Redefined Information Leading to Matter and Energy

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Abstract: In this paper we define information as any observable difference which exists only at boundaries. We hypothesize, based on this, that matter (particle) is composed of many small interfaces (differences) in space and energy becomes a function of the distribution of differences (distinguishability) and no differences (indistinguishability). Based on this definition of information, superposition in quantum mechanics will be shown to be analogous to statistical thermodynamics. An observable consists of two processes: the observation which is limited by the uncertainty equation, $\Delta E \Delta t \geq h$ and the entropy change in the observer. When combined, these are shown to result in a modified Heisenberg Uncertainty.

Keywords Energy · Matter · Information · Uncertainty · Measurement

1 Introduction

The relationship between information and energy has been investigated since Shannon’s initial equation demonstrating the similarity between the equation for information and the equation for entropy, $i = -k \ln \omega$ [1]. The investigation was significantly advanced by Landauer [2-5], following indications by Brillouin [6], which concluded that energy is used in the reset process, not in the computing process. This was further developed and applied by Bennet [7-9] to many different examples. Feynman [10] verified the accuracy of the basic mechanism and provided illustrations. However, in none of these works is information defined, except occasional reference is made to a bit being a “1” or “0” and sometimes relating this to bipolar states such as spin where spin + is a “1” and spin - is a “0”. Currently, the negative information state has not been defined or applied to information theory although negative entropy exists and, by analogy, negative information should also exist.

In this paper we will discuss a new definition of observational information and its consequences. A bit of observational information is defined as the minimum observable finite difference which is designated as a “1” and where there is no difference is designated as a “0”. Here, we consider the “difference” is a fundamental concept that leads to other physical phenomena. Since the difference appears at a very small distance, it will require high-energy experiments to find out its structure. The minimal difference results in distinguishability. Our use of boundaries that result in matter will be shown to be a result of a combination of the Landauer/Bennet discovery and the equation for black hole entropy.

Information can only exist as a relationship across a two dimensional boundary that exists as part of a three or higher dimensional structure since it is interaction across the boundary that converts information to an observable requiring an energy change. The number of differences is proportional to the number of boundaries. With this definition, both spin + and spin - would represent a “1” since they both are a result of differences and a vacuum a “0”. The difference may be between real and imaginary space, real and empty space (vacuum), differences in magnitude of states in real space, etc. Boundaries become the basis for existence resulting in mass and when changed, results in changes in matter or energy. Although boundaries can occur in various dimensions, the focus here will be on 3-D space. To simplify the discussion, we will divide the boundary into rectangular shapes, where no dimension is less than Planck’s length, l_p. An area cannot be smaller than l_p^2 forming a square with l_p on each side which will be considered the fundamental or quantum area unless specified differently in the paper. ‘The area of a surface is a measure of its capacity to transmit information’ [11]. Only the surface is observable and observations can occur only over a surface.

These relationships can be represented by two overlapping different “Type” surfaces, resulting in a two-dimensional interface (boundary) between them which defines their relationship and consequently information. We will consider one type area from an object and the other type area from the environment creating a boundary between them. If one type of surface is a vacuum, which may be the environment, the other type must be distinguishable and have material existence. These differences are most prominent in black holes. Schrodinger described ‘Differences of property itself […] is really the fundamental concept rather than property itself […].’ [12]

Matter will be postulated to be a function of the number of differences that are observable:

$$m_o = \frac{kT}{c^2} \ln \left(\frac{N!}{(\frac{N}{2})!(\frac{N}{2})!} \right) \approx \frac{kT}{c^2} N \ln 2 \tag{1}$$

where N = number of differences, k is Boltzman constant, T is absolute temperature, c is the speed of light. For a change in matter due to a change in information, the final matter state is:

$$m_f = \frac{kT}{c^2}(N + \Delta N)\ln 2 \tag{2}$$

where ΔN is proportional to the information change, Δi. It is positive when information (differences) enters the matter and negative when information leaves matter or is converted to energy.

Because of the importance of a “difference” in this paper, there is a focus on the interaction between observed distinguishability (information is available) and indistinguishability (information is missing). Distinguishability and indistinguishability have been used in quantum mechanics routinely. We will apply these concepts to thermodynamics. In thermodynamics, the entropy of a system is given as $S = k \ln \omega$, where ω is the number of system configurations. Here, we present a new interpretation of ω using the concepts of distinguishability and indistinguishability. The indistinguishability of the states is a consequence of lack of information of the system. These states “co-exist” and their transitions are permutations of each other and have no effect on the final thermal state. We define positive entropy as existing whenever there are multiple possibilities and entropy is proportional to the ln of this number. For the case where $\omega = 1$, there is only one possibility which implies there can be no observable differences. In this case, the information about the system is completely known which we are defining as a completely distinguishable state and $S = 0$. This can occur when all the particles are in the same state. However, more than one possibility implies there is an observable difference. In this case, the information about the system is not completely known and there are now at least two indistinguishable states. This is what we use to define indistinguishability. As indistinguishability increases, the denominator of ω decreases and the entropy increases. In the extreme case where the denominator is $1!^n$, complete indistinguishability, the observer has minimal information regarding each possible state and there is the maximum possible energy change difference between the maximum possible energy in the system and the current state. This can occur when all the particles are in completely different states. Based on this definition of indistinguishability, the completely distinguishable state is where indistinguishability is zero. We can use an interpretation of ω that differentiates the numerator from the denominator where the numerator is the maximum number of possibilities and the denominator is due to the relative proportion of distinguishability and indistinguishability.

This definition is based on entropy where:

$$E_o = kT \ln \frac{(D)!}{(D_1)!(D_2)!...(D_i)!...(D_n)!} \tag{3}$$

and

$$\sum_{i=1}^{n} D_i = D \tag{4}$$

where D is the total number of possible distinguishable plus indistinguishable states and where a minimum energy change of $kT\ln 2$ is necessary to define distinguishability. D_1 to D_n is the number of indistinguishable particles with n different states and distinguishability is due to the existence of information. There is an emphasis on the information that the observer has available so, without an observer, work cannot be performed. For a change in information, the new energy state is:

$$E_f = kT \ln \frac{(D)!}{(D_1+\Delta D_1)!(D_2+\Delta D_2)!...(D_i+\Delta D_i)!...(D_n+\Delta D_n)!} \tag{5}$$

where $\Delta D_i, (i = 1, 2, ...n)$ is proportional to information and is negative when information is taken out of the system (and goes into the environment) so the denominator decreases, increasing the change in energy and positive when information is added to the system (denominator increases and ΔE decreases).

Unlike mass where we postulate there is only one type of mass, there are multiple different or distinguishable kinds of energies. Also, there exist multiple distinguishable states of energy. For example, particles can have $E_1...E_n$ different energy states leading to the multiple distinguishable energies in the denominator of the above equation.

It is necessary to have distinguishability to have an energy change: $\Delta E = E_f - E_o$.

The 2-slit experiment will be used to demonstrate the relationship between multiple possibilities and distinguishability and indistinguishability in quantum mechanics and thermodynamics. However, for our purpose, we will consider each possible path between the source and detector in the 2-slit experiment as a separate state (each path represents one possibility or configuration) and since entropy is proportional to the ln of the number of configurations, the entropy in this case will be proportional to the ln of the number of different paths. If there is an observer at the slit there are two possible paths between the source and destination so entropy in this situation is proportional to ln2. If there is no observer at the slits, we can consider that there are more than two paths between the source and screen so entropy is proportional to something greater than ln2. By considering each path as a separate state, we can associate an entropy with Feynman’s Sum over Histories.

In a N-slit indistinguishable system, each particle can be modeled as passing through each of the slits simultaneously so the number of paths and corresponding possibilities is maximized resulting in the maximum possible entropy. Each slit has two possible states, a "1" represents a particle or "part of a particle" interacting with the slit or a "0" represents no interaction. The total number of paths or possibilities is $2 \times 2 \times 2 ... \times 2 = 2^N$. Therefore, the entropy calculated from this is $S = k \ln 2^N = Nk \ln 2$. Whenever there are multiple possibilities, there is entropy, and for any change in these possibilities, there is an energy change resulting from redistribution between distinguishability and indistinguishability. In the case of multiple slits, for every increment of distinguishability that is added (or removed), due to the addition (or removal) of an observer, there are multiple indistinguishable states removed (or added). When $(N-1)$ observers are added, complete distinguishability is established requiring $(N-1)kT \ln 2$ energy.

Information can be represented by a "1" or "0" but there are other possibilities where information is possible but is missing which corresponds to the superposition state in quantum mechanics and will be designated as negative (-) information. There are thus two ways to describe information:

1. + information-Any observed difference (boundary) corresponds to distinguishability that is convertible to energy when randomized. In the extreme case, with complete distinguishability, i.e., complete information, $\omega = 1$, $S = 0$.
2. – information -This is lack of information, i.e., information that is not observed. It is any superposition of states. All quantum superposition states are a result of negative information. There is knowledge that differences (information) exists but there is no observation as to what the differences are. Superposition is a consequence of quantum indistinguishability and it will be shown that it is related to entropy, irreversibility in thermodynamics, and Heisenberg Uncertainty. In the extreme, where there is no information, entropy is maximized which represents the maximum missing information.

The following equations are postulated to define the relationship between information and are interchangeable:

|+ Information change| + |- Information change| = |Total Information change|

$$|+\Delta i| + |-\Delta i| = |Total \Delta i|$$

Initial Information + Added Information + Missing Information = Total Information

where i is information, the actual information that can be converted to energy (i will be used for information, I is used for intensity, Im will be used for imaginary). Information at the observer, i, is what is left after the disorganization (associated with superposition states) is taken away from the total possible organization.

The minimum difference defines a quantum, where information must change in discrete increments, since differences by definition must be discrete. Either there exists a difference resulting in information or not, but there is no in-between state. Changes in information or entropy is an embodiment of the quantum process of changes between indistinguishability and distinguishability. This is the essence of the creation of information and the essence of the quantum which is based on the difference between not having information so all possible states exist simultaneously and a change, where the number of possible states would decrease with increased distinguishability, resulting from added information (an observation).

2 Energy

We will now investigate differences in time which we postulate results in energy change. There are multiple models that demonstrate this conversion of information to energy. These include computer gates, the 2-slit experiment, partitioned chambers and Maxwell's Demon. We will first demonstrate how this conversion occurs and its implications using the computer gate model and then compare this to the other models. In each model, energy is dissipated when there are more inputs than outputs and energy is required, not in the computing process, as has been demonstrated [13], or in the observation (or measurement) process, but to reset the observer's inputs so they can be reused, which we are postulating is equivalent to activating the observer or measuring instrument.

As we discussed previously, matter is postulated to be a result of differences and now we are postulating energy is a function of the change in differences. In other words, an increase in the number of boundaries (relationships) results in an increase in the amount of matter and, in a closed system (where N, as defined previously, does not change), would result in a decrease in energy in the system. A decrease in observed boundaries results in a decrease in the amount of matter and, in a closed system, results in an increase in energy of the system and is a result of eliminating distinguishability, similar to removing the dividing barrier between two chambers which also changes distinguishability into indistinguishability. Creation of information or, equivalently, restoring to a known state (reset) results in an increase in the number of boundaries which uses energy. Any change in information, whether it is creating information (adding relationships) or erasing information (eliminating relationships), results in an energy change whereas copying information, where there is no change in the number of boundaries, does not. Situations where information are re-arranged such as changing which side the particle is observed in a 2-chamber system by flipping the 2-chamber system with a particle known to be on one side is equivalent to copying of information which neither uses nor generates energy [14]. Energy transferred to an object decreases order so information in the object increases. For energy entering matter and increasing information by one bit, the energy increases by $kT\ln 2$ equivalent to a mass increase $\frac{kT\ln 2}{c^2} \approx T10^{-40}$ Kg. Energy transferred from an object increases order, so there is less information in the object.

2.1 Computer Gate

The literature frequently uses the example of certain gates [15,16] to illustrate how a greater number of inputs than outputs requires energy to reset to the initial conditions. The differences (boundaries) were eliminated so it requires energy to generate new differences (boundaries), again at the input of the gate, if the process is reversed. Eliminating an input reduces distinguishability and results in dissipation of energy which results in increased temperature in the gate (randomization of information in the gate adding energy to the environment). In all our examples, we consider ideal cases only, so any energy can be converted to any other energy with no losses.

Landauer's results, followed by in-depth analysis by Bennet, demonstrated that in a typical gate used in the computational process where the number of inputs is greater than the number of outputs, as in an ideal AND gate, energy is consumed not in the computational process but in the reset of the gate so it can be re-used, the equivalent of adding distinguishability. The information is copied into the inputs of the gate at no energy cost since copying does not require energy, no change in the magnitude of distinguishability [17]. The output of the gate is represented by only one value and so has less information than the input. The information from the inputs is decreased (similar to a particle in a divided chamber where the dividing barrier is removed). No energy is used until we attempt to reverse the process to reset the inputs, basically the reverse of the computing process, in which one input (the previous output of the gate) results in two outputs (the two previous inputs to the gate) which are now in a superposition of states so the value at these outputs cannot be determined and are thus not reset (which requires known states). In any situation where there are bits that are not stored or, equivalently, usable by the algorithm that created them (such as when one input of the gate is no longer available at the output so it can no longer be used by the gate), information is lost. To reset or convert the superposition states that now exist at the original input to information so they can again be used as inputs requires the addition of another input and adding an input (creating information) requires energy. If we stored one of the original inputs in a separate memory location, then combining this with the output of the gate provides all the information to reconstitute both of the original inputs and no energy is required to reset the gate. Once this additional input is added, the value at each of these new outputs (former inputs) is deterministic. It makes no difference what these values are, as long as they are known because one known value can be changed to another known value with no use of energy [18]. This is described by Kondepudi: '[…] a series of conversions of one sequence of digits to another, can be performed reversibly […]' [19].

We have postulated that energy is due to "changes of differences" in time. The energy-matter conservation law, $E = mc^2$, is equivalent to the interchangeability between differences in time and differences in space. For example, using additional memory (space) to store not used input states in a computation reduces the energy used by the computer which is using space boundaries or relationships (matter) to compensate for time boundaries (energy). Since all information in a closed system is accounted for and balanced, information is conserved. Entropy always increases when information decreases and information decreases when differences are not stored in additional memory locations (space). If this additional information is stored, entropy does not change.

2.2 Two-Slit Experiment Analogy

We will define our system as the 2-slit experiment consisting of an emitted source of particles centered on two separated equal sized slits, optional detectors at the slit and a final distant detector screen. The two slits represent a spatial binary system analogous to a two chamber system.

As we previously discussed, in the 2-slit experiment, indistinguishable case, we postulate there is no environment or measuring apparatus that can register the difference between the particle and its surroundings or equivalently, a difference between slits (no observer), i.e., there is no path information, and in the distinguishable case the environment or measuring apparatus does have the ability to register the difference between the particle and its surroundings, i.e., there is path information. The 2-slit system, distinguishable case, represents a spatial binary system where, after a source emits one particle, a determination of a particle at one slit (observational information 1) determines there is no particle (observational information 0) at the other slit. The indistinguishable case represents a spatial binary system as above plus an additional binary system where the particle can be modeled as interacting with both slits simultaneously, resulting in additional paths or as two coupled particles as was done previously [20].

A similar situation just described with computer gates applies to the 2-slit experiment. The slit observer's information in the distinguishable case is equivalent to a memory location in the computer gate. A possible mechanism operative in the 2-slit experiment would be to consider the reset in the observer to be a conversion of energy to matter (modeling the observer as a 2-chamber system, this process is equivalent to localizing the side of a particle which creates differences in space, postulated to be matter in this paper and the subsequent randomization is the conversion of this matter to energy) so the energy in the entire system decreases with a concomitant decrease in entropy and increase in information leading to the distinguishable observation. The number of outputs in the distinguishable case is less than the number of inputs from the indistinguishable case providing the energy that is converted to matter. The energy used to return the system to its initial state of four inputs is provided by the conversion of matter to energy when the information in the matter is randomized so all subsequent observations will be indistinguishable until the process resets. Although the observer is localized, the process is not necessarily localized so this interchange between energy and matter can either occur at the localized observer or is non-localized, either of which can help explain the observations in delayed choice experiments. Furthermore, any change in the number of possibilities in Feynman's Sum over Histories can be associated with an energy/matter change. The energy/entropy analysis of the two-slit experiment may have implications regarding the quantum mechanical mechanism active during this process which needs to consider conservation of energy/mass and the transfer of information. The mechanism operative in conservation of energy may be the same mechanism that leads to the observation in 2-slit experiments, so elucidating this mechanism may be necessary to define an observation in quantum mechanics. The basis of a measurement may depend on this conversion between matter and energy. Furthermore, wave/particle duality appears to be related to this indistinguishability (wave)/distinguishability (particle) distinction in both quantum mechanics and thermodynamics. Careful thermal/energy experiments, where energy changes are observed in a closed system with multiple slits with and without observers, may help elucidate this mechanism.

To show how the new theory applies to the 2-slit experiment, we can consider the following situation where we have a 2-slit experiment setup set inside a box and the observer sits outside of that box as shown in Figure 1.

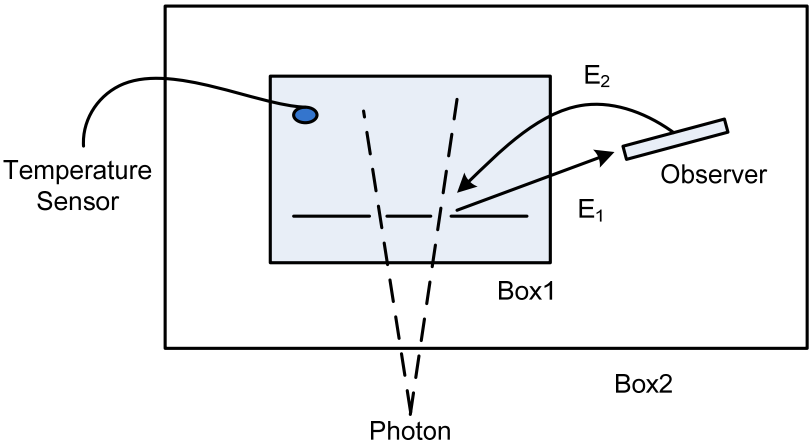

Figure 1. Two-slit experiment enclosed in a transparent isothermal box. An observer sits outside the transparent box (Box1) but inside a bigger box (Box2).

According to the new theory, before the observer makes an observation, i.e., receives information from the experiment setup, the two-slit is in a distinguishable state. It changes to an indistinguishable state after the observer makes an observation.

1. During the observation process, energy E_1 has to be transferred to the observer from the setup in order to transmit information.
2. If the entropy of the setup is considered, there would be energy transfer from the observer to the setup. State changed from distinguishable to indistinguishable implies entropy increase according to the new definition for the two-slit experiment setup. Thus, the setup absorbs energy E_2 from the observer.

   $$E_2 = kT \ln 2$$

3. The temperature of Box1 changes because its total energy is changed. Because there is additional energy transfer described in 2 above, the predicted temperature changes will be different from this theory than from existing theories.

4. When the observer is reset, the setup changes from the indistinguishable state to the distinguishable state. This means the energy E_2 is transferred from the setup to the observer.

The energy involved here is very small. However, a practical experiment for verifying the theory may be designed based on this.

The difference between the indistinguishable and distinguishable cases is relevant to the essence of the observation process. In the 2-slit, indistinguishable case, which is equivalent to a two chamber system where a particle can be in any location, energy is required to ADD or activate an observer resulting in a change from the no observer condition. The addition of the observer is equivalent to the creation of information which can then locate the particle. Once the observer is established, the observation does not require energy since it is only a copy process. *This is why we are postulating that it is not the observation that requires energy, but the addition of the observer which is equivalent to the reset and requires energy.*

The 2-slit experiment will provide a means to quantify the effect of knowledge or information on observed results where we first take a position (some Δx^2 at some x) on a final detector screen and determine the number of photons that would be detected at that point on the screen for the I) the distinguishable (no interference) case and II) indistinguishable (interference) case where the difference between the pattern of intensity is very different and is due to the effect of information at the slit.

We will consider the 2-slit situation where we look only at one intensity on the final detector screen, at x_1, where the intensities are equal for the two cases (distinguishable and indistinguishable). A way of analyzing and differentiating between Case I (no interference) and Case II where there is no observer at the slit (interference) would be to evaluate the information. This is a result of two different configurations and two different probability equations. For one observed photon at x_1 where the entire system is at the same temperature, T:

Entropy for Case I -distinguishable: $S_I = k \ln 2$
Entropy for Case II-indistinguishable: $S_{II} = 2k \ln 2$

where the entropy of Case I is due to quantum distinguishable and the entropy of Case II is due to quantum indistinguishability where information was removed [21]. The difference between these two cases represents the missing information in the system and represents $k \ln 2$ of information, the information of one bit.

The component of entropy due to distinguishability was recognized by Zurek: 'Zurek arrives at his definition of what he calls physical entropy: *Physical entropy is the entropy of missing information, plus the algorithmic randomness of the information that has been recorded.'* (italics in original) [22]. There are other proposed methods of incorporating known information into entropy.

2.3 Particle in Partitioned Container and Maxwell's Demon

The particle in a partitioned container represents a "1" if there is an observed difference between the chambers. It makes no difference whether a particle is in the left or right chamber since either of these cases can be changed to the other without expenditure of energy. Until the particle is observed, there is no difference between chambers so there is negative information and the particle is in a superposition of states in the same way a particle's interaction with two unobserved slits is in a superposition of states so, for unobserved particles, a piston could not do work.

It takes a minimum of $kT\ln 2$ energy to create the information of a bit and until it is observed, neither a difference, a "1", nor a no difference, a "0", can be established. $kT\ln 2$ is the energy of order of 1 bit so it is the minimum energy of creation of information, to know if a difference exists, which is analogous to determining which side contains the particle in an equally partitioned system.

This demonstrates the similarity between entropy and quantum mechanics. In determining entropy, we initially assumed all locations are available for all particles until particles are observed, like in quantum mechanics. In both examples (2-chambers and 2-slits), previous to the observation, more possibilities exist for the indistinguishable case than for the distinguishable case in the chamber or slits since they are in a superposition of states which corresponds to the entropy for indistinguishability. If a particle is known to exist in a certain chamber, it becomes quantum distinguishable; the same quantum distinguishability that applies to the 2-slit experiment with an observer at a slit.

Maxwell's Demon starts in a standard state [23,24]. The measurement that Maxwell uses substitutes for this standard state. Since the new information is copied from one object to Maxwell (and not created), no energy is required. However, for Maxwell to do another measurement, so this next information is relative to the same state and can be used to determine what to do with the next information, Maxwell must reset to its previous known state which does cost energy. Equivalently, a new observer could be brought in which also requires energy.

Maxwell acts analogous to the computer AND gate where there are initially two bits of information at the input and one at the output so energy is required to recover the information at the inputs. Maxwell, who is dealing with vectors such as speed and direction, requires two inputs to make a decision regarding any particular particle (equivalent to the two inputs to the gate). There is only one output, the determination as to which side the particle should be placed. In either case, the inputs require a comparison that determines the existence of a difference or not. If we designate a certain threshold speed then a difference or a “1” is when the threshold is greater than this and a “0” is when the difference is less, equivalent to our no difference situation. Each time a difference is defined, it is always compared to a threshold which requires a minimum change of energy of $kT \ln 2$. This represents the information that is copied by Maxwell’s Demon. There is equivalently a direction threshold related to whether the particle is approaching the barrier. It requires an energy change to determine direction as well. This also represents the information that is copied by Maxwell. In general, going from two components of a vector to one component of a vector is going from two bits of information to one and does not require energy but going from one component to two components of a vector requires additional information and does require energy to determine the initial states. To reset Maxwell with only the information as to which side the particle is in requires making a decision about Maxwell’s state based on only one bit of information (the side the particle is placed) and more information is required.

For certain computer gates, the 2-slit experiment, 2-chamber system and Maxwell’s Demon, the energy requirement depends on the lost information (the number of inputs and outputs). Energy is not used if there exists enough memory locations to store the unused intermediate steps so the entire process is reversible from the information content and energy would only be used in the output step which uses at least the minimum energy of $kT \ln 2$ [25]. Maintaining the information of the intermediate states is equivalent to copying/storing information at each step. However, not keeping this information (copying or storing) results in the process not being reversible when the reverse process is attempted. Any change in the number of superposition states is associated with an energy change. In each of these experiments, the energy is not used in the observation (recording information which is a copying process) but in the bringing or activating or resetting the observer (all of which are equivalent) that can then copy this information.

In each case when the number of inputs is greater than the number of outputs, a superposition condition is created if there is an attempt to reverse the process. As this difference increases, the number of superposition states increase resulting in increased entropy or, generalizing the reverse, decreasing the number of superposition states due to increased information, decreases entropy. As there is more indistinguishability, there are more combinations that can lead to a particular observation resulting from the decreased information. As there is less information (less certainty as to what is in any location), entropy increases.

3 Matter

There is a well-established equivalency between mass and energy which implies that if energy is a result of information, the mass must also be a result of information. Information is defined as differences and we are proposing differences in time results in energy changes and differences in space results in mass. We are postulating boundaries result in mass which, when completely randomized, involves the entire conversion of mass to energy ($E = mc^2$), with complete destruction of the mass. Each state defines the existence of the other. From the previous equations for ΔE and Δm we have determined that for any changes in matter, there are corresponding changes in energy. As one changes, the other changes in the opposite direction so, as we defined it: $c^2 \Delta m + \Delta E = 0$.

We will demonstrate how this is related to what gradation we use in determining entropy. Here we will use the minimal gradation of Planck's length (l_p) which results in the maximum entropy change. It also depends on the relative motions of the observer and observed [26].

As was done previously, we will consider isothermal situations only so the only dependence on energy changes in statistical thermodynamics where $S = k \ln \omega$ will be on ω. In most cases we consider the environmental observer to be external so the observation is of the surface only. In this situation all possibilities depend on the total number of boundaries between the surface and environment. For two different equal number of type boundaries, the number of observable configurations is $\dfrac{N_1!}{(.5N_1!)(.5N_1!)}$ for a total number of N_1 boundaries.

The extreme mass in black holes can lead to additional insights regarding the relationship between mass and information changes. We are postulating the total entropy of the whole universe does not change during the formation and evaporation of the black hole. The entropy of the universe (excluding the black hole) decreases as the entropy of the black hole increases; that is, the number of changes in the universe decreases as the number of changes in the black hole increase. In the evaporation process, the entropy of the black hole decreases and the entropy of the rest of the universe increases. In the formation of a black hole, bits are lost from the environment. When an environmental boundary is incorporated into a black hole, it seizes to exist from the environment. (It is as though it disappeared.) Any object entering a black hole is converted to its primary components that maximize entropy for the minimal area of the black hole so as energy or mass enters the black hole, the area of the black hole must increase. There is the maximum number of inputs because everything in the black hole is an input with no output.

For any sized black hole, there cannot be more inputs. Even if information leaves black holes and the area decreases, the entropy (proportional to N) of the black hole remains at a maximum for this smaller size. Since the formation and evaporation of the black hole are reversible processes, the amount of information that went into forming the black hole is equal to the amount of information that returns to the environment when the black hole evaporates. All the information in a black hole is on the surface and if the entire area evaporates, the information radiates back into the environment. This can occur with no net energy change since for a reversible process no net external energy is necessary to put the system back to its original condition.

Information is a known arrangement of bits. We will determine the number of bits in a sub-atomic particle using the formula for entropy: $\frac{\mathrm{E}}{\mathrm{T}} = Nk\ln w$ where E-energy, T-absolute temperature of the particle, k-Boltzmann's constant $=1.38\times10^{-23}J/K$ and $\omega = 2$ (for only two options: $\ln\omega = \ln\frac{2!}{1!1!}$) and N is the number of fundamental boundaries. For a neutron (so we do not have to deal with the effect of charge):

$$E_{neutron} = 1.53\times10^{-10}\frac{kg.m^2}{\sec^2} \tag{6}$$

$$NT = \frac{E_{neutron}}{k\ln 2} = 1.61\times10^{13}(bits.K) \tag{7}$$

It is not clear how to define temperature for a particle but since a particle consists of various combinations of quarks and gluons, it is reasonable to consider that it has a temperature. This is generally true for any particles. There may also be some variation in ω due to Heisenberg Uncertainty which will be considered later.

Black holes represent a special case of matter where matter, or the number of differences, is maximal for a given spherical area. For a non-rotating black hole with no charge, $S_{BH} = \frac{A}{4l_p^2}k = Nk$ where N is the number of bits of the black hole and the fundamental black hole boundary is defined as a square where each side is $2l_p$ [27,28]. Combining this with $m_{BH} = \frac{r_{BH}c^2}{2G}$ results in $\#Bits_{BH} = \frac{S}{k} = \frac{4\pi G}{\hbar c}m_{BH}^2$ demonstrating the relationship between mass and bits. Furthermore, the ratio of $\frac{m_{BH}^2}{\#Bits}$ is a constant. By substituting T for m_{BH} and since $T_{BH} = \frac{\hbar c^3}{8\pi G m_{BH} k}$, we have $\frac{m_{BH}}{\#Bits} = \frac{2k}{c^2}T_{BH}$. From previous isothermal thermodynamic considerations, we determined for non-black holes, the conversion is: $\frac{m_{non-BH}}{Bit} = \frac{kT\ln 2}{c^2}$. It is worth pointing out that the ratio of mass to bits in a particle differs from that of the black hole by $\frac{1}{2}\ln 2$ which may be a result of the approximations used.

4 Measurement and Heisenberg Uncertainty

As an example of the information basis of a measurement, when a photomultiplier tube (PMT) detects a photon, the photon is incorporated in the PMT and the mass of the PMT increases, even if transiently.

A necessary condition for a measurement is a relationship between matter and energy which requires a relationship between differences in space and differences in time. The environment, which may be the measuring instrument, must change for an observation. Sieife [29] also considers '[…] Nature-the universe itself-is, in a sense, continuously making measurement on everything.' Neither the source nor the receiver of the information is in their initial state after this change of information and only with an observation can we say that there is existence. This is a somewhat modified adaptation of the Copenhagen interpretation of quantum mechanics where there may be mass existing without an observation but an observation is necessary to demonstrate existence. Note that this may only apply to mass and may not apply to other parameters of any particle such as polarization, charge, etc. We are saying mass exists without observers but an observation requires an energy change. In each of the previous examples of the 2-slit experiment, 2-chamber system or Maxwell's Demon, the state of the particle is not known until it is observed as in some of the Copenhagen interpretations of quantum mechanics. This also applies to all of statistical mechanics where all possible configurations are considered to exist simultaneously until observed or distinguished. Fundamentally, there is no difference between the meaning of entropy in statistical thermodynamics and quantum mechanics since the determination of either is based on all possibilities existing simultaneously in space and time until observed. This has been discussed previously [30]. In quantum mechanics, you can only make predictions based on probabilities and whenever you have probabilities, you can associate an entropy and therefore a $\Delta E / T$. This would imply a quantum superposition dependence on temperature. There are some indications that this exists [31]. Furthermore, elucidating the relationship between entropy and temperature in quantum superposition may be useful in testing some of the hypothesis proposed in this paper.

Observations of a particle includes a large number of differences which have a probabilistic distribution so any observation is an observation that the particle is in a certain probabilistic state. A probability not equal to one (multiple not identical possibilities) is due to the existence of more than one possibility which requires a difference. The measurement is based on measuring the amount of information at any one time which may fluctuate, resulting in differences in the measurement, leading to a probability distribution to the measurement of $\Delta E_{OBSERVED}$.

In a perfect vacuum, the observable differences or boundaries are zero. However, the probability of a difference, even in a vacuum, must be greater than zero as demonstrated by the existence of fluctuations in the vacuum [32] or virtual particles, so no measurement of the vacuum is perfect. B. L. Hu [33] in *Physical Origins of Time Asymmetry* states: 'It (vacuum) is far from devoid of information, because everything can in principle be obtained from it, given some viable mechanism (e.g., pair production) and some luck (probability and stochasticity). There the mechanism which transforms the vacuum into physical reality is of special interest. It is for this reason that some understanding of the statistical properties of the vacuum is essential […] "to get everything from nothing […]"'. Creation and distribution of virtual particles also demonstrates the ability for differences or changes in time (energy) to be converted to changes or differences in space (particle). A probability of 1 implies there is no difference between what is possible and what is observable so the observation has a certainty that what can exist, must exist. A probability of zero implies non-existence (existence of an absolute vacuum) is certain. The reality of observations indicates neither condition can be certain. Thus, the probability of observed existence or boundaries or information is between 0 and 1 but not equal to 0 or 1. As we go from complete indistinguishability to complete distinguishability, our knowledge of the boundary changes. A component of both distinguishability and indistinguishability is then required to make an observation which defines existence per some interpretations of the Copenhagen interpretation of quantum mechanics. There cannot be order without disorder since observations are subject to an uncertainty.

As $\ln \omega$ changes, there is a change in entropy that has a corresponding change in probability. For $\omega \neq 1$, there are multiple possibilities. For $\omega = 1$, there is only one probability of an observation. If we assume space exists where there is a finite probability of an energy change, then for space to exist there must be multiple possibilities ($\omega \neq 1$) and a vacuum is where there is no possibility of a difference ($\omega = 1$). Differences in space are associated with multiple possibilities that ultimately affect the entropy of the system. In other words, the possibility of the existence of differences affects the entropy. If matter is differences in space and space exists because a finite probability exists, then matter also exists because finite probabilities exist. There is a change from a high probability of an observable difference when there are few differences to a lower probability of a particular observable difference as the number of differences increases. In essence, the entire discussion about information, randomization, known states, superposition states, etc. is a discussion of these probability differences.

In the reversible cycle, the starting point and ending points are the same so you know the initial starting point from the end point. In the irreversible cycle, this is not the case since you do not know the initial conditions from the final result, equivalent to the situation with more inputs than outputs. All real world situations have a component of irreversibility and, as we postulate, a related uncertainty. The reversible laws of physics are based on not losing information. With lack of information there is uncertainty resulting in irreversibility. Lloyd [34] states: 'The laws of physics preserve information as it is transformed. In mathematical parlance, the dynamical law of physics of a closed physical system are one-to-one. *Each input state goes to one and only one output state, and each output state can have come from one and only one input state.'* (italics in original).

In the same way you cannot determine the measured energy of a particle with greater accuracy than that related to Heisenberg Uncertainty, you cannot determine the energy of a bit, a component of the particle, with greater accuracy than defined by $kT \ln 2$. Heisenberg Uncertainty can be considered to result from the interaction of the quantum nature of the observer with the quantum nature of the observation. Reichenbach

[35] describes: ‘The indeterminacy, which for an experimental arrangement of this kind still exists, appears, rather, as a relationship between the measuring instrument and quantum phenomena, and thus a relation between physical objects alone.’ In discussing decoherence, Zeh [36] refers to something similar: ‘Branching into components which contain definite observer states has to be *taken into account* in addition to the unitary evolution as an *effective* dynamics in order to describe the history of the (quasi-classical) “observed world” in quantum mechanical terms.’ (italics in original). Also, Seife [37] states: ‘information is an inherent property of objects in the universe, and Heisenberg’s uncertainty principle is a restriction upon information. Therefore, Heisenberg’s principle is actually a law about the quantum state of objects in the universe, not just about the measurement of the quantum state’.

We are postulating Planck’s constant, h, is a quantum due to the interaction of an observation process with the quantum nature of the observer characterized by another quantum, $k \ln 2$, resulting in a measurement. Both are necessary for an observation and both are fundamentally quantum, i.e., the existence of a difference and its observed effect. There are two uncertainties to consider, that due to thermodynamics and that due to Heisenberg uncertainty resulting in: $\Delta E = kT \ln \omega, \;\; \Delta E \Delta t \geq \hbar$:

For uncorrelated uncertainties:

$$\Delta E^2 \geq (\frac{h}{\Delta t})^2 + (kT \ln \omega)^2 \tag{8}$$

$$\Delta t \geq \frac{h}{\sqrt{\Delta E^2 - (kT \ln \omega)^2}} \tag{9}$$

For $\omega = 1$: $\Delta t \geq \frac{h}{\Delta E}$. This results in the standard Uncertainty equation and is the case for complete order.

Considering the possible quantum nature of the uncertainty of the observed (ω_D) and the quantum nature of the uncertainty of the observer (ω_R), independent of the quantum nature of the observation and each other we get:

$$\Delta E^2 \geq (\frac{h}{\Delta t})^2 + (kT_R \ln \omega_R)^2 + (kT \ln \omega_D)^2 \tag{10}$$

$$\Delta t \geq \frac{h}{\sqrt{\Delta E^2 - (kT_R \ln \omega_R)^2 - (kT \ln \omega_D)^2}} \tag{11}$$

5 Discussion/Speculations

There are many implications from this definition of information, energy and matter; the dual observer/observation quantums; origins of Heisenberg Uncertainty and irreversibility in thermodynamics; the similarity and co-dependence of superposition, entropy and uncertainty; the temperature of an atom; and other previously discussed ideas that still present issues. We will discuss some of these here.

Because of uncertainty in an observation there cannot be perfect knowledge and, therefore, the change in entropy cannot be zero so the observation process cannot be a completely reversible process. All observed information has a component of disorder associated with it. Irreversibility and Heisenberg Uncertainty are a result of the same phenomena, lack of information. If, as in some interpretations of the Copenhagen interpretation of quantum mechanics, an existence is defined by an observation, instead of just determining the value of some parameter, the Uncertainty may be interpreted as uncertainty in what is known to exist instead of uncertainty in that parameter.

For black holes and possibly fundamental particles, the boundary that defines the black hole (fundamental particles) separates what is observable from what is not observable; the boundary separates unobservable states from the environment (observer). The effect of a Schwarzschild area may represent a general principle where a boundary separates the observable (knowable) from the unobservable (unknowable-interior of a black hole) for an observer and, as such, could define the fundamental particle as an area. For any particle entering a black hole, the boundary of that particle is added to the surface of the black hole and the unobserved states of the particle become part of the interior of the black hole. Since there are no observable boundaries in the interior of the black hole, there is zero contribution to the entropy of the black hole.

It is worth considering whether the thermodynamics of the sub-atomic particle (neutron used here as an example) is what makes it fundamental and speculating on what the temperature of a neutron (or any sub-atomic particle) might be. It consists of three quarks with a continual energy exchange between them through gluons. This results in a certain temperature which is considered to be the same for all neutrons. However, there may be no heat exchange with the environment. The inside of a fundamental particle is not observable so the temperature of the particle may not be detectable externally and there would be no or very minimal thermal transfer of energy.

If there is an observation of a difference requiring a reset, which can be considered a computation, there is conversion of information to energy. All energy in the universe may be from information converted to energy. Information that is at the edge of the universe may represent a difference between the universe and non-universe or existence and non-existence for a particular observer. There must be an interface to the environment which defines information and consequently, existence.

In the same way adding information to a black hole would increase the Schwarzschild area of the black hole: modeling the universe as a black hole, any additional information resulting in an increased number of bits increases the size of the universe. Lloyd [38] states: ‘We need […] look no further than the laws of quantum mechanics, which are constantly injecting new information into the universe in the form of *quantum fluctuation*’ (italics in original). There are multiple mechanisms that can be envisioned that would result in expansion of the universe when modeled this way. They are imperfect but may provide some insight as to what may be happening at the edge of existence. First, like a black hole, evaporation at the boundary of the universe could be resulting in the expansion of the universe but at a slower rate than the speed of light. However, like with the black hole, it would also result in the diminution of the size of the universe unless there was some addition of information to the environment that compensated for the loss of information. If we apply this same analysis to the whole universe, we could imagine the surface of the universe as a large set of boundaries. Objects in the universe are limited organization within this relatively empty space, like a particle being constituted from fundamental information bits separated by relatively empty space.

Another possible mechanism for the expansion of the universe is again based on modeling the periphery of the universe, if this exists, as a surface of a black hole where the expansion is due to each l_p^2 element enlarging. Since $l_p^2 = \frac{Gh}{2\pi c^3}$, this would require a change or continuous changes in one or all of the natural constants, G, h, or c, from the origin of the universe, representing conditions at the periphery of the universe, to today, measured on earth. This would imply that there are no constants of nature. Any change in l_p^2 could result in a major expansion of the universe but still may be undetectable since it represents a very small percentage change in l_p. It might be worth considering whether the changes in these fundamental constants are non-linear and possibly a function of changes in the background temperature.

We are postulating that pre-Big Bang there exists complete order (where $\omega = 1$ and only the present exists, but no future), and post-Big Bang there is a degree of disorder which enables the conversion of this information (presumed to be on some surface) into energy and represents the creation of future. Davies [39] describes ‘[...] the origin of the arrow of time always refers back to the cosmological initial conditions. There exists an arrow of time only because the universe originated in a less-than-maximum entropy state […]. The expansion of the universe has caused it to depart from equilibrium.’ Also, Lloyd [40] describes: ‘Then, all at once, the universe sprang into existence. Time began, and with it, space. The newborn universe was simple; the newly woven fabric of quantum fields contained only small amounts of information and energy. At most, it required a few bits of information to describe. In fact, if-as some physical theories speculate-there is only one possible initial state of the universe and only one self-consistent set of physical laws, then the initial state required *no* bits of information to describe. Recall that to generate information, there must be alternatives-e.g., 0 or 1, yes or no, this or that. If there were no alternatives to the initial state of the universe, then exactly zero bits of information were required to describe it; it registered zero bits. This initial paucity of information is consistent with the notion that the universe sprang from nothing.' (italics in original). The initial act of the Big Bang may have been the addition of distinguishability. Each measurement that converts internal information to external energy is then potentially modeled on the Big Bang. As indistinguishability increases so the difference between what is possible and what is observable increases, the universe expands. Carroll [41] describes '[…] as the universe expands, it can accommodate more kinds of waves. More things can happen, so the space would appear to be growing […]. But if a space of states changes with time, the evolution clearly can't be information conserving and reversible.' This is similar to the reverse AND gate example previously discussed.

The process of the bit being communicated between two masses requires the energy of a photon, $h\upsilon$. $kT\ln 2$ is the energy of one bit of information. A state which requires an observation consists of the bit of information and the communication of it, an energy change, which defines its existence. For a photon of energy $h\upsilon$ to be converted to a stationary bit where $\omega = 2$ requires energy where $\upsilon \approx \frac{kT\ln 2}{h}$. This frequency varies with ω. The energy in this situation varies with the temperature of the emitting particle.

5.1 Limits on Information Density

Halliwell [42] describes a situation where: 'Decoherence is then often regarded as a generalized measurement process […] the physical significance of decoherence is that it ensures the storage of information about the decohering system's properties somewhere in the universe […]. Environmental information storage capacity limits the permissible amount of fine-graining of the system histories consistent with decoherence.' The environmental capacity for change is limited in time by c and storage in space at the density of black holes. When the mass approaches the density of a black hole, more boundaries between the mass and environment cannot be added to the mass without the mass radiating or increasing its size. At the other end, in the Heisenberg Uncertainty relationships, Δt and Δx cannot be arbitrarily small. Δx is limited to being equal to increments of l_p. Similarly Δt is limited to being equal to Planck's time.

5.2 Fundamental (Quantum) Mass

Since a quantum of entropy is $S_Q \approx 1\times 10^{-23}\frac{J}{K}$, the equivalent mass for $E \approx 1.0\times 10^{-23}T$ and for a fundamental boundary is: $m_Q = \frac{E}{c^2} = 1.1\times 10^{-40}T$ Kgs. This is compared to $m_{neutrino} \geq 1\times 10^{-37}Kg$ [43] or there are at least approximately $\frac{1000}{T}$ of these units in a neutrino. It is then possible that the neutrino is the smallest form of matter and exists as a quantum of mass and may represent the fundamental mass. The difference in mass between m_Q and $m_{neutrino}$ may be due to the temperature, T, or there are more than one fundamental particle (boundary) in a neutrino or the entropy is proportional to a value greater than $\ln 2$ or the mass is increased due to the increased velocity or a combination of these.

5.3 Measurement

We will now consider observations (described by Schrödinger's Equation). After an observation, the observed particle is currently considered to be in one state out of all the possible superposition states. Energy is required, not in the observation, but in adding or activating (resetting) the observer. In the ideal case of an observation, adding or activating an observer is equivalent to the reset of the observer and requires energy, but the observation is a copy process and does not require energy. Removing an observer is the reverse process of adding an observer.

We have to consider two cases after the observation. First, the particle again is in a superposition of states immediately after the observation. Secondly, we need to consider the possibility that the particle remains in the observed state until the observer is reset. As an example of this second possibility we take the case of two possible energy levels of an electron, where an observation eliminates one of these possibilities (which were in a superposition state prior to the observation). In this case, the observed energy level (without additional interaction) and observer would remain coupled until the observer is reset. In some of the Copenhagen interpretations of quantum mechanics, something exists only when measured, so existence would be maintained as long as the measurement is maintained, which is until the measuring instrument resets resulting again in a superposition of states of the two energy levels. An interaction or observation of the particle by another observer may result in decoupling the initial observer and the particle.

From our analysis and the Copenhagen interpretation of quantum mechanics, it appears the information change is in the measurement or in the measurement apparatus which is consistent with the observations seen in the 2-slit experiment and delayed choice experiments. The measurement apparatus, like the environment, interacts with the differences of the particles. This was described by Patrovi [44]: '[…] it is the interaction with the environment which brings about the reduction of the state of the system.'

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