Physics, Biology and the Origin of Life: The Physicians' View

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ABSTRACT: Physicians have a great interest in discussions of life and its origin, including life's persistence through successive cycles of self-replication under extreme climatic and man-made trials and tribulations. We review here the fundamental processes that, contrary to human intuition, life may be seen heuristically as an ab initio, fundamental process at the interface between the complementary forces of gravitation and quantum mechanics. Analogies can predict applications of quantum mechanics to human physiology in addition to that already being applied, in particular to aspects of brain activity and pathology. This potential will also extend eventually to, for example, autoimmunity, genetic selection and aging. We present these thoughts in perspective against a background of changes in some physical fundamentals of science, from the earlier times of the natural philosophers of medicine to the technological medical gurus of today. Despite the enormous advances in medical science, including integration of technological changes that have led to the newer clinical applications of magnetic resonance imaging and PET scans and of computerized drug design, there is an intellectual vacuum as to how the physics of matter became translated to the biology of life. The essence and future of medicine continue to lie in cautious, systematic and ethically bound practice and scientific research based on fundamental physical laws accepted as true until proven false.

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There are few of us, especially practitioners of medicine, who after an encounter with birth or death do not come away, no matter how tired, with wonderment at the origin and significance of these two events. With age, we become more involved in philosophical issues of death and in the broader issue of whether we are alone in our galaxy. Medieval doctors were often philosophers in the wider sense of their own time/environment and were very much concerned with the inseparable issue of 'what' is life and 'how' it relates to inanimate matter. Physicians of those eras were more concerned about religion and the role of man and God than about physical science. One wonders what they would think today, with physical science dominated and puzzled by the apparent incompatibility between two fundamental concepts: general relativity (gravitational) theory that views matter-energy as an expression of a time-space continuum and quantum theory that considers matter-energy in terms of discrete quantities (quanta) and waves and their counterintuitively weird behavior. The long-held desire to unify these two fundamental laws of physics in a theory of everything remains a mirage [1].

However, we cannot escape the physical nature of life and the direct relationship of genetics, the brain and the life sciences in general, with the dualities of mass/energy and gravitational continuum/quantum discretion, thus not only with chemistry but also with the fundamental physics of the universe. Indeed, in 1946 it was proposed that the transfer of genetic information in discrete bits evidences a quantum mechanical world [2]. Just as physicians of today quickly took to the principles behind MRI (magnetic resonance imaging) and PET (positron emission tomography) imaging, they will not be troubled by the finding that a single photon of radiation passes at one and the same time through each of two slits in an opaque barrier placed transverse to its trajectory, and that the waves associated with that photon after it has passed through the slits interfere with each other, as seen on a suitable screen. Yet, the photon itself is detected only as a single spot on the screen. Such counterintuitive principles are not black magic, nor are the pairs of directly unobservable, 'virtual' subatomic particles that are thought to come into existence in a vacuum, but may then immediately annihilate each other. As principles of modern physics are absorbed increasingly into such fields as clinical imaging, neurophysiology, behavioral psychology, protein crystallography and drug design, they also enlighten the ever-present wonder on the nature of life.

WHAT IS LIFE?

There is no shortage of definitions of life [3]. Often, scientists quote the terse definition adopted by NASA in 1994: a selfcontained chemical system capable of undergoing Darwinian evolution. A compendium of current thought could be that an entity is 'live': a) if it replicates through successive generations of physical embodiment energized by thermodynamically favorable metabolic processes, b) if the store of information on which the replication and processes depend is inherent in and propagated together with the embodiment, and c) if random changes in the store of information are manifested in the embodiment and increase its chance of surviving a changing geophysical environment and challenges from other self-replicating internal or external entities.

Life may be discussed heuristically as a fundamental process in the universe at the interface between the complementary forces of gravitation and quantum mechanics

Overall, life as so defined is most favored selectively when the rate of random change in a replicating information store is most suited to the rate of change in the different challenges faced. A too rapid change in challenges, e.g., a new virus spread by air travel, may catastrophically overwhelm adaptation of immunity. At the same time, although a relatively stable information store and its physical embodiment may best survive minor challenges, a rapidly randomizing store may best survive extreme change, e.g., that caused by wind-spread irradiated dust from nuclear explosions. What universal fundamentals stand behind life and its survival?

PHYSICS AND THE PHYSICIAN

TOWARDS MODERN PHYSICS

There are multiple advances in physics that have had unique medical applications; some of these are highlighted in Table 1. For example, in the late 17th century, Newton propounded laws universally relevant to the motions of matter such as the planets and apples, established the spectral nature of light, considered it to be corpuscular without explanation, and built the first reflecting telescope, while believing matter to be transmutable by alchemy. In 1827, Young and Fresnel demonstrated that light had a wave-like quality but could not explain it. In 1856, following the remarkable experimentation of the barely educated Faraday, Maxwell confirmed mathematically that electricity and magnetism are related phenomena, together constituting electromagnetic waves radiating in all directions at a constant speed, e.g., visual light [4-7]. Then in 1895, Roentgen discovered that non-visible radiation could reveal internal details of living bodies. These findings were the beginnings of the revolutions that led to the marriage of science, technology and medicine.

BIRTH OF QUANTUM PHYSICS

In 1900, Planck described laboratory findings in which the rise or fall in the temperature of a heated chemical element was continuous, whereas the frequency of the wavelengths of light emitted from it changed discontinuously by integral multiples of a mathematical constant. However, he regarded "his constant" only as a convenience, not the signature of a fundamental physical law that assigns a particulate property to light. In 1905, the statistical treatment by Einstein of Brownian motion (the quivering of very minute objects such as pollen in a liquid medium) suggested that the pollen was moving continually under the impact of unseen particles, i.e., matter too could be considered in terms of discrete subdivisions [8]. Experimentation soon confirmed that such motion demonstrated the existence of atoms and molecules:

Table 1. Physics and medicine

Year(s)	Scientist	Contribution	Utility
1672	Newton	The spectral nature of light	Newton's rings in crystalline lenses
1827	Young	The wave quality of light	Optical aberration
1895	Roentgen	Non-visible radiation revealing internal detail of some living bodies	Radiographic evaluation of pathologies
1905	Einstein	Electromagnetic radiation occurs in packets (photons), i.e., is particulate as well as wavelike explaining Planck's 'quantum' constant and the photoelectric effect	Clinical imaging, irradiation in photo-dynamic therapy and for neonatal hyperbilirubinemia, laser surgery, bedside electronic instrumentation
1909	Rutherford	Discovery of the atomic nucleus following on from earlier work on atomic decay and its rate	Nuclear medicine
1925-1927	Heisenberg	The more precisely one of la pair of related variables is measured (e.g., position and momentum of an electron in an atom), the more indeterminate is parallel measurement of the other (Uncertainty Principle); a related postulation that during measurement of variables of motion, the result only exists at the moment of observation and depends on randomly fluctuating probabilities	Quantum mechanical considerations in study of brainfunction, consciousness, cognition and behavior and related pathologies and therapies
1926	Schrödinger	Specific atomic qualities combined in an equation expressing the waves of electrons orbiting the atomic nucleus as a smeared out, continuous 3D 'cloud'	Basic tool in study of configuration, bonding and reactions in molecular biochemistry
1928	Dirac	Electrons can carry negative or positive charges, implying existence of a 'positive' ('anti-') electron (observed in 1932 and named 'positron), thus initiating the concept of 'anti-matter' and anticipating that collision of a positron with an electron (both have the same mass) annihilates both, producing gamma photons	Positron emission tomography (PET) employs injected radionuclide that emits positrons that, on annihilation with electrons, produce gamma photons for 3D internal imaging

decisiveness after a millennia-long argument about matter's divisibility [6].

Despite the enormous leap in physics due to the earlier elucidation of basic physical laws of light, the science of physics was stood on its ears in 1905 by two novel concepts. In the first, Einstein demonstrated that energy and mass interchange in a fixed ratio dictated by the constant speed of electromagnetic radiation in a vacuum. In the second, Einstein postulated that electromagnetic radiation is particulate and occurs in "packets" or quanta, later termed photons [4-8]. This explained the previously mysterious experimental finding that emission of electrons from a light-irradiated material, e.g., a metal plate (the photoelectric effect), is related to the frequency of the irradiation, i.e., its energy, and not to its intensity. This divisibility of energy into photons, now regarded as particulate as well as wave-like, underlies all clinical imaging. The quantum revolution was then disturbed by another postulation by Einstein: the general theory of relativity (in 1916), reflecting gravity as a geometric property of unified space time, curvature of which is directly related to universal mass and radiation [4-7,9]. The theory has not been refuted to date by experimental and other phenomena, including the expanding scale of modern cosmology; neither has it been reconciled with the quantum theory, which has continued to develop and receive experimental confirmation.

Enormous advances in clinical medical science, including integration of modern technology, have depended on increased understanding of fundamental processes of physics and their translation to biology

THE NEW (ORTHODOX) QUANTUM PHYSICS

Following Rutherford's discovery in 1909 that atoms have a nucleus, in 1913 Bohr explained the separation between observed spectroscopic peaks by suggesting that the electrons in an atom are restricted to closed orbits around its nucleus and that movement of electrons between orbits takes place as discrete, instant 'jumps' from one orbit to another. These jumps require a gain in energy of the electron (by photon absorption), or loss (photon emission), depending respectively on whether the jump is to a higher or lower orbit. In 1924, de Broglie demonstrated mathematically that not only the electron but all subatomic particles have wave as well as particle characteristics and that the length of the closed standing electron wave around a nucleus is an integer multiple of its wavelength. It was soon recognized by Heisenberg that matrices of measurements of variables, such as position, momentum and energy of an electron and of all other subatomic particles, enable a quantitative analysis of their motion and the more precisely one of a related pair of such variables is measured (e.g., the position and energy of an electron in an atom), the less precise is measurement at the same time of the other. Moreover, the difference in precision is always a certain minimum [4-7]. Such limitation on experimental determination prevents knowledge of the future of a particle, an unpredictability that has acquired the label, Uncertainty Principle (not a law).

In a different approach, Schrödinger in 1926 combined specific atomic characteristics in an equation that represented the waves of electrons orbiting the atomic nucleus as a continuous 3D "cloud." This approach, more intuitive than matrix maths, quickly enabled a deeper understanding of chemical bonding in terms of the overlap of electron clouds. However, discontinuity was soon emphasized again when Born adapted the wave equation to statistical analysis of the distribution of the probabilities of finding an electron. Then, two more novel far-reaching quantum mechanical propositions added support for quantum unpredictability: during measurement of the variables of motion, the observer influences the result, and the result only exists at the moment of observation [4-7]. Thus, prediction of future material events depends on randomly fluctuating probabilities and potentialities: a motivation for mystical incursion into scientific debate, biology and thereby medicine [10-13]. Indeed, despite eventual basing of quantum mechanics on a rigorous mathematical foundation [14], some now orthodox quantum concepts would have long ago lost support if they had not accurately substantiated otherwise unexplained atomic and sub-atomic experimental data. Consequently, most though not all physicists have continued to deny causality, one of the most obvious of human intuitions.

Nevertheless, supporters of the older, 'classical' quantum theory continued to claim that denial of the objectivity of natural physical properties is a result of the incompleteness of quantum theory as a whole [8,15]. Moreover, although matrix mechanics stipulate that at the moment an atomic electron is precisely located (observed) its wave quality and probability distribution are momentarily abolished ('collapse'), data on atomic electrons were found by Dirac to be equivalent whether calculated by wave equation or matrix math [4-7]. However, although the meaningfulness of the 3D wave nature of a particle and its associated wave function have not been abolished by quantum 'uncertainty' and observational subjectivity, phenomena even stranger than momentary disappearance of wave quality haunt human intuition.

QUANTUM WEIRDNESS

Consequences of quantum mechanics are increasingly being considered on the cosmological scale [1,16]. For example, if pairs of quantum particles mentioned above as appearing in vacuo are not annihilated, they can be 'entangled'. Though according to the Pauli exclusion principle that paired sub-atomic particles cannot be in the same quantum state, under quantum theory they can have both their states in the same event superposed on both of them [8]. Consequently, later measurements of properties of one of the particle pair will be instantly affected by a characteristic of its 'entangled' twin, even if it is many millions of miles away. This troubles human intuition, and its instant nature controversially seems to contradict relativity theory that nothing, mass or information, can travel faster than light.

QUANTUM AND LIFE

Do 'weird' aspects of quantum mechanics, including energy tunnelling, electron spin flip, particle superposition and entanglement and virtual particles, participate in life? Though some such phenomena are already realized in electronic and clinical technology, thoughts such as "...biogenesis as a phase transition analogous to bubble nucleation in quantum field theory," and "... the nucleated lower-energy state as a community of interacting replicators occupying a mesoscopic region of a condensed matter system" [17] may be of little interest here. However, with the origin of life in mind, a view that life is "... such an exceptional state of matter that its formation from an arbitrary initial state would be extremely improbable if quantum mechanics did not drastically speed up the route from matter to life through the parallel processing allowed by quantum superposition...," does at least suggest a solution to how life could develop within the currently accepted time frame of the universe [17]. This is controversial. Indeed, it may be wondered how superposition of sub-atomic states can distinguish and select a 'living' from among an infinity of 'non-living' states – a teleological nightmare.

There are those who believe that the enigmas of quantum mechanics may account for the differences between live and inanimate matter [18-20] and may have enabled life to emerge directly from the atomic and molecular world as a self-replicating information storage and processing system [17]. Yet, even if living matter does process information quantum mechanically at the biomolecular or cellular/neuronal levels [21,22], an overall view of biology as interaction between information processors [17] seems to regard life itself as 'information'. Though 'information' is fashionable, alone it is as accessible as a list in a locked drawer and as useful as a book read in the dark. The significance of information is in its application. Without physical embodiment, metabolic machinery, and self-initiation, i.e., without an independent dynamic content, information seems as 'alive' as a thinker who can no longer think. As does "intelligent design," information as 'life' begs a question: can current physics lead to understanding of what constitutes life, in the same way that a description of sub-atomic spectroscopic lines can be related to a fundamental law of physics? Many will continue to prefer that non-mystical approach to biological science.

QUANTUM BIOLOGY

Modern quantum physics has found a still relatively limited role in biology. More commonly this is in the study of protein-associated light gathering molecules (e.g., in photosynthesis and vision) and of excited electronic states (e.g., in energy transfer and proton chemistry). Here, of particular interest is a quantum mechanical approach to a relatively simple chemical structure, the peptide bond [23]. However, quantum application to complexity of intertwined nucleic acid chains and of genes is still in its infancy as it regards the interplay between genes and soma and the awesome, endless complexities of immunity. On the other hand, modern physics has notably been called on for interpretations of the human brain.

THE QUANTUM AND NERVE SIGNALLING

A relatively cautious view is that understanding of brain activity needs knowledge of currently unknown physical laws [24] concerning definable physical issues. Thus, one model posits closely spaced, quantum mechanical molecular condensations in the microtubule structures well known to extend in and along neurons [25]. The condensations are regarded as stable for a microperiod long enough for physiological information transfer over distance to synapses crossed by quantum tunnelling, thus influencing brain activity regionally or as a whole [26]. The stability is proposed to be protected from randomizing, room-level thermal influences by the aqueous environment surrounding the microtubule framework [27]. Though controversial [28], the model exhibits how a non-mystical quantum approach to nervous activity is possible, as it is also to wider questions on life and its origin.

The essence and future of medicine depends on a systematic and ethically bound practice of scientific research based on fundamental physical laws

THE ORIGIN OF LIFE

A common view is that life 'emerges' rather like a rabbit from a hat, on earth, in space, or both. 'Emergence' pedestals life as a secondary, not fundamental property of the universe. Thus, earliest thinking was on observed emergence from pupae, cast skins and the womb and, prior to the microscope and Pasteur, from spontaneous generation: origins no more likely than the emergence of Venus from the sea. Whether 'emergence' of life is humbling, 'ascent' through natural selection (Darwin referred to descent), modern physics suggests a less emotive, more fundamental status for life. Here, life is conceived as an ab initio, universal manifestation of quantum/gravitational influence predating earth's formation. Yet neither gravity post-Einstein nor quantum wave/particle probabilities and subjective observation have clarified how and where life as we know it originated, whether only on earth, elsewhere or both.

LIFE'S LOCATION

Since spontaneous generation was disproved, it has been asked: which came first, chicken or egg? How could information storage and application, for systematic biological replication enabling earthbound adaptation to environmental change, precede the machinery of cell metabolism? Many theories have required the presence of one or more of an earthly chemical 'soup', cold ocean depths, hot volcanic vents [3], or mineral templates [23,29-31]. Moreover, under conditions assumed to have been present on primeval earth, experimental synthesis and spontaneous self-assembly from substrates have produced many of the essential amino acids and their polymers, nucleobases (e.g., adenine and thymine), nucleotides and other organics [32-36]. However, the origin of the remarkable left-handed chiral dominance of amino acids remains unsolved despite numerous theories, including recent ones [30,37].

Irrespective of diluteness of the baryonic matter, a thermodynamic equilibrium unfavorable to life's order and uncertainties mentioned above, overall the likelihood is that life did not start on earth but developed with the universe, prior to earth's existence. This would allow immensely more time for life's development than the four-plus billion years of earth's existence, and the possibility of initiation may have increased due to an earlier Hubble universe with a greater density. A smaller universe may also have eased transfer from the earliest locations of life to galaxies across the universe. A further argument for life's spatial origin unrelated to time is that despite cosmological uniformity observed on the large scale, the apparent overall asymmetry of the universe may be the source of ubiquitous biological homochirality [38].

More general is a theory proposing how in a non-randomly evolving universe, spontaneous self-organization can develop from a random starting point into the origin of life [39]. Teleological non-random randomness? If indeed the origin of life is entailed with development of the universe itself, randomness of starting points seems amorphous in contrast to specific events 'non-random' per se and to causally clear outcomes of universal materiality and ambient conditions. Similarly preferable to statistically improbable happenings, will be natural, observable outcomes of interplay between gravitational and quantum mechanics expressed at more than one time or location in the universe. Such could be, for example, a primordial ribosome developing well before earth's formation.

SEARCH FOR LIFE IN SPACE

There are more than a trillion galaxies, each with a trillion stars of which approximately 10% are thought to have planets. To estimate the likelihood of life on a particular planet, the so-called Drake Equation [40] calculates the relationships between stars, planets, time and intelligence. Notwithstanding a number of negative factors, there is a high likelihood of life in each galaxy. The Milky Way disk galaxy, ours, is approximately 100,000 light years in diameter and 1000 light years thick. From assumptions about existing civilizations, it was estimated that in 30–40 million years our galaxy could be populated. However, as the Drake Equation sums multiplication between many approximations, it does not reliably support or deny extraterritorial alien life.

Given the age of the Milky Way, it seems that aliens should have reached earth long ago. Where are they? Sadly, some authors have proposed that a civilization with nuclear energy is invariably doomed. However, whether conjectures about the origin of life, its location and future are nurtured by 'weird' science or mysticism, natural philosophers of medical science of our times will continue to take a special interest in life's origin, while ensuring that the essence and future of medicine continues to lie in cautious, systematic and ethically bound practice and scientific research based on fundamental physical laws accepted as true till proved false.

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