

*Article*

## A Proposal for Testing the Energetics of Consciousness and its Physical Foundation

Gerard G. Nahum

Global Clinical Development US Women's Healthcare, Bayer HealthCare Pharmaceuticals, Box 159, Wayne, NJ 07474, USA; email: gnahum2003@yahoo.com

*Received: 16 Feb 2010; Published: 02 Mar 2010*

### Abstract

---

Theories of consciousness suffer universally from a lack of experimental verifiability. Proposed here is a quantitative method for studying the energetics of biological consciousness as a means for placing its investigation within a testable experimental framework. Three well-established physical relationships underlie the proposal: (a) conservation of energy, (b) the equivalence of energy and or negative entropy with informational system content, and (c) mass-energy equivalence. By combining these concepts, the internal energy and entropy of physical systems can be used as the basis for designing objective tests to evaluate hypotheses concerning biological consciousness. To do this, the measurable biological system energy losses of a conscious organism can be evaluated upon death for their equivalence to the concurrently measurable biological system mass losses as a function of time. Based on the results, there may be quantifiable evidence for the preservation of a subset of system information, in the form of a measurable quantity of energy reflecting an amount of preserved negative entropy and or information, to suggest a degree of system immortality that may persist after the death of a previously conscious biological organism.

---

### Background

Theories abound concerning the phenomena necessary to explain consciousness. Modern hypotheses range from non-linear information processing in complex neural networks, to non-deterministic diffusion effects, to non-calculable objective reduction of molecular quantum

superposition, among others.<sup>1</sup> Such purported biological mechanisms of consciousness have consumed the efforts not only of neuroscientists, but also of many physicians, psychologists, philosophers, physicists, cosmologists, and theologians. Still, there is no consensus concerning an overall theory of consciousness, and even a formal definition has not yet been satisfactorily formulated.<sup>2</sup> This most basic failure of definition exemplifies the difficulties associated with previous efforts to study consciousness: it is uncertain precisely what phenomenon researchers have endeavored to investigate, and this has made it impossible to evaluate the success of their theories and methods of explication. In addition, different investigators have had fundamentally disparate objectives in searching for manifestations of consciousness within their own disciplines and it is probable that they have also had somewhat differing notions concerning the phenomenon of consciousness itself. Within this framework of disagreement and relative ignorance, the present theory is proposed as a means for re-examining the central issues surrounding the phenomenon of consciousness by suggesting an objective physical test for its presence and possible quantification.

## Definitions

The term consciousness describes a phenomenon that is concerned not with what a sentient entity does, but with what it experiences.<sup>3</sup> The phenomena that allow for consciousness must be internal, in the sense that no manifestations or correlates of consciousness need to be outwardly discernable. Although these phenomena must be viewed as the basis for what we generally term individual or subjective experience, the internal events themselves that provide for consciousness may be nonetheless objectively discoverable and capable of scientific scrutiny.

Any proposed theory of consciousness must be sufficiently broad to account for the seemingly variable levels of consciousness that exist during different physiological states within ourselves, as well as the divergent manifestations of consciousness that occur in other people and higher animals.<sup>4</sup> It is not clear whether these seemingly different manifestations of consciousness are attributable to varying aspects of consciousness itself, or if they represent potential differences in other closely linked but potentially separable mental phenomena such as attention, memory, processing capacity, information access time, processing tempo, or other related but superimposed phenomena.

Much has been said about different ‘states of consciousness’ in humans, suggesting quantitative, or perhaps even qualitative, differences among these various conditions, including those of heightened awareness, relaxation, sleep, meditation, hypnosis, etc.<sup>5</sup> It is also well recognized that disease processes can have profound effects upon consciousness, many but not all of which are either neurological or metabolic in nature. Ontogenetic studies have demonstrated that most complex biological systems evolve from single cells into embryos, newborns, adolescents and adults according to a sequence of well defined and energy-consuming developmental processes,

thus making it unclear when to first attribute consciousness to such developing and maturing complex systems.<sup>6</sup> Most investigators agree that consciousness appears to exist within a wide range of animals, although the outward manifestations of this are highly variable and species dependent. What continues to be lacking in every theory of consciousness thus far proposed is confirmatory and incontrovertible experimental evidence that is both objectively measurable and consistently reproducible. What is needed is an objective method to measure the *presence of subjective experience* such that the investigation of consciousness can be placed on an experimental footing.

The notion of consciousness must be clearly separated from any potential for its outward manifestations. Even those who might advocate the most mechanistic of explanations for consciousness generally agree that a motor response is not an intrinsic requirement for its presence. Although this non-linkage might severely limit the evaluation of systems for consciousness by any type of Turing test, it should not be confused with a necessary condition for its presence.<sup>7</sup>

In view of the profound difficulties that have arisen in formulating even a definition of consciousness, it would seem not only wise but necessary to define two incontrovertible states: one in which biological consciousness is *agreed to be present*, and one in which *it is not*. Therefore it would appear reasonable, if not obvious, to postulate that biological consciousness cannot yet exist in beings not yet conceived. Similarly, it would seem equally obvious to assert that no measure of biological consciousness can persist in organisms following their irreversible death. These definitions, based on the logical biological endpoints of the normal organismal life cycle, are in keeping with our most commonsense definitions of consciousness. During life, we may freely admit the possibility that different levels of consciousness may occur. But, as with the investigation of any phenomenon about which little or nothing is yet objectively known, we would do well at the outset to confine ourselves to studying the differences between the states of two well defined and indisputable extremes, namely *normal consciousness during adult life* and *the absence of biological consciousness after death*, to discover the most fundamental attributes of consciousness itself.

A necessary constraint of an initial investigation of this type is the irrevocable transition of a sentient being from a state of intact living consciousness to a state of biological death. This restriction is not onerous because (a) sentient beings regularly make the transition spontaneously from life to death, and (b) models of consciousness are likely to exist in lower organisms that have temporally brief life cycles, making these models sufficient for initial experimentation. Thus, the experimental substrates for investigating the energetics of consciousness are ubiquitously available and most of the tests to be described may be characterized as observational in nature. Stronger experimental designs that require active intervention into life processes are also possible, but they are not essential. However, any potential alternative

experimental designs that might provide for the mere interruption or suppression of consciousness, e.g., as might be expected, for instance, with general anesthesia, are inadequate for such a study because the underlying substrate and mechanisms of biological consciousness are not actually lost, but merely constrained or suspended, allowing it to be potentially reconstituted at a later time.<sup>8</sup> In such cases, there is no necessity for biological consciousness itself to be either dissipated or transferred and the basis for the experimental measurements to be proposed cannot be guaranteed. What is required for an initial study of the energetics of consciousness is the conveyance of the presumed *underlying energy* and *associated negative entropy* of consciousness from a biological system in the form of an *energetic transfer*, and this becomes an absolute necessity only in the event of the irreversible death of an organism, when biological consciousness cannot be locally reconstituted and when its underlying biological substrate and mechanisms are lost. Thus, the assessment of organisms following a temporary ‘loss of consciousness’ due to either brain injury or metabolic derangement, or any other imaginable but potentially reversible physical phenomenon, is insufficient within the theoretical framework to be outlined to make any legitimate observational inferences concerning the underlying energetics of consciousness.

## Introduction

The *internal energy* and *entropy* of all physical structures are system properties that have the potential to provide a basis for designing objective tests to support specific hypotheses regarding the energetics of consciousness. This is because, regardless of the underlying mechanisms and structures that allow for biological consciousness, the macroscopic features of consciousness must be expected to conform to certain well-known physical laws and these are potentially testable.<sup>9</sup> The most important of these laws are the constraints imposed by the *first* and *second* laws of thermodynamics.

The act of discarding or irrevocably erasing information results in an unavoidable transfer of system energy to the environment.<sup>10</sup> This finding suggests that all *information storage devices*, biological or otherwise, when induced to make irreversible transitions from containing potentially retrievable information to complete and unreconstructible information loss, should demonstrate *energy* and *mass changes* consistent with the irretrievable loss of this information.

As long as the information contained within the original physical system has meaning, i.e. is non-random, it should not matter whether the storage device contains supposedly ‘cogent’ information from a semantic standpoint, that is, information with potential for decipherability by another machine or sentient being, or not.<sup>11</sup> Such energy and mass changes occur universally as a result of such *physical transitions*, depending only upon the minimal *algorithmic entropy* content of the original system and the subsequent unreconstructible ‘erasure’ of *system information*.<sup>12</sup> Arguments concerning the nature of system entropy as being either subjectively or objectively

definable should not be relevant in this regard, because the notion of subjective entropy is defensible only from an analytic standpoint and should not have bearing upon the internally defined energetic properties of physical entities themselves.<sup>13</sup> Accordingly, it should be the *algorithmically definable minimal information content* of an organized physical system, and not the supposed subjective ‘quality’ of its retrievable information, that is operative in defining the amount of negative entropy and associated system energy contained within each information-laden system. In the case of a living organism, the information inherent in its organizational complexity may be algorithmically defined as the *minimum number of bits of information required to describe its structure*.<sup>14</sup> Alternatively, it may be quantitatively expressed as the reduction in entropy of the set of complexions calculable with all system constraints and interactions operating, relative to a state of zero organization where there are no interactions constraining the relationships between the individual elements comprising the system.<sup>15</sup>

### Thermodynamic system

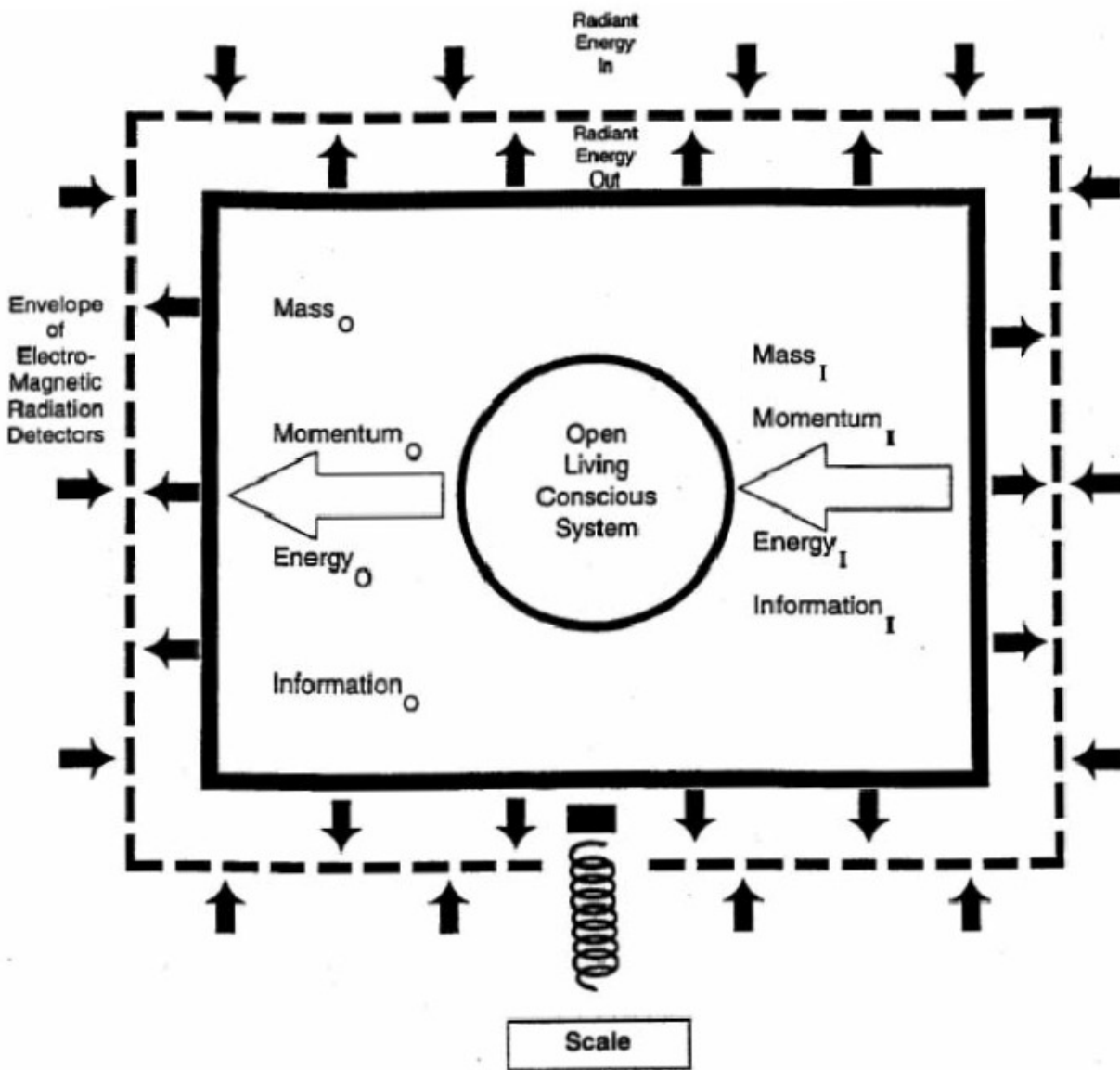
It has been argued that the entropy of living systems cannot be defined in classic thermodynamic terms because they do not exist at equilibrium, but instead in an open and metastable steady state.<sup>16</sup> Despite this, it has been suggested that the entropy of such dynamic living systems that are clearly not at equilibrium might be properly defined as the sum of all the positive thermodynamic entropies that each system constituent would possess in isolation minus the entropy equivalent of the information required to construct the physical system from its dissociated state.<sup>17</sup> This definition is potentially applicable to any open non-equilibrium system by simply closing it instantaneously. Furthermore, since the selection of boundaries for any thermodynamic system is arbitrary, it is possible to consider any open system as part of a larger closed system, thus allowing for the larger system's overall thermodynamic properties to be determined.<sup>18</sup>

The thermodynamics boundaries for the experimental apparatus system proposed to be investigated herein are depicted below, in which a conscious organism (circle) is contained within an isolated chamber (rectangle) for observation at the time of death. In this model, the organism, while alive, exists as an open system in a quasi steady-state. Through the organism flows mass, momentum, energy and information, depicted by arrows both entering and leaving the circular sub-system, but all such exchanges occur within the confines of the larger thermodynamically isolated container (rectangle). The larger system is closed to all but the obligatory exchange of radiant energy, emitting and absorbing radiation, as must any black (or gray) body that exists in an environment of non-equal temperature.

A ring of electromagnetic detectors immediately surrounds the apparatus to quantitatively measure the efflux and influx of radiant energy, so that the net efflux of radiant energy can be measured as a function of time. The entire system (minus detectors) is poised on a scale for

continuous weight measurements. If there is a measurable difference between the net efflux of energy from the larger system (rectangle) and the energy equivalent of its corresponding change in mass, as reflected by the change in its weight, this excess energy is unaccounted for and may be regarded as apparently 'lost'.

This unaccounted energy might possibly be transferred to a dimensionality that is higher than our ordinary four-dimensional space-time and may represent a 'preserved', albeit exteriorly inaccessible, negative entropy that is attributable to consciousness. The subscripts 'I' and 'O' refer to inflow and outflow from the open biological system that is contained within the larger thermodynamically isolated system contained within the rectangle, respectively.



## Observer bias

It might be asked how one might propose to ascertain from outside a thermodynamically isolated environment the particular timing of the death of a conscious organism, since it occurs within the confines of an isolated container that has no means of communication with the outside world. This is because, in order not to violate the experimental premises, the apparatus that is proposed permits no method of interrogation from without. Clearly, aside from the methods already mentioned that comprise the basis for the proposed experiment, there is no means of communication between the environment that is thermodynamically isolated within the vessel that contains the experimental organism(s) and the surrounding environment where other worldly observers exist. This is aside, of course, from the obligatory cross-exchange of radiant energy, as previously described.

Depending on the particular species of organism, one could propose to wait a sufficiently long time relative to the known mean life span of the organism to guarantee its demise by means of the externally elapsed time since confinement. The supposition, of course, is that the evolution of time within the isolated vessel should proceed in accordance with the amount of time that elapses outside of the isolated vessel. Although this might seem an obvious inference because the location of the thermodynamically isolated box is within the confines of the surrounding environment where all else exists, it is, in fact, unprovable. Were the progression of time within the isolated environment to be different than that which occurred outside its limits, this would be unperceivable to an outside observer by necessity. Thus, should the passage of time elapse more slowly within the isolated vessel than without, how would an outside observer discern it? Without the ability to observe its demise, a conscious organism that is isolated from its surrounding environment might not die within the outwardly observable time frame allotted for its death, but merely remain alive indefinitely if the passage of time within the vessel were slowed sufficiently relative to outside observers.

It might seem that this potentially confounding methodological flaw of a possible time difference might be surmounted by simply ‘guaranteeing’ that the environment within the thermodynamically isolated vessel be made incompatible with the conditions known in the outside world to be compatible with life, such as in the case of the ‘strong’ version of the proposed experiment that requires active intervention to terminate life processes. This might be accomplished, for example, by adding sufficient amounts of energy to the closed system to effectively vaporize the contents within the thermodynamically isolated vessel, such as might be done, for instance, using a bomb calorimeter. Again, however, an assumption must be made in this circumstance that the environment and physical characteristics within the isolated vessel (e.g., its heat capacity) will remain the same as when previously measured by an outside observer in a contiguous environment and respond to the addition of external energy in the same manner as such a vessel would in the outside world; this assumption is necessary despite the fact of the

system's intrinsic isolation and its inability to be probed for useful information from without. Although this assumption might appear reasonable, an outside observer cannot guarantee this set of circumstances without violating the experimental design, which specifically precludes the exchange of useful information between the isolated system and outside observers. Thus, this assumption is also reduced to mere conjecture and cannot be objectively proven without quantitatively accounting for the specific information that is specifically permitted to elaborate from the otherwise isolated chamber.

Because of these considerations, only a positive result in terms of a measurable difference between the system weight change and net energy efflux beyond that expected for a gray body at non-equilibrium temperature with the surrounding environment can be regarded as conclusive for confirming the hypotheses under investigation, which is the persistence of an intact energy and or information following the biological death of a previously conscious organism.

## Mass of bits of consciousness

It has been shown previously that a single bit of information represents the physical equivalent to the following in units of entropy:

$$\text{Bit} = k \ln 2 \quad \text{eq. 1}$$

where  $k$  is the Boltzmann constant; the units being  $9.56 \times 10^{-22}$  Joules per molecule-degree.<sup>19</sup> Using the first law of thermodynamics, second law of thermodynamics, and the mass-energy equivalence equation, we will now show that energy changes on the order of  $3 \times 10^{-21}$  Joules and mass changes on the order of  $3 \times 10^{-38}$  kg should be discernable per bit of information degraded at room temperature for physical systems undergoing unreconstructible information loss, including biological systems that undergo the irreversible transition from the highly organized physical states associated with life to the progressively disorganized states resulting from death.

To prove this, for any closed physical system, the principle of conservation of energy must be satisfied. According to the first law of thermodynamics:<sup>20</sup>

$$\Delta Q = \Delta U + \Delta W \quad \text{eq. 2}$$

where  $\Delta Q$  is a quantity of heat added to the system,  $\Delta U$  is a change in the internal energy of the system, and  $\Delta W$  is work done by the system. The second law of thermodynamics, which arises naturally as a consequence of the first, states that for any change in the state of the system:<sup>21</sup>

$$\Delta S \geq \frac{\Delta Q}{T} \quad \text{eq. 3}$$

where  $\Delta S$  is the change in the entropy of the system,  $\Delta Q$  a quantity of heat added to the system, and  $T$  the absolute temperature of the system. This can be rewritten as:

$$\Delta Q \leq T \Delta S \quad \text{eq. 4}$$

In addition, statistical mechanics has shown that the entropy change associated with any macroscopic system can be expressed as:<sup>22</sup>

$$\Delta S = k \ln \Delta P \quad \text{eq. 5}$$

where  $P$  is the statistical probability that the system will exist in an allowed system microstate that gives rise to a particular and indistinguishable system macrostate (Planck complexions). For the case of information represented in a binary format, the change in physical system entropy associated with the representation of a single bit of information reduces eq. 5 to:

$$\Delta S_{\text{bit}} = -k \ln 2 \quad \text{eq. 6}$$

Substituting this expression into eq. 4 yields:

$$\Delta Q_{\text{bit}} \leq -T k \ln 2 \quad \text{eq. 7}$$

Using this expression, an explicit energy calculation can then be made per bit of system information that becomes irretrievable at normal human body temperature (310° K):<sup>24</sup>

$$\begin{aligned} \Delta Q_{\text{bit}} &\leq - (310 \text{ } ^\circ\text{K})(1.38 \times 10^{-23} \text{ J/ } ^\circ\text{K})(0.693) \\ &\leq - 2.96 \times 10^{-21} \text{ Joules} \end{aligned}$$

Appeal to the mass-energy equation then results in an estimate of the mass deficit to be expected for each bit of information that becomes irretrievable:

$$\Delta E = \Delta m c^2 \quad \text{eq. 8}$$

where  $\Delta E$  is the change in energy,  $\Delta m$  the change in mass, and  $c$  the speed of light. Substituting the energy deficit value per bit of information lost at 310° K and solving for  $\Delta m$ , this becomes:

$$\begin{aligned} \Delta m_{\text{deficit/bit}} &\leq - 2.96 \times 10^{-21} \text{ J}/(3.00 \times 10^8 \text{ m/sec})^2 \\ &\leq - 3.29 \times 10^{-38} \text{ kg} \end{aligned}$$

This derivation argues, subsequently, that  $3.29\text{E-}38$  kilograms of mass will be lost per bit of information destroyed in the mind of the consciousness. This presupposes that the act of dying results in irretrievable and unreconstructible loss of biologically stored information.<sup>25</sup> In support of this, prior investigators have concluded that there is liberation of heat associated with the transition from life to organismal death.<sup>26</sup>

It has been asserted previously that the negative entropy and associated internal energy of biological systems are *practically incalculable* due to their organizational complexity, but this analytic limitation does not preclude the experimental measurement of these macroscopic system properties.<sup>27</sup> In confirmation of this, investigators have measured the quantity of heat liberated by the multiplication of bacteria, allowing a quantitative estimate to be made of the environmental entropy changes that result from the incorporation of information into the physical structure of new biological cells.<sup>28</sup>

As a minimum description, living organisms can be characterized as *highly organized physical structures*, with low *intrinsic system entropy* that is maintained by the continuing consumption of biological energy resources.<sup>29</sup> They are also describable as *open systems* that are in a state of dynamic and quasi-stable organizational and, hence, informational equilibrium.<sup>30</sup> Within these living systems, it is reasonable to assume that some types of biological information and their associated physical structures are qualitatively more important than others.<sup>14</sup> Accordingly, some types of organismal information may be regarded as *biologically purposeful*, and some minimum amount of this type of primary or ‘absolute’ information, as opposed to redundant or derivative information, can be assumed to be necessary for biological survival.<sup>31</sup> In the case of a single living prokaryotic cell, for example, this must be some fraction of the total quantity of information stored within the organism, which has been previously estimated as  $5 \times 10^{10}$  bits.<sup>28</sup> It has been further postulated that there must be dynamic conservation of some minimum quantity of such biologically specific information to successfully allow for ongoing life processes.<sup>14</sup>

When the *death* of a living organism occurs, the metabolic processes underlying the maintenance of essential cellular organizational structures are lost and progressive, *irreversible dissolution* of the system ensues. Because of this irreversible loss of system organization, an associated *increase in system entropy* must occur.<sup>32</sup> A significant fraction of this loss of negative entropy and associated system energy can be assumed to be attributable to what might be termed ‘vegetative’ biological functions, such as cellular homeostasis, maintenance, and repair, among others. Some other fraction of the total loss of negative entropy and associated energy from the system must be attributed to biologically stored information that is not intrinsically necessary for ongoing cellular and organismal homeostasis. Additional types of biologically retrievable information may serve as the basis for memory and computation, while other potentially different reservoirs of information may subserve the functions that allow for the dual phenomena of internal experience and self-awareness that we refer to more generally as consciousness.

Under most normal circumstances, the time course for the death of a complex biological organism is itself complex.<sup>33</sup> It might be expected, therefore, that the losses in negative entropy and internal energy that occur during organismal death should occur in stages with sequential loss of retrievable system information and structural and or organizational negative entropy over a variably long period of time. This is because living organisms are distinguished, in part, by having large amounts of information compactly coded directly within their structures, and the dissolution of this organizational complexity occurs only gradually after death.<sup>34</sup> Different facets of organismal death may thus extend over a protracted period due to the varying survivability of different organs and tissues following irreversible biological death.<sup>33</sup> This is evidenced most forcefully by the fact that organs may be transplanted to other living recipients at variably prolonged intervals following the irreversible overall death of a donor.

Because overall organismal death in a complex mammalian organism occurs well before most individual organ system and individual cellular deaths, it might be reasonably assumed from the time course of irreversible loss of consciousness that the first ‘phase’ of negative entropy and internal energy loss upon organismal death is related to the biological irretrievability of stored information that once constituted the basis of thoughts and, possibly, the information specific to the phenomenon of consciousness. Once large-scale and irreversible cellular death occurs, it is likely that the associated organismal loss of negative entropy and energy will be due to irreversible structural and organizational degradation alone, but this time course should be different from that attributable to the system information loss that occurs most rapidly and that subsumes the phenomenon of consciousness.

## Propositions

Using this background information as foundation, the following propositions concerning biological organisms and consciousness must be endorsed to successfully pursue a scientific investigation concerning the energetics of consciousness:

### Proposition

### Description

1. Biological consciousness is a phenomenon that is present within a biological system only during the lifetime of a conscious organism:
  - A. Biological consciousness depends on the presence and biological representation of energy and or information; in the global absence of potentially retrievable biological information, no biological consciousness can exist;
  - B. Once irreversible biological death occurs, biologically stored information that might once have acted as the representation of consciousness within a conscious organismal framework can no longer be

physically retrieved;

C. As a result of points A and B, biological consciousness can no longer exist in a previously conscious biological organism once global and irreversible death has occurred.

2. The energy equivalent associated with the negative entropy content of stored biological information must necessarily be either dissipated, radiated or otherwise transferred after the biological death of an organism. The physical correlates of this dissipation, radiation and or transfer of the energy equivalent of the previously stored and potentially retrievable information and or negative entropy must necessarily take the form in our four-dimensional spacetime of one of the following:
  - A. Physically measurable thermal changes and emissions of electromagnetic radiation from the organism.
  - B. A change in organismal mass upon irreversible biological death by an amount directly proportional to the energy equivalent of the previously stored and irretrievable information and or negative entropy content, as defined by the mass-energy equivalence equation.
  
3. If a change in organismal mass occurs upon death that is in excess of the energy losses that can be accounted for by its observable temperature changes and emissions of electromagnetic radiation, then an additional mechanism for informational and or negative entropy and associated energy transfer must be postulated to assure that the conservation of energy is satisfied within our four-dimensional spacetime. Relevant in this regard may be generalized versions of the second law of thermodynamics, which posit that the sum of the entropies existing beyond the collective event horizons of singularities, both microscopic and macroscopic, and the 'ordinary' entropies existing within our usually accessible four-dimensional universe, cannot decrease.<sup>35</sup> In the event that there is a non-equivalence of the mass loss of the biological system upon death and the mass equivalent of the energy that is emitted, these theories may allow a role for hyperspace in permitting energy and information to be transferred from our present four-dimensionality into a different dimensionality elsewhere.<sup>36</sup> If so, then these additional dimensions can be expected to exist below the threshold at which our usual space-time remains smooth, with fundamental lengths on the order of  $10^{-33}$  cm (Planck length), or smaller.<sup>37</sup> It may be further postulated that the transfer of information to these regions may occur on such a potentially small time-distance scale as to be undetectable by macroscopic measuring devices that employ conventional techniques. If these classically inaccessible regions of differing dimensionality exist, their additional dimensions can potentially be

thought of as embedded within our own four-dimensional spacetime, possibly arising from pairs of fluctuating and or spontaneously originating microscopic singularities, beyond whose event horizons there is no access to internal structure and information for any outside observers existing within our four-dimensional spacetime.<sup>38</sup> Regions of this type might then act as potential sinks for specific types of energy and or negative entropy, allowing it to potentially ‘leak’ across the event horizons into areas of inaccessibility for anything existing within our four-dimensionality.<sup>39</sup>

The situation outlined above may be summarized by the following equation applicable to the period following the irreversible biological death of a conscious living organism:

$$\int_{t_0}^t W(t)dt = \frac{g}{c^2} \left( \int_{t_0}^t E(t)dt + \int_{t_0}^t C(t)dt \right) \quad \text{eq. 9}$$

where  $W(t)$  is the weight of the system containing the experimental subject as a function of time,  $E(t)$  is the energy radiated or dissipated by the system as a function of time over all spatial dimensions,  $C(t)$  is the time dependent energy deficit not accounted for by measurable system energy radiation or dissipation,  $t_0$  is the time of death of the biological system,  $t$  is the time elapsed since the death of biological system,  $g$  is the local acceleration of gravity, and  $c$  is the speed of light.

Alternatively, the protracted and complicated course of biological system information loss immediately surrounding organismal death can be potentially obviated by inducing the instantaneous vaporization of the biological system to a state of random gas. The ethical dilemmas of this type of interventional experiment involving higher animals, as opposed to observation, should not be of prohibitive concern with lower organisms, those such as bacteria, yeast, and plants, where such types of interventional experiments are typically regarded as ethically permissible. Although the detailed time course of spontaneous information loss following ‘natural’ organismal death would necessarily be lost in such an experiment, a concomitant and virtually immediate evaluation of the energy flux from the experimental apparatus would reveal whether any inequality exists between the observed mass change of the experimental system, allowing, of course, for the amount of energy added to the system to effect vaporization, and the measurable energy losses emitted from the experimental apparatus.

## Proposed experiment

A specific experiment to test for the presence of consciousness can now be proposed. Firstly, if biological consciousness requires for its existence information content, and, hence, a negative entropy and associated energy equivalent, then upon the death of a conscious organism, this energy equivalent of consciousness must be dissipated, radiated, or otherwise transferred. Accordingly, if one observes the energetic phenomena surrounding a biologically conscious organism at the time of death, the following physical changes should be measurable:

(1) Physical evidence of conversion of system energy to other forms, namely heat production, indicative of non-specific information degradation, and other forms of emitted electromagnetic radiation, indicative of the possible preservation and or conversion of portions of such pre-existing information content. The precise time course of such system energy losses can be expected to be prolonged, variable, and multiphasic. They can be measured using concentric arrays of electromagnetic detectors spanning the entire range of electromagnetic frequencies, as diagrammed in the figure.

(2) An organismal mass change (i.e., weight loss) upon death that is directly proportional to organismal energy losses, which encompass all of the losses attributable to information degradation and transfer, including those that pertain to the phenomenon of consciousness. As with system energy losses, the precise time course of such a weight loss can be expected to be prolonged, variable, and multiphasic. In the absence of an instantaneously induced dissolution of the system, the absolute quantity of mass loss as a result of such changes can be expected to be small over short time frames, but within the range of experimental measurement using modern scientific equipment.

(3) Comparison of the time-dependent energy equivalent of the weight loss to the sum of the directly measured energetic losses from the demised system to determine whether they are equivalent.

The specific requirements to perform such an experiment are:

(a) An organism or group of organisms (e.g., bacteria, fungi, or plants) to be observed at the time of death within the confines of an isolated environment. Although living organisms are open, dynamic systems through which mass, energy, and information and or negative entropy must flow, there is in principle no objection to constructing an isolated chamber to contain and temporarily support the life functions of such organisms, where such quantities are exchanged within an isolated local environment that is itself in isolation from anything outside, as diagrammed in the figure.<sup>18</sup> All chambers of this type, however, represent the equivalent of 'control vessels' for experimentation, as the chamber will always provide less than complete

system isolation due to the gravitational attraction between the experimental chamber and its surrounding environment and the necessary cross exchange of radiant energy between the chamber and the environment when they are at different temperatures.<sup>40</sup>

The 'time of death' can be reasonably defined in terms of standard species-specific medical or veterinary criteria, such as the lack of production of metabolic exchange products (in the case of bacteria, fungi, and or plants), or lack of electrocardiographic activity or, possibly, the absence of electroencephalographic activity in primates, for example.<sup>33</sup> True organismal death and dissolution of biological consciousness can be assumed to occur soon thereafter, but the exact timing of this experimentally critical event cannot be precisely defined prior to experimentation. An estimate for the time of irreversible death can be assumed not to be less than several minutes or more than an hour in most circumstances.

(b) The apparatus should preclude the inward flux of mass, momentum, energy, and information to the fullest extent possible (ideally) or, more practically, it should measure any such inward fluxes quantitatively.

(c) The limiting surface of the system must be monitored continuously for quantification of emitted (and absorbed) electromagnetic radiation before, during, and after the time of death of the organism(s).

(d) Continuous and suitably sensitive weight measurements for the system must be recorded before, during, and after the time of organismal death.

Additional information regarding the state of the system can be obtained if its heat capacity is known and its temperature is monitored as a function of time, such that the amount of heat energy contained within the system can be directly calculated. The proposed experimental apparatus is shown in the accompanying figure.

Questions that should be answered from these observations include the following: How much of a mass deficit is measurable for different organisms upon their biological death as a function of time, and what is the time-course of this mass loss? Is there an increase in body and or system temperature indicative of energy degradation due to non-specific information loss (i.e., negative entropy loss)? If so, when does it occur and to what extent? Is there measurable emission of electromagnetic radiation other than that attributable to the usual black body radiation (or gray body radiation)? If there is, then what is the spectrum and time course of the flux of electromagnetic radiation that is emitted? What is the total information and or negative entropy equivalent of the energy that is radiated? What fraction if any of the radiated energy can be assumed from its time course to have arisen as a result of information subsuming vegetative or strictly computation functions, versus that potentially attributable to consciousness? What if any

energy inequality, which is denoted as  $C(t)$  in eq. 9 exists between the time-dependent organismal mass loss and the associated time-dependent dissipated and radiated energy outputs of the system? If an energy deficit exists that cannot be physically accounted for in our four-dimensional spacetime, does this imply the transfer of intact information from the previous biological entity to another dimensionality and, if so, is this indicative of an informational (and possibly conscious) persistence after organismal death?

## Discussion

The chief deficit of all prior theories of consciousness has been the universal lack of credible experimental evidence to support their underlying hypotheses. What is needed is to place the study of consciousness on an experimental foundation that is both quantitatively measurable and rigorously testable.

The primary issue of whether mental phenomena are derivable from physical interactions is far from new. It has been a subject of debate for millennia and, in modern times, was cast most notably as a dilemma by Leibniz in his celebrated *Monadology* of 1714. It has served as the basis for many divergent theories of consciousness, including such fundamentally irreconcilable doctrines as materialism, idealism, and dualism. It now appears, however, with the advent of successfully predictive theories demonstrating the non-calculability of both quantum effects and the 'chaotic' dynamics associated with complex non-linear systems, that most causality-based tenants that have previously suggested a necessity for mind-body duality, e.g. issue of free will, are no longer compelling.<sup>41</sup> Mental phenomena, and the hard problem of consciousness, i.e. how physical processes can give rise to subjective experience, may be potentially reducible to physically analyzable occurrences.<sup>42</sup>

The current proposal is designed to reduce the energetic phenomena that must be associated with consciousness to a testable set of hypotheses. The absolute quantity of negative entropy (and energy) associated with this phenomenon is likely to be very small. Thus, the success of experiments designed to identify and quantify the amount of energy associated with the phenomenon of consciousness will depend primarily on three separate experimental design issues:

- (1) Suitably isolating experimental organism(s) from their surrounding environment to allow for the quantitative measurement of all influxes and or effluxes of energy from the system within which they are contained at the time of death (and immediately thereafter). This goal of relative thermodynamic isolation should be attainable using equipment and technology that is currently available.

(2) Making precise quantitative measurements of the net efflux of energy from the system containing the biological organism(s) at the time of death. This will require the use of highly sensitive and concentrically arrayed electromagnetic radiation detectors capable of measuring the quantitative influx and or efflux of energy across their boundaries over the entire electromagnetic spectrum. Although technically challenging, this goal is attainable using equipment and technology that is currently available.

(3) Making precise and reliable mass measurements (i.e., weight determinations) of the container housing the biological system at the time of organismal death and during the period immediately thereafter. This will require the use of highly sensitive scales that are capable of quantifying mass changes at the lower limit of detectability using equipment and technology that is currently available.

Assuming that these three experimental goals can be achieved, then the quantity of negative entropy and or energy that is associated with the phenomenon of consciousness should be, in principle, both measurable and quantifiable.

The temperature dependence for the energy equivalent of information that appears in eq. 7 is particularly interesting. It implies that the energy value of a bit of information represented by a particular state or conformation of a physical system, biological or otherwise, must contain some minimum amount of internal energy with respect to ambient system temperature in order to guard against 'random' fluctuations to misinformation as a result of thermal noise. This minimal amount of energy is generally accepted to be on the order of several multiples of  $kT$ .<sup>43</sup> It is notable that this relationship is independent of both the physical medium and information storage mechanism. From an experimental standpoint, therefore, it makes no difference what the underlying mechanisms are for the biological representation of consciousness, only that some dedicated information specific to consciousness is contained within a physically retrievable biological substrate during life that is irretrievably lost, in a biologically reconstructible sense, after death. Because of this, any physical mechanism underpinning the basis of consciousness, even a highly controversial one like the quantum objective reduction hypothesis proposed by Hameroff and Penrose (1995), does not pose a barrier to the performance of the experiments that have been proposed.<sup>44</sup>

It is also interesting to note an important corollary: since a homogeneous universe in thermodynamic equilibrium has no free energy available for either the storage or transfer of negative entropy or information, a fundamental prerequisite for the existence of consciousness in our four-dimensional spacetime is thermodynamic disequilibrium.<sup>45</sup> This condition is satisfied in abundance within our present universe, as evidenced, in part, by widely available 'energy reserves' (e.g., fossil fuels, etc.), that exist in kinetically metastable states, but cannot be presumed to have been uniform throughout the universe's evolution.<sup>46</sup> Therefore, another

corollary is that the information content of the universe at any particular instant depends necessarily on the non-uniformity of its energy distribution. It may, furthermore, be logically inferable that biological systems are particularly efficient (but potentially non-exclusive) transduction devices for the organization, storage, and manipulation of information within our local four-dimensional physical reality.

The success of the present proposal depends on discovering either the presence or absence of an inequality between the measurable biological system energy losses that occur surrounding the biological death of a conscious organism and the concurrently measurable biological system mass loss (eq. 9). Although such an energy disparity, if it exists, cannot be presumed to represent an 'energy of consciousness' a priori, it may nevertheless be reasonably assumed to represent such an entity if it is found to be present only upon the death of conscious living organisms and not upon the dissolution of systems that are agreed to be without phenomenological consciousness (e.g., rocks). If there is such an inequality, it may be assumed that the undocumented energy must nevertheless still exist, so as not to locally violate the first law of thermodynamics, and that it has somehow 'escaped' from the system without detection.

If this occurs, it might be reasonably inquired why such unaccountable energy losses related to the phenomenon of consciousness might arise when, under ordinary circumstances, such an unexplained non-conservative loss of energy to regions of hyperspace do not occur. Although several potential explanations exist, it may be that none is wholly satisfying because they appear to presuppose a privileged position for the particular variety of energy associated with consciousness. One possible explanation may depend on the precise time-frequency spectrum of the energy that is liberated as a result of the loss of biological consciousness, possibly imparting to it a particular signature that may allow it passage to these other domains, whereas other more 'usual' forms of energy existing in other conformations do not permit access.

If consciousness itself is an emergent phenomenon dependent on the organizational and functional complexity of higher organisms, then it should be expected to admit of degrees in different species and the 'energy of consciousness', as previously postulated, might be expected to vary by species commensurately.<sup>47</sup> If an independent psychological scale of consciousness is devised on the basis of neuropsychological criteria, for example, then a correlation might be expected between the degree of this 'energy of consciousness' measured by experimentation in different species and such a scale. But, if the phenomenon of consciousness is instead a unitary phenomenon, then it may be assumed that the macroscopic appearance of the observed variability in different organisms and among varying 'states of consciousness' in humans is somehow an overlay of organismal information processing, capacity, tempo, storage, discrimination, and other types of information retrieval and manipulation abilities. This would make it appear that differing degrees of consciousness exist when, in fact, they intrinsically do not. If so, then a unitary 'energy of consciousness' should be measurable in all cases independent

of the type of species or its rating on such a scale. In either case, it might be expected that at least an order of magnitude estimate should be obtainable for the quantity of energy responsible for the 'consciousness effect' that is being investigated.

A final possibility exists with regard to the energetics of consciousness. This is that the underlying phenomenon of consciousness, when stripped of its entire functional overlay, is so basic and intrinsic to the fabric of nature that only a very small but highly specific information content is necessary to achieve what would be termed phenomenological consciousness. If so, then the transition of consciousness to a potentially higher order dimensionality at the time of death may exist but be nevertheless unmeasurable due to its profoundly small energy magnitude relative to surrounding background radiation and quantum effects. Although an upper limit still might be placed on the magnitude of the quantity of energy that comprises it, the fundamental imprecision of energy measurements at such small magnitudes might necessarily limit the certainty of these types of experimental determinations. If such a residual negative entropy and or information or energy were to persist, however, it would seem reasonable to suggest, whatever its magnitude, that it would represent the existence of an intact and transcendent informational entity after biological death that may be akin to the notion of a theological soul.

## Summary

The aim of this paper is to elucidate a theory to investigate the energetics of biological consciousness, assess its energetic order of magnitude, and assess the possibility of its persistence after death. In sum, three well-established physical relationships can be integrated to form the theoretical basis for investigating the physical foundation of consciousness, namely: conservation of energy, the equivalence of energy and or negative entropy with informational system content, and mass-energy equivalence. By combining these three concepts, the physically measurable internal energy and entropy of physical systems may be used to design objective tests to evaluate hypotheses concerning the nature of biological consciousness.

A pivotal experiment using this paradigm is to measure the loss of biological system energy of a conscious organism upon its death, and to compare these system energy losses concurrently for equivalence to the time-dependent biological system mass loss. If an inequality is demonstrated between these two measurements, i.e., that there is a lesser net energy efflux from the biological system during its dissolution than can be accounted for by its simultaneous time-dependent energy mass loss equivalent as a function of time, this may represent evidence for the preservation of a portion of system information, i.e., organization, that previously constituted the basis for consciousness within the living organism.

Based on the results of this experiment, there may be quantifiable physical evidence for the endurance of an extracorporeal form of system information after the death of a sentient

organism: if a net energy deficit is documented compared to the energy equivalent weight loss that is measured upon system dissolution, this implies that there is an energetic persistence after death and it may suggest some degree of system immortality that transcends the system's prior biological existence. If no such energy deficit is documented, then this may either suggest that (a) consciousness is an intrinsically non-local phenomenon or (b) it is entirely lost upon death without any possibility for its extracorporeal persistence or reconstruction.

## References

---

1. (a) Chalmers, David J. (1996). *The Conscious Mind: In Search of a Fundamental Theory*, Oxford University Press.
- (b) Hameroff S. and Penrose R. (1995). "Orchestrated Reduction of Quantum Coherence in Brain Microtubules: A Model for Consciousness." In: *Scale in Conscious Experience: Is the Brain Too Important to be Left to Specialists to Study?* (Ch. 12. pp. 243-74). Editors: J. King and K.H. Pribram. Lawrence Erlbaum Associates, Mahwah, NJ.
- (c) Greenfield, Susan A. (1995). *Journey to the Centers of the Mind: Toward a Science of Consciousness*. W.H. Freeman and Company.
- (d) Coveney P. and Highfield R. (1995). *Frontiers of Complexity: The Search for Order in a Chaotic World*, Random House.
- (e) Scott, Alwyn. (1995). *Stairway to the Mind: The Controversial New Science of Consciousness*, Springer-Verlag.
- (f) Penrose, Roger. (1994). *Shadows of the Mind: A Search for the Missing Science of Consciousness*. Oxford University Press.
- (g) Herbert, Nick. (1993). *Elemental Mind: Human Consciousness and the New Physics*. Penguin Books USA.
2. (a) Chalmers, David J. (1996). *The Conscious Mind: In Search of a Fundamental Theory*, Oxford University Press.
- (b) Greenfield, Susan A. (1995). *Journey to the Centers of the Mind: Toward a Science of Consciousness*. W.H. Freeman and Company.
- (c) Scott, Alwyn. (1995). *Stairway to the Mind: The Controversial New Science of Consciousness*, Springer-Verlag.
3. (a) Chalmers, David J. (1996). *The Conscious Mind: In Search of a Fundamental Theory*, Oxford University Press.
- (b) Herbert, Nick. (1993). *Elemental Mind: Human Consciousness and the New Physics*. Penguin Books USA.
4. (a) Chalmers, David J. (1996). *The Conscious Mind: In Search of a Fundamental Theory*, Oxford University Press.
- (b) Greenfield, Susan A. (1995). *Journey to the Centers of the Mind: Toward a Science of Consciousness*. W.H. Freeman and Company.

5. (a) Greenfield, Susan A. (1995). *Journey to the Centers of the Mind: Toward a Science of Consciousness*. W.H. Freeman and Company.  
(b) Herbert, Nick. (1993). *Elemental Mind: Human Consciousness and the New Physics*. Penguin Books USA.
6. Greenfield, Susan A. (1995). *Journey to the Centers of the Mind: Toward a Science of Consciousness*. W.H. Freeman and Company.
7. Turing, Alan M. (1950). "Computing Machinery and Intelligence". *Mind*, 59:433-54.
8. Note: within a biological framework, it cannot be definitively stated whether consciousness is intrinsically suspended during a non-fatal biological insult, or just merely suppressed. In the case of general anesthesia in higher animals, one might be tempted to summarily conclude that since no outward manifestations of consciousness occur, and since no reproducible memories of events occurring during the anesthetic period are generally recallable after normal consciousness has been restored, that consciousness itself was not present during the anesthetic period and that such anaesthetized but previously conscious biological systems might constitute suitable subjects for investigation. Although this is a potentially plausible inference, two equally credible alternative explanations exist. The first, and most obvious, is that all afferents (i.e., inputs) to consciousness may have been suppressed or suspended during the anesthetic interval such that no experiential events are available to interact with consciousness during that period. The second is that all memory of such conscious sensory interaction with the environment by consciousness during the time of anesthesia is either globally suppressed or lost as a result of anesthetic actions. Clearly, the argument can be made that even if one were fully conscious of external stimuli during a period of anesthesia, if the necessary biological mechanisms for constructing and storing memories are interrupted as a result, no subsequent report of consciousness concurrent with the anesthetic period can be expected. An analogous argument can be made for any potentially reversible "loss of consciousness" that may result from medical ailments, traumatic injuries, or the induction of any drug-induced or self-provoked "altered states", among others. Thus, for the purposes of an initial study designed to investigate and quantify the energetics of consciousness, the irreversible death of a previously conscious biological organism would appear to be the only suitable subject for investigation.
9. Chalmers, David J. (1996). *The Conscious Mind: In Search of a Fundamental Theory*, Oxford University Press.
10. (a) Bennett, Charles H. (1982). "The Thermodynamics of Computation." *A Review. Int J Theor Phys* 21:905-40.  
(b) Landauer, Rolf. (1961). "Irreversibility and Heat Generation in the Computing Process." *IBM J Res Dev* 5:183-91.  
(c) Leff H.S. and Rex A.F. (1990). *Maxwell's Demon: Entropy, Information, Computing*, Princeton University Press.
11. Shannon, C.E. and Weaver W. (1949). *The Mathematical Theory of Communication*. The University of Illinois Press.

12. (a) Lindgren, Kristian. (1988). "Microscopic and Macroscopic Entropy." *Phys Rev A* 38:4794-8.
- (b) Bennett, Charles H. (1982). "The Thermodynamics of Computation." *A Review. Int J Theor Phys* 21:905-40.
13. (a) Denbigh, Kenneth. (1981). "How Subjective is Entropy?" *Chem Brit* 17:168-85.
- (b) Rothstein, Jerome. (1957). "Nuclear Spin Echo Experiments and the Foundations of Statistical Mechanics." *Am J Phys*, 25:510-8.
14. Johnson, Horton A. (1970). "Information Theory in Biology after 18 Years." *Science* 168:1545-50.
15. Rothstein, Jerome. (1962). "Discussion: Information and Organization as the Language of the Operational Viewpoint." *Phil Sci*, 29:406-11.
16. (a) Bertalanffy, Ludwig von. (1950). "The Theory of Open Systems in Physics and Biology." *Science*, 111:23-9.
- (b) Raymond, Richard C. (1950). "Communication, Entropy, and Life." *Am Sci* 38:273-8.
- (c) Reiner J.M. and Spiegelman S. (1945). "The Energetics of Transient and Steady States, with Special Reference to Biological Systems." *J Phys Chem* 49:81-92.
- (d) Lehninger, Albert L. (1971). *Bioenergetics: The Molecular Basis of Biological Energy Transformations*. W.A. Benjamin.
17. Raymond, Richard C. (1950). "Communication, Entropy, and Life." *Am Sci* 38:273-8.
18. Bertalanffy, Ludwig von. (1950). "The Theory of Open Systems in Physics and Biology." *Science*, 111:23-9.
19. (a) Tribus M. and McIrvine E.C. (1971). "Energy and Information". *Sci Am*, 225:179-88.
- (b) Jacobson, Homer. (1951). "The Role of Information Theory in the Inactivation of Maxwell's Demon." *Trans NY Acad Sci* 14:6-10.
20. Jauch J.M. and Baron J.G. (1972). "Entropy, Information and Szilard's Paradox". *Helv Phys Acta* 45:220-32.
21. (a) Costa de Beauregard O. and Tribus M. (1974). "Information Theory and Thermodynamics." *Helv Phys Acta* 47:238-47.
- (b) Jauch J.M. and Baron J.G. (1972). "Entropy, Information and Szilard's Paradox". *Helv Phys Acta* 45:220-32.
- (c) Rothstein, Jerome. (1952b). "Information and Thermodynamics." *Phys Rev* 85:135.
- (d) Klein, Martin J. (1970). "Maxwell, his Demon, and the Second Law of Thermodynamics." *Am Sci* 58:84-97.
22. (a) Frisch, David H. (1966). "The Microscopic Interpretation of Entropy". *Am J Phys* 34:1171-3.
- (b) Rothstein, Jerome. (1951). "Information, Measurement, and Quantum Mechanics." *Science* 114: 171-5.
23. Shannon, C.E. and Weaver W. (1949). *The Mathematical Theory of Communication*. The University of Illinois Press.

24. (a) Bennett, Charles H. (1982). "The Thermodynamics of Computation." *A Review. Int J Theor Phys* 21:905-40.
- (b) Weinberg, Alvin M. (1982). "On the Relation Between Information and Energy Systems." *Interdisc Sci Rev* 7:47-52.
25. Note: although it is known that some highly information-laden biological macromolecules can persist at normal environmental temperatures for relatively long periods following biological death (e.g., DNA [deoxyribonucleic acid]), even these molecules will ultimately decay from their metastable states when given enough time and high enough ambient temperatures.
26. Bertalanffy, Ludwig von. (1950). "The Theory of Open Systems in Physics and Biology." *Science*, 111:23-9.
27. Brillouin, Leon. (1949). "Life, Thermodynamics, and Cybernetics". *Am Sci* 37:554-68.
28. Morowitz, Harold J. (1955). "Some Order-Disorder Considerations in Living Systems." *Bull Math Biophys* 17:81-6.
29. (a) Brillouin, Leon. (1949). "Life, Thermodynamics, and Cybernetics". *Am Sci* 37:554-68.
- (b) Lehninger, Albert L. (1971). *Bioenergetics: The Molecular Basis of Biological Energy Transformations*. W.A. Benjamin.
30. (a) Johnson, Horton A. (1970). "Information Theory in Biology after 18 Years." *Science* 168:1545-50.
- (b) Bertalanffy, Ludwig von. (1950). "The Theory of Open Systems in Physics and Biology." *Science*, 111:23-9.
- (c) Lehninger, Albert L. (1971). *Bioenergetics: The Molecular Basis of Biological Energy Transformations*. W.A. Benjamin.
31. (a) Brillouin, Leon. (1950). "Thermodynamics and Information Theory". *Am Sci* 38:594-9.
- (b) Johnson, Horton A. (1970). "Information Theory in Biology after 18 Years." *Science* 168:1545-50.
32. (a) Rothstein, Jerome. (1952a). "Organization and Entropy." *J Appl Phys* 23:1281-2.
- (b) Rothstein, Jerome. (1962). "Discussion: Information and Organization as the Language of the Operational Viewpoint." *Phil Sci*, 29:406-11.
33. Nuland, Sherwin B. (1993). *How We Die: Reflections on Life's Final Chapter*. Alfred A. Knopf.
34. (a) Rothstein, Jerome. (1951). "Information, Measurement, and Quantum Mechanics." *Science* 114: 171-5.
- (b) Lehninger, Albert L. (1971). *Bioenergetics: The Molecular Basis of Biological Energy Transformations*. W.A. Benjamin.
35. (a) Hawking S. and Penrose R. (1996). *The Nature of Space and Time*. Princeton University Press.
- (b) Bekenstein, Jacob D. (1973). "Black Holes and Entropy." *Phys Rev D* 7:2333-46.
- (c) Hawking, Stephen W. (1976). "Black Holes and Thermodynamics". *Phys Rev D* 13:191-7.

36. Kaku, Michio. (1994). *Hyperspace: A Scientific Odyssey through Parallel Universes, Time Warps, and the Tenth Dimension*. Oxford University Press.
37. (a) Bekenstein, Jacob D. (1980). "Black-Hole Thermodynamics". *Phys Today* 33:24-31.  
 (b) Kaku, Michio. (1994). *Hyperspace: A Scientific Odyssey through Parallel Universes, Time Warps, and the Tenth Dimension*. Oxford University Press.
38. (a) Hawking S. and Penrose R. (1996). *The Nature of Space and Time*. Princeton University Press.  
 (b) Hawking, Stephen W. (1976). "Black Holes and Thermodynamics". *Phys Rev D* 13:191-7.  
 (c) Hawking, Stephen. (1971). "Gravitationally Collapsed Objects of Very Low Mass". *Mon Not R Astr Soc* 152:75-8.
39. Susskind, Leonard. (1997). "Black Holes and the Information Paradox". *Sci Am*, April, pp. 52-7.
40. Welty J.R., Wicks C.E., and Wilson R.E. (1976). *Fundamentals of Momentum, Heat, and Mass Transfer, 2nd ed.*, (Ch. 23). John Wiley and Sons.
41. (a) Coveney P. and Highfield R. (1995). *Frontiers of Complexity: The Search for Order in a Chaotic World*, Random House.  
 (b) Kellert, Stephen H. (1993). *In the Wake of Chaos*. The University of Chicago Press.
42. (a) Chalmers, David J. (1995). "The Puzzle of Conscious Experience". *Sci Am Dec*; 273:80-6.  
 (b) Chalmers, David J. (1996). *The Conscious Mind: In Search of a Fundamental Theory*, Oxford University Press.
43. (a) Bennett, Charles H. (1982). "The Thermodynamics of Computation." *A Review. Int J Theor Phys* 21:905-40.  
 (b) Johnson, Horton A. (1970). "Information Theory in Biology after 18 Years." *Science* 168:1545-50.  
 (c) Johnson, Horton A. (1987). "Thermal Noise and Biological Information." *Q Rev Biol* 62:141-52.
44. (a) Hameroff S. and Penrose R. (1995). "Orchestrated Reduction of Quantum Coherence in Brain Microtubules: A Model for Consciousness." In: *Scale in Conscious Experience: Is the Brain Too Important to be Left to Specialists to Study?* (Ch. 12. pp. 243-74). Editors: J. King and K.H. Pribram. Lawrence Erlbaum Associates, Mahwah, NJ.  
 (b) Note: The theory proposed by Hameroff and Roger Penrose involves the possible spontaneous orchestrated objective reduction of superimposed quantum states of tubulin molecules in intracellular microtubules. It is asserted that this process may arise spontaneously due to the instability of superimposed spacetime geometries and may constitute the basis for the fundamental transduction of non-calculable quantum effects to macroscopic non-deterministic neurocellular operational effects that may then influence neurophysical events on a global neurophysiological scale.
45. Tribus M. and McIrvine E.C. (1971). "Energy and Information". *Sci Am*, 225:179-88.
46. (a) Brillouin, Leon. (1949). "Life, Thermodynamics, and Cybernetics". *Am Sci* 37:554-68.

- (b) Tribus M. and McIrvine E.C. (1971). "Energy and Information". *Sci Am*, 225:179-88.
47. (a) Greenfield, Susan A. (1995). *Journey to the Centers of the Mind: Toward a Science of Consciousness*. W.H. Freeman and Company.
- (b) Coveney P. and Highfield R. (1995). *Frontiers of Complexity: The Search for Order in a Chaotic World*, Random House.
- (c) Scott, Alwyn. (1995). *Stairway to the Mind: The Controversial New Science of Consciousness*, Springer-Verlag.
- (d) Herbert, Nick. (1993). *Elemental Mind: Human Consciousness and the New Physics*. Penguin Books USA.
- 

Creative Commons Attribution License © 2010 by the Authors  
([CreativeCommons.org/license/by/3.0/](http://CreativeCommons.org/license/by/3.0/))