

Do Thermodynamic Entropy and Quantum Non-locality Have a Common Basis?

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Abstract. Both researchers and educators have expressed displeasure with the definition of entropy as a measure of disorder. Instead, it is argued by Leff, Lambert, and others that the increase of entropy can be far more accurately described using terms such as ‘dispersal of energy,’ ‘spreading and sharing of energy,’ and ‘spatial and temporal spreading.’ In decoherence theory, a similar metaphor is used to describe the phenomena involved with quantum non-locality, superposition, and entanglement. Specifically the wavefunction of a quantum entity, such as a sub-atomic particle or photon is not seen to collapse but rather is transferred through interactions to a system and/or its environment. This suggests there may be a common basis for entropy and non-locality. I explore the idea that energy is motive and extensive by nature, and that all its forms of expression involve motion, action, and propagation, which clearly leads to its being spread and shared when unconstrained, among the available microstates of its local system and the larger environment. Thus a single description, focusing on this universal quality of energy, explains both 2nd Law entropy and quantum non-locality.

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INTRODUCTION

Entropy is central to a wide range of subjects in Physics, and is therefore something important to understand. But the generalization that entropy is a measure of disorder has been found problematic in a variety of settings. Fortunately, there is another way to approach entropy which avoids these problems, and provides a means to make better sense of things than the disorder metaphor allows. However; the idea that entropy is disorder has become so fundamental to our working model that it will be hard to displace – even with a far better description. Recent work suggests that, instead of studying how disorder progresses; we need to examine the flow of energy in a system, and to study the mechanisms by which energy is propagated. Tracing how energy spreads and is shared in that system, dispersing in space and over time, gives a truer picture as well as providing an accurate measure of entropy.

The cover of the November 2008 issue of Scientific American asks us to examine ‘How Nature “Breaks” the Second Law of Thermodynamics,’ but once the story is read, and the research of J. Miguel Rubi and his colleagues is examined, it is found that the 2nd law is never violated, and the only thing broken is our view that disorder and entropy are the same thing. The fact that order can arise from chaos – while the

2nd law holds sway and entropy progresses – is highlighted. This fact is quizzical to someone steeped in the ‘disorder’ paradigm, but validating to those believing entropy is about the ways that energy can be spread, shared, or exchanged – with the various aspects of a system displaying degrees of freedom which store or deliver that energy. This new approach makes it easier to understand and describe entropy’s evolution, for both systems near equilibrium, and non-equilibrium systems.

The idea of energy being shared or spread among possible modes of a system (or possibility states) aptly explains quantum non-locality too, if we note that particles embody properties of energy. The framework of decoherence theory – as envisioned by Erich Joos, H. Dieter Zeh, and their colleagues – brings our discussion of energy deep into the quantum realm. Given only the mass-energy equivalence ($E = mc^2$) and wave-particle duality, we can formulate much of quantum mechanics, provided we interpret things appropriately. In another paper, I argue that while relativity emerges from assuming space and time are aspects of a single entity we call spacetime, quantum mechanics is what emerges by assuming that matter and energy are likewise dual faces of one entity or phenomenon. Decoherence theory appears to take this as a starting point, and further asserts that all aspects of a system can be described by tracing the evolution of only the energetic and/or wave-like components. In this context, what we see as the collapse of a wavefunction and the localization of a particle is actually the decoupling of components of the global wavefunction (of the universe), which remains coherent. Only when the number of decoupled components equals the degrees of freedom is the particle found to be entirely localized.

ORIGINS AND BASIS

Frank Lambert has had a huge impact on Entropy in Chemistry education, where 22 of the textbooks most-often used to teach this subject have revised their approach, some completely eliminating any mention of disorder from their discussion of entropy. This is due, in large measure, to Lambert’s many papers in Science educator journals, which champion this new view, or call the “entropy is disorder” view into question. He spells out that entropy is not disorder, but instead measures the dispersal of energy within a system. Central to this formulation is the idea that energy tends to spread out or disperse – whenever it is unconstrained. This is the basis for all 2nd law entropy, according to Lambert. Harvey Leff took up the same issue for Physics educators, independently at first, arguing that disorder is misleading as a measure for entropy, because it is an ambiguous term which is hard to precisely define and sometimes gives the wrong answer – when used as a basis for solving problems. He advocates changing the language of entropy within the Physics community, as well, using a ‘spreading and sharing’ or ‘spatial and temporal spreading’ metaphor to model the processes associated with the increase of entropy.

In the world of Quantum Mechanics, decoherence plays a similar role to 2nd law entropy in thermodynamics. It is the inevitable decay of activated or coherent states, as their energy is spent through interactions and absorption, which also act as measurements of quantum states. But decoherence theory suggests that what happens during this process is more interesting than simply a collapse of the wavefunction. Rather; the non-local information and energy associated with any quantum becomes

spread out, and is shared among individual entities which have interacted – forming a web of entangled particles, atoms, or molecules. Instead of disappearing, each unit's wavefunction is transferred – either a little at a time or all at once – depending on whether interactions and/or measurements extract quantum or classical information. Weak measurements – such as determining one axis of polarization – leave some quantum information intact, but once a photon or particle strikes our target film, and its exact location is knowable, that entity's classical description has been observed, and any wavelike or quantum-mechanical attributes it had are no longer available to detect. It would appear that the wavefunction is no more, once this happens. But decoherence must be understood as a dynamical delocalization of the wavefunction, not merely a collapse, to make sense of the quantum world – according to Zeh. While decoherence typically happens very swiftly, it is not quite instantaneous, and this distinction is important.

Much of what is said above flows from a single unifying concept – the idea that energy is by nature motive and extensive, rather than localized. In all its expressions, energy tends to move, act, propagate, oscillate, spread, or disperse – and to be exchanged or shared. Energy manifests by flowing or circulating, moving or propagating, traveling or oscillating. Embodying motion or change, it is essentially non-local, or spread out. Energy often displays a wave-like or field-like aspect, rather than the particle-like nature of the objects or substances it permeates. If concentrated in one place, energy will spread, unless it is constrained by atomic and molecular binding forces, chemical activation energies, or other quantum-mechanical barriers. The importance of such barriers is not easy to overstate, since they allow for the constancy of form and the orderly progress of chemical reactions that facilitates or constitutes life. But energy remains dynamic, even when bound. Individual photons can be captured or localized, but when this happens their energy is spent or transferred to the detector. The energy which had been a photon does not cease to move, once this occurs, but it becomes part of the system including the detector, where it circulates – within that new system – and is eventually radiated to the environment. However, we will detect a passing photon when it strikes.

Applying the definition of entropy as dispersal of energy, the fundamentally dynamic *nature* of energy noted above is sufficient to require or explain the 2nd law. But accounting for non-locality requires far more explanation. If we assert that the material or particle-like aspect and the energetic or wave-like aspect of physical entities are equally real, we are half-way there. But few imagine what this means. Putting the material and energetic view on an equal footing implies that the quantum wavefunction is a physical reality rather than a mere abstraction, equally genuine or actual though not objective, strictly speaking, as it pertains to the energetic aspect (dynamics) rather than the material one (objects). Decoherence theory takes this notion a step further, by asserting that the energetic, wave-like, and quantum mechanical aspect of nature is more fundamental, or perhaps even more real than the material component, where decoherence provides the *appearance of* Classical reality, and helps to explain the Quantum-Classical transition. What this outlook and its rationale suggest (in my opinion) is that matter is *comprised of* energy, and retains many properties thereof (such as wave-like nature), even when that energy constitutes sub-atomic particles which form atoms, molecules and so on.

Art Hobson has proposed that we use the terminology of Quantum Field Theory to resolve the confusion involved with speaking about matter and energy in such terms, by viewing both radiation and matter as continuous fields, and referring to both photons and particles as quanta of those fields. He suggests that using the term ‘field quanta’ for both photons and sub-atomic particles allows more accurate descriptions of quantum phenomena, and this metaphor fits especially well with decoherence theory, while helping to make sense out of more conventional interpretations of quantum mechanics. The idea of a particle as an independent material entity persists, but we have learned that atoms – which were once thought of as solid balls – are mostly empty space inhabited by fields which keep the material components together. So it is reasonable to assert that there is a similar mix of natures for sub-atomic particles also. They are not only particle-like. Wave-particle duality appears to be universal, as an essential aspect of all quanta. All sub-atomic particles, photons, atoms, and small molecules exhibit this dual nature. For some of the largest molecules, such as the long chains found in plastics, a nearly classical or more purely material nature is observed, while all smaller molecules exhibit distinctly quantum-mechanical properties (such as occupying eigenstates). Where the idea of existing in a superposition of states is curious for a material entity, this is not so surprising for a field quantum.

When particles are seen as field quanta, non-locality and non-local connections which entangle them are no mystery either. Where particles are localized, fields are pervasive and connective. Likewise; if a particle is seen as a collection of components of a global wavefunction, we can show how the dynamical decoupling of individual components results in robust entanglement between discrete entities, and the appearance of non-local effects at work between them. With recent evidence of entanglement of entities separated by 144 km, in an experiment by Anton Zeilinger and his team, we begin to see how robust entanglement is and how non-local the effects can be. Interestingly; the test for entanglement in such experiments often involves weak measurements like the determination of an axis of polarization – which are conducted on each of the separated entities, until all three directions have been tested for both (or all). It is the crucial third measurement which lets us determine whether they are entangled or not. That is; only when the components for all the degrees of freedom have decoupled and complete decoherence is observed can we verify that our test quanta have behaved quantum-mechanically.

Although the experiment above was done with photons, electrons would work also. To this author, the reason for this is clear; while these entities are bound into form, they remain energetic field components all the while. Although they take on particle-like attributes, and appear to be independent units of physical material – they are comprised of energy – which never stops being energy to become units of form. They have wave-like or field-like properties, as well as particle-like nature. However; there is another side to the story. Each unit contains or embodies a specific amount of energy, not more or less. And activated states of particles, atoms, and molecules, occur at specific levels of energy, rather than over a continuous range – giving each species a distinctive tone, spectrum, or energy signature, which is characteristic of that sample. Thus we can easily distinguish between samples of neon and argon gas, for example, by passing an electric current through them and observing the spectral lines emitted by the atoms as a result of their activation and decay.

CONCLUDING REMARKS

The goal in this research is demonstrating that fundamental properties of energy, combined with the observation that particles retain many wave-like or field-like attributes of unbound energy, are sufficient to explain both thermodynamic entropy and quantum non-locality. The metaphor ‘energy dispersal,’ ‘spreading and sharing,’ or ‘spatial and temporal spreading’ is seen to come directly from observing the natural attributes of energy, but this concept can easily be extended to include the diffusion and mixing of different species of miscible but non-reactive substance. The same concept can be extended into the realm of a more purely energetic description, by way of the concepts found in decoherence theory and quantum field theory. To some extent, this requires us to adopt a radical view of reality. When Dieter Zeh wrote the paper “There are no Quantum Jumps, nor are there Particles” (1993) I suspect it was a tongue-in-cheek pedagogical exercise, but he aptly shows that no paradox exists if we consistently apply the wave-like description of reality, or so long as we resist the temptation to mix Quantum and Classical variables. If we simply acknowledge the existence of a global wavefunction – which does not decohere – quantum effects including non-locality and entanglement are easy to explain via Schrödinger.

Both kinematical non-locality (positional indeterminacy) and dynamical non-locality (entanglement-based connections) are easily understood if we view particles as field quanta, or components of a global wavefunction, not material jots. Likewise; consistently applying a framework where we trace the spreading and sharing of energy allows various types of entropy to be easily explained and understood – provided we resist temptation to sneak in variables or criteria pertaining to the ‘entropy is disorder’ metaphor. Difficulties come from views shaped by years and layers of hidden assumptions which color attempts to make sense of current scientific data. Many feel that, to be objective, we need to see objects as fundamental. We have also come to believe entropy is disorder. But those views came from a time when we lacked the knowledge of quantum-mechanical reality we have today. Whether we trace the idea that entropy is disorder to Boltzmann, or back to Clausius, the quantum-mechanical nature of reality was unknown when this characterization was put forward, to describe the phenomenon of entropy. However; the concept of microstates encountered in the molecular formulation of entropy is especially well-explained by the notion of quantum indeterminacy and non-locality, showing that it is by quantum-mechanical means that the observed character of entropy emerges, even in macroscopic systems! Thus; it is seen that fundamental properties of energy, including its tendency to spread out and to be shared among available states, are sufficient to describe both entropy and non-locality. In addition to the conference poster; a full-length paper is in preparation, which will address more of the technical details.

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