UNIFICATION AND THE LIMITS OF KNOWLEDGE

An essay by Marcelo Gleiser*

for the contest

"WHAT IS ULTIMATELY POSSIBLE IN PHYSICS"

> *The only truly serious questions are the ones that even a child can formulate. Only the most naïve of questions are truly serious. They are questions with no answers. A question with no answer is a barrier that cannot be breached. In other words, it is questions with no answers that set the limits of human possibilities, describe the boundaries of human existence.*
>
> Milan Kundera, *The Unbearable Lightness of Being*

ABSTRACT: I examine the question of whether it is possible to construct a final theory of Nature in a reductionist sense. Complete unification implicitly assumes total knowledge of physical reality. Can such knowledge be obtained? I examine two fundamental limitations which indicate that the answer is in the negative. To begin, science cannot explain the problem of the first cause, even within a valid quantum mechanical formulation of gravity. Also, our knowledge of reality depends on a fundamental way on our measuring devices. These, in turn, are subject to technological and, at a deeper level, to quantum mechanical limitations. Since we cannot measure all there is, we cannot know all there is. Thus, the boundaries of measurement set the limits of physics and of our explanations of physical reality.

INTRODUCTION

Are there unanswerable questions? Or can scientists, through their remarkable ingenuity and inventiveness, answer all questions related to physical reality? Since Thales of Miletus wondered about the material composition of the world some twenty-five centuries ago, a sense of invincibility has characterized the rational quest for knowledge: given enough time, Nature's secrets will all be revealed to us. And indeed, as Galileo framed his telescope on the silvery disk of the Moon in 1608, the pace of scientific

* Department of Physics and Astronomy, Dartmouth College, Hanover, NH 03755, USA. mgleiser@dartmouth.edu

discovery has been remarkable and inspiring. We have learned much about the nature of the universe, the composition of the stars, the origin of our solar system and of the chemical elements, the inner workings of the atom and of the fantastic metamorphoses of matter into energy and back that characterize the world of subatomic particles. There are also all the discoveries in the biological sciences that I am leaving out. Science has completely reshaped the landscape of human culture. As a result, our worldview has changed with it. Throughout the past four centuries, two fundamental paradigms ran hand-in-hand, feeding on each other: that it is possible to study the behavior of complex systems by reducing them to their smallest constituents and then work our way from the bottom up; and that the laws of Nature spring from symmetries writ deep into the fabric of space, time, and matter. Our description of physical reality is anchored on the relationship between reductionism and symmetry. If we want to answer the opening question of this essay in the negative, that is, if we believe that all questions about Nature can be answered through these twin paradigms of science, then it follows that they should ultimately lead to a final, complete description of natural phenomena: a theory of everything that encompasses the most embracing symmetry principle within a reductionist framework, what Steven Weinberg has called a "final theory" [1]. In this essay, I will briefly argue that such a goal is unachievable. There cannot be such a thing as a "final" theory, even in principle. Physics, as a constructed narrative of material reality, can never achieve completeness. To set unification of the fundamental interactions as the most pristine of the goals of theoretical physics is to embark on a trip to fabled Eldorado: some remarkable discoveries will happen along the way, but the destination will never be reached for the simple (and humbling) reason that it cannot be reached by the human intellect.

FIRST CHALLENGE: THE PROBLEM OF THE FIRST CAUSE

No question mirrors humanity's age-old yearning for understanding as deeply as the mystery of creation. Every culture that we know of, past and present, has tried to make sense of our origins [2,3]. Through their narratives, creation myths define the beliefs and faith of a community. Invariably, in order to explain the origin of everything, these myths

make use of a transcendent force, an absolute power which exists beyond the confines of space, time, and matter. Gods, being supernatural entities, are not subject to the constraints of physical laws. Thus, to explain how the world and life came to be, creation myths assume the existence of a parallel reality, which may interact with ours but that exists outside of it.

Science, of course, cannot make use of supernatural entities to explain the mechanisms of the natural world. Even before the dawn of what we now call science, natural philosophers in Ancient Greece were trying to make sense of this issue. How to explain creation within the rational logic of Nature? The pre-Socratics, in particular those of the Ionian school, believed that there is a fundamental unifying material principle, that is, that there is a single substance that explains and contains all there is. Thales, whom none other than Aristotle considered the first Western philosopher, suggested that water was the primal substance. His choice encapsulates the belief that the essence of Nature is dynamic: just as water can transform itself and cycle through earth and sky, Nature is alive, pulsating with its rhythm of creation and destruction. The noted philosopher and historian of ideas Isaiah Berlin called the Ionian belief in the unity of matter, the "Ionian fallacy": "A sentence of the form 'Everything consists of…' or 'Everything is…' or 'Nothing is…' unless it is empirical…states nothing, since a proposition which cannot be significantly denied or doubted can offer us no information" [4]. The problem consists in trying to construct an argument to explain an absolute. Invariably, the question "but where does the water or whatever primal substance come from?" will remain unanswered.

Aristotle tried to bypass the issue by assuming two material realities: that of the four basic substances of the earthly realm (earth, water, air, fire, all below the lunar sphere)—where change is possible—and that of the heavens, the aether of planets and stars—where change is impossible. His cosmos was a giant mechanism of spheres within spheres, from the inner lunar sphere to the outer sphere of the fixed stars, where motion was imparted from the outside in. To deal with the question of the first cause, Aristotle assumed the existence of an "unmoved mover," a deity capable of generating all cosmic motions without needing an impulse himself. As in mythic narratives concerning

creation, Aristotle made use of an absolute power that exists beyond the realm of causation.

As we enter the Renaissance, the scientific description of Nature becomes more quantitative and mathematical. Galileo and Kepler showed that it was indeed possible to construct empirical laws that described in a precise way the unfolding of physical phenomena, be it on earth or in the heavens. The publication of Newton's *Principia* in 1687 marks the definitive transition into the era of causation: matter behaves in predictable ways based on simple cause and effect relationships encapsulated in the three laws of motion and on the law of universal gravitation. To Newton, there was no question that the first impulse, that which originated the motions of the planets about the Sun, was of supernatural origin: God was the First Cause, as He was the only uncaused being. Even if Newtonian mechanics was to change the world, the question of the First Cause remained outside the scientific realm.

Laplace is often quoted as the one who changed all that. When Napoleon remarked about the absence of God in his masterful *Celestial Mechanics*, Laplace quipped that he "had no need for that hypothesis." Laplace's confidence was based on his model for the origin of the solar system from the contraction and rotation of a nebula, where he extended Newton's physics to include the conservation of angular momentum. Of course, Laplace still had nothing to say about the origin of the nebula or its initial rotation, although he wouldn't say any of that to Napoleon.

During the twentieth century, the question of origins received renewed attention. If, as Einstein's general relativity has shown, space-time is plastic, and if, as quantum mechanics has shown, there is a fundamental limitation as observers try to extract information about the material world, it follows that, as we attempt to combine quantum mechanics with relativity, the very structure of space and time must be reinterpreted. In particular, within the framework of the big bang theory, as we travel backwards in time, we must understand how quantum gravity will confront the existence of a classical singularity: the problem of the first cause enters the quantum realm.

Models of quantum cosmology, such as those pioneered by Hartle and Hawking, and further refined by Linde and Vilenkin [5,6], creative and elegant as they are, do *not* solve the problem of the first cause. Neither do superstring cosmologies, or brane

cosmologies [7]. Any scientific description of natural phenomena which lies beyond the empirically tested must, by construction, rely on a series of unproved assumptions. In the case of quantum cosmology, we use certain physical laws—such as the law of conservation of energy-momentum and of charge, or the severe reduction of spatial degrees of freedom when applying mini-superspace models to the wave function of the universe to obtain reasonable-looking solutions—well beyond their currently known limit of validity. In other words, we are using a theoretical framework that relies on the general theory of relativity and on quantum mechanics well beyond the scales where these theories are known to work.

This is not, as some readers may think, a surmountable problem, that will go away as we discover more and more of the natural world and extend the validity of our physical models to higher and higher energies. It is also not "business as usual," in the sense that science naturally progresses as we continually strive to test theories beyond their limits of validity. Here, the question is of a different nature; there is a fundamental limitation in trying to construct a physical theory based on notions of causation and of quantum indeterminacy to deal with the first cause. Every equation embodies an implicit conceptual structure. Science needs a scaffolding, a structure upon which to operate. It cannot explain the first cause because it cannot explain itself. It is not enough to say that all is encapsulated in the multiverse, that the string landscape contains all possible universes, including ours [8]. There will always remain the question of where did the multiverse come from, where did the fields used to write the Hilbert action come from, how was the measure of the quantum path integral chosen, and so forth. The current popularity of weak anthropic arguments to constrain the universe in which we live is a perfect illustration: in order to explain our universe we need to start with the existence of "typical observers" [9]. Even if a consistent model of the origin of the universe is formulated one day, it will still be a scientific model of creation, unable to explain its own structure. The first cause is an *a priori* limitation of any rational explanation of reality.

SECOND CHALLENGE: INDETERMINACY AND THE LIMITS OF KNOWLEDGE

Leaving aside the question of the first cause, we should now move on to a more immediate issue, that of the construction of knowledge [10]. How do we acquire knowledge of the physical reality around us? As we all know, the cornerstone of science is the scientific method. We measure the world, create inferences and, at least in the physical sciences, construct quantitative theories to describe what we measure and, in some cases, predict the existence of yet unknown phenomena. Such theories are constantly subjected to the skeptic questioning of the community: to extend our knowledge of Nature, we probe theories to their limit and beyond their limit. New knowledge springs from the cracks of old knowledge. Inherent in this mechanism is the reliability of our measurements. An idea is not accepted as an acceptable description of a phenomenon until it is tested. More to the point, theories must be falsifiable to be considered part of the scientific canon. We only know what we can measure: measurement plays a key role in the advancement of knowledge, although this is often forgotten in the heat of theoretical speculation.

The uncertainty principle of quantum mechanics places a fundamental limitation on what we can know. Our instruments designed to measure spatial positions and velocities, or time and energy scales, are constrained by it. As a consequence, the wave-particle duality carries with it a profound lesson, which so much bothered Einstein, Schrödinger and many others: the ultimate essence of reality is unknowable. The information we extract is limited: as our devices interact with a system, they select its behavior. To measure is to corrupt. Let me restate this with an analogy. An anthropologist finds a new tribe in the Amazon forest. The tribe has never had any contact with Western civilization. The anthropologist hides and observes the tribe for a while, taking careful notes of their behavior. Then, one day, a sentinel finds him hidden behind some bushes. After much confusion, the tribe agrees to let the scientist remain in their midst. He keeps writing about the tribe, although their behavior is markedly different now: through his interaction with the tribe, the anthropologist has biased (corrupted) their behavior. They will never be the same again. Fortunately, the anthropologist has the notes he kept before contact.

A quantum scientist is not as fortunate as our anthropologist. She doesn't have the privilege to observe her system while "hidden." There are no measurements before contact; in the quantum world, all measurements *are* contacts and all contacts interact irreversibly with the system being measured. In other words, the knowledge we attain of the quantum world is never intact knowledge. Since the construction of a physical reality is thus observer-dependent, it is *a priori* biased and incomplete.*

This quantum limitation has profound consequences to the search for a final theory. Not only our construction of knowledge, but our measuring devices are fundamentally limited. We can always improve the accuracy of our measuring devices, but never beyond what is allowed by the Heisenberg relations. The "clicks" of our devices depend on interactions that take place in space and time and that involve momentum and energy transfer. If we only know what we can measure, and quantum indeterminacy constrains our measuring, we will never be able to measure the totality of physical reality. And if we can't measure the totality of physical reality, we will never know if a theory is final, in the reductionist sense that it provides an irreducible description of matter and its interactions. There will always be the realm of that which lies beyond the limited accuracy of our measuring devices.

Even if we could, based on general theoretical principles, argue that there should only exist four fundamental interactions, that the coupling constants of the three gauge forces (electromagnetic, weak and strong) run toward each other with increasing energy to meet, at least in some supersymmetric models, at energies of order 10^{16} GeV, we cannot know for sure if other interactions may not be lurking in the "desert" between that scale and our currently testable scale of 1 to 10 TeV. This is why experiments keep probing for a fifth force, and why models with large extra dimensions have received much attention in the past few years: we only know what we measure and all sorts of unexpected new physics may exist out there. Beyond that, there may be more physics, and so on.

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* One may argue that the anthropologist's view of the tribe will never be unbiased, even before contact. Her analysis will necessarily carry all the cultural and experiential biases that make her the person she is. But I will refrain from entering into this sort of argument here.

TOWARDS A HUMANCENTRIC SCIENCE

The arguments presented above point toward a different kind of physics, one that is less preoccupied with final questions. To begin, the very construction of physical theories relies on a fundamental framework that cannot explain the question of the first cause. Saying that our universe started from an Euclidean, timeless realm, and that it quantum-mechanically jumped into a classical, time-evolving cosmology, interesting as it is, still depends on the construction of models that rely on several assumptions. We do not know how to formulate a scientific theory without them. As with any builder, we need the materials and the joining rules. Beyond that, there is only metaphysics. Second, our knowledge of physical reality depends on our measuring devices. Our ever-changing vision of the cosmos, from Earth to Sun-centered, from static to expanding to accelerating universe, is fundamentally tool-driven, a point often made by Freeman Dyson [11]: as our tools evolve, our vision evolves. This is true both in the world of the very large and of the very small. We may speculate about what's beyond our measuring abilities, and some of theses speculations may even be correct. But we can only know once we test and measure. Even though, thanks to our remarkable creativity, our tools will advance and become ever more accurate, there will always be that which lies beyond their measuring ability.

Our physical description of the world should be seen as an ever-evolving, self-correcting narrative. There is no final theory because there is no end of physics, even in the reductionist sense of elementary particles and their interactions. Even if we can contemplate a totality of knowledge, we surely cannot ever attain it. This, in a sense, is the predicament of being human, to be able to dream the infinite but not to embrace it. Theories that search for final, unified answers are attempts to embrace the infinite, make it real, measurable and concrete. They were the starting point of Western philosophy and remain with us today. And yet, how much more wonderful it is to accept the simplicity of not knowing! Questions with no answers, as wrote Kundera, describe the boundaries of human existence. Physics does not need a pact with an absolute reality, the ultimate explanation of all there is, to justify itself. It is enough that we keep on going, stumbling toward that boundary, knowing only too well that it is always in motion, receding from us.

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