Thermal Approximations: Probability, Energy, and the Unknowable

At the beginning of the 19th century, physicists could confidently claim a greater understanding of the dynamics of the universe than their peers at the beginning of the 20th century. At the beginning of the 20th century, physicists could confidently claim a greater understanding of the dynamics of the universe than their peers at the beginning of the 21st century. If this trend continues, will poor 22nd century physicists be able to make any confident claims about the structure of reality? Physicists today might point out that the confidence of their 19th century peers was misplaced, and today's abundance of uncertainty signals how much we have learned about how much there is yet to learn. Is it peculiar that the more we learn, the more we realize we do not know? Is this an intrinsic facet of all branches of knowledge? Or is it unique to fundamental physics?

Less optimistically, has physics has been developing down a wayward trajectory? Perhaps some fundamental assumptions have sent the quest for cosmological truths and a complete knowledge off course over the past century. Modern observations and interpretations have constructed a model of the universe which is 95% utterly inarticulable (in the form of Dark Energy and Dark Matter). What percent of the universe was deemed inexplicable to 19th century physicists? Riding high on the determinism of Newton's Mechanics, presumably much less. This is not to suggest that today's physicists are less adept at conceptualizing and solving the dynamics of the universe, indeed the opposite seems true. It is odd though that we have pursued a course of knowledge production in which new observations and insights produce new sets of problems and paradoxes. Is this not exactly the kind of inextricable mess one would expect if they had a deeply embedded error—like a crossword puzzle that cannot be solved due to an early mistake?

This article plummets such speculative depths. Particularly, I trace the concepts temperature, probability, and energy from their germination to their convergence in the 19th century in the steam engine. The socio-economic entanglement of these concepts has, for better or worse, guided the development of physics over the past 150 years. I further explore how the constructed relationship between probability and energy has underwritten the numerous irreconcilable uncertainties, indeterminacies, uncomputabilities, and unpredictabilities that have emerged over this time.

Something's Off

Arkani-Hamed (2012, 2013) has suggested that something is not quite right with spacetime as currently formulated. As more and more energy is required to observe (or even mathematically articulate) smaller and smaller space, eventually the pursuit of smallness manifests an energy density too high to permit spacetime. This theoretical space at the black hole frontier, the Planck length, measures roughly 1.6×10^{-35}m. Anything smaller than this does not oblige current formulations of spacetime. Thus, a Planck length threshold seems to invalidate the very notion of matter being able to occupy a discernable patch of gravitational space. "Space-time is doomed" (2013: 1). While the Planck scale is well below anything that should concern a macrofaunal entity or even a proton, the implications are undeniable—the architecture of modern physics' understanding of the universe is inconsistent. Most acknowledge this but disagree on the provenience of the inconsistency.

Arkani-Hamed has offered the hypothetical scenario of going back in time to inform 19th century physicists that the universe was not deterministic. By declaring the universe fundamentally unpredictable, such a time traveler would undermine the ground on which contemporaneous physics was built—Newton's Mechanics. These 19th century physicists would not be able to derive the non-determinist universe of 20th century physics from simple tweaks to existing theories, but would need a total reframing, as was eventually offered by the breakthroughs of relativity and quantum mechanics. Arkani-Hamed translates this scenario to today, asking how present physicists should respond to a future time-traveler informing us that there is no spacetime. This, Arkani-Hamed claims, approximates the position of physics today. Arkani-Hamed and his colleagues are at this juncture now asking themselves how to proceed. Which fundamental principles might be wrong? Where should we look to fix this glitch?

Spacetime is an appealing candidate, as there is widespread agreement that spacetime's old-fashioned gravity simply has breaking points. However, singling out spacetime carries with it some assumptions. As mentioned, small high-energy domains introduce paradoxes that render spacetime problematic. This conclusion, however, takes for granted "energy." If the relationship between spacetime and energy is inconsistent, is it presumptuous to assume only one side of the equation is flawed? Could the issue be with energy rather than spacetime? Energy has a well-documented convoluted historical development that should trouble its highly reified naturalization in physics (and popular culture). Dare we wonder what would happen should our time-traveler tell us that in the future they discover energy is a dead-end paradigm? What doors could this open for today's research?

Retracing the socio-history of prevailing assumptions in physics reveals them to be products of contingency, just like presidential elections or football games (that is, assumptions are historically contingent even if what they assume is not). In the social sciences, anthropologists are acutely aware today of the colonial and ethnocentric assumptions of 19th century practitioners of the discipline and the extent to which these hampered progress in their field, reifying structural inequality and prejudice. Is it time for physics to similarly consider the colonial predispositions of Carnot, Regnault, Clausius, Joule, Thomson, and Maxwell, among others? "For Carnot, the steam engine embodies…the distinction between civilization and savagery" (Gold 2012: 129). Does such a sentiment call into question Carnot's work on thermodynamics? The history of the steam engine amply demonstrates that physics is fraught with such colonial assumptions.

In flirting with such heterodoxy, I do not wish to claim any of the physics discussed within is incorrect, but rather to trouble the conceptual framing within which some prevailing axioms are situated. Einstein once quipped that all theories are true provided you suitably associate their symbols with observed quantities. Indeed, many concepts surrounding energy are by the very structure of their mathematical formulation incapable of being defined as incorrect. They were developed to make mathematical equalities align. That is, quantities and scales were defined and structured in such a way that would elicit numbers that allowed equations to be worked out correctly, temperature being a pointed example.

Temperature & Energy

"Thermodynamics is one of the most widely misunderstood branches of physics. Laypeople and scientists alike regularly use concepts such as temperature, pressure, and energy without knowing their rigorous meaning and subtleties" (Rubí 2008: 62). Critical to this confusion is that temperature was invented two centuries before it was defined. Quantified thermal fluctuations began to be observed by thermometers in the first half of the 17th century (Taylor 1942). This quantification was rather arbitrary and lacking in standardization until the early 18th century, with Fahrenheit's model coming into use by 1724. While Fahrenheit's scale (as well as Rømer's, Celsius's and Réaumur's) was tethered to material phenomena (freezing and boiling points), it would be another century before the quantification of thermal flux observed by thermometers had any rigorous meaning in physics. "The thermometer, as it is at present construed, cannot be applied to point out the exact proportion of heat....It is indeed generally thought that equal divisions of its scale represent equal tensions of caloric; but this opinion is not founded on any well decided fact" (Gay-Lussac 1802: 208).

As evidenced in this 1802 sentiment, despite a well-established thermal metric by the 19th century, temperature did not concretely correspond with any particular paradigm of physics. It was not until the theory of the conservation of energy (first outlined by Mayer in 1841) and the subsequent insights of Helmholtz, Clausius, Maxwell, and Boltzmann in the mid-19th century that physicists settled on what temperature is. A number was invented around which the physics later conformed—temperature's definition (the average kinetic energy of particles) was crafted to fit heat into a mathematically sound relationship with work. The definition of what a thermometer measures (temperature) did not become *the average kinetic energy of particles* until this definition was needed by thermodynamics.

In the 18th century, as industry was primarily carried out by watermills, studies of energy (or *vis viva* to use the contemporaneous language) focused on hydrodynamics—the relationship between water, pressure, and work. In the 19th century, as the steam engine overtook the watermill as the primary method of industrial production, the focus shifted toward the relationship between heat, pressure, and work,. The emphasis was on turning "heat into mechanical motion" (Stengers 2010: 193). To this end, 19th century physicists developed formulae (equalities) that equated heat with work (movement). They figured out a way to put heat on one side of an "=" sign and work on the other in a manner that is mathematically true. Stengers accuses the "=" sign itself of this subversion, "The = sign serves as the...condition of possibility for reducing mechanical problems to a problem of mathematical analysis" (Stengers 2010: 127-8). It was Joule's work that allowed, "the conversion of mechanical work into heat [to be] characterized by a 'mechanical' equivalent of heat... *the amount of work* necessary to increase the temperature of a kilogram of water by one degree" (192, my emphasis).

Joule's original formulation of heat required the physical material caloric to be worked upon. When a warm object was placed near a cool object the caloric of the warm object was supposed to move toward the cool object. Subsequent experiments disproved the existence of the substance caloric. Caloric would eventually be replaced by the immaterial relationship between motion and mass called energy. Clausius' 1857 work "On the Type of Motion We Call Heat" is credited with replacing a substance (caloric) with a conceptual relationship (energy).

Replacing caloric with energy dematerialized work. This is not to suggest that caloric was ever real, but rather that there was an assumed materiality to work where now there is only the immaterial compulsion of particles (behaving probabilistically) to tend toward an equilibrium velocity. To sum up this "victory" of energy in the history of physics, Stengers writes:

> The hypothesis claiming that heat was nothing other than an invisible form of motion of the constituents of matter was ancient, and hardly prestigious... it produced no practice of measurement, unlike caloric theory, and it was derided by the calorists as sterile speculation. Yet, it was always available, and when the conservation of energy killed the caloric theory, James Joule and others immediately referred to it as a promising alternative to the theory of heat-as-substance (2010: 238).

Steam & Energy

"The early development of thermodynamics found its inspiration in the steam engine. Nowadays the field is driven by the tiny molecular engines within living cells…These engines share a common function: they transform energy into motion" (Rubí 2008: 67). Sadi Carnot is most frequently noted for pointing thermal physics toward the steam engine in his 1824 analysis of an ideal heat engine, "Reflections on the Motive Power of Heat." Through this work he quantified the relationship between pressure, volume, and heat. Henri Regnault, the most acclaimed experimental physicist of the 1840s, went to great lengths to relate temperature to reality via the steam engine, writing three 700-page volumes on the engine. Much of temperature's utility in engineering was subsequently developed in William Rankine's 1859 *Manual of the Steam Engine and Other Prime Movers*.

While the development of thermodynamics took dozens of physicists in the 19th century, most major insights were conceived around the steam engine—both efforts to mathematically understand the steam engine's workings and to improve its efficiency (ability to move faster and more forcefully on less fuel). Wittingly or not, Carnot, Coriolis, Clausius, Regnault, Helmholtz, and Rankine all used a culturally developed machine whose ultimate purpose was to grow wealth exponentially (the steam engine) to formulate what they considered to be a natural phenomenon—the relationship between heat, movement, and pressure (energy). This relationship could not have been formulated without the quantity temperature, which offered a numerical variable to fill in the formulae equating work to heat—the hydrodynamics of Bernoulli and metabolodynamics of Mayer lacked a quantity like temperature to formulate a compliant notion of energy.

Summarizing, temperature existed as a standardized thermal metric that offered thermometer-users an indication of present sensible warmth. However, these numbers were not tethered to any underlying physics; they were culturally agreed upon arbitrary points relating to phases of H_2O. These numbers were later utilized in equations describing the functioning of the steam engine—a human-made machine designed for the purpose of moving things quickly. From this work, the thermodynamics of energy was derived, which still prevails as the dominant explanation for "the capacity to effect change" (Rankine 1855: 126). Today, the concept energy (not to mention temperature) has become highly naturalized, yet it was built out of what some might consider the "unnatural" workings of the culturally produced steam engine.

The steam engine was not a scientific instrument. That scientists should look toward a commodity-moving machine to understand fundamental laws of physics is not irrelevant. Basing knowledge off the workings of the steam engine naturalizes the engine, as well as the epistemology and motives behind the engine. Today, university physics classes almost invariably use the piston as a conceptual mechanism for explaining dynamics, but the piston is an instrument engineered to perform certain functions. This is like using the behavior of a microscope to explain how cellular biology works; using a machine that allows us to see a phenomenon in order to explain the causality of that phenomenon.

Probability & Temperature

Like the steam engine, the invention of probability was driven by money. Cardano's early efforts in the 16th century to lay down the mathematics of probability were driven by his gambling addiction (Ekert 2008). While Pascal and Fermat's more famous and definitive 17th century work on probability was also framed in terms of gambling, the results of these two merchant-class thinkers were soon adopted by insurance, finance, and banking. Ayache writes, "Money and finance are key in the definition of probability. If anything, money is the ground, not probability" (2017: 33). By this, Ayache means that the formulation of probability is derived from monetized valuation systems.

Cardano, Pascal, and Fermat employed no distinctively novel mathematic operations that were unavailable earlier or elsewhere. As Daston (1988) notes, earlier scholars, going back to Aristotle, simply rejected the idea of a science of chance (probability). It was not that probabilistic math could not have been done earlier, but rather that no one considered it of any use or value. Up to the 17th and 18th centuries the phrase "merely probable" was used derisively to describe assertions drawn from such knowledge (Hacking 1975).

The last three-hundred years have seen an increasing reliance on probability mathematics to describe reality—entropy is now best understood as a probability, probability amplitudes describe the quantum world, and physicists increasingly rely on probabilistic computational modeling rather than actual experimentation (Düben et al., 2014). This development demonstrates the diminished relevance of tactile interaction in knowledge production. The resonance of material interactions has become deferred to mathematical outputs. No longer are physical iterations of an experiment necessary to "know" its outcome.

For example, instead of actually rolling dice to see how many times "7" occurs out of one-hundred rolls, one can do a probabilistic equation. Probability allows the swapping out of the material experience of actually doing something for a calculated likelihood of the result of this doing. Probabilistic reasoning was invented to explain how materials should behave in the absence of an event. Today, however, probability is used as an explanation for why and how materials behave as they do. Probability evolved from a substitute for reality into an explanation for reality. This dematerialization of work offered by probability mirrors the dematerialization of work offered by energy (more on this below), which is itself underwritten by probability (a probabilistic understanding of where, when, and how fast particles are moving).

In the definition of temperature—*the average kinetic energy of particles*—the *average* denotes the inability to know with certainty the precise velocity of individual particles in a body. Taking apart the definition of kinetic energy ($\frac{1}{2}mv^2$), the mass of the particles is known, but their velocity can only be approximated by their aggregate effect (e.g., the movement of mercury in a thermometer). It is the Maxwell-Boltzmann distribution that is used to describe this velocity. This distribution probabilistically ascribes a velocity to any given particle of concern. As Kuhn puts it, transforming heat "into a quantitative theory of significant scope depended on the development of a model of material aggregates to which mathematics could be easily applied" (1978: 18).

The characterization of temperature as an average epitomizes the general move in physics toward mathematical and statistical modeling as driving knowledge production. Specific to the probabilistic measurement of heat, Stengers writes, "we are not obliged to follow the motion of every individual particle: what matters is the average effect and, therefore, the relative frequency, of the different types of events that contribute to what we observe" (2010: 240). As temperature became "associated with molecular movements on the microscopic level, heat now refers to a realm of reality radically different from our tangible macroscopic world… Thermodynamics became a science of averages and probabilities, since the motion of molecules escapes all our methods of observation" (Schrader 2012: 127). Averages are idealizations, not representative of any embodied physical instance—thermodynamics is hypothetical. "Physics is always about 'as-if-realities'" (Englert 1999: 328).

While most point to Einstein's Relativity and the Copenhagen Interpretation of Quantum Mechanics as the key revolutions that dethroned Newton's Mechanics, the contention here is that equally or more significant was the adoption of probability distributions such as the Maxwell-Boltzmann. Despite Boltzmann's continued efforts to make the Second Law of Thermodynamics deterministic (Kuhn 1978), their work replaced determinism with probability. It is this move that opens the door to the wave functions of Quantum Mechanics and Bohr's coronation of an indeterminate universe.

The implication herein is that the "glitch" in the relationship between spacetime's gravity and quantum mechanics may be resolved by looking deeper into the history of physics, as opposed to deeper into outer (NASA) or inner (CERN) space. That is, there may be answers in revisiting the assumption of a probabilistic notion of energy as the foundation of causality. Probabilistic reasoning is not incorrect, but its development has a history, and this history centers on maximizing the profitability of financial instruments. Using such tools to underwrite the basic concept of causality (energy) should raise an eyebrow. To this end, Einstein's groundbreaking 1905 paper on Brownian motion had largely been presaged by Louis Bachelier's 1900 treatise on stock options pricing. Maurer suggests, "This convergence is itself symptomatic…that someone interested in, of all things, finance, would hit on the same mathematical formula to model their objects [as someone trying to understand physical laws of motion]" (2002: 22). Such peculiarities should not be used to naturalize finance, but to denaturalize energy.

Not unrelated, it may be added that knowledge production in physics today requires copious amounts of energy. Significant fossil fuel must be combusted to see into deep space and deep inside atoms. The irony here is that fuel is finite, but energy is not. Energy is just a relationship between mass and velocity, yet fuel is needed to control and exploit this relationship. Coal is not energy. Uranium is not energy. These are fuels. We consume fuel. We do not consume energy; we calculate energy. We burn fuel in order to make the formula $\frac{1}{2}mv^2$ output greater numbers. Much could be said here about the linguistic slippage between energy and fuel and the overexploitation of resources often referred to as the Anthropocene.

Indeterminism, Unpredictability, Uncomputability

As a mathematical relationship, the concept energy promotes an understanding of reality as an output (of an equation), as opposed to an instance occurring in the present. That is, the present is a less reliable reflection of reality than is a trajectory of causes—the present can be unrepresentative and thus deceptive. Good knowledge (or valued knowledge) is denoted by its ability to map and predict this trajectory of causes—parse cause and effect. The capacity to accurately forecast subsequent conditions is a primary epistemological virtue today. I argue that this approach to knowledge production incubates the unpredictability and uncomputability it seeks to reconcile.

Perhaps counterintuitively, probabilistic reasoning does not make the world more predictable, but rather more "predict-able" (the hyphen denotes an ability to predict unconcerned with the accuracy of the prediction). Today's world is highly predict-able—there are numerous quantified attributes of the universe that can be run through probabilistic calculations to output the likelihood of a scenario coming to pass. Models, forecasts, projections—these are constructed to accumulate possible futures. Their utility is not in determining the future, but opening an array of predict-able futures. If resolutions or answers were ever reached with certitude, this would make the world predictable, thus "unpredict-able"—predict-ability being redundant in a certain universe. Perpetual unpredictability is a necessary precondition for a system of knowledge built on a probabilistic ontology.

Negarestani (2015) has described a Turingian revolution (after Alan Turing). As opposed to Newtonian, Darwinian, and Einsteinian revolutions, "The Turingian revolution suggests that the future will not be a varied extension of the present condition. It will not be continuous with the present. Whatever arrives from the future… will be discontinuous to our historical anticipations" (149). This perpetual novelty makes the future always predict-able, but never predictable. Change and novelty must be constant. Expectations can never be met or satisfied, but the possibility of meeting and satisfying them must be constantly calculable (though not accurately calculable). If there is no surprise, there is no information, and computational knowledge production requires constant flows of information.

In Gregory Chaitin's terms the entropic tendency of algorithmic processing adds data to output, meaning that computation creates output that is not causally beholden to its input. Or, as Luciana Parisi describes it:

> In every computational process…the output is always greater than the input. For Chaitin something happens in the computational processing of data, something challenges the equivalence between input and output…algorithmic sequences tend to become bigger in volume than programmed instruction and take over, transforming the pre-set finality of rules (2015: 132-133).

The Turingian revolution reframes the temporality of output and the cause-effect relationship more generally. The future is framed as the source of the resolution (the cause).

Turingian problems appear undecidable because their cause has yet to occur. "With Maxwell's introduction of probability theory into thermodynamics, the opposition between the 'natural tendency' of a thermodynamic system and our subjective experience of temporality sharpened" (Schrader 2012: 127). This is to say, our dominant means of knowledge production lead us toward unpredictability and uncomputability because this is how they are designed. Total predictability would obviate the perpetual novelty necessitated, in part, by the financially-derived mechanics of probability that underwrites our understanding of causality. While there are many socio-historical factors involved, the "Great Accelerations" of nearly every economic category since 1945 (the onset of the Turingian revolution) are enabled by the conceptual opening of the present to a spectrum of trajectories not beholden to material finitude. There are no material limits on the calculations of probability, and if probability is taken for reality, this elides the limits of material finitude.

The big data aggregation practiced in computational knowledge production, specifically machine learning, does not clarify the future. The more data collected, the more calculative power necessary to compute this data, and thus the greater entropy it manifests. Big data collection simply multiplies Hume's problem of induction, in which nothing can ever be known for certain because each passing moment serves as additional evidence that could contradict any claims to certitude. If we succumb to Hume's problem, the process of knowledge production is no longer a search for correct answers or truths, but rather a search for ever-increasing statistical certitude. Machine learning today is simply aimed at reducing uncertainty. Our machines are programmed from inside Hume's problem.

Conclusion

Arkani-Hamed's own work on the inconsistencies of gravity does away with locality and unitarity, suggesting such notions are emergent aspects of a positive geometry (Arkani-Hamed & Trnka 2014). The formulation of this idea through the "Amplituhedron" and its echoes of John Wheeler's geometrodynamics (1962) make this work very alluring. It is beyond the purview (or ability) of this article to comment on the ultimate veracity Arkani-Hamed's figuration. Notably though, it does eliminate probability as an explanatory device, which, if the above critiques are valid, is certainly a useful step in reconceiving dominant epistemological approaches to addressing foundational questions.

Considering foundational reconfigurations, Einstein wrote, "Nobody doubts the reality of kinetic energy because otherwise one would have to deny the reality of energy per se" (Hecht 2016: 10). While Einstein may not have been so brash, denying energy would not be to deny the utility of the output of the equation $\frac{1}{2}mv^2$, rather it would question this relationship's role as the underlying explanation of causality, an explanation which has come to semantically and mathematically dominate our understanding of the dynamics of the universe.

Interestingly, most physicists today are certain that the universe is indeterminant. To replace Newtonian determinism, the universe has largely come to be seen as probabilistic. Deterministic and probabilistic, however, are just two paradigms of potentially many for perceiving physical foundations—it is not one or the other. I suggest that due its historically situated history in European colonial capitalism and its reliance on the future as a source of causality, probabilism is an inadequate paradigm. While it is not a very satisfactory resolution, perhaps as Meillassoux (2008) argues, the universe is radically contingent—nothing is necessary except that nothing be necessary.

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