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The Conceptual Foundation for Energy Physics and Thermodynamics' Dual Foundations

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The conceptual Foundation for Energy Physics and Thermodynamics' Dual Foundations

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Abstract: Energy physics, or thermodynamics, is a theoretical system based on a *conceptual foundation of free energy* defined by its two fundamental laws in what is referred to as the "combined first and second laws of thermodynamics." The thesis of the essay is that energy physics theoretical system, which led to the false truism of energy as nature's driving force while entropy growth as drag to the driving force, can be better understood by focusing on its two fundamental laws as well as its dual, conceptual and methodological, foundations. On a new conceptual foundation of entropy growth, we arrive at an understanding of entropy growth as the universal driving force of macroscopic processes while energy conservation as closure condition to all processes.

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Sara Walker, a theoretical physicist and astrobiologist, is quoted as expressing in a NYT piece on her new book, "Life as No One Knows It: The Physics of Life's Emergence," that "*She was struck by how hard it was to explain life with standard physics theories*" [1]. This is a commonly shared sentiment, that though physics is the most powerful explanatory theorical-framework in science, the fact that such a powerful framework cannot explain life implies something is missing in physics. Here, we argue that such pessimistic assessment, rather than a reflection of something that is missing, results from certain misunderstandings in physics, which includes thermodynamics, or energy physics. (Conventionally, the two terms are used synonymously, but we shall propose a distinction of the two and argue for the advantage for making the distinction.)

It is a truism universally accepted that "entropy and the dissipation of energy are as inseparable as Siamese twins in the thought of every student of thermodynamics" [2]. The truism is one part of the misunderstandings, the energy physics part that has a lot to do with phenomena of life [3]. Energy physics is a scientific theoretical-system that places "energy" as nature's **driving force** whereas "entropy growth," in its inseparable association with the energy dissipation, as drag to the driving force: One often comes across statement such as the following in lectures or, for instance, on a web-site, The second law of thermodynamics - how energy flows from useful to useless. (ftexploring.com), "Energy makes everything happen, and every time something happens, there is an energy change. There are two important natural 'laws of energy' that describe what happens to the energy involved in every change," the first and the second law of thermodynamics. The first law asserts that total energy stays the same in every event of change, even though the energy of a system may change, e.g., decrease. That decrease is often characterized as the consumption of energy. But in view of the fact that there is never any change in total energy, the correct characterization of decrease in a system's energy is not as the consumption of energy but as the consumption of a "form of energy" of the system. It is the disappearance of energy of a certain form, to be called *free energy*, which makes everything happen.

Thermodynamics, or energy physics, is the study of "free energy consumption" events. While all events are "energy conservation" events in accordance with the first law, free energy consumption events are "*transformation*" events. Energy physics, as the term is used here, is a theoretical system based on a *conceptual foundation of free energy* defined by its two fundamental laws in what is referred to as the "combined first and second laws of thermodynamics" [4]:Lecture 11]. The thesis of the essay

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is that energy physics theoretical system, which led to the false truism, can be better understood by focusing on its two fundamental laws as well as its dual, conceptual and methodological, foundations. This leads to the proposed use of "thermodynamics," or "Unisical Thermodynamics," as a new theoretical system, resulting from the reformation of the energy physics theoretical system, to be based on a new conceptual foundation of entropy growth.

Dissymmetry in Events of Transformation

Both the first and second laws are inexorable laws of nature. The first law is a law of conservation, the inexorable conservation of total energy in every event. The second law is a law of transformation, the inexorable growth of entropy in the universe in every transformation event. Thermodynamics, the study of transformation events, emerged in the eighteenth and the nineteenth centuries from mechanical sciences, sciences that succeeded in describing nature in terms a set of the laws of "locomotion" of mechanical entities, e.g., "positions and momentums" of atoms and molecules. The set of Newton's laws of motion is one example. The mathematical versions of such laws of locomotion are referred to with the general name of *equations of motion* (EOMs). Inferences from EOM have proven to be so successful that EOMs themselves, "though non-physical," are considered as "timeless, absolute, and unchangeable essences of all things," an idea goes all the way back to the Platonic Cartesian ideal.

Events of locomotion, as governed by EOMs, are reversible and deterministic, i.e., events involving no change or happening. Equations of motion also ensure such events to be energy conservation events—with the central role of EOMs, no *independent* assertion of energy conservation is necessary. Moving from events of locomotion to events of transformation, which are no longer necessarily governed by EOMs, phenomena of transformation are new phenomena in physics for which it is necessary to have an independent assertion of energy conservation. These new phenomena of transformation can manifest true happenings, challenging the Platonic Cartesian ideal. The establishment of this revolutionary understanding of nature was initiated by Mayer and Joule in 1842-43, known as the mechanical equivalent of heat (MEH), followed by three decades of contributions and consolidation [5]. This challenging to the Platonic Cartesian ideal has been referred to as the 1842-72 MEH Revolution [6]. Energy physics was the outcome of the 1842-72 MEH Revolution. But this traditional narrative of the Revolution, by threading narrative of energy conservation which applies to events of locomotion *and* transformation, misses the explication of the fundamental characteristics that make certain kinds of transformations as events of true happenings (see Clausius' treatment below): a theory of transformations that are events of true happening requires not only an independent assertion of energy conservation but also the application of the second law that is independent of, i.e., differentiated from, the first law. That is, an event of true happening manifests its "indeterministic" nature (via a discussion of "entropic indeterminateness" in paper [6]) through independent application of the second law [6]. (Transformation events of heat transmission studied by Fourier in 1822 are not events of true happening, for these kinds of events the "equations of change for 'energy'" are governing equations incorporating both the first law and the second law, no independent application of which is required.)

The energy physics truism results from the traditional narrative of the MEH Revolution by placing the first law front and center, as Kipnis, the historian of science, noted, "it was the principle of convertibility that constituted the essence of the First Law of Thermodynamics" [5]:2023. The prominence of the first law obscures the role of the second law. For untangling what separates transformations that are true happening from transformations in general we need to go back to the origin of the second law.

We are referring to an earlier, pre-MEH, revolutionary discovery, by Carnot in his 1824 investigation of heat and heat engine, of preferred directions or dissymmetry's in nature. He described the operation of heat engines as driven by heat flow from a high temperature to a low temperature. His assumption on the *nature* of heat was controversial. What was not controversial is his thesis that the directional heat flow is what drives heat engines. When heat's true nature was later determined to be disordered or disorganized energy, the preferred direction in heat flow can be

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categorized to be the preferred direction found in disordered energy. Let us call this Dissymmetry #1, Carnot's entropy dissymmetry.

When, in 1840s, Mayer and Joule established the MEH, the historic advancement of linking work and heat not only established, quantitatively, equivalence between work and heat but also was a discovery that there is preferred direction between ordered energy of work and disordered energy of heat. Let us call this Dissymmetry #2, Joule's energy dissymmetry, in the dissipation of ordered mechanical energy into disordered heat energy.

The Conceptual Foundation of Free Energy for Energy Physics

When Thomson (later, Kelvin) in 1852 published his formulation of the second law in a four pages paper with the title, *On the Universal Tendency in Nature to the Dissipation of Mechanical Energy* [7]: 511-14], it was a short but extraordinarily influential paper: The paper established the concept of free energy or available energy, the concept that though energy cannot be destroyed it is being subject to continuous and spontaneous degradation. Thomson made it clear that by mechanical energy he was talking about both mechanical energy (thus, having to do with Dissymmetry #2 of dissipation of ordered energy into heat) and available energy (having to do with Dissymmetry #1 of *managing* dissymmetry in disordered energy into mechanical energy, opposite to its original preferred direction). But the wording of the paper title led many scientists and engineers to associate dissymmetry's with Dissymmetry #2 mainly, while Thomson's handling of Dissymmetry #1 in terms of the concept of free energy and its conversion—instead of the management of Dissymmetry #1—also led to the interpretation of Dissymmetry #1 in terms of a corollary of the energy physics truism, "whereas ordered energy can be completely converted into heat in a spontaneous degradation, there is a strict limit to the amount of heat energy that can be transformed into mechanical energy." This is a consideration of the dyadic relationship between heat energy and mechanical energy.

That is a distortion of Carnot's Dissymmetry #1 conception of mechanical energy derived from "heat flow in its preferred direction from a high temperature to a low temperature." Carnot's conception has been carried out and refined by Clausius with his Second Fundamental Theorem: "*all transformations occurring in nature may take place in a certain direction, which I have assumed as positive, by themselves, that is, without compensation; but that in the opposite, and consequently negative direction, they can only take place in such a manner as to be compensated by simultaneously occurring positive transformations*" [8]:364].

Clausius introduced the treatment of "compensation" of transformations in the cyclic setting, quantitatively, in terms of the condition of "equivalence" between transformations. This led to the introduction of entropy in 1865. The idea of compensation as "equivalence" between transformations has been generalized into the concept of entropy growth potential (EGP, introduced in [9]) of a system that possesses "spontaneity" in a setting of the system in interaction with its environment reservoir. Whether powered by *compensation of positive transformations* or by *EGP*, the conception of Carnot and Clausius is a triadic relationship among "*entropy growth*," "*availability of a heat reservoir*," and "*management of entropy growth for powering heat extraction from the reservoir*" [10].

By asking rhetorically the difference between the outcomes resulted from heat transmission, *whether* it is a managed event of heat transmission as the positive transformation driving a Carnot cycle *or* it's a spontaneous heat transmission event, Thomson offered his answers: The first outcome is what Carnot prescribed—with the correction that mechanical work comes from the transformation of heat. The second outcome is that, though no destruction of energy whether under Carnot cycle management or spontaneously, something is lost in the spontaneous happening, the opportunity for "the work is *lost to man* irrecoverably" (in Thomson's own words in a draft to another paper predated his 1852 paper, see paper [11]: Appendix II, p.281). This is Thomson's "free energy answer" to his conundrum of "what is lost in workless heat conduction [12]:281]. The concept of free energy became the foundational stone for Gibbs' formulation of equilibrium thermodynamics. For directional tendency, Gibbs needed the assertion of *spontaneous* dissipation of free energy.

Such a conception of spontaneous dissipation of free energy could have been made to be consistent with Carnot and Clausius' treatment of the second law. (Such treatment unifying

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equilibrium thermodynamics and Carnot and Clausius' engineering-thermodynamics treatment has been made, referred to as Unified Classical Thermodynamics [UCT, [13].)

However, in the "Universal Tendency" paper Thomson also held the "irrecoverably lost opportunity to man" to mean the "irrevocable degradation of free energy," i.e., free energy not only dissipates spontaneously but also universally. In the former case, with spontaneous dissipation of free energy, the question is whether an equivalent amount of free energy can be restored, while in the latter it rules out the possibility.

Lost opportunity does not rule out availability of new opportunities. If one applies triadic-relationship thinking, given availability of new opportunities of entropy growth and of heat reservoir, an equivalent amount of free energy can always be restored. How much mechanical energy is "consumed" depends on the kind of entropy growth and the details of the entropy growth management. However, Thomson was guided with a dyadic thinking declaring, without proof, "any restoration of mechanical energy, without more than an equivalent of dissipation, is impossible." That is, once mechanical energy dissipates spontaneously into heat, "there is a strict limit to the amount of heat energy that can be restored back to mechanical energy." That, however, has been falsified, by Planck [9]: see Sect. 5.10] among others. The important point is that there is no *intrinsic* limit to the "consumed" mechanical energy that is necessary—directly against Thomson's declaration of what may be referred to as "conversion doctrine." Our analysis surmises, therefore, that the free energy formulation of energy physics is erected on the conceptual foundation of free energy defined, in addition to the <u>concept</u> of free energy, by, in ruling out availability of new possibilities, the inclusion of the <u>conversion doctrine</u> of free energy—which is at the root of the energy physics truism.

The conceptual foundation of free energy is defined, therefore, by the idea of free energy as both a concept and a conversion doctrine. We just argued that the way to think about events of true happenings requires triadic relationships thinking; that conversion doctrine discourages such way of thinking bares its deficiency. In the following, a closing argument against the doctrine is made.

The Methodological Foundation of Thermodynamics and the Compatibility of Its Dual Foundations

The centrality of "classical thermodynamics as a science based on two axioms or laws, independent of hypothetical or unobservable entities" [11]:278] suggests that thermodynamics is based on, in addition to a conceptual foundation, a methodological foundation of *conceptual differentiation* (of caloric into energy and entropy [as well as heat])—the foundation that all three founders of thermodynamics, Thomson and Clausius, as well as Rankine, embraced. It follows from this understanding that the theoretical system of thermodynamics is based on a **presupposition of dual foundations for the system**, its conceptual foundation and its methodological foundation. Here, we examine the compatibility of the conceptual foundation with the methodological foundation. The question that comes up in this examination is how the first law is understood, as our understanding of the second law depends on how we understand the first law.

The best explanation of the essence of the first law in the spirit of *conceptual differentiation* is given by Richard Feynman:

There is a fact, or if you wish, a law, governing all natural phenomena that are known to date. There is no known exception to this law—it is exact so far as we know. The law is called the conservation of energy. It states that there is a certain quantity, which we call energy, that does not change in manifold changes which nature undergoes. That is a most abstract idea, because it is a mathematical principle; it says that there is a numerical quantity which does not change when something happens. It is not a description of a mechanism, or anything concrete; it is just a strange fact that we can calculate some number and when we finish watching nature go through her tricks and calculate the number again, it is the same. [14]

Feynman's penetrating grasp on energy is in full display. Energy cannot be defined by what it is, or in terms of its mechanism, or its conversion, certainly not in terms of "ability to do work" (an idea that was carried over from "mechanical energy is the ability to do work" in frictionless setting);

 doi:10.20944/preprints202412.1474.v1

energy is the *abstract idea* of "a numerical quantity which does not change when something happens," i.e., the closure condition for every event and all events of happening.

This is not how the first law is typically stated in texts of thermo-dynamics, as it is understood as energy physics. A typical one is, "energy can be neither created nor destroyed; only the form in which energy exists can be transformed from one form into another" [9]: 44]. A more complete statement of the law can be found in "Fact or Fiction?: Energy Can Neither Be Created Nor Destroyed," *Scientific American* [15]—an excerpt of which can be accessed in Endnote 4 of [6]. As it has been argued in [6], "The law statement is a sweepingly powerful statement evidencing that Thomson was correct that there was something new beyond force. But is it energy? More precisely, what does energy consumption mean? Since energy can be neither created nor destroyed, what is consumed is not energy but some form of energy; energy of one form is consumed to become energy of another form. So, the operative 'part' of the above first law statement is '*the form in which energy exists can be transformed from one form into another*.' Since energy form and the direction of energy transformations are the purview of the second law of thermodynamics, this first law statement is not a statement of the first law per se but a statement of the combined first and second laws…" [6]: 2].

The inability of energy physics to demarcate the first law and the second law, thus violating the spirit of methodological foundation of conceptual differentiation, is inevitable with the fact that *conceptual foundation of free energy for energy physics* begins with the premise of "combined application of the first and second laws of thermodynamics"—the premise in contradiction to the very premise of methodological foundation of differentiating the two laws. We may refer to this as the dual foundations' conundrum.

We hereby propose a distinction between energy physics and thermo-dynamics, or "Unisical Thermodynamics" (see below for term's introduction): Both are theoretical systems subject to the presupposition of dual foundations, with the same methodological foundation. For energy physics, the concept of free energy is its conceptual foundation while, for thermodynamics, or unisical thermodynamics, the concept of entropy growth is its conceptual foundation.

The presupposition of dual foundations is of foundational significance for both systems. It crystalizes the issue to be whether *energy* as "the *abstract idea* of a numerical quantity which does not change when something happens" applies to the system. Dependent on the answer to the question, a watershed implication is "what the foundational lesson of the theoretical system is?".

For energy physics, the answer to the "energy as the abstract idea" is negative, thus, energy in accordance with the truism, rather than the abstract idea of closure conditions, "assumes," as heat energy, " a schizophrenic double role that it cannot fulfill" [16]: 180]. The double role refers to the role of closure condition and the role of a driving force. With these, the foundational lesson of energy physics is: (Le-1) energy is conserved; (Le-2) entropy inexorably grows, these two remain the bedrock of physics; as well as doctrinaire ones such as (Le-3) it is often accepted without question that the first law and second law can be expressed as "equation of change for 'energy'" and "equation of change for 'entropy'" respectively (see [13]: p. 335); and (Le-4) as the conversion doctrine asserts, whereas ordered energy can be completely converted into heat in a spontaneous degradation, there is a strict limit to the amount of heat energy that can be transformed into mechanical energy.

In paper [13], with the central message of primacy of dissymmetry's over free energy, numerable examples are given in support of the argument of "Lost opportunity does not rule out availability of new opportunities," supplanting Le-4. In a second paper [6], the concept of entropic indeterminateness is introduced to argue for rejecting Le-3 supplanting it with entropic indeterminateness. These are two papers of a trilogy, arguing against the doctrinaire part of the foundational lesson of energy physics.

Their rejection sets the stage for enhancing the explanatory power of physics. This paper, the third of the trilogy of three papers, incorporates the advances of the earlier two into *thermodynamics based on dual foundations*, which has been referred to as Unified Classical Thermodynamics (UCT in [13]). Or the theoretical system of *Unisical* (pronounced "unicycle" [yo͞onĭ-sīkəl]) *Thermodynamics*—transcending physics from its ironclad objectivity into an explanatory framework for phenomena of life.

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The foundational lesson of "thermodynamics based on dual foundations," or Unisical Thermodynamics, is Le-1; Le-2; and entropic indeterminateness (supplanting Le-3); the supplanted Le-4 (heat extraction powered by entropy growth potential); and one additional watershed-lesson of the new theoretical framework.

With entropy growth as the driving force, an inference of the heat-work equivalence theorem is that a reversible transformation requires a heat reservoir—the intrinsic role of such a reservoir is as a heat source for extraction of heat powered by the management of entropy growth. If so, there will be no "irrevocable degradation of free energy or mechanical energy" transcending the limit of (Le-4), nor "irrevocable accumulation of waste heat." These happen only when phenomena of entropy growth involve chemical-affinity driven combustion processes releasing heat at high temperatures. In these cases, entropy growth potential requires the heat reservoir to serve doubly as a heat sink for actualizing EGP (see [13]). The so-called waste heat includes in large part the "reversibly necessary" heat—for the classical Carnot cycle, heat by the amount of $Q_2 = Q_1\left({}^{T_2}/_{T_1}\right)$, where T_2 is the temperature of the reservoir—to be disposed to the heat sink.

Renewable energy sources are examples of entropy growth requiring no heat sink for actualizing EGP. Deployments of which do not lead to large waste heat, in fact, the opposite can happen in principle. "That the equivalence theorem demands, cumulatively, the prodigious production of heat to be disposed of is an incorrect scientific interpretation of the theorem. In the scheme of true reversibility, the necessity of the discharged heat results from the irreversibility of combustion heat release. Prodigious production of heat to be disposed requiring sizable heat-sink is not demanded by the equivalence theorem [in accordance with Unisical Thermodynamics of the renewable age], but the consequence of … the imperfect philosophical accord of the [combustion-powered] Industrial Revolution" [13]:340].

Concluding Remark

Feynman pointed out the slipperiness of energy in his *The Feynman Lectures on Physics* ***Volume 1*** (Ch 4), on that, Coppersmith noted, "if Feynman says the concept of energy is difficult, then you know it really is difficult" [12]: p.3].

That thermodynamics is difficult is notorious. Most engineers can do the calculation but are mystified by the meaning of equivalence theorem, as Job and Lankau noted, "Doubts about the meaning of the heat-work equivalence--accepted without question for one and a half centuries--appear hopeless and almost heretical" [16] :pp.171-172]. The author has been in the last ten years laboring in numerous papers (some of them, such as [13], are quite long ones), making a similar case—with the realization, finally, that the key to the issue is the interpretation of the equivalence theorem in terms of the conversion doctrine, unproved, readily falsified, but universally accepted as "ironclad truth."

This paper, therefore, tries once more, in a platform with strict focus on a single topic, to argue why the doctrine should be rejected including the rejection of the energy physics truism and the theory of exergy (again, not rejecting the concept of free energy or exergy as concepts used in calculation but their energy physics foundational lesson of Le-3, Le-4, and necessity in prodigious production of heat). Two new elements separating the paper from previous ones, are (1) - the specific error in Thomson's unproven assertion of equating "irrecoverably lost <u>opportunity</u> to man" with the "irrevocable <u>degradation</u> of free energy." And (2) - the dual foundations' conundrum: the fact that *conceptual foundation for energy physics* begins with the premise of "combined application of the first and second laws of thermodynamics"—the premise in contradiction to the very premise of methodological foundation of differentiating the two laws. With the two previous papers, the three papers together propose a new thermodynamics, with the central conclusion, "*On the new conceptual foundation of entropy growth for Unisical Thermodynamics, we arrive at an understanding of entropy growth as the universal driving force of macroscopic processes while energy conservation as closure condition to all processes*" (see also [13]: p.342, Sect. 8).

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