a flat response over their surface area, and are processed individually. Sensitivity is increased by increasing the number of pixels per unit area. On the other hand, sensor arrays that demonstrate hyperacuity have pixels with a Gaussian angular sensitivity that overlaps with neighboring pixels. The superposed signals are assimilated using parallel processing and analog electronics to greatly improve sensitivity relative to the number of pixels. “Superposed signals” means that light waves overlap *before* being detected by photoreceptors; “parallel processing” refers to photoreceptors that oscillate sympathetically with the same wave signal despite being isolated from each other physically; and “analog electronics” refers to the use of continuous wave signaling as opposed to digital signaling. All three mechanisms are consistent with a classical wave model that shares information laterally by overlapping neighboring cells with continuously variable signaling rather than by communicating information by means of sympathetically coordinated spike discharges. Although the research on hyperacuity would seem to be more appropriate as a component for robots or in weapons technology than for organisms, optical signals that originate as electromagnetic waves are also an essential part of our own visual systems. After being transformed by the retina, which is a part of the brain, into visual images they lead ultimately to the conscious recognition of the images in thought processes.

3. The Laws of Thermodynamics and Life Processes

Studies of hyperacuity indicate that early vision operates according to the laws of optics similarly to the way a camera operates. Light rays pass through a lens, are focused, and are then recorded in the brain in a smooth transition, with only a negligible exchange of energy with the environment due to the absorption of light. This is not at all the same as the internal processes of organisms in general which conduct a continuous exchange of material with the environment and because of it are referred to as *open systems*. In contrast to life forms the open systems of ordinary matter are “dissipative”, meaning that the entropy of the system increases as it rapidly loses energy. If the energy flow increases until it is far from equilibrium “dissipative structures” are generated, which implies a reversed entropy that has been compared to life processes. However, the formation of dissipative structures also causes locally irregular flows of energy to the environment so that energy equipartition no longer applies to the system as a whole. Increasing energy in a *closed system*, on the other hand, disperses energy evenly so that the law of energy equipartition necessarily holds. It is essential to study the visual system under the same conditions it evolved; that is, consistently with the laws of energy. This is possible if the organism is treated as a closed system over short periods of time when energy exchange with the environment is negligible. In all of the following discussions life forms will be approximated as closed systems so that the law of energy equipartition applies.

3.1. Equipartition

The laws of energy are few in number, but far reaching. One that has a significant impact in all of nature is equipartition. Like energy conservation it has never been known to fail and is able to explain energy exchange in classical systems extending from the level of atoms on up to and including cosmological systems such as white dwarfs and neutron stars. At the atomic level the kinetic energy of atoms evens out. At the molecular level it becomes more complicated as the rotational and vibrational bonds also share energy. As the level of complexity increases to cell level and beyond we would expect the properties of equipartition to embrace more and more diffuse modes of expression. As a universal law its influence will be present even if it cannot be measured and quantified so we need to recognize it by its various contributions to physiology and behavior.

If the life form is treated as an isolated system in the short term then equipartition can be extended to the organism by hypothesizing that it constitutes a fundamental tendency of energy to distribute itself uniformly throughout material systems; whether biological, physical, or cosmological. In fact properties of equipartition that are visible in life forms may be observed in the mechanisms of homeostasis. Current research in biological science cannot confirm that homeostasis operates at a level deeper than the cell because instruments cannot perform measurements simultaneously throughout the organism to verify it. In general, however, it is well known that homeostasis regulates organisms at the molecular level (fluid composition, temperature, regeneration of bodily constituents), the cellular level (metabolic rate, osmotic pressure, ion migration, blood composition), the organ level (air and blood pumps), and the organismic level (gas and heat transport). This is precisely how we would expect equipartition to manifest itself; beginning at the molecular level and spreading out over ever more complex pathways to *simultaneously* encompass the entire organism.

Central regulation wastes energy because it is not sensitive to local needs and may destabilize other parts of the body. Instead regulation is fine tuned through peripheral feedback and results in a well-balanced compromise between flexibility and control. Homeostasis is a tension reducing mechanism which tends toward equilibrium without the need for a command, while the organism itself often acts in opposition to the steady state. It is accomplished by means of a delicate balance between control by central nervous system mechanisms in the hypothalamus on one hand, and spontaneous regulation that occurs locally. Homeostasis is consistent with the idea of equipartition because it controls the energy balance of organisms, smoothing out irregularities, acting spontaneously and automatically. It serves the same purpose for cells as equipartition does for gas molecules, but on a much slower time scale.

The flow of energy is regulated in time, in terms of flow rate, while being constricted in space by the physical boundaries of the organism so we classify it as a "global property" of organisms. Thus the internal causal processes of the organism are in principle different from its external behavior. Internal causal sequences operate simultaneously at many levels: the cell, the organs, and in autonomic and conscious processes. On the other hand, external causation in the form of activity and behavior operates locally and is directed.

3.2. Causality

Although homeostasis is regulated at the cell level it cannot originate at that level because there are no independent control mechanisms evident to connect the more than a dozen homeostatic mechanisms operating concurrently throughout the organism to maintain stability and control. To understand the function of homeostasis with respect to the external behavior of organisms we shall compare causality in life forms with causality in physical processes. Causality in life processes seems at first to be radically different because it involves innumerable microscopic events that are apparently unconnected by trajectories. Consider, for example, a causal sequence which is initiated and carried to completion in a short period of time: the startle response. A loud sound initiates the response which may be observed physically as a slight movement. It is expressed in the cortex in terms of EEG readings after .4 seconds and at the skin in terms of skin conductance in 1 second [4]. Because the startle response is causal and involves an ever increasing number of cells as it evolves, it may be conceived of as a chain reaction of microscopic processes within the organism, a sort of domino effect branching outward from the central nervous system, a symmetrical tree of causal events emanating from a central source. Unlike causality in physical processes, the causal sequences of life have very little velocity associated with them. Motion within the body is attenuated such that kinetic energy and momentum may be neglected without a significant loss in accuracy.

Although there is negligible kinetic energy associated with life processes, causation due to energy is nevertheless present within the organism. As is well-documented in the field of microbiology, the energy associated with a causal event in life processes is termed "Gibbs free energy". The energy exchanges of a causal sequence may then be viewed as a series of transformations of potential energy into free energy. This procedure has been used in microbiology to document the metabolic pathways and other processes; and in psychology to describe the causal sequences which result in behavior [5]. Although studies of behavior do not attempt to break a causal sequence down to its individual energy transformations there is no reason to believe that a detailed view does not exist. The internal processes of organisms may then be described as a steady state flow of energy. In principle both energy transformations and energy flows may be resolved into highly complex chains of causal events, so both are actually exercises in causality. A single event occurs in about a millisecond, thus energy flows in biological matter occur more slowly and in smaller increments than for physical processes such as when information is transferred electrically along a wire at the speed of light. Visual signals travel along the optic nerve at a speeds of up to 2 meters/second while electrical signals travel at a speed that is 10 orders of magnitude faster. It would seem that organisms could improve their performances by adopting electrical mechanisms to increase the speed of signaling as are commonly employed in software programs used in artificial intelligence or in robotics. To see why life forms do not avail themselves of advantages possible with electronic circuitry we shall look more closely at the properties of energy as manifested by life processes.

3.3. Conservation of Energy

The law of energy conservation states that the total energy of a system remains constant. In other words energy can neither be created nor destroyed; rather, it can only be transformed from one form to another. The life form is an independent system that maintains a constant flow of energy divided between Gibbs free energy and potential, or stored energy. Though we cannot verify the conservation of energy empirically by measuring energy before and after an activity or interaction as is often possible in the science of mechanics, it can explain certain characteristics of behavior of a physiological or psychological nature. For example, if an individual is frightened a quantity of stored energy will be activated by adrenalin as free energy and released in the form of a "fight or flight" experience. The free energy that is transformed from a stored state cannot return to its original state. It must be released in some form. The process of activation, transformation, and release is an experience we have all had when waiting to perform on stage, in sports, or when called upon in class. If the energy is focused it will be successfully expressed coherently as an action due to thought processes, but if it is released in an unfocused state it will result in disorientation and confusion as disordered energy. Once the energy is activated internally it must be released even if an immediate outlet is not possible. Its release may result in nervous activity in the form of uncontrolled verbal expression no matter how hard the individual tries not to. In contrast, an individual who was exposed to severe trial and as a result has expended a great quantity of energy does not have an excess of internal energy and therefore may not be inclined to share that experience until a later time. These are largely short term manifestations of energy flow due to the law of the conservation of energy, but there is also long term regulation that dictates an optimal level of activity for the life form in order to dissipate energy promptly without undue accumulation. It has more to do with career and life choices than ordinary behavior.

There is another feature of homeostasis that is consistent with energy conservation. When an external stress or stimulus displaces the organism from its internal resting state the organism resists this change and seeks to restore the original state. The reaction towards stability that occurs is the principal distinguishing feature between life and death, and also between life and non-life. Why? Because the basal homeostatic state of the organism represents a condition of minimal energy consumption not just for a particular function, but for the entire organism [6]. Because it causes organisms to function at a level of minimum energy it serves to conserve energy, a desirable quality because it improves the chance for survival. Metabolic processes alone are not a distinguishing feature of life forms because a dying organism also metabolizes, but in an uncontrolled manner without central control. Artificial processes that perform the same function differ because much greater amounts of energy are required to perform the same tasks. We could imagine a robot, for example, that is more intelligent, stronger, and faster than a person, but it would require huge amounts of energy to function. What makes homeostasis unique is the autonomous control of energy independently of the cells that generate and support it in the form of a global property. It is more representative of the individual than any number of local, quantifiable properties. Its significance is often underestimated and under appreciated because the flow of energy that homeostasis controls and which forms the basis of a life form's existence is neither directly observable nor measurable, acting simultaneously and on many fronts throughout the organism. Due to homeostasis the body maintains a perfect balance with the environment between the supply and demand of energy. It operates on the microscopic level as a utopian society would: Each cell is coordinated globally for the good of the whole, at times slowing its processes, at times speeding up; its workload dependent upon the requirements of the organism. Understanding it is crucial to an understanding of brain function and ultimately to visual processes as well.

The reasons we tend to ignore the significance of homeostasis are not hard to understand. It is a "global property" meaning that representations are not possible in space and time other than specifying the boundary conditions that define their limits. Ordinarily in the physical sciences we describe physical variables by referring them to a reference system. When this is attempted for homeostasis serious difficulties arise because we cannot describe its function mathematically as a causal process by by integrating over space and time as is customary in science. The only way to describe homeostasis mathematically is to assign boundary conditions, the mathematical equivalent of a global property and apply them to the surfaces of organisms. Ordinarily integration would proceed over the entire volume of the organism at a specific point in time. However, that is not possible because homeostasis is neither homogenous nor static. The physical processes that occur within the boundaries rather than being restricted by the boundaries of cells from point to point, share a common origin due to the flow of internal energy that is confined and channeled there. This allows the properties of the organism to be approximated to those of a closed system for short periods of time. Although we can examine different areas within the global boundaries and distinguish them by their function there will always be something missing, their contribution to the whole, their global properties.

Biological energy has inherent unifying qualities that it exhibits as it flows through organisms, and it is most apparent where mechanistic descriptions fail. In early vision, for example, abundant evidence indicates that the architecture of retinal and neural activity is parallel and information is contained in spatial distributions of neural activity rather than spike discharges. Consequently global descriptions and spatial representations have had some success when used as models of vision, optic flow, and cooperative computation, but are not in general usage among researchers because they are not easily defined and then modeled. Descriptions of neuron function, on the other hand, are much more easily documented by directly measuring neuronal activity and their interrelationships with different subsystems so that their methods are much more commonly employed. The conduction of neuron discharge along axons may be measured and defined electrically in terms of very precisely measured signals, while chemical mechanisms are used to describe transmission at the synaptic gap. The most distinguishing feature of life as opposed to non-life is the autonomous activity of life forms, internally or externally, whether on the microscopic or macroscopic level. To describe any aspect of life forms, especially vision, without taking energy into account is a study in futility. A model of vision that is more complete than one of neurons and their properties is possible, but only by studying an unobservable property, the flow of energy at both local and global levels. A unified description of the observable and unobservable features of life forms will then be possible by joining spatial distributions of neural activity with the properties of energy.

4. Global Properties

The use of mathematical boundary conditions to describe a natural phenomenon first occurred during the development of quantum mechanical descriptions of atomic structure when it became evident that it is impossible to map the trajectories of atomic electrons in space and time. This led to the derivation of Heisenberg's uncertainty principle. The atom cannot be described as a sum of parts, electrons and a nucleus, because its properties are dictated by how energy is absorbed, transformed, and released rather than by the interaction of its parts. As a consequence the mathematical description of an atom's probabilistic behavior by a wave function cannot be further simplified. The wave function of an atom is defined as a probability statement that refers to the motion of a particle in a large number of identical non-overlapping regions of space; or to a large number of independent repetitions in the same region of space at distinct times [7]. The measurement of a physically meaningful quantity at a particular time will not be the same for all the regions; rather, there will be a distribution of numbers that can be described by a probability function. These properties may be compared to those of memory. Access of the memory at a particular time, for example, is not always the same, rather there will be a distribution of values that is similar to a probability function. The properties of memory that may be compared to a wave function become especially noticeable when we attempt to recall an elusive fact by focusing attention on it for short periods of time and at distinct time intervals rather than by applying our complete attention for an extended time period. What is obtained is a probability statement of *possible* values rather than a definite result. In contrast models based upon neuron interconnectivity provide uniformly inconclusive descriptions of the properties of memory.

The properties of atoms and organisms favor the view that mental processes have global rather than specific, or linear patterns. The physiological process controlling activity and behavior, or arousal; not only cannot be understood in terms of linear causal sequences, but it has been shown to be a global process since the entire organism contributes to its development [8]. In other words, the causal sequences of the organism and in the brain have global properties whose functional difference with respect to energy is the size of the "container" which confines them. Both atomic and life processes function globally, so they behave as a whole rather than the sum of parts. Analyses of the organism which use the spatial separation of structure or process, such as anatomy, physiology, and neural networks; are valid as partial descriptions, however they neglect global properties so they fail in attempts to explain behavior as an interaction of parts. Therefore ordinary space and time cease to apply for descriptions of internal processes and it explains why the causal sequences of arousal do not have repeatable, or linear patterns. Spontaneous processes are more energy efficient than linear processes because constraints other than the physical boundaries of the organism are unnecessary. If life processes were linear in the manner of electronic circuits; they would occupy a greater volume, require stricter internal control, and be more inefficient leading to their eventual extinction due to natural selection.

4.1. At Cell Level

With each new application of energy transformation and flow through the nervous system we gather more of the necessary tools to be able to understand how optical signals lead to vision. Signals are transmitted by nerve impulses from the brain stem, or "action potentials", which activate muscle fibers and initiate cortical arousal. They are detected as variations, with respect to time, of the potential difference in millivolts across nerve cell membranes. A voltage in an electrical circuit results in current and a flow of energy. However potential differences in biological processes may be characterized as measures of energy stored locally. Therefore as the action potential moves along a nerve pathway, potential energy is being converted to free energy. The free energy is then used to drive osmotic pumps and restore the imbalanced sodium ion concentration across cell membranes. Osmotic pumps, as well as the chemical signals transmitted at synaptic gaps, are metabolically powered. The chemical communication of nerve cells by means of the transport of proteins and other macromolecules through axons is also determined by the local rate of metabolism. In other words, metabolic energy is the underlying medium of all communication activity within the organism. Because it is a cell-based phenomenon, metabolic energy is both diffusely distributed and immobile within the organism. There is no movement of matter or energy associated with an action potential. The firing of action potentials in the optic nerve which transmit the visual image creates the illusion of motion caused by localized, sequentially activated osmotic pumps. The fact that the action potential is a sharp pulse is not so much an indication of a “firing”, or discharge; rather it demonstrates that the energy expenditure for communication between nerve cells is highly localized and therefore energy efficient.

The sequential firing of action potentials within the organism may be compared to the way a wave rides on the surface of a pool of water. Although we see the waves move outwardly in expanding circles, i.e., linearly; the water molecules themselves move only locally. Just as water waves may be analyzed in terms of the motion of water molecules, the action potential represents a localized free energy pulse which rides on the surface of an unseen “pool” of potential energy. Thus a continuity exists below the observed mechanisms of nerve cell communication that may be expressed in coordinates of energy and time, but is not directly observable. The function of the nerve cells themselves, and all communication between them, is dependent on the local availability of this energy. Cells operate similarly to water molecules by communicating locally to give the appearances of a wave. This makes for a seamless transition for light waves when they are transformed from electromagnetic energy to the localized cellular energy of an optical signal in the most energy efficient way possible. Armed with an improved understanding of the way nerve impulses are able to propagate throughout the organism, we return to a discussion of the visual system.

4.2. In the Visual System

The life sciences are in the habit of bypassing empirical evidence or technological information which is difficult to explain or not quantifiable. As we have seen this is certainly true of the global properties of organisms such as homeostasis, but it is also apparent when the physiological properties of nerve cell communication are compared with electronics. As a result questionable or blatantly incorrect statements are made. For example, papers have been published that describe nerve impulses digitally in the form of bits/second with the assumption that they can carry a corresponding amount of information [9]. However, it is well known in data transmission technologies that digital signals must be tagged to be meaningful and no tagging is evident. Ganglion cells in the retina receive amplitude modulated signals from four different types of photoreceptors and convert them into pulse-frequency modulation, but there is only one method of transmitting that information. The visual cortex cannot correlate nerve cell inputs with photoreceptor data or with their locations because pulses are physically indistinguishable. A direct link from each photoreceptor cell to the brain would be necessary to identify the type and location of digital signals, but information from the retina is compressed from 125 million retinal cells to only 1.2 million fibers in the optic nerve [10]. Although the compression of information is referred to in the literature as “neural superposition”, it is unclear from a neuroscience standpoint what is being superposed. These physical incongruities are not explained in the literature and seldom mentioned at all. On the other hand, a wave interpretation explains the compression of the signal as the result of a superposition of fields which activates cell energy relative to field intensity. The cell activity caused by field superposition may give the impression that loosely organized networks of cells are the origin of thought processes, but only if global properties are dismissed.

4.3. In Evolution

The oldest preserved visual system, that of the trilobite (Figure 2), is over 500 million years old. Its compound eyes have hundreds, sometimes thousands of protruding lenses composed of the transparent mineral calcite, $CaCO_3$. Calcite crystals are normally birefringent meaning that they cause light to be split into two rays. The effects of birefringence are avoided in the lenses of the trilobite eye because the crystals are oriented along the main mineralogical axis, the c axis. Additionally the crystals in each lens are shaped into a spherical surface allowing an increased angular range of vision. In later evolutionary developments the spherically shaped outer lens is followed by a second lens with a curved surface of a different shape, referred to in optics as a doublet lens, to increase contrast sensitivity [11]. This allowed trilobites to correct an optical deficiency in lens design that scientists first solved in the 1600's, spherical aberration. In other words, the primitive trilobite organism orchestrates the location and orientation of calcite molecules in order to form hundreds of identical crystalline structures, or lenses, simultaneously organizing them into matrices with regularly spaced geometric packing to maximize the visual capabilities of an eye fixed on the body's surface.

The process by which lenses are formed and organized into the completed eye is reminiscent of our discussion on global properties; properties that emerge as a complete whole, existing throughout an entire volume yet contained within well-defined physical boundaries. The eye first appears in the fossil record as a finished visual component with very few irregularities rather than as a series of "trial and error" modifications that might be expected from a process governed by natural selection. This calls into question whether genetic codes control global processes which are fundamental to the structure, function, and behavior of life forms, and act both microscopically and macroscopically; or if the reverse occurs. The human genome contains over 3 billion base pairs, 1% of which are recognized as protein coding genes, and they determine the nature of life processes of much greater complexity. However, for evolution to qualify as an elementary theory of nature it must demonstrate not only that it is hereditarily important, but that it also complies with the laws of physics at the atomic and molecular level, among them energy conservation and equipartition, which operate at a *more fundamental level* than genetics.

Although the trilobite eye has much larger lenses than the housefly, a coarser matrix, and the inability to focus; many of the same structural characteristics are maintained. If hyperacuity is based upon a physical property of light as experiments and evolutionary progress show, it should be reflected in the cellular architecture of trilobite eyes. In fact the identical conclusion was reached by researchers in the biological sciences, "such an eye could form a coherent image only if the individual images for each lens are superimposed, without blind spaces between." In other words, blind spaces will appear in the spaces between lenses unless light waves superpose before being absorbed by photoreceptors as is indicated by hyperacute vision experiments. The fact that the earliest known visual systems functioned according to the same general principles as insect vision means that the physical continuity of the signal from eye to brain has been maintained throughout evolution. The structure of our own visual system, which arose in response to the same evolutionary process, should have developed similarly; that is, with a smooth transformation from one wave medium to another rather than an abrupt change to a digital format.

4.4. Energy Transformation and Flow

The retina is considered to be part of the brain so if a wave is formed there initially as hyperacuity experiments and the forces of evolution suggest we would expect it to maintain physical continuity as it proceeds along the optic nerve to other areas of the brain. Considerable evidence suggests that this is precisely what happens. High quality images can be easily transmitted by means of wave superposition and analog processing if light waves arriving in the retina oscillate sympathetically generating nerve conduction currents. In analog transmission the signal is not analyzed into parts and later reconstructed so it is not as energy intensive as digital transmission, an important concern for the survival of the life form. Studies show that the computing efficiency of the brain is at least seven orders of magnitude greater than a digital microprocessor and there can be up to five orders of magnitude savings in power consumption for analog devices such as cochlea implants when compared to digital [12]. Therefore considerations of energy usage preclude the possibility that the nervous system operates in a completely digital manner. Digital models raise other questions of a physical nature as well. How can a continuous wave signal be duplicated by pulses? How can pulse signals be compressed 100 fold without losing data? If images are transmitted by pulse signaling how are they restored later upon entering the visual cortex? Image processing can no longer be left as an open question by simply citing the highly wasteful complexity of neural interconnectivity.

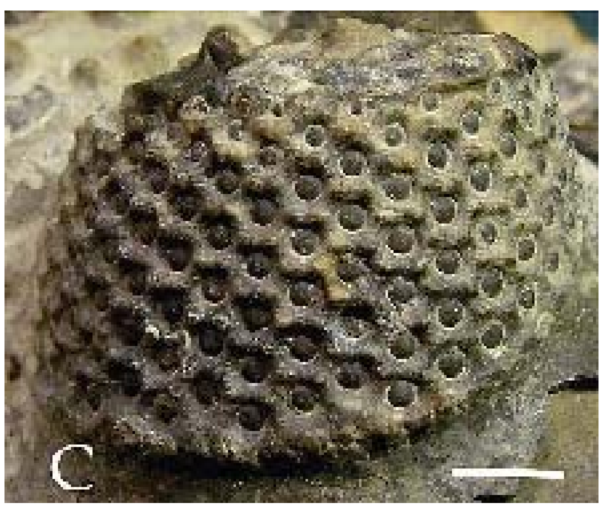

Figure 1. Trilobite eye (see ref [11]). Scale bar equals one mm. Reprinted with permission from Elsevier.

The analog transmission of images by alternating currents and amplitude modulation in electrical circuits is well known. Information travels not with the electrons but rather by means of electromagnetic fields at close to the speed of light. The signals are superimposed on wave forms carried by an incoherent flow of electrons with negligible drift velocity. The data is tagged with precisely timed signals in order to later reconstruct images by scanning them line by line on a screen. On the other hand, nerve conduction currents in the optic nerve are produced by ion-transporting enzymes, Na+, K+ -ATPase. It is hypothesized therefore that nerve conduction currents are constrained by molecular cotransport processes and that images are transmitted by means of their associated electromagnetic fields. Thus light waves can maintain signal continuity upon entering the retina by oscillating sympathetically with electron fields in ganglion cells in order to transmit complete images in real time.

Nerve cell conduction currents may be modeled deterministically by using batteries, capacitors, resistors, and transistors in hard wired circuits and this is the intent of programs designed to model the brain such as the BRAIN initiative and the Human Brain Project. However, actual nerve cell function is fundamentally different from electrical models. Signaling has both excitatory and inhibitory aspects. Thus feedback mechanisms continually adjust behavior and information processing in response to sensory data as they occur in real time. What hard-wired circuits gain in shorter response times is lost due to a less coordinated central control. The reciprocal nature of excitatory and inhibitory processes together with the wave properties of nerve signaling have the appearances of a standing wave. This allows the use of much more powerful parallel processing mechanisms to transmit signals and enact complex brain functions such as consciousness. Deficiencies in electrical circuit models have also been noted in physiological studies. Electrical fields may be detected at the surface of the brain as monopole, dipole, and multipole charge distributions. Electrical currents are also present and are detected via electromagnetic waves or magnetic fields. Researchers have used these noninvasive measurements to try to determine source configurations and make clinical diagnoses. In spite of concentrated efforts little progress has been made. In the field of neuroscience the direct determination of thoughts by means of external measurement is no longer believed to be a realizable goal.

Consider the previously described properties of the visual system; nerve conduction currents, standing waves, and indeterminacy; along with experimental findings that hyperacuity is due to wave superposition. Add to these properties the fact that nervous system processes derive from a steady state supply of energy due to homeostasis and we recognize in them the properties of a wave function. If the boundary of a life form is considered momentarily closed to the environment then it can be described for brief time periods by the superposition of standing waves. Biology describes life forms in terms of cells and their components as a sum-of-parts whereas wave functions are used to describe the global features of material systems. They are complementary models since neither one provides a complete description of observable properties. The nervous system is conceived of therefore as a cellular medium that expends energy to support standing waves by means of nerve conduction currents such that wave amplitudes propagate and superpose in loss free states. A standing wave in the cortex is the source of consciousness while smaller structures such as the thalamus, hypothalamus, cerebellum, claustrum, and superior colliculus; act as resonant chambers to modify wave amplitudes.

Global properties are evident in brain functions such as memory and vision where signals are received from many different areas of the brain indicating the presence of a diffuse input. Global processing requires the visual cortex to be organized for orientation, color, motion, and eye dominance; and to operate concurrently and in parallel to create an image. As a result facial recognition and memory depend on analyzing the global configuration of a stimulus rather than its parts. The fine timing essential for visual, auditory, and somatosensory inputs to merge flawlessly requires the *continuous* superposition of many inputs. These are properties of the mind that favor the continuity of standing waves rather than a system of synchronized nerve cells located distant from each other.

Analysis of the nervous system requires a balanced approach employing the use of both localized and global properties. Research that focuses too closely on the properties of neurons often misses the significance of diffuse wave properties. Thus a highly detailed, comprehensive study on the temporal discharge patterns in a frog's optic nerve led to a proposal that "the distribution of excitability in the terminals of (axon) fibers would at any time constitute a record of the relative times between all of the impulses that had previously passed through the parent axon." [13] This conclusion is based on the assumption that characteristics of nerve impulses provide a *complete* description of nervous system behavior. What was missed in the analysis is that global properties can also influence the propagation of nerve impulses by causing changes in the excitability of surrounding tissue which in turn influences impulse distribution. These influences have been observed, but only in relation to neighboring neuron activity. A comparable situation occurs when a wave function determines the probability density of electrons in an atomic orbital. In general both discrete and continuous properties must be taken into account when describing a material system.

4.5. Matter Waves

It is hypothesized that upon entering the eye electromagnetic waves initiate matter waves in the retina conducted by nerve conduction currents that propagate along the optic nerve, and then disperse throughout the neocortex and are experienced as consciousness. No hard evidence has as yet been presented other than anatomical and functional characteristics of the brain that are conducive to wave behavior. If matter waves are indeed created in life forms in response to electromagnetic waves then they will have physical measurable characteristics as well. The wavelength of matter waves as determined by the de Broglie wave relation, $\lambda = h/mv$, is normally very small so they are not believed to be relevant in every day life. To see if the waves that conduct visual images are indeed matter waves we must calculate their wavelength. The velocity of optical signals may be calculated by determining the elapsed time from the eye to the visual cortex and dividing it by the distance [14]. The elapsed time is simply the visual threshold, the minimum time necessary to distinguish one image from another, or 70 milliseconds [15]. The distance from the retina to the primary visual cortex, located in the extreme back of the head is about 14 cm, so an approximate value for the velocity of an optical signal is 2 m/sec. A wavelength for matter waves may be calculated by applying the de Broglie wave relation, where m refers to the mass of an electron, v is the velocity of the nerve conduction currents, and h is Planck's constant.

$$\lambda = \frac{h}{mv} = \frac{6.6 \times 10^{-27} erg - sec}{\left(9.1 \times 10^{-28} gm\right)\left(200 cm / sec\right)} = 0.36 mm$$

The value arrived at for the wavelength is nearly identical to the size of the foveola, a small pit 0.35 mm in diameter, lying at the center of the retina on the visual axis (Figure 2). To have theory and measurement compare so favorably, especially in the life sciences, is unusual. No other theory has predicted either the size of anatomical structures or proposed why they form the way they do.

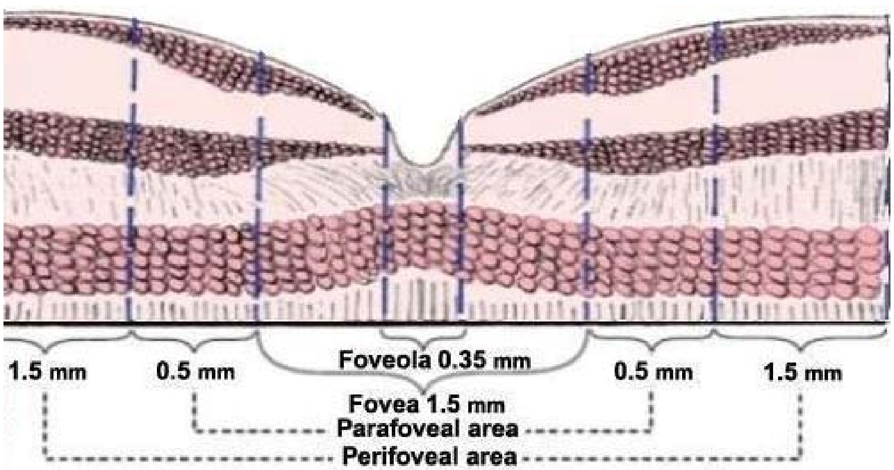

Figure 2. Central retina (see ref. 16). Reprinted with permission from Elsevier.

The result of the above equation is plausible because the foveola is tightly packed with cone cells, each of which is connected to a separate nerve fiber. The cone cells are precisely mapped on both the retina and the visual cortex and are sources of the sharpness of visual images because they have the smallest cross-sectional diameters of all the photoreceptors [16]. Since the foveola is the same size as the wavelength no loss of information is experienced due to a wave representation. Thus frequency specific cone cells convert light waves into waves carried by nerve conduction currents. Optical signals that pass along the optic nerve by means of sequential nerve cell activation may be compared to electronic signals conducted at the speed of light by electrons with a small drift velocity. In both cases loosely bound electrons serve as an underlying medium for the wave. This allows the transmission of the visual signal without the loss of information and with great energy efficiency. The value arrived at for the wavelength sets the norm for many physiological parameters related to the brain and vision. The diameter of the optic nerve gradually increases from 1.6 mm at the eye to 4.5 mm so it can be pictured as a wave guide for gradually dispersing waves.

Optical signals from the left and right eyes meet and combine in alternate layers within the lateral geniculate nucleus (LGN) adding support to the hypothesis that the signals merge by means of a field effect. The fact that the signals from the two eyes are combined seamlessly when they arrive in the visual cortex also supports that idea. The signals are assimilated by layer 4C of the primary visual cortex, which from Figure 3 has a thickness of .3 mm, before being distributed to other areas of the cortex. The folded, layered structure of the cortex is consistent with the idea that it acts as a resonant cavity containing a standing wave and that perturbations are able to move laterally along layers throughout the brain. This interpretation explains why the brain never shuts down and why it is so energy intensive. The standing waves are constantly modified during waking hours by sensory stimuli and sustained during periods of sleep as is evident from dreams.

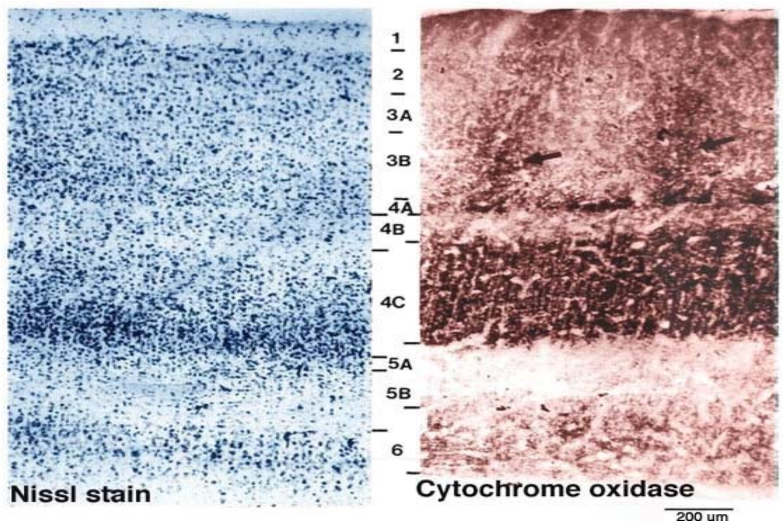

Figure 3. Visual cortex detail (from Webvision).

The neocortex is the part of the cortex that is involved in the higher functions of sensory perception; motor commands, spatial reasoning, conscious thought, and language; and therefore forms the anatomical basis of the mind. Evolutionary progress favors the idea that the layered, skin-like structure of the neocortex is important. “Evolutionary changes in neocortex have occurred mainly parallel to the cortical surface (horizontally)” [17]. Its surface is folded such that in the human brain more than two-thirds of it is buried in the grooves. In general the greater the area of the neocortex the more advanced the cognitive skills of the organism. Its large area serves no particular purpose in a neurological model of the brain; but in a wave model it dramatically increases the space available for processing and synthesizing sensory perception. The compact, convoluted surface allows waves to interact with neurological pathways that lead into and out of the brain while at the same time maintaining global properties such as consciousness and personality.

Neuronal activity is often cited as an indication of brain function, but its descriptions also fit well to a standing wave model. Cell level evidence obtained by using multiple microelectrodes in the brain demonstrates that mental processes are composed of locally random events that are synchronized globally to form the wave patterns of EEG measurements. "The concept of the brain as a dynamic system is based on the fact that in addition to the neurons whose activity goes on and off with the arrival of the incoming information, other neuronal systems maintain a continual and rhythmic barrage of impulses that 'sweep' or 'scan' through the networks of sensory receiving neurons interacting with them, influencing them, and being influenced by them." [18]. Other researchers have arrived at similar interpretations. "It is a matter of considerable interest that in the visual cortex the oscillatory responses of two cells responding to the same visual stimulus can be in synchrony. Cells tend to synchronize their responses if they have overlapping receptive fields, but may synchronize even if they do not overlap. . . synchrony in the oscillatory responses of spatially separate neuron clusters signals coherence inherent in the stimuli." [19]. The synchronization of spatially separated neuron clusters is physically incompatible with digital signaling but not so in the case of a wave model. These clusters are temporary and composed of cells whose allegiances may shift from one state to the next even over short periods. Global properties of neural processing also occur in areas outside of the cortex. In a study of primates it was found that, "the information needed to generate signals concerning saccade amplitude or directory is not contained within the spike discharges of individual collicular neurons but must be extracted from the spatial distribution of activity within the superior colliculus." [20]. These studies all indicate that information processing is widely distributed and that information is not contained in the spike discharges, but in the spatial distribution of activity through parallel processing; indications that favor the presence of a standing wave.

The width of layer 4C, where forward projections of sensory information such as vision terminate, changes the least suggesting that it conforms well to a specific physical parameter, the wavelength of the optical signal. Neuronal networks that conduct feedback to the conscious mind terminate in the layers surrounding 4C. The dendritic trees of neurons are often two-dimensional, oriented perpendicular to cortical layers favoring the idea that lateral communication occurs by wave transmission rather than nerve fibers [21]. While moving longitudinally along area V3A we encounter columns of neurons with regularly varying orientation relative to visual stimuli. Horizontal penetrations of the area find neurons with the same angle [22]. The connections responsible for orientation selectivity are already present at birth indicating that it is due to constitutional rather than acquired properties of the visual system. These findings are also consistent with the idea of a standing wave and are consistent with the properties of its phase.

Nerve conduction velocities of integrative areas of the brain such as the corpus callosum and claustrum are slow suggesting that they act as resonance chambers to modify different aspects of cortical waves rather than for communication. Large diameter axons normally conduct at higher velocities, but the conduction velocity of “rather stout” claustral axons is only 2.4 m/sec [23]. Neurons in layer 4C of the visual cortex are arranged in vertical columns, referred to as ocular dominance columns, with diameters that are the same dimension as the wavelength of the optical signal when it first enters the visual cortex. The formation of synaptic sites into columns is described as a competitive interaction of visual inputs from the two eyes [24]. However, the columns have been shown in monkeys to develop a few weeks prior to birth [25]. This could not occur unless the wave characteristics of neural connectivity were already present before visual input. The “columns”, which are more similar to slabs in structure, are also present in the somatosensory cortex which is sensitive to touch, pressure, and joint position.

When kittens are raised with one eye sutured shut for as little as 3 days the ocular dominance columns do not develop properly [26]. To compensate the primary visual cortex organizes itself by responding almost entirely to the undeprived eye. It was found that there is a critical period during development up until the kittens are about 4 months old. Because the mechanism controlling the formation of ocular dominance columns is internal and the diameter of the columns is consistent with earlier calculations of wavelength, it supports the idea of a wave model which causes the columns to appear due to the reinforcement and cancellation of standing waves. Field reinforcement causes neurons to fire sympathetically thereby enhancing permanent synaptic connections, while field cancellation would reduce neuron signaling. As expected the columns are sharp in layer 4C where optical signals arrive and are blurred in neighboring layers where neuron connectivity dominates. A similar process occurs prior to birth in the lateral geniculate body.

Physiological evidence of a wave model may be personally experienced and are documented in studies of nerve conduction velocity. If the skin of a finger is pricked by a needle there occurs first a short burst of impulses carried by nerve fibers towards the central nervous system conducting at around 100 meters/sec. There follow impulses at other velocities, many at about 20 m/sec; and finally a trail of numerous impulses at about one m/sec. [27]. The hand withdraws quickly in response to the fast nerve signals, which do not register in the conscious mind due to a relatively short wavelength. However, the slower impulses have a longer wavelength and can modify standing waves in the cortex and elsewhere thereby providing an awareness of the needle prick and an inclusion into the memory. The diffuse pattern of a wave form more closely resembles the plasticity and illusory nature of memory function than it does rigidly assembled patterns of neural connectivity.

Conclusion

No physically defined theory of life has been approved by the life sciences. It should not be assumed as a consequence that material from the physical sciences can be assimilated in arbitrary ways. There is an obligation to become familiar with subject matter from another discipline before using it and then to follow established guidelines set by its founding principles. Speculative statements such as comparing spike discharges to the digital transmission of information cannot be stated as fact without providing detailed supporting evidence. Similarly the claim that cortical processing compensates for a 100 fold reduction in the number of nerve fibers in the optic nerve needs to be substantiated by demonstrating that the quality of vision in insects without a cortex is inferior as a consequence. However, the most serious inadequacy of research methods in the life sciences is a disregard for the importance of energy conservation. It has been shown, for example (see reference 12), that digital models of the brain demonstrate a loss in efficiency of at least *seven orders of magnitude*, yet it is the digital model that is being promoted in two international projects. In contrast, projects in the physical sciences are *normally abandoned* when theoretical models deviate from what is observed by less than a magnitude.

The more fundamental a law the greater and more widespread its influence. The laws of energy conservation and equipartition have been confirmed with respect to all material structures whose energies are measurable, from the smallest (subatomic particles) and most complex (dissipative structures) to the largest (stars); and as a consequence they are believed to be universal. Because they may not be immediately recognizable as they modify and change in appearance from one type of material structure to another, it is often necessary to look behind the appearances to confirm their presence. Minimizing their importance or failing to recognize them can delude the researcher into drawing unrealistic conclusions as happened in the early history of quantum mechanics when the possibility of non-conservation of energy and momentum was proposed by Niels Bohr [28]. A similar condition exists today in the life sciences; in particular the biological, physiological, and evolutionary theories; topics that concern life at its most fundamental level. The properties of a life form's energy are not understood clearly so very little attention is devoted to them at a fundamental level; however, there is no question that they are present. By clarifying their physical meaning in section 4.5 and analyzing them quantitatively their significance is brought into focus and experimental tests are made possible. The de Broglie relation predicts an inverse relationship between cortex thickness and optical signal velocity. For humans signal velocities of 2 m/sec along the optic nerve are consistent with a thickness of 1.4 mm for the visual cortex (see Figure 3). On the other hand, the thickness of the cerebral cortex in reptiles and primitive mammals is slightly less [29]. This means that optical signals in reptiles should be transmitted faster than in humans.

When the de Broglie wave relation is used to describe particles it is the particle velocity that is measured whereas in vision it is the signal velocity. For the theory of matter waves to be self-consistent the ambiguity between how velocity is measured, with respect to particles or to signals, must be resolved. By settling this question a property of life may influence our interpretation of physical theory, which implies that the laws of nature are universal and fundamental to all matter.

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