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Energy Transformation and Flow

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ABSTRACT

Energy is the driving force behind everything we know and experience. To ensure its availability we seek out energy sources of every type real and imaginable. Its presence in every aspect of our lives gives us the illusion that we understand what it is. Yet every branch of science has a different description of energy that is suitable in its own area of expertise, but is not applicable in general. It may come as a surprise then that energy has properties of its own, verifiable by experiment, that are universal and extend throughout all of Nature from the tiniest particles to the heavenly bodies and life itself. When we explore the universal properties of energy we will find that they are embodied most intensely in the phenomenon of life. We conclude in these pages that any scientific theory that claims to be complete must include life.

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Introduction

Quantum mechanics claims to understand how a life form's microscopic atomic and molecular interactions function, but the life form as a whole remains a mystery. It fails to comprehend life because it lacks a complete understanding of the nature of energy; that is, how energy is absorbed from the environment and transformed from its microscopic origins into the global energy of a life form we observe as behavior [1]. A quantum mechanical description of energy is with respect to point electrons undergoing specific transitions. Energy is expressed as a characteristic of the transition and cannot be compared with other transitions whose energy levels differ. However, if energy is treated as a dynamic variable by combining it with time to create a flow, the flows will be seen to have much in common since they are independent of the material structures that support them. Transformations of energy flow may also be compared since they evolve in similar ways whether energy refers to an atom or an organism. As our analysis evolves it will be evident that the physical variables, energy and time, composing energy transformation and flow are being ignored in the life sciences because they cannot be quantified, but that they define properties of life that are complementary to and so closely intertwined with observable properties that neither one can be properly understood without the other.

We begin by considering the simplest and most fundamental of all energy transformations, the emission and absorption of radiation, which refers to the four-dimensional localization of a radiation field that results in the release of a photon. It may be expressed mathematically in a way that is equivalent to nonrelativistic quantum theory [2].

$$S[\phi_i(t)] = \int_{R_2}^{R_1}\int_{t_2}^{t_1} £(\phi_i \phi_{i,\mu}) d^3x dt = h \qquad (1)$$

It differs from nonrelativistic theory because it conceives of the emission of radiation not as a reversible process occurring randomly at a single point in time, but in two-steps as a continuous classical excitation followed by a discrete quantum mechanical decay. During excitation independently oscillating wave train fields superimpose randomly to stimulate a bound electron. If a sufficient field intensity is realized the electron will be raised to a higher energy state along a continuous trajectory. A photon is then released and the electron returns to the ground state. *Spontaneous emission may therefore be viewed as a transformation of field from continuous to discrete forms, or equivalently as a localization of field energy*. The flow of field energy to the electron during excitation occurs continuously (as in biological growth), while quantization in the form of a photon happens abruptly and is irreversible (as in birth and reproduction). In complex systems and organisms energy and time are macroscopic variables that cannot be precisely measured. What we lose in our ability to measure life's properties we hope to gain in the form of an improved understanding of life processes. We begin our analysis of energy flow at the microscopic level.

Classical Thermodynamics

Equipartition

In classical thermodynamics energy flow is described by the kinetic theory of gases in terms of particles with reversible trajectories and deterministic equations of motion. The mass of gas molecules plays a significant role in these models and due to the second law an increasing entropy suggests the eventual "heat death of the universe". The field interpretation of increasing energy differs from particle models because the mass of the electron provides an insignificant contribution to energy flow. Energy in the field model, as for example in life forms, is conducted primarily by electron bonds thereby reversing the trend to disorder by transforming energy from a diffuse to a localized form. In order to avoid inaccuracies inherent to a particle interpretation we shall describe flows using the conjugate variables energy and time (E,t) and include energy equipartition which demands the unrestricted flow of energy. As energy flows through the system it disperses due to equipartition by distributing itself uniformly among the available degrees of freedom and microstates. Equipartition is universal in nature, and is routinely used in astronomical studies to determine the conditions for star formation from a molecular cloud and to estimate star temperature [3]. Because energy dissipates as it flows it provides a description of increasing entropy that refers to energy rather than matter so it is complementary to the second law. As energy flows through a system it will distribute itself uniformly over all available energy states beginning with the lowest. The "law of equipartitioned flow" cannot be expressed mathematically in any useful way because energy is both diffuse and indeterminate, but we can see in it precursors to the division of labor in life forms by homeostasis. It is superior to kinetic theory for describing energy flow in complex systems because it includes the second law of thermodynamics, equipartition, and ergodicity in a single statement.

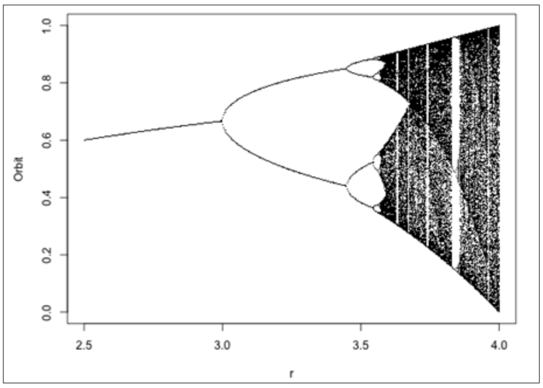

Figure 1: Feigenbaum diagram showing bifurcations

Complex Systems

During far-from-equilibrium processes such as turbulence energy dissipates to the environment more quickly thereby increasing the entropy of a complex system. However, these processes also generate "dissipative structures" implying negative entropy. Such paradoxical behavior may be explained if we use our description of emission described in the introduction in which reversible increases of energy are followed by irreversible energy discharge and structural change. Thus we shall describe a gradual increase of entropy followed by the sudden appearance of dissipative structures as the time evolution of an emission process. The transformation causes new structures to be created to support increasing flow. We may interpret ΔE for a transformation simply as a continuous change in energy with discrete endpoints and Δt as the duration of the change.

Consider the continuous equipartitioned flow of thermal energy as it is conducted by liquid helium confined in a box. Energy occupies the lowest permissible states, and the most stable, first; the way a liquid fills a container. If a temperature difference of a mere 0.001°C is now applied to the upper and lower sides of the box, cylindrical rolls of fluid are created by thermal currents [4]. The rolls conduct a continuous flow of energy from high temperature to low. As the heat is increased a wobble appears and then the period doubles, or "bifurcates" as a second oscillation is added (Figure 1). The flows superpose continuously so they do not interfere with each other; however, the appearance of the new output frequencies occurs discontinuously. The pattern of bifurcations for increasing energy flow due to temperature difference is precisely determined by the Feigenbaum constant [5].

Dissipative systems approach bifurcation asymptotically so we can compare dissipation rates at the point of bifurcation. To analyze energy flow quantum mechanically we must first decretize the flows by dividing the total flow by the flow associated with a single period, or $\Sigma\dot{E}/\dot{E}\tau$, where $\dot{E}\tau=(E/t)\tau$. Now let Q represent the decretized flow and let three successive bifurcations n, (n-1), and (n-2) be given by Q_n, Q_{n-1}, and Q_{n-2} [6]. Then the bifurcations are invariants of the flow rate and the rate at which the period of the system doubles is obtained as follows:

$$F_n(\dot{E}) = \frac{Q_{n-1} - Q_{n-2}}{Q_n - Q_{n-1}} \qquad (2)$$

This gives the quantum mechanical interpretation of Feigenbaum's universal constant. As expected the quantization of a rate is also a rate, the rate of the system's degeneration into chaos. Quantization occurs because of the relationship of energy flow to periodicity and serves the same purpose for complex systems as an action integral does for atomic systems. Thus the combined action of energy flow and equipartition can cause quantization to take on many forms.

Organisms

Physiology

If energy flows naturally disperse, and due to quantization they localize; then it is natural to ask whether energy transformations occur elsewhere in nature. Life forms are open systems that conduct bounded flows of energy and they are in dynamic equilibrium with the environment. Thus we may ignore obvious structural differences with non-living matter and analyze them by using energy-time variables (E,t), where energy is small and time duration is large. It then becomes apparent that characteristics of energy transformation and flow are readily observed and are seen perhaps most clearly of all in humans. Indeed there is already a widespread realization among researchers that energy plays an important role in every aspect of human existence. In cell biology athletic performance has been shown to relate to mitochondrial density; physiological studies show that skin conductance is in direct correspondence with the rate of energy transformation in physical activity; in psychology activity level is related to several personality traits; and in behavior "every response of the organism is fundamentally concerned with energy transformation and release" [7-11].

We are beginning to see the advantages of using the four-dimensional action integral 1) to describe quantization, where action has the units of energy times time. Energy flows may be used to describe life forms at any level, microscopically or macroscopically, by consolidating their innumerable observables into a single property. Although difficult to measure, due to energy conservation no other physical variable is as precisely defined. Thus we shall view the life form from the microscopic level to the macroscopic level as layer upon layer of energy flow, each deriving its existence from still wider systems of material structure so that the final superposition state determines a life form's global behavior in its interaction with the environment. The internal organs are assumed not to have independent influence on energy flow and may therefore be ignored. Stimuli from the environment cause the organism to respond by means of energy discharge.

This causes a displacement from equilibrium and the imbalance is then restored by homeostasis. In other words, organisms act as transducers of energy. They absorb energy that is dispersed throughout the environment and then localize it by applying it towards a specific function, task, or purpose as directed behavior. The organism exhibits the same gross characteristics of energy flow that an atomic oscillator does, but with an extremely slow characteristic time.

The characteristics of energy transformation for an atomic oscillator are also present within life forms. The behavior of neurons follows closely the general properties of spontaneous emission: an increasing flow of energy through the cell builds to a climax and is followed by a sudden discharge (figure 2). This flow pattern suggests that neurons attain a higher flow rate than other cells and in fact this is known to be true. During communication along nerve fibers each neuron signals the next forming a continuous chain. However, the maximum speed of the signal is a mere 120 m/sec and compares unfavorably to the much greater speed and efficiency of an electrical signal. Although it may appear initially that this manner of nerve cell communication places organisms at a disadvantage because it is relatively slow; it also means that nerve conduction is globally controlled rather than an interconnected organization of electrical signals. In other words, local performance is sacrificed in order to optimize the global properties of the organism through equipartition. Because energy equipartition is a universal law of nature it is more fundamental than global structures, in particular the genome. We may conclude therefore that genes are structural characteristics that evolve due to equipartition; and that they act not as templates or patterns, but as conduits that enable the flow of energy to different areas of the organism at precisely determined times. *The genome enables an equipartitioned flow, while homeostasis maintains it*.

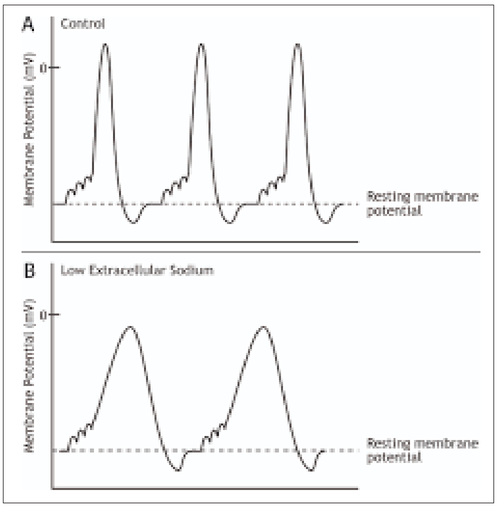

Figure 2: Action potentials

Consciousness

We have traveled inward to analyze the microscopic properties of matter at the atomic level in 1) and compared it with the way the energy of life forms is expressed in large scale structures. Energy absorption is the first half of a transformation and energy emission is the second half. Due to equipartition energy is absorbed as a diffuse flow. When energy is subsequently emitted it is manifested as specific actions in the form of localized behavior. The completed action requires a shift from the global coordinates of consciousness to the localized coordinates of directed behavior. Analyzing life form's behavior requires an entirely different approach than the objective methods of empirical study. The empirical sciences treat consciousness the same as other natural phenomena and analyze it by using electronic monitors and other sophisticated instruments. It is thereby suggested that creativity, emotions, and other thought processes must be reduced to a series of instrument readings before they can be incorporated into a scientific theory. Nevertheless we are all acutely aware of the importance of even the most subtle of thought processes. Although these thoughts cannot be detected or quantified, they are unique to us as individuals and essential to our survival. Fear and love are not learned from experience nor can they be detected by scientific instruments. They are innate at birth and we require them to survive. They are an essential part of our existence, they are real, and perhaps they can help us to understand how other objects and organisms behave.

How can internal, unobserved processes be analyzed? Our thought processes are immersed in a space-time that is unavailable to outside inspection, and by assuming that the same relationship exists throughout nature we acknowledge the presence of "unknowable" properties in all things. On the other hand, empirically determined properties occupy ordinary space-time and are referred to as the "knowable" properties of life, or its "appearances". For example, eyes and vision are two completely independent aspects of the same process; the eyes are objects whose properties are anatomically well understood and shared by all individuals, while vision is an experience that is unique to each individual. It is impossible therefore to describe an individual or organism with a single set of space-time coordinates. We occupy the environment physically in one set of space-time coordinates and simultaneously we perceive the environment in another. The two space-times coexist, are independent of each other, and are linked by consciousness. An objective analysis of consciousness is necessarily incomplete and must be complemented subjectively by examining actual experiences through introspection. Consciousness changes day to day during sleep and wakefulness, and minute by minute according to the intensity of experience. The memory provides a record that varies according to the intensity of experience and is a more complete register than possible by empirical methods because it is continuously active. We all share the same types of experiences, and they can be analyzed and compared. Through introspection we can confirm similarities with other individuals and verify that during times of stress consciousness intensifies and time appears to slow. These feelings cannot be shared with anyone because they occurred in an independent set of space-time coordinates that are unique to us as individuals.

Physical Energy

The Energy Mechanism

Energy is a much used but poorly understood concept. It takes on many different forms and can be transformed from one form to another so it is difficult to say exactly what it is. We use the same term "energy" to describe natural phenomena as diverse as a hurricane, life forms, and nuclear reactions, but we cannot compare the different uses of energy with each other because the material systems that support them differ widely. The energy of a hurricane, for example, refers to an area of the atmosphere hundreds of miles across. Empirical science tells us that its energy is due to the sum of the kinetic energies of the air molecules, but a hurricane has a distinct form and behavior, and due to equipartition its molecules share energy to create these appearances. In practice hurricane behavior is predicted by studying energy flow due to wind speed, barometric pressure, and temperature; rather than molecular motion. We treat the hurricane as having an existence that is independent of the material system that supports it. The same question may be applied to life forms. When science analyzes the life form empirically it refers to energy in terms of metabolic reactions and the transport of energy rich molecules at the molecular level. Life's microscopic processes are thought to be the result of electron transitions, so that analyzing them quantum mechanically is the best way to understand them. However the problem with the analytic approach of quantum theory is that it emphasizes quantitative measurements of energy without including the actual properties of energy such as equipartition. It ignores the unobservable aspects of nature so it fails in its interpretation of life processes. We saw in the case of a hurricane that its shape cannot be understood by analyzing the motions of air molecules. We know what energy does, but as theoretical physicist Richard Feynman noted, "we have no knowledge of what energy is". In other words, why does atmospheric energy take the shape of a hurricane? Just as there is no way to make a mental leap from an understanding of air molecule behavior to hurricane behavior the same situation exists with regard to life forms.

In the life sciences energy is treated as just one more of the many components necessary for life. Thus biology treats energy as a constant by defining it at the microscopic level in terms of energy rich molecules, adenosine triphosphate, that store and transport energy within the cell. It ignores the fact that all of the characteristics used to define life; reproduction, mobility, communication, and consciousness to name a few; are meaningless without energy to fuel them. As a result the important conclusion, that energy is more fundamental than any other property, is missing. *The single most defining property of life is also its least understood*.

We know what energy does in the life form. It causes all the characteristics of life; growth, reproduction, activity, and consciousness; but we don't know what energy is. Biologists will be confused when asked how energy produced by the cell is transformed into the global energy of physical activity, growth, and consciousness. We know that they are not the same thing because experiments show that cell metabolism continues for at least 4 to 10 minutes after death. At the moment of death blood flow stops, the brain ceases to function, and physical response is absent; but cells continue to metabolize for a short time so the body remains warm beyond what would be expected. The connection between cellular energy and organismic energy is interrupted at death, but energy continues to be metabolized at cell level. The difference is that now it is no longer being transformed into organismic energy. We see signs of life at the microscopic level, but what is missing is the "life force"; the global energy that we observe as behavior in other life forms and we experience in ourselves as consciousness.

Detailed physiological studies show that energy generated at cell level expands to organismic level through homeostasis, and is then focused for use in directed behavior. Empiricists have created a false sense of optimism by choosing to disregard the connection between a life form's microscopic and global energies. When the first cloned animal, Dolly the sheep, was produced it was identical to its forbears with respect to its observable features; however, as is well known it had a shortened life span. Its total energy, as determined by summing over the life span, was much less than that of a naturally born animal. Cell biologists know a lot about the metabolic processes used to run a cell's machinery, but they don't know anything at all about how microscopic energy is transformed through equipartition and homeostasis into directed behavior. Science ignores the unobservable properties of life because they can neither be measured nor controlled.

Clearly, there is no hard and fast connection between cell energy and the energy of physical activity and consciousness. The cells do not "know" whether they are alive. They function as simple biological machines. The fact that they continue to function after death provides proof that life cannot be analyzed as a "summation of parts". Microscopic and macroscopic energy are functionally separate. Instead of picturing life processes in terms of energy quanta being emitted and absorbed quantum mechanically, we must imagine life energy as being both dispersed and integral at the same time, as a global property. The global energy is spread out over the entire organism due to equipartition and acts at all levels to drive the various life processes. Recognizing energy as an unseen underlying force that drives all of life's observable processes, including genetics, means that the theory of evolution is questionable as a theory of nature. Evolution may be characterized instead as the ordering of life systems in such a way that they are able to generate increasing energy flows. In order to make that connection we will distance ourselves from the use of "fitness" and adopt characteristics that are applied universally rather than to specific life forms. To illustrate we shall examine how an ecosystem evolves.

Integrated Energy Flows

The existence of the rain forest cannot be logically explained. Mutations occur randomly, but the unusual life forms and over-sized plants that populate rain forests are not randomly located. They appear at exactly those locations where they can most fully realize their potential. A rich, fertile environment and abundant sunlight seem to have triggered an energetic plant response. The competition within rain forests is not among the plants in a struggle to survive, rather it is a competition to collect sunlight. Plant species have developed their own unique method of competing for sunlight, and plants distinguish themselves individually in their ability to collect and utilize energy. The access of giant redwood trees to energy is aided by their great height, while ferns though short have extremely large leaves for the same purpose. When we observe a three thousand year old tree as it soars from its immense base to a practically invisible peak it is impossible not to appreciate the energy required to build and sustain its enormous size. Natural selection in the rain forest is not the result of a struggle to survive, rather it is a competition to obtain sunlight. By supporting numerous methods for accumulating energy the plant collective extracts maximum possible energy from the sun. The energy of individual plants is maximized by characteristics of growth and the collective energy of the forest is maximized by plant density and efficiency.

Rain forests represent the highest expression of evolution in the plant world while civilizations occupy the same position with respect to the animal kingdom. We can compare them with each other since they both evolved according to the same evolutionary law. Both originated in conditions of ideal weather and fertility where energy is readily available. Rain forests are tied to a particular area, but the location of civilizations is only limited by the availability of food. Greek and Roman civilizations owed their success to the mild climate and easily accessible food sources that exist around the Mediterranean basin. Similarly the success of today's societies is due to easily obtained energy. We are constantly exploiting new sources of energy to fulfill every conceivable need. The success of a civilization is determined by its success at collecting and utilizing energy, and the success of individuals is measured by their ability to apply energy in new and useful ways. The abundant availability of energy has caused the influence of natural selection through survival to be practically eliminated in modern societies. Like the plants in a rain forest we strive to enhance the availability of energy by improving our

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ability to collect it and increasing the number and variety of our methods of collection. That this will ensure our survival has been our experience historically.

Conclusion

We need energy to survive, and we seek excess amounts to prosper. We embody energy physically, physiologically, and psychologically; both consciously and unconsciously. Nearly everything living or contributing to life has something to do with energy. Although the energy we feel within us is unobservable it can be described in terms of the changes it undergoes as it moves from one physical support system to another. Thus food energy that begins at cell level is soon transformed into myriad forms of blood flow, nerve activity, growth, and muscular motion; which are finally combined and expressed as activity. Because all of these processes have the same underlying source we refer to them simply as energy flow. The flow initiates in the cell, expands its influence due to equipartition, and then merges with other microscopic flows by superposing to perform directed behavior and generate consciousness. However, we are not always in control of our energy, as is very evident in psychological studies of behavior. Energy has certain properties independently of matter. We have all had the experience of having too much or too little energy. It can affect our behavior by moderating it or intensifying it, sometimes in a good way and other times adversely, but seemingly without conscious intervention or control.

The importance of energy in human behavior and throughout Nature is indisputable, but it defies attempts at interpretation empirically. Quantum mechanics has volumes to say about the energy of simple material systems such as atoms and molecules, and almost nothing to say where energy is most evident, in the life sciences. With this study we have shown that it is possible to describe molecules and life forms with a mathematical description.

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