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Article

Reconsidering the Foundations of Thermodynamics from an Engineering Perspective

Terry Bristol

Institute for Science Engineering and Public Policy, Portland State University; bristol@isepp.org

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Abstract: Currently, there are two approaches to the foundations of thermodynamics. One, associated with the mechanistical Clausius-Boltzmann tradition, is favored by the physics community. The other, associated with the post-mechanical Carnot tradition, is favored by the engineering community. The bold hypothesis is that the conceptual foundation of engineering thermodynamics is the more comprehensive. Therefore, contrary to the dominant consensus, engineering thermodynamics (ET) represents the true foundation of thermodynamics. The foundational issue is crucial to a number of unresolved current and historical issues in thermodynamic theory and practice. ET formally explains the limited successes of the 'rational mechanical' approaches as idealizing special cases. Thermodynamic phenomena are uniquely dissymmetric and can never be completely understood in terms of symmetry-based mechanical concepts. Consequently, ET understands thermodynamic phenomena in new way, in terms of the post-mechanical formulation of action. The ET concept of action and the action framework trace back to Maupertuis's Principle of Least Action, both clarified in the engineering worldview research program of Lazare and Sadi Carnot. Despite the intervening Lagrangian 'mechanical idealization of action', the original dualistic, indeterminate engineering understanding of action, somewhat unexpectedly, re-emerged in Planck's quantum of action. The link between engineering thermodynamics and quantum theory is not spurious and each of our current formulations helps us develop our understanding of the other. Both the ET and quantum theory understandings of thermodynamic phenomena, as essentially dissymmetric (viz. embracing complementary), entail that there must be an irreducible, cumulative historical, qualitatively emergent, aspect of reality.

Keywords: Foundations of thermodynamics; Boltzmann vs. Carnot; engineering thermodynamics; quantum thermodynamics; Principle of Least Action; complementarity; Maupertuis; Lazare Carnot

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1. Introduction

Historically, there were two paths to thermodynamics: the engineering path of Sadi Carnot and the mechanical path of Clausius and Boltzmann. Oxford's Peter Atkins, in his book, *The Second Law*, maintains: "The aims adopted and the attitudes struck by Carnot and Boltzmann epitomize thermodynamics. … Carnot traveled toward thermodynamics from the direction of the engine, then the symbol of industrial society: his aim was to improve its efficiency. … Boltzmann traveled to thermodynamics from the atom, the symbol of emerging scientific fundamentalism, his aim was to increase our comprehension of the world at the deepest levels then conceived [1]."

Despite many unanswered questions, the modern consensus at least in the physics community, favors Boltzmann's mechanistic formulation of thermodynamics and the corresponding historical narrative of development of thermodynamics. Sadi Carnot and the caloric theory are presented as 'mere' historical footnotes. That is how I was taught thermodynamics in my physics and chemistry education at UC Berkeley. And yet to my surprise Atkins adds: "Thermodynamics still has both aspects, and reflects complementary aims, attitudes, and applications [1]."

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I confess that it took me a full three years of digging into the foundations to convince myself that not only was Atkins correct about the history, but that, in actual practice, there are indeed, two distinct modern formulations of thermodynamics. One typically favored in the physics community, the other in the engineering community. As a rough initial characterization, the former uses a closed system paradigm and the latter uses an open system paradigm (viz. hot source-working system-cold sink). The Clausius-Boltzmann paradigm embraces the concept of entropy and the objectivity of the standard Four Laws [2]. The engineering paradigm identified with Sadi Carnot is often identified with the limit of efficiency and the Carnot cycle.

Discussing Atkins's two formulations theme with a colleague, Robert Ulanowicz, he offered: "Oh, yes! When completing my Ph.D. in chemical engineering at Johns Hopkins, in my orals, in response to the obligatory thermodynamics question, if I had answered in terms of the Boltzmann paradigm, I would have been on the street the next day looking for a job selling real estate."

In convincing myself of Atkins's historical thesis and the continuing modern separation in current practice, I also discovered to my satisfaction that the two resulting formulations are not compatible. The crucial foundational question then presents itself: what is the relationship between mechanical thermodynamics and engineering thermodynamics? Atkins suggests that they are complementary, and I can see that in a certain sense, the open-closed difference makes this plausible. At the very least neither one is reducible to the other. The differences suggest a difference of type, a qualitative conceptual difference. They appear to be logico-mathematically incommensurable.

Certainly, the dominant representation of thermodynamics that comes from the physics and philosophy of physics community favors the Clausius-Boltzmann formulation [3][4][5]. In history of science scholarship, the engineering thermodynamics tradition is frequently represented as based on misconceptions, such as the caloric theory. And although key features of the open systems model are taught, such as limit of efficiency and the Carnot cycle, there is a presumption that engines are not fundamental or foundational and are somehow reducible to their component particles and to closed system mechanics.

I came to thermodynamics from physics, later expanding my perspective in philosophy of science. In the Popperian tradition of bold hypotheses [6], my thesis here is that: engineering thermodynamics, properly understood, is more general and more fundamental than mechanical thermodynamics. According to this thesis, all the mechanical formulations of thermodynamics must involve idealizations making them special cases of limited validity within the more general engineering framework. The bold hypothesis entails that engineering thermodynamics is foundational, formally subsuming and superseding all possible mechanical formulations. It is important to be clear that I understand 'science' as 'mechanics', and all mechanical frameworks as defined by classical presupposition of symmetry and conservation. An entailment of the bold hypothesis is that these symmetry and conservation principles must be limited, based on idealizations.

Atkins further maintains that the empirical research that discovered and defined thermodynamic phenomena as 'real', and, per hypothesis, as not reducible to the classical mechanical phenomena, in effect, discovered a fundamental, post-mechanical dissymmetry in the nature of reality [1]. [1]

2. Approach and Methods: Subsume and Supersede

To claim that one theory subsumes another means that all the successes of the subsumed theory can be accounted for by the more general subsuming theory [7]. However, the subsumed theory is 'not even wrong'. A simple analogy illustrates. For instance, the flat earth theory worked quite well,

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[1] Atkins (page9) [1]: "The Second Law recognizes that there is a fundamental dissymmetry in Nature: the rest of this book is focused on that dissymmetry, and so we shall say little of it here. All around us, though, are aspects of the dissymmetry: hot objects cool, but cool objects do not spontaneously become hot; a bouncing ball comes to rest, but the stationary ball does not spontaneously begin to bounce."

apparently for millennia. The advanced spherical earth theory is more general and accounts for all the successes of the flat earth theory. The historical reasonableness of the flat earth theory is pointed out in that we are very small observers on a very large sphere. The flat earth theory still works quite well within certain boundary conditions. However, the more general, subsuming, advanced spherical earth theory does not include the falsity content and predictions of the flat earth theory, such as falling off the edge of the earth at some point. Similarly, NASA's Apollo mission to land on the Moon programmed their computers using Newtonian physics even though it was presumed that Newtonian physics is subsumed by the more advanced Relativistic physics. For the Apollo mission, the nine-mile correction suggested by relativistic effects was well within the practical uncertainty of the positions resulting from each rocket-burn.

In the later developments of quantum theory Bohr offered a formal criterion of proper succession, what he called The Correspondence Principle: the later, more general theory must be able to account for the successes of the earlier theories without including their falsity content [8].

To claim that one theory supersedes another is more subtle and conceptual [7]. The transition to a more general, superseding theory is conceptually discontinuous, meaning that you cannot simply reason your way from the initial theory to the superseding theory. You cannot derive the more general superseding conceptual system from the superseded theory. The conceptual discontinuity entails the logical discontinuity. In his seminal book, *The Structure of Scientific Revolutions,* physicist and historian of physics, Thomas Kuhn, highlighted the conceptual discontinuity that characterized advances in knowledge and understanding [10]. Kuhn appropriately branded major advances as 'revolutionary' and, as involving a paradigm shift in both concepts and experimental techniques. The advanced, superseding theory adopts a qualitatively distinct, conceptually novel, framework. The successes of the previous theories are subsumed, albeit understood, conceptually, in a new way. Characteristic of advanced conceptual tools is that they allow one to generate novel questions, qualitatively new types of questions that were inconceivable in the previous, limited conceptual framework. Again, by analogy, in the spherical earth theory one can imagine new types of exploration and investigation such as circumnavigation and launching artificial satellites. The range of meaningful inquiry expands – emerges qualitatively. [2]

Per hypothesis, engineering thermodynamics subsumes and supersedes all possible mechanical representations of thermodynamics. Kuhn's paradigm shifts are represented as from one scientific theory to a more general scientific theory, always remaining *within* an overall scientific (mechanical) framework, defined by some sort of symmetry and conservation principles. The paradigm shift to the engineering thermodynamic framework is a step more general. As the flat earth is understood as a limited idealization from within the spherical earth theory, the symmetry and conservation principles definitive of all possible mechanical worldviews are to be understood as limited idealizations from within the more general understanding of the engineering thermodynamic framework.

An important consequence of the conceptual advances involved in paradigm shifts is that just as one cannot logically derive, for instance, Einstein's relativistic physics from Newtonian physics, it is also the case that one cannot understand the conceptual apparatus of Einstein's relativistic physics from within the conceptual framework of Newtonian physics. Similarly, the more sophisticated post-mechanical conceptual framework of quantum theory cannot be either derived from or understood from within the conceptual frameworks of either Newtonian particle mechanics or Maxwellian electromagnetic wave mechanics.

The point of all this is that according to my bold hypothesis the conceptual apparatus of the engineering framework cannot be derived from or understood in terms of any classical mechanical conceptual framework. Stated another way, the concepts of the more advanced engineering

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[2] This emergent aspect of actual advances remains largely unexplained. In the idealized scientific (mechanical) model, advances should be systematic, logico-mathematically consistent and convergence toward complete knowledge, wherein the range of meaningful questions should narrow as the uncertainty declines.

thermodynamics framework, by their very nature, are not reducible to, or properly understood in terms of, classical scientific, mechanical concepts.

An illustrative consequence, in the recent philosophy of engineering literature, is offered by Stanford aeronautical engineer, Walter Vincenti, in his seminal book, *What Engineers Know and How they Know It* [11]. He argues that engineering knowledge is conceptually distinct from scientific knowledge. Concerning the common representation of engineering as 'applied science', Vincenti responds: "Engineers know from experience that this is untrue." Vincenti challenges us to develop a more general epistemology that is not, by its very nature, reducible to any possible classically scientific, mechanical epistemology.

Duke engineer, Henry Petroski, in his book, *The Essential Engineer*, argues that what we have previously imagined to be scientific inquiry and scientific knowledge, is only properly understood, from within a more general superseding engineering framework as engineering inquiry and engineering knowledge [12].

Per hypothesis, engineering knowledge and engineering activity, by their very nature, can only be properly understood within the more general, foundational, engineering thermodynamic framework. In the engineering worldview the universe evolves thermodynamically, a way of understanding that subsumes and supersedes all possible classical scientific, mechanical worldviews. Engineering is thermodynamics. Thermodynamics is engineering.

3. Strategy and Transition

In order to develop and defend the bold hypothesis there are two closely related tasks. First, we need to articulate engineering thermodynamics from within an engineering conceptual framework. For instance, rejecting attempts to represent Carnot's insights in the terms of a rational mechanics. Second, the proper understanding of engineering thermodynamics requires a reconsideration of the *actual* history of the emergence of thermodynamics. Despite acceptance that thermodynamics originally arose from engineering and was not the result of any scientific research program, many historians have offered 'rational reconstructions' from a mechanical perspective. These begin with the presupposition that the 'real' development must have happened a certain way, consistent with a 'rational mechanics', because 'we know' that, ultimately, in the long run, the correct representation of knowledge and advances in knowledge must be rational mechanical, as in the postulated scientific Theory of Everything [13].

3.1. Donald Cardwell and the History of Thermodynamics

Historian of science and technology Donald Cardwell, being based at University of Manchester, naturally took a special interest in the history of the industrial revolution and the crucial influence of heat engines. More than other historians Cardwell realized that many of the 20th century histories of science and technology misrepresented the history of thermodynamics. Cardwell came to believe that the late 19th and early 20th century dominance of the mechanical worldview had led to misguided 'rational reconstructions' of the history of science and technology [14].

If one accepted the dominant cultural belief that the universe is governed by one universal mechanical order, 'it stood to reason' that advances in understanding reality must have occurred 'rationally', mirroring the supposed 'one' logico-mathematically, rationally consistent mechanical order governing reality. Whether advances could even potentially proceed in this way was the core controversy animating the latter half of 20th century history and philosophy of science [9]. Thomas Kuhn had served to crystalize a large body of diverse research suggesting the need for an alternative approach to the history of science and technology. What has been lacking philosophically, over the ensuing period, is a more general framework that can properly subsume and supersede the limited mechanical theories and their apparently limited ways of representing both successful practice and conceptual advances. Per hypothesis, we have been lacking a clear understanding of the more general engineering conceptual framework [15]. [3]

Cardwell came to believe that the dominant histories of thermodynamics, largely built on the work of Clausius, Kelvin, Joule and Boltzmann had misrepresented both the actual history of thermodynamics and, as a consequence, the correct understanding of engineering thermodynamics as foundational. Cardwell reflects [16]:

"Almost traditionally, it seems, accounts of the development of the concepts of work and energy have tended to describe them within the classical framework of Newtonian mechanics. They are seen as the end products of the celebrated *vis-viva* dispute in the eighteenth century: the outcome of a debate within the confines of the science of rational mechanics. I would like to suggest that this may be to take too narrow a view of the case."

I will argue that reconsideration of 'the celebrated *vis-viva'* debate reveals the origin of what Atkins identified as the 'two paths' to thermodynamics. Cardwell's careful scholarship on the history of thermodynamics also led him to recognize the competition between the two historical approaches to the formulation of thermodynamics [17]. The 'rational mechanics' approach, favored by theorists, mathematicians and logicians, represented thermodynamics as one logically consistent axiomatic system. This approach tacitly implied that advances in understanding must occur by means of some logically consistent rational process. The alternative, 'empirical mechanics' approach, favored by engineers, rejects the rationalist formulation wherein advances in understanding are 'rationally' foreseeable. In the 'empirical mechanics' approach advances require genuinely exploratory hands-on empirical investigation resulting in novel discovery. [4]

Cardwell re-introduced historical consideration of the practical, 'empirical mechanical' tradition. He soon recognized this as the engineering tradition. Appropriately Cardwell discovered the research and innovations of engineers such as Roger Smeaton [17] concerning the power and efficiency of waterwheel designs. And he recognized these as historical antecedents of Sadi Carnot's later investigations of the power and efficiency of steam engine designs. Questions such as how to design an engine for either maximum power or maximum efficiency are at the foundation of engineering thermodynamics. Such fundamental engineering questions have ancient roots and yet don't even arise within the 'just-so stories' of the rational mechanical narrative of the history of

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[3] We have been lacking a philosophy of engineering and engineering worldview that could subsume and supersede the previously dominant philosophy of science and the scientific (viz. mechanical) worldview. We need to reexamine both current scientific epistemology and ontology from a new post-mechanical point of view.

[4] What has been particularly misleading is that after each conceptually discontinuous advance the new way of understanding is re-axiomatized using the new concepts and definitions. Superficially, it can 'appear' that the sequence of advances have all occurred within one logico-mathematical framework, now, 'more clearly understood' in the concepts and definitions of this new latest axiomatization. Such an attitude is at least reasonable if one presupposes that the eventual final theory of everything will have a single, unified axiomatizable structure. Only with careful historical scholarship can it be established that the axiomatized advances are a sequence of logically discontinuous axiomatizations, each involving a paradigm shift to a more general conceptual framework that supersedes the prior axiomatized understandings. Only with quantum theory and the abandonment of the presupposition that the final theory will be mechanical, does a new approach begin to be taken seriously. Only with the embrace of post-mechanical quantum framework does the 'rational mechanist' dream of a conceptually uniform, logico-mathematically consistent final theory seem to be impossible.

thermodynamics. [5] Cardwell's evolving hypothesis was that the real history of thermodynamics requires a post-mechanical framework.

The emergence of the post-mechanical framework of quantum theory was completely unexpected from the perspective of the rational mechanics research program. Quantum theory challenged the rationalist historical narrative by undermining the claim that the classical, objectivist, mechanical framework could be foundational. Quantum theory is, by its very nature, more general than all possible mechanics, superseding, in particular, both Newtonian mechanics and the complementary Maxwellian mechanics [18]. Following Cardwell's insight as to the need to reconsider the history and foundations of thermodynamics from a post-mechanical perspective, it should not perhaps have been entirely surprising to discover a fundamental link between the real origin and nature of engineering thermodynamics and quantum theory.

Cardwell was eventually led to the work of Lazare Carnot.

3.2. Lazare Carnot's Engineering Worldview Project

Anyone who has studied the history thermodynamics is at least aware of Sadi Carnot, whose *Reflexions on the Motive Power of Fire* [19], first published in 1824 but unnoticed until 1834, is often cited as the founding treatise of thermodynamics. There is far less awareness in the thermodynamics community of his father, Lazare Carnot, who was writing on 'engineering mechanics' (viz. per hypothesis, thermodynamics) a decade or more before Sadi was born. As has recently been argued, and I agree, Sadi's founding treatise on heat engines is best understood as a direct application of Lazare's earlier engineering approach to understanding 'the fundamental laws of the communication of movement' [20].

The obscurity of Lazare's important, foundational work calls for an additional comment. Very, very briefly, Lazare was one of the three principals managing the French Revolution and had become the General in charge of the army of the revolution. Lazare was a key influence in the decision to behead Louis XVI. Subsequently, when the Bourbon monarchy was partially restored in France, Lazare books were banned. It was well into the 20th century before Princeton University historian Gillispie rediscovered and appreciated the significance of Lazare Carnot's fundamental contributions [21]. Since then awareness of his work has been growing [20]. [6]

Lazare's scholarship was not isolated. He was one of a number of engineers, physicists and mathematicians clustered in time around the new École Polytechnique in Paris during an extraordinarily productive intellectual period. Among the other faculty and students were Ampere, Cauchy, Lagrange, Navier, Poinsot, Fourier, Fresnel, Clapeyron and Coriolis.

Lazare Carnot clearly differentiates his empirical engineering mechanics project from the dominant alternative rational mechanics projects. Lazare points out, definitively, that "Every person knows, that in machines in movement, we always lose in time or in velocity what we gain in power [22]." He continues, that after carefully examining all the rational mechanics he finds that they are unable to explain this. Moreover, such options, such choices, can't even arise, can't even be made sense of in any fully deterministic rational mechanics.

Lazare is pointing out the obvious presupposition of all engineers, that there are alternative courses of action – with tradeoffs. There are options as to how a task might be accomplished, for instance, to lift something directly or, more slowly by using a pulley. Lazare's 'everyone knows' might more sympathetically be expressed as 'every engineer knows', although anyone active in the world tacitly knows that there are typically different approaches available to accomplish any task.

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[5] Stephen Jay Gould introduced the metaphor of 'just-so stories' into the philosophy of biology as a critique of imagined explanations that 'make sense' and 'stand to reason' but lack any real empirical basis. Gould's 'just-so stories' reference is to Rudyard Kipling's 1902 *Just So Stories*, deliberately fanciful stories for children in which the stories pretend to explain animal characteristics such as the leopard's spots or the elephant's truck.

[6] I am currently involved in a project translating, from French into English, Lazare Carnot's two mature works of 1803: The Fundamental Principles of Equilibrium and Motion and, The Geometry of Position.

Prominent in Lazare's thinking is the role of simple machines identified in the ancient engineering tradition.

Another way to characterize Lazare's project is as an attempt to develop a more general, post-mechanical worldview that is able to make sense of the place the engineer, common engineering knowledge and engineering practices, in the universe. The rational mechanics (viz. scientific) worldviews have no way to make sense of the creative freedom presupposed in engineering.

3.3. Pierre Maupertuis

Just as Cardwell reached back in the practical engineering tradition to see the relevance of Roger Smeaton to Sadi Carnot's work, it is important to seek earlier theoretical considerations contributing to Lazare's seminal engineering project. The intellectual milieu in physics and mathematics in the 150 years prior to Lazare Carnot's (1753-1823) investigations was defined by the contributions of Galileo Galilei (1564-1642), Rene Descartes (1596-1650), Isaac Newton (1642-1727) and Gottfried Leibniz (1646-1716).

In the more immediate 50 years the work Jean d'Alembert (1717-1783), Leonard Euler (1707-1783), Daniel Bernoulli (1700-1782) and Pierre Maupertuis (1698-1759) are most relevant to our narrative. One foundational debate among physicists, engineers, philosophers and mathematicians centered on the *vis-viva* controversy.

Lazare Carnot identifies Pierre Maupertuis's proposed resolution of the *vis-viva* debate as crucial to his mature engineering mechanics project [22]. And it is an understanding of Maupertuis's proposed resolution, I will argue, that clarifies the unexpected connection between engineering thermodynamics and quantum theory.

The *vis-viva* debate is commonly represented as concerned with the proper understanding (viz. conception) of the quantity conserved in motion and interactions. Before proceeding it is important to clarify why what is conserved is a crucial foundational issue. Symmetry and conservation principles are what define any mechanical framework. Therefore, the identification of just what quantity is actually conserved provides the conceptual foundation of the mechanical framework. Rene Descartes, in his *Mechanics* [23], had quite reasonably argued that the correct conception of the quantity of motion was momentum, the product of mass times velocity (mv). For Descartes, the total quantity of motion in the universe is conserved. [7] Newton agreed, in his *Principia*, that the momentum of bodies at rest or in uniform motion is conserved, in a closed (viz. isolated) system.

Gottfried Leibniz initiates the *vis viva* controversy, rejecting the Cartesian (viz. and implicitly Newtonian) proposals. He argues that what is conserved is properly conceived of as the product of mass times velocity squared (mv^2) [24][25]. However, following Cardwell's insight it is possible that many of the modern accounts of the *vis viva* controversy offer us only a 'rational reconstruction' of the history and supposed resolution from a mechanical perspective.

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[7] Bertrand Russell, in his *An Essay on the Foundations of Geometry*, points out that all possible geometries require a Principle of Equality (e.g. the Axiom of Free Mobility (or Congruence)). Symmetry and Conservation Principles are analogously required to define any possible rational, axiomatizable mechanics.

See also "The Meaning of Symmetry", Introduction, page 2 "First, we have the interpretation of the *equality of the parts with respect to the whole* in the sense of their *interchangeability* (equal parts can be exchanged with one another, while preserving the whole). Then, we have the introduction of specific mathematical operations, such as reflections, rotations, and translations, that are used to describe with precision how the parts are to be exchanged. As a result, we arrive at a definition of the symmetry of a geometrical figure in terms of its *invariance* when equal component parts are exchanged according to one of the specified operations." *Symmetries in Physics: Philosophical Reflections (*edited by Katherine Brading and Elena Castellani)

As physicist Patrick Hamill points out, although Isaac Newton and Gottfried Leibniz both invented the calculus, they had quite different conceptions of reality and how it evolved in time [26]." [8]

Leibniz reasoned that every kinetic event generated a new equal and opposite potential event. To illustrate he notes that the kinetic event of raising a body to a certain height against gravity results in an equal and opposite potential kinetic event [27]. [9] Leibniz new dynamic equilibrium of kinetic and potential events was proposing a new more general type of 'metaphysical' framework (viz. post-mechanical), a new way of understanding reality and how it changes. The postulate that the 'quantity of motion' in the dynamic equilibrium is conserved later became the central feature of Lagrange's analytic mechanics. It is well beyond the scope of this essay to argue for a definitive resolution of the *vis-viva* debate, but Leibniz's conception of a living force (*vis viva*) appears to supersede the previous conceptions of the dead force of Cartesian and Newtonian mechanics. The 'entities' of Leibniz's reality are not inherently passive particles. In Leibniz's ontology, his entities embody the living force, like agents, and 'change' naturally on their own, by their very nature. By contrast, Newtonian entities move/change only by the action of an external agent. At least superficially, Leibniz's dynamic ontology seems to have anticipated the thermodynamic phenomenon of Brownian motion.

Following Cardwell's suspicion that the history and nature of thermodynamics has been misrepresented as mechanical, it seems likely, as one might have expected, that the same misrepresentation applies to the supposed resolution of the *vis viva* controversy. Indeed, Cardwell in last chapter of his book, *From Watt to Clausius*, he is quite explicit in criticizing Peter Tait's supposed resolution that dominated the English-speaking literature for 100 years [28]. As will become clear I suspect, as did Cardwell, that the *vis viva* controversy remains unresolved in the modern milieu.

One of the illustrative technical problems concerning motion in the *vis-viva* debates had to do with understanding of the shortest path between two points. In Cartesian mechanics the answer was simple: a straight line. But with Leibniz's tacit introduction of Newtonian gravity as a consideration there were now two components of any motion. First there was the simple linear motion with constant velocity 'v', thought of as the horizontal component. Second was the vertical component of motion governed by continuous gravitational acceleration – 'v^2'. Assuming two points are neither perfectly horizontal nor perfectly vertical with respect to each other the path between the two points must be the result of some sort of combination of the two components. The empirical observation was that the actual path was quite definite and repeatable. In the ideal case this path came to be

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[8] Hamill (page 16) [26] "It is well known that Isaac Newton and Gottfried Leibniz both invented the calculus independently. It is less well known that they had different notions concerning the time development of a system of particles. Newton's second law gives us a vector relationship between the force on a particle and its acceleration. … Leibniz believed that the motion of the particles could be better analyzed by considering their *vis viva*.

[9] Leibniz (page 20) [27]: "Our new philosophers commonly make use of the famous rule that God always conserves the same quantity of motion in the world, In fact, this rule is extremely plausible, and, in the past, I held it as indubitable. But I have since recognized what is wrong with it. It is that Descartes and many other able mathematicians have believed that the quantity of motion, that is, the speed multiplied by the size of the moving body, coincides exactly with the moving force, or, to speak geometrically, that the forces are proportional to the product of the speeds and [sizes of] bodies." However, after considering an example of a body raised to a certain height and descending, Leibniz goes on. "Hence, there is a great difference between quantity of motion and force… Force must be calculated from the quantity of the effect it can produce, for example, by the height to which a heavy body of a certain size and kind can be raised; this is quite different from the speed that can be imparted to it. Nothing is simpler than this proof."

represented as the brachistochrone curve (viz. later recognized as a portion of a cycloid). The problem was how to explain this particular path, this particular combination.

Following his reanalysis of Fermat's earlier account of the shortest-time path of refracted light, Pierre Maupertuis argued that the brachistochrone curve, the actual, observed path, was not just any combination of the two components, but was the path optimized to take the shortest time. In fact, geometrically, by distance, it is a longer path. The continuously accelerating vertical component is what serves to differentiate the shortest time-path from the simple uniform straight line path expectation by the Cartesian and Newtonian mechanics.

Maupertuis's insight matured, leading to his general proposal, his Principle of Least Action: that all actual motion was an optimized combination – time-minimizing, least-effort – of these two idealized type of mechanical motion. Maupertuis's bold hypothesis was that all change and all structures and functions in the universe manifested this divine optimization [29].

These two idealized types of mechanical motion – one the perfectly horizontal 'mv' and the other, the perfectly vertical 'mv^2' – taken individually – can only provide incomplete descriptions of actual motion. The horizontal is an idealized uniform mv-motion where the vertical component is zero. The vertical is an idealized continuously accelerating mv^2-motion where the horizontal component is zero. Since they are orthogonal the one way of describing motion cannot be reduced to, cannot be expressed in terms of, the other. They are contraries. In modern parlance, they are conjugates. They are logico-mathematically and conceptually incommensurable, per hypothesis, complementary [30].

In so far as mechanical frameworks are defined by their symmetry and conservation presuppositions, each of these opposite types of motion defines a different type of mechanical framework. Each framework with its corresponding principles of conservation and symmetry. Maupertuis's great insight is that both perspectives must be valid, depending on the choice of frame of reference. Maupertuis is pleased that the greatest mathematician of the era, Leonard Euler, comments approvingly of his insight. Specifically, Euler points out that it applies to, and helps us to understand, the orbits of the planets as optimized combinations of their linear and curvilinear components. [10]

Maupertuis eventually takes us one step further to denying that perfectly horizontal (mv) mechanical motion and perfectly vertical (mv^2) mechanical motion are realizable. Consequently, no actual motion can be completely described or explained mechanically – that is, in terms of *one* idealized mechanics (viz. consistent with the symmetry and conservation presuppositions of one type of mechanics). Furthermore, since the actual paths are a combination of orthogonal, conjugate components, the paths cannot be characterized as any sort of simple sum of the two incommensurable types. [11]

Maupertuis needs a new way to portray the actual optimized path between any two points. Here he brilliantly introduces the notion of 'action'. All possible paths are possible actions and the actual paths, the actual actions, are the optimized paths of least action. What is important to recognize here is that, with the introduction of the notion of action, Maupertuis is introducing a conceptually novel framework – the action framework.

Maupertuis's action framework subsumes and supersedes all possible mv-mechanical frameworks and all possible mv^2-mechanical frameworks. By subsuming, Maupertuis's action framework is able to explain the limited, incomplete successes of each opposite, idealized mechanics.

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[10] The stable and regular planetary orbits also serve to illustrate Maupertuis's emerging post-mechanical worldview. The stabilities and regularities (viz. the mechanical-like relations) of reality are to be understood in a new way in Maupertuis action framework. These specific optimizations are like 'creative design solutions'. Optimization is unique to engineering where problem solving is value actualization. From an engineering point of view Maupertuis's optimized actions are the result of engineering work.

[11] More generally the paths cannot be related by any continuous, logico-mathematical function.

Maupertuis's action framework is post-mechanical, conceptually superseding, understanding all mechanical concepts and frameworks in a new way, as partial, limited idealizations of actual phenomena. The action framework understands the idealized mechanical conceptions of motion in a new way – the new way being is in terms of action.

That these opposite idealized mechanical types are actually incommensurable is suggestively supported by the historical independence within Newtonian mechanics itself of the Three Laws (viz. where motion is always linear) and the Law of Gravitation (viz. accounting for the curvilinear component of actual motions). Newton's Three Law might be reasonably represented as a sort of generalization of the Cartesian mechanics since all motion in both cases is presumed to be naturally rectilinear. Newton's Theory of Gravity however stands apart in so far as it entails an accelerating curvilinear component that is not reducible to uniform rectilinear motion. [12]

3.4. Engineering Thermodynamics and Quantum Theory

In the context of my overall bold hypothesis there seems to be a foundational link, generally unexpected, between engineering thermodynamics and quantum theory.

In the several decades before quantum theory one might have characterized our uncomfortable situation as having an embarrassing over-abundance of different types of 'objectivities', for instance, the Newtonian and the Maxwellian. With quantum theory we have something more like a range of potential objectivities – each practically optimized combination, valid within its defining constraints. Maupertuis's thesis that there is an irreducible component of each opposite type of idealized mechanics in all change is entirely analogous to Louis de Broglie's quantum theory thesis that every observation involves an irreducible component of the complementary particle and wave aspects of reality. [13]

With even superficial reflection there are other connections, at least analogies, between Lazare Carnot's engineering thermodynamics project and quantum theory. Both require an active agent, an actualizing observer or a participant engineer, as an essential, irreducible component of any self-referentially coherent representation. This participant aspect of quantum theory has been thoroughly enigmatic in the attempts at a mechanical representation of quantum theory. Per hypothesis, in a more general, superseding engineering worldview 'the observer of quantum theory' is understood in a new way, as a naturally active, inquiring, actualizing engineer.

In both quantum theory and engineering thermodynamics prior to the choice of the appropriate frame of reference, boundary conditions and experimental setup the future is indeterminate. The present, although constraining, does not determine a unique future. The observer's choice in quantum theory that collapses the wave function is usually characterized as 'analytically arbitrary'. The 'indeterminate situation' in engineering thermodynamics, by analogy at least, might be represented in terms of the Gibbs free-energy situation – constrained but enabling. However, it is important to recognize, per hypothesis, that the Helmholtz free-energy situation is complementary. The Gibbs and Helmholtz situations define the possibility of performing two alternative, opposite types of work.

It is perhaps helpful to recall that quantum theory was, and still is, a theory of thermodynamics. Max Planck's investigation of black body radiation is properly understood as an engineering

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[12] Of all the possible combinations what selects what is optimum? Maupertuis suggests that the order of the universe, the structures and functions and, how they evolve, reflect design solutions and, consequently, some sort of purpose (teleos) – practical and perhaps divine.

[13] Bohr's insight was that not only are idealized particle and wave phenomena complementarity, but the idealized structure and function of the experimental designs required to observe them must be complementary. Indeed, the sequence of actions required to generate those mechanically idealized experimental designs must be complementary.

thermodynamics research project. Per hypothesis, the proper history of quantum theory requires an engineering thermodynamics framework.

3.4.1. A Little Confusion

Euler's endorsement certainly emboldened Maupertuis. Then something strange and truly confusing happened. Euler says in effect: 'Yes, Maupertuis's fundamental insight about the optimized structures and functions of reality is correct', but it's not very 'useful' [29]. Here is where the two historical paths identified by Atkins acquire their more modern characteristics. If I understand Euler, he is saying that Maupertuis's insight isn't very useful for empirical mechanical inquiry and practical problem solving.

What emerges is the Euler-Lagrange line of development defining a new type of mechanics – Lagrangian. What differentiates Lazare's engineering thermodynamics from the new Euler-Lagrange advance is that the latter adopts symmetry and conservation principles that keep it well within the foundational tradition of determinate mechanics. Despite the introduction of the new types of dynamic equilibrium between kinetic and potential, Lagrangian mechanics is still mechanically symmetric and, ontologically, 'energy' is conserved.

However, as Coopersmith [31] notes Lagrangian mechanics falters in its ability to account for dissipation. Per hypothesis, this 'dissipation' is the conjugate mechanical component. [14] In Lagrangian mechanics what is conserved, the energy, is of *one type.* In the Lagrangian system each present defines a unique determinate 'objective' future in the classical scientific sense. And yet there are no actualizing observers and, no constructive engineering agents.

The confusion, according to this analysis, generated by the Euler-Lagrange path is compounded by their introduction of idealizing mechanical definitions of both 'action' and the Principle of Least Action.

Historically, despite theoretical limitations, as Euler envisioned, Lagrangian mechanics has been tremendously useful. This led to further advances in the work of William Rowan Hamilton, plausibly still within the mechanics research program. However, whether 'energy' is conserved has been questioned and, the nature of the defining symmetry is arguably somewhat ambiguous. Nonetheless the Hamiltonian toolkit has proved quite useful in experimental investigations and applications of quantum theory.

Lazare Carnot actually provides the clearest, most accessible account of what is behind Euler's not very 'useful' critique of Maupertuis's insight. In one of Lazare's earliest contributions, later published as *Reflexions On the Metaphysical Principles of the Infinitesimal Analysis*, notes that the use of infinitesimal analysis lacks formal rational justification [32]. Basically, it doesn't make sense. To see his point, one need only reflect on the inherently ambiguous or, perhaps outright self-contradictory, statements common in modern thermodynamics such as – 'the piston moves infinitely slowly'. Lazare argues that infinitesimal analysis, nonetheless, is an essential tool in empirical mechanics research. If reality involves complementary orders, then to empirically discover the 'useful' relationships of one idealized mechanical order you need to minimize the complementary aspect, making it practically irrelevant, 'ignorable'. In suggesting a superseding understanding of infinitesimal analysis, Lazare is suggesting a superseding engineering understanding of the use and value of idealizations in empirical inquiry.

In Lazare's superseding understanding 'objectivity' is 'real' but always bounded. Engineering 'objectivity' is never the universal time-space invariant objectivity imagined in the classical scientific

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[14] Coopersmith (page 36) [31]: "It is very strange to say, but this profound yet banal human experience of time plays no part whatsoever in the dynamics of either Newton or Lagrange. Even though the dynamics examines macroscopic effects (but, crucially, microscopic dissipative effects, like friction or air resistance, are ignored) there is no sense of time flowing, no difference between making time run forward or backward in the equations. As Einstein wrote: "… the distinction between past, present, and future is only an illusion, however persistent."'

tradition. From within a more general engineering worldview Lazare presents a justification of differential calculus as not only 'useful', but as an essential tool in empirical research. Inquiry is newly understood as seeking to discover the regularities and uniformities describable by idealizing continuous functions within 'objective' boundary conditions. At the same time, Lazare is offering a more general, non-standard logic justification of induction – within uniform boundaries [33]. In standard, formal logic, induction is not deductively valid, but within the boundaries of a stable uniformity, within an engineering 'objectivity', it is valid. In the modern post-mechanical context, Newtonian mechanics and Maxwellian mechanics are both 'objectively valid' in the engineering sense, within boundary condition and with respect to specific types of experimental setups.

Lazare's representation of 'science' is similar to Henri Poincare's conventionalist model wherein scientific inquiry, by its very nature, must always be idealizing [33]. In the modern debate about the falsifiability of scientific theories, University of London philosopher of science Imre Lakatos argued in keeping with Lazare's understanding that all meaningful scientific theories are necessarily false – in the sense of being inherently incomplete (viz. bounded). No meaningful, falsifiable theory (viz. knowledge) can achieve the classical objectivist ideal of being demonstrably reproducible over changes in time and location, of being universally time-space invariant. Lakatos attributes a similar position to George Hegel who suggested that 'to conceive is to falsify' in that it requires selecting a way to conceive, to observe, to understand [34]. One way to express this is to say that reality is more ample than any single conception, than any single way of observing. In Lazare's engineering worldview reality is more ample than any single mechanical description.

Bohr emphasized that to observe and investigate the particle-like aspect of reality you need a different type of experimental setup than if you wish to investigate the wave-like aspect of reality. When Bohr's colleagues pressed him as to the nature of underlying quantum reality, he responded: 'There is no quantum reality. Get over it.' Bohr was emphasizing that quantum theory is post-objective as well as post-mechanical, subsuming and superseding the idealized particle and wave ontologies of the corresponding mechanics. Consequently, there are no particles and there are no waves in the Newtonian or Maxwellian senses. Physicist Nick Herbert offers what remains as one of the best presentations of the problem of making sense of quantum reality [35].

Einstein expressed the problem of replacing the classical ideal of 'physical reality' with a more general, more advanced quantum reality (page 81) [36]:

"[Classically] Physics is an attempt conceptually to grasp reality as it is thought independently of its being observed. In this sense one speaks of "physical reality." In pre-quantum physics there was no doubt as to how this was to be understood. In Newton's theory reality was determined by a material point in space and time; in Maxwell's theory, by the field in space and time. In quantum mechanics it is not so easily seen."

Einstein's critique had pointed out that Newton's physics tacitly presupposed absolute simultaneity, entailing that everything happens at the same time. However, this is only possible if everything happens in the same place, thus – Newtonian reality is a 'material point in space and time'. In Maxwell's physics reality is the idealized field completely distributed in space and time. Newtonian reality is ideally completely local and Maxwellian reality is ideally completely non-local. I have argued previously that the Newtonian space-time framework and the Maxwellian space-time framework are complementary. If correct, then Einstein's preference for the Maxwellian space-time framework in Relativity reflects a 'useful' bias to a mechanical framework, away from the more general indeterminate action framework [7]. Per hypothesis, both quantum theory and relativity share the same foundation and they are more completely understood as one theory from an engineering thermodynamics point of view.

Wolfgang Pauli begins to articulate the characteristics of the new more general, post-mechanical framework of quantum theory (page 36) [37]:

"The relation of indeterminacy, which is inherent in the laws of nature, just makes mutually exclusive the experiments which serve to check the wave properties of an atomic object, and the other experiments which serve to check its particle properties. The significance of this development is to give us insight into the logical possibility of a new and wider pattern of thought. This takes into account the observer, including the apparatus used by him, differently from the way it was done in classical physics, both in Newtonian mechanics and in Maxwell-Einstein field theories.

"In the new pattern of thought we do not assume any longer the *detached observer*, occurring in the idealizations of this classical type of theory, but an observer who by his indeterminable effects creates a new situation, theoretically described as a new state of the observed system. In this way every observation is a singling out of a particular factual result, here and now, from the theoretical possibilities, therefore making obvious the discontinuous aspect of physical phenomena."

In the early days of quantum theory Pauli worked out the mathematics of Werner Heisenberg's initial insightful theory. In presenting the results to Heisenberg, Pauli comments: 'You can investigate in the p-way or you can investigate in the q-way, but if you try to do both at the same time it will drive you crazy [37].'

Quantum pioneer Louis de Broglie made the point that in the quantum worldview, in all idealizing particle experiments there is an irreducible wave aspect and in all idealizing wave experiments there is a quantized particle aspect [38]. In Newton's original particle mechanics there are no waves and in Maxwell's original wave mechanics there are no particles (viz. no discontinuities or localizations). Quantum theory is post-mechanical subsuming and superseding all possible mechanics in conjugate, complementary pairs. [15]

3.5. Quantum Theory as Engineering Thermodynamics

In the early 20th century, from a mechanical point of view, something completely unexpected and enigmatic happened. Quantum theory gradually emerged and matured. Central to my bold hypothesis is that what connects the engineering origin of thermodynamics with quantum theory is the concept of action. Maupertuis's original indeterminate, dualistic notion of action, that was mechanically idealized in Lagrange's analytic mechanics, reappears in Max Planck's quantum of action.

Many modern portrayals of quantum theory emphasize the ontological enigma of particles and waves associated with the two-slit experiment. These depictions have unintentionally served to deemphasize that quantum theory is a theory concerned with thermodynamic phenomena. Planck's research into black body radiation was thermodynamic research both practically and theoretically. His research was funded by the new German electric light industry seeking the optimum relationship between power input and light output. Planck himself was hoping to overturn Boltzmann's introduction of statistical mechanical concepts into thermodynamics (viz. into physics) [39].

Schrodinger's popular wave function is clearly an 'energy' formula. Schrodinger had originally imagined his approach to quantum theory was a return to 'sensible' wave mechanics [40]. In both Maupertuis's and Planck's action frameworks, prior to making a choice of the appropriate boundary conditions, and how to engage (viz. the choice of experimental setup), the situation facing the observer/agent is indeterminate. Max Born made clear that the 'situations' characterized by Schrodinger's approach were initially indeterminate, prior to the observer's choices [41]. In Lazare's framework the constrained indeterminacy defines the engineer's 'problematic' situation, the constrained range of opportunities to perform work to solve a problem and actualize value [42].

3.6. Atkins's Dissymmetry Thesis and Maupertuis's Evolution

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[15] Of course, in the intellectual milieu of Maupertuis and the Carnots, there was no electromagnetic theory. However, in fact, conjugates are ubiquitous throughout physics and per hypothesis, in all the sciences and mathematics. From ancient times the question of a geometric relation between lines and curves was of central concern (viz. squaring the circle). Newton's famous thought experiment, 'Newton's Bucket', highlighted his concern with the relation between linear and curvilinear motions. See also Euler on lines and curves. I think it is somewhat embarrassing that even in today's mechanics, rotation is accounted for in terms of 'fictional forces'.

Peter Atkins dissymmetry thesis is relevant to the question of the proper foundations of thermodynamics [1]. Atkins argues that the historical discovery of the dissymmetric character of thermodynamic phenomena meant that thermodynamics phenomena could never be reduced to mechanical phenomena as defined within symmetric mechanical frameworks. Atkins suggests that the discovery of thermodynamics phenomena constitutes the discovery of an essential, irreducible dissymmetric aspect of the nature reality. If true I take it to be supportive of my bold hypothesis. Per hypothesis, if the dissymmetric characteristic of phenomena is more fundamental than the idealized symmetric characteristics, it means that we need a more general, subsuming, superseding, post-mechanical framework to understand the actual thermodynamic character of reality. In such a broader view, the success of any possible mechanics would be understood as a limited special case within the more general, foundational dissymmetric engineering thermodynamic worldview. Similarly, since the more general indeterminate 'action' of quantum theory cannot be reduced to the concepts of classical particle mechanics and/or wave mechanics, a more general post-mechanical framework is required to understand the dissymmetric quantum worldview.

There is another important entailment of the dissymmetry thesis. Classically symmetric systems are always conservative – zero-sum games. In a simple Newtonian system every action has an equal and opposite reaction. If the action and the reaction are of *the same type*, then the net change is zero. In closed, isolated mechanical systems with one type of ontology, one uniform type of 'energy', the net change of the ontological quantity must be zero. Cambridge physicist John Barrow, in his *The Book of Nothing*, develops the implication of a scientific worldview defined by symmetry and conservation principles (viz. where the universe is a closed, isolated mechanical system) [43]. Barrow argues that if you add up all the charge in such a universe it perfectly balances and cancels, so there is no net charge. Similarly, if you add up all the motion (as in $E = mv^2$) it must also balance and add up to zero. The curious implication is that the sum of any symmetric, conservative mechanical universe –is zero, the reality is nothing. [16]

Maupertuis had certainly noticed that since the components of all action, of all change are opposites (viz. per hypothesis, complementary), they are *not of the same type*. As a Consequence, neither the result of any action nor the sum of the actions of a system over time can be net zero. Even though the opposite components form a new type of dynamic equilibrium, it is not 'net zero' symmetric in the classical sense. Therefore, all systems must have an irreducible aspect of net change. They must develop. Because they are different types, the optimizing action-reaction processes in Maupertuis's worldview produce a net, non-zero change. Per hypothesis, since the net change is post-mechanical (viz. can't be understood in terms of only one type of mechanics) the change is, plausibly, properly represented as having an irreducible an emergent, quality. In the action framework processes are necessarily generative of a net historical product. What is the product? Per hypothesis, the net product over time is a cumulatively actualizing, historically evolving non-zero-sum universe. It is not coincidental that subsequent to his insights leading to the Principle of Least Action, Maupertuis composed two major works on evolution [44][45]. If the engineering thermodynamic

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[16] Atkins (page 9) [1]: "In 1851 Kelvin adopted that, after all, physics was the science of energy. Although forces could come and go, energy was here to stay. This concept appealed deeply to Kelvin's religious inclinations: God, he could now argue, endowed the world at the creation with a store of energy, and that divine gift would persist for eternity, while the ephemeral forces danced to the music of time and spun the transitory phenomena of the world.*"

"*A mischievous cosmologist might now turn this argument on its head. One version of the Big Bang, *the inflationary scenario*, can be interpreted as meaning that the total energy of the Universe is indeed constant, but constant at zero! The positive energy of the Universe (largely represented by the energy equivalent of the mass of the particles present, that is, by the relation $E = mc^2$) might exactly balance the negative energy (the gravitational attractive potential energy), so that overall the total might be zero. Thus, Kelvin's God may have left a nugatory legacy."

framework turns out to the more general, post-mechanical foundation for understanding reality, it seems plausible that Maupertuis's contribution to the theory of biological evolution will subsume and supersede the mechanistically-based Darwinian, and neo-Darwinian approaches.

All this is completely consistent with various post-mechanical, participant representations of quantum theory, for instance, by Princeton's John Archibald Wheeler [46], Berkeley's Henry Stapp [47] and Harvard's Alfred North Whitehead [48].

The hypothesis that the evolution of the universe is a qualitative, cumulatively emergent, recursively enabling engineering enterprise requiring an experimental research and development, requiring a concomitant evolving engineering intelligence is certainly not new. It is the theme of Plato's dialogue, *Timaeus* [49], where the question being explored is: How did the universe come to be as it is? The answer suggested by Timaeus is that the evolution is an engineering enterprise of an architekton (viz. master craftsman (engineer) and/or a demiurge (the public worker) [50]. Timaeus assures us that the 'plan' is never analytically, deterministically pre-specifiable. Yet the recursively enabling path of development is constrained, always seeking a more desirable future

3.7. Reflection on Current Thinking

Physicist Jim Baggott, in his excellent review of the current situation in his book, *Farewell to Reality: How Modern Physics Has Betrayed the Search for Scientific Truth*, emphasizes that the questions of quantum realism remain unresolved [51].

Despite expressions of serious misgivings current prominent physicists continue to move to the default mechanical framework (viz. defined by symmetry and conservation principles) in their representations of thermodynamics. Columbia University physicist Brian Greene, in his book, *The Fabric of the Cosmos*, relates his experience on learning of Loschmidt's critique of Boltzmann's mechanical representation of thermodynamics (page 168) [4]:

"When I first encountered this idea many years ago, it was a bit of a shock. Up until that point, I had thought I understood the concept of entropy fairly well, but the fact of the matter was that, following the approach of textbooks I'd studied, I'd only ever considered entropy's implications for the future. And, as we've just seen, while entropy applied toward the future confirms our intuition and experience, entropy applied toward the past just as thoroughly contradicts them. It wasn't quite as bad as suddenly learning that you've been betrayed by a longtime friend, but for me, it was pretty close."

String Theory was initially conceived as a more enlightened physics based firmly in taking thermodynamics as foundational [52]. String Theory's all-important beta-function comes directly from thermodynamics. Yet Greene, endorsing String Theory, assured me [Personal Communication] that it is fully deterministic, keeping it within the mechanical paradigm.

Cal Tech physicist Sean Carroll, in his book, *From Eternity to Here* offers a number of penetrating critiques of the standard mechanical Boltzmannian representation of thermodynamics. In his course The Mysteries of Physics: Time, Carroll offers (page 220) [53]:

"What Boltzmann had bequeathed was a set of machinery that didn't have an arrow of time built in. It could explain entropy going up toward the future, but it also explains entropy going up toward the past, which nobody thought was true. The challenge was could you use these time-symmetric underlying laws of physics to derive a time asymmetric conclusion. The answer is no. Loschmidt was right. It was not that he was making some mistake or that Boltzmann wasn't careful enough. Loschmidt's reversibility objection is absolutely valid.

"If all you have to work with are underlying laws of physics that are symmetric with respect to past and future, you do not derive a different behavior for the future than you do for the past. You need to add something to that machinery, you need to add an extra assumption, and you need to add an extra assumption that is explicitly asymmetric with respect to past and future. That extra assumption is what we call the past hypothesis."

Columbia University philosopher of physics, David Albert, has offered still the best presentation of the past hypothesis [54]. Although the introduction of an essential asymmetry (viz. dissymmetry) would seem to entail the need for a post-mechanical framework, in his latest contribution Carroll reassures us that the 'real', hidden, underlying reality has no participants, is completely symmetric and 'energy' is conserved [55].

Perimeter Institute physicist Lee Smolin in his 2006 book, *The Trouble with Physics: The Rise of String Theory, The Fall of Science, and What Comes Next* [56], expressed the growing dissatisfaction with the state of physics of many within the physics community. However, in his recent attempt to explore 'what's next', *Time Reborn: From the Crisis in Physics to the Future of the Universe*, he has been unable to find a way out of the tradition of the mechanical paradigm [57]. Smolin offered the following personal reflection to an incoming class of physics graduate students [58]:

"When my generation entered physics in the 1960s and 1970s, we were enthusiastic and quite hopeful about our prospects of resolving the questions of quantum reality. The founders of quantum physics and the subsequent generation had simply given up. – – It's now 2010, and it has become rather Kafkaesque that we have made no progress whatsoever."

Philosopher of physics Craig Callender, at UC San Diego, originally one of best and most prominent critics of the mechanical interpretations of thermodynamics has most recently taken a turn to the dark side (viz. deterministic mechanics) explicitly abandoning any role for participant agency [5].

On a more hopeful note, leading Los Alamos particle physicist, Geoffrey West having morphed to become the President of the Santa Fe Institute, the leading edge think tank founded by Nobel Laureate physicist Murray Gell-Mann, expresses what I take to be a more enlighten view [59]:

"All the laws of physics can be derived from the principle of least action which, roughly speaking, states that, of all the possible configurations that a system can have or that it can follow as it evolves in time, the one that is physically realized is the one that minimizes its action. Consequently, the dynamics, structure, and time evolution of the universe since the Big Bang, everything from black holes and the satellites transmitting your cell phone messages to the cell phones and messages themselves, all electrons, photons, Higgs particles, and pretty much everything else that is physical, are determined from such an optimization principle.

"Optimization principles lie at the very heart of all of the fundamental laws of nature, whether Newton's laws, Maxwell's electromagnetic theory, quantum mechanics, Einstein's theory of relativity, or the grand unified theories of the elementary particles. Their modern formulation is a general mathematical framework in which a quantity called the action, which is loosely related to energy, is minimized." [17]

4. Discussion and Conclusions

Following the hints from Peter Atkins that there were two distinct historical paths in the development of modern thermodynamics, and that both approaches and corresponding formulations are still alive and well, I considered the relation between them. Atkins postulated that they are complementary. I offered a bold hypothesis that engineering thermodynamics (viz. properly understood) is more general than any mechanical formulation of thermodynamics.

I argued that engineering thermodynamics is post-mechanical and formally subsumes and supersedes all possible mechanical formulations of thermodynamics. The limited successes of the mechanical formulations are to be explained as based on idealizations and understood in a new way, more generally, in the context of optimizing engineering action. I concluded that engineering thermodynamics is the true foundation of thermodynamics.

Accordingly, the true history of thermodynamics is the history of engineering thermodynamics. I argued in support of Donald Cardwell contention that most modern historians misrepresent the history of thermodynamics. Because they reason from mechanical presuppositions they generate

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[17] In mechanical frameworks the ontology (viz. 'energy') is of only *one uniform homogeneous type*. There is no need to optimize – just calculate the unique determinate future from the present. Per hypothesis, optimization of qualitatively distinct conjugate (viz. complementary) components is characteristic of both post-mechanical engineering thermodynamics and quantum theory understandings of reality.

misguided 'rational reconstructions' of the history of thermodynamics. Cardwell's proposed research program is to reconsider both the history and proper understanding of thermodynamics from a post-mechanical perspective. I reaffirmed his thesis that thermodynamics should be understood as part of the engineering tradition that reaches back to ancient times.

I argued that engineer Lazare Carnot, the father of Sadi Carnot, is a crucial contributor in the history of engineering thermodynamics. Lazare Carnot differentiates his engineering research program by emphasizing the inadequacy of any rational mechanical worldview to account for what 'everybody knows' – that we always lose in time or in velocity what we gain in power. Lazare sought a more general, empirical engineering framework that would provide a coherent understanding of the place of engineers and engineering in reality. His engineering framework is overtly post-mechanical, intended to subsume and supersede all possible rational mechanical frameworks.

Per hypothesis, Lazare's engineering mechanics is, literally, engineering thermodynamics. The history and foundations of thermodynamics makes sense only from within a self-referentially coherent engineering understanding of reality.

Lazare identifies Pierre Maupertuis's resolution of the *vis-viva* debate and his post-mechanical Principle of Least Action as a key intellectual antecedent. Although Maupertuis formulation was 'somewhat vague' Lazare realized that he had proposed a post-mechanical theory of change. In Maupertuis's new action framework, the present is both constrained and enabled and does not uniquely determine the future. The present is indeterminate and the future emerges through the optimizing choices of the embedded agency (viz. quantum observers or constructive engineers). In quantum theory and Lazare Carnot's engineering framework it is the choices, always involving uncertainty, that actualize the future. Since the choices could have been different, within the constrained range of possible actions, it must be that the narrative history might have evolved differently.

Unexpectedly, Maupertuis's inclusive resolution of the complementary mechanical frameworks involved in the *vis-viva* debate, followed by Lazare's clarifications, suggested a link to modern quantum theory. In keeping with Cardwell's initial suspicion, I argued that the deep link could be understood in terms of their common concept of 'action'. Dominated historically by the fully determinate, mechanical idealization of action in Lagrangian mechanics, Maupertuis's original dualistic, indeterminate conception finally re-emerges in Planck's quantum of action. Since quantum theory arose from Planck's thermodynamic research and both quantum theory and engineering thermodynamics require an embodied agent to actualize an otherwise indeterminate future I reasoned, per hypothesis, that they share, in some fundamental, foundational sense, the same post-mechanical framework.

I argued that Atkin's thesis, that the discovery of thermodynamic phenomena constituted the discovery of an irreducible, post-mechanical dissymmetric aspect to reality, is further support for the bold hypothesis. The classical mechanical principles of symmetry and conservation are valid but limited special cases to be understood in a new way within the more general, foundational dissymmetric engineering thermodynamic worldview. I argued that the action-reaction dissymmetry of complementary types of action entails that reality is not historically zero-sum in the mechanical sense. The engineering thermodynamic worldview must have a naturally generative aspect resulting in an irreducible cumulative, historical, qualitatively emergent aspect of reality.

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