# What is Ultimately Possible in Physics?

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Abstract: In this essay some of the possible futures of physics are considered. Historical and philosophical illustrations are made to show the continuity and reasonableness in these concepts. A few novel connections are made and a final opinion is expressed.

The word ultimate denotes finality: a final state of being, the last event or goal of a process. The word may also include the notion of something final that is basic or fundamental. When we say something is possible, we mean that it could be done; it is possible if it is within the capacity of some agency to do it. Possibility is not necessity; these are modal complements. What is *considered* possible or impossible depends on what one knows and one's point of view. These things are notoriously fluid.

For example, at one time, no one knew what the moon was made of; it was anyone's guess. If I had asserted that the moon is made of green cheese, or whatever, then my say would be just as good as any other uniformed guess. However, when scientist started looking at the moon with telescopes and such they became better informed. The *Green Cheese Hypothesis* was then seen to be untenable if not outright impossible. We see on the moon, through our telescopes, a lifeless expanse of mountains and craters and we think that this is like the earth stripped of its air, water and all living matter. When we come to visit the moon, it is seen that this possibility is reasonably accurate. The enormous range of possibilities collapse into a single basic truth.

Physics, and science in general, is both and cognitive and practical activity. These activities are directed to the systematic study of the structure and behavior of the natural world through observation and experiment. Physics is an activity and its obvious goal is to obtain a satisfactory understanding of the physical world. An opinion of how satisfactory understanding is depends on ones knowledge and viewpoint. We are usually satisfied by a physical theory or an experiment if we are convinced, whatever the topic, that it tells us something true of the world or at least gives a good accounting for the subject. Could we form a physical theory that is ultimately satisfying?

When considering how satisfactory a physical theory is there is another aspect we should consider. An example comes from the research of the Swiss philosopher and physicist Pierre Prévost (1751-1839) known for his radiation principle. A modern statement of Prévost principle may be put as follows: *all objects are continuously radiating heat energy; in a state of thermal equilibrium the amount of energy radiated per second from an object is equal to the energy absorbed by it from of radiations from surrounding objects.*

In Prévost day, heat and radiation were thought of in very different terms than we now use. Heat was thought of as a kind of material substance composed of very small particles. The phlogiston (fire substance) theory of heat and fire was on its way out and would soon be replaced by Lavoisier's caloric (heat substance) theory. The exact nature of caloric was an outstanding question. The leading candidate theory was a corpuscular theory à la Isaac Newton (1642-1727).

In Newton's corpuscular view, there were several theoretical kinds of fluids used to explain real fluids. [1] A *rarified fluid* consists of spread out particles. The particles of this kind of fluid interact with each other and the surroundings by impacts. The *elastic fluid* was supposed to be like a rarified fluid, but the particles repel one another. The *continuous fluids* are made up of particles so close together that they touch. In Prévost's day, the rarified fluid was the popular one in physics circles. Prévost regarded heat as an elastic fluid and he says of this [2]: "The elasticity [of the discrete fluid] consists in its expansive force. And this is the effect of the movement of its particles. This movement is caused by the impulse of a much more subtle fluid whose effect upon its particles is determined." This gives us two kinds of heat particles. One type, the larger, is identified with the common heat, while the other, smaller particles, are identified with free or radiant heat. The radiant heat particles move very fast and follow rectilinear paths in their motions so Prévost likens radiant heat to light.

As thermodynamics developed, after Prévost's time, the corpuscular theories of heat were seen to be untenable and the mechanical theory of heat became acceptable. In spite of this Prévost's principle did not vanish along with phlogiston and caloric. Why not? The answer is that even with the ancient baggage in hand Prévost used careful observation and description. In the decades following his death the doctrine of energy conservation was established and his ideas were rectified in light of this. The conservation of the material caloric was reinterpreted in terms of the conservation of energy. The result of this is the above statement of his principle.

In his day, Prévost's theory was regarded as quite satisfactory and well in line with the general lay of contemporary science. It survived after being paraphrased because it contains a core of truth and relies upon a sound method. Matters of fact provide the core. The method includes systematic observation, measurement and experimentation and the formulation, testing and revision of hypotheses in light of these activities. Of course, there are many other aspects to the method, nothing is ever that simple [4], but, in outline, that is it.

It might seem that the formulation, testing and revision of hypotheses is the main business of physics. It is not, but we can use it as a touchstone for our discussion. Also, it shows some of the character of physical reasoning. When we use the method of hypothesis testing we are not seeking to affirm, but rather to negate it or at least strip away the false.

An analogy that comes to mind is the principle of "innocent until proven guilty" in jurisprudence. The lawyer for the plaintiff might ask where the accused was on Wednesday night. The accused might reply that he was home alone that night. However, if the lawyer asks a witness if he saw the accused on Wednesday night the answer could well be the crucial testimony. These testimonials have a different character. The former can never be established while the later may be the truth. The purpose of the court is to establish guilt and meet out appropriate consequences. Its purpose is not to establish innocence since this has no legal consequences and is usually impossible. The physicist is in a position similar to the lawyer. Rather than affirming a hypothesis and attempt is made to falsify it. It is assumed that all hypotheses are at least partially incorrect and usually based on incomplete information. The physicist must whittle away what is false or irrelevant and find a path to some part of the truth.

The method of hypothesis testing is not the be-all and end-all of physics. It is part of the attempt to gain understanding of the physical world. To understand something is to perceive the significance, an explanation of or cause for that thing. Physicists usually make a distinction between description and an explanation. Theories that are descriptive are called phenomenological and explanatory theories are called fundamental. This distinction is more a matter of degree rather than of substance. When something is described an accounting is given that should contain all the important characteristics, qualities, etc. When we explain something, we attempt to make that thing clearer by describing it in more detail or by making known additional facts or ideas. A good example is the relation between the thermodynamics of gas and the kinetic theory of gas.

Thermodynamics is the prototype of a phenomenological theory. The first law simply recognizes heat as a manifestation of energy and it is really an extension of the energy principle. The second law is recognition that all processes have a preferred temporal direction. These laws are based on countless experiences of the phenomena involved. The theory coordinates these experiences and provides comprehensive description. The only explanation offered is "that's the way things are."

The kinetic theory starts out with the hypothesis that a gas is made of atoms or molecules. The details of the motions of these particles provide an explanation for the behavior of gas. In thermodynamics the temperature and pressure of a gas are, more or less, givens derived from experience. In the kinetic theory, the temperature of a gas is seen to be proportional to the average kinetic energy of the gas particles. The pressure is found to be proportional to a certain average of the kinetic energy density.

The method of hypothesis testing reminds one of the "moving boundary problem" studied by Joseph Stefan (1835-1893). Stefan was poorly funded and this had a major impact on his research. [3] Without funding for experimental apparatus, he was forced to rely on the experiments and observations of others. This dependence was fruitful. He formulated his fourth power law of radiation by rechecking the data provide by the Dulong-Petit experiments and the newer results of John Tyndall (1820-1893) and others. He also formulated a moving boundary theory of polar ice evolution using data from several polar expeditions.

The polar explorers had gathered a mass of information for the polar environmental. The growth rate of the polar ice was recorded along with readings of atmospheric pressure, temperature and atmospheric condition. When the polar ice freezes or melts there is a phase change and a heat transfer at the ice-atmosphere boundary. These processes make the boundary change (move) and this in turn has an effect on the processes involved. The homotopic deformation of the boundary adds to the complexity of the problem.

The boundary of physics, where the method of hypothesis testing is most relevant, shows a similar kind of deformation. It passes from fanciful green cheese to mundane rocks and ice. The hypotheses offered change along with the boundary running the gamut from lofty philosophical speculation to the more prosaic realities. Does the moving boundary of physics have ultimate limits where we will be forced to metaphysics?

Here I am thinking of metaphysics as the part of philosophy that concerns itself with first principles, i.e., the conceptual or substantial starting point for a philosophy or other system of ideas. This is not as far removed from physics as first sight might suggest.

Deterministic clockwork has been replaced by quantum theoretic probabilities.

We wish to find the nature of matter. We start by analyzing and describing the motions and transformations of bodies. We then enter another level of description where bodies are composed of substances with properties. At still finer levels, we see mixtures and compounds, then molecules formed of atoms that are formed from still smaller particles. At the lower levels of scale we use the quantum theory where the laws of chance dominate. We are told that there are no hidden variables that can be used for another level of description. Chance, in this view, is a first principle, i.e., it is metaphysical! Is the boundary of what is possible in physics necessarily metaphysical? Many thinkers, e.g., Gottfried Leibniz (1646-1716), thought so. Still, somehow, this does not satisfy. Metaphysics is so often speculative that it makes a physicist uncomfortable. However, the metaphysics of physics is different; it is securely rooted in matters of fact. With a comprehensive list of (metaphysical) first principles there would be nothing left to do. The principles could be codified, made mathematical and the results would be as final as Euclid's geometry and dead as Latin. A dogmatic physics would surely be defeated by lack of interest.

Can there be an escape from metaphysics? Several "outs" occur to me. The first is that physics may have developed in a different way and still might. By analogy we might think of how European history might have developed differently. At many points history things could easily have diverged from the actual tale and the story would have come out very differently. Does this apply to physics?

Suppose, for example, that physics takes on a religious tone. The idea is not as absurd as it may seem on first glance. Isaac Newton wrote more on theology and occultism than science. In Newton's view, God, acting as creator and overseer, was an integral part of the physical world. Many of Newton's contemporaries also had strong religious convictions. In modern times this view, that God is an integral part of the physical world, has survived. The astrophysicist John Polkinghorne has expressed the belief that both religion and science are considering the same thing from different points of view. [5] In his view, God exists and this is the most important aspect of reality. Polkinghorne is not a lone voice in the wilderness. Indeed, there are many who regard physics and science in general as a kind of faith. Some want to study religion from a scientific perspective while others regard science itself as a new kind of religion. A recurring theme is the need to account for the very fact of existence.

There is another, more scientific, view expressed by Erwin Schrödinger (1887-1961) that might spell a change of mode for physics. He asks if the laws of physics and chemistry can account for living beings. His preliminary answer to this question is that present day science cannot provide such an accounting, but that it is not completely out of reach. He thought that new laws of physics would be required and that these would become an integral part of science. His thinking on the subject is neither supernatural nor mystical in the usual sense of these words. [6]

Physics as we find it today has a limited interest in living matter. Such things are reserved for the life sciences. Biophysics is gaining importance, but it is still regarded as an interdisciplinary study rather than a main current within physics proper. If we believe Schrödinger this will come to pass. The emphasis, significance and content of physics could be very different than it is now.

Some thoughts on the direction of physics have been offered by Ilya Prigogine (1917-2003). [7] In his thinking, determinism is no longer a meaningful belief in scientific reasoning. He held that determinism is incapable of explaining irreversibility and instability. In his opinion, both classical and modern physics need an overhaul in light of his concept.

When Planck discovered his formula for black body radiation he was not trying to find quantum theory. [8] In fact, he was attempting to find the source and nature of irreversibility. While he was not entirely successful in this regard, his ideas did lead to quantum theory. To this day, our thinking on irreversibility has not gelled. Perhaps Prigogine's ideas contain the seed of future physics.

There is an ancient idea that is starting to regain a foothold. The first of the ancients to express a notable opinion on the nature of the universe as a whole was Thales of Miletus (c.624 BC–c.546 BC). [9] He was known as one of the 'Seven Wise Men of Greece' and the founder of the Ionian school of philosophy. He believed that the universe is uniform and unbounded in both space and time. It is essentially the same everywhere and consists of a homogeneous stuff, i.e., it is mono-substantial, which he pictured as a chaotic liquid. He held that the world, the Unbounded or the *kosmos*, is not unique, but one of infinitely many *kosmoi*. All of these, he asserted, are derived from the original water stuff and would return to it in the end. He seems to have thought of the kosmoi as islands in a sea of shapeless primal stuff. Everything within an island is fashioned from this shapeless, fluid-like substance and large expanses of this formed an observable kosmos.

A modern version of this is seen in the Landscape proposed by Leonard Susskind. [10] The initial came from an attempt to understand hadrons, which are subatomic particles that interact through the strong nuclear force. The motions and deformations of an ideal (i.e., mathematical) string were used to model these particles. While this approach was not entirely successful, it has not fallen. Gradually, over the last few decades, it was developed more as mathematics than physics. This was motivated by the search for a unification of Einstein's theory of gravity and quantum mechanics. The mathematics of string theory, perhaps unexpectedly, suggests there are things beside the desired unification.

The cosmic landscape that Susskind describes is an analogy to what he calls the "landscape of biological designs". A DNA molecule, when unraveled is like a ladder with a billion rungs. Each of the rungs is made of a pair of four compounds; adenine, thymine, cytosine and guanine. Not all pairs of these compounds are seen. Adenine and thymine go together and cytosine pairs with guanine. Even with these limitations there are an enormous number of possibilities. To get some idea of how many there are think of how many complementary pairs of base four numbers with one billion digits there are. Of the many possible DNA sequences only a fraction are possible candidates for expression as living organisms. This fraction is still an enormous number and of these only another fraction will actually become manifest. Charles Darwin (1809-1882) suggested that the environment selects which will prosper and which will vanish. The mechanisms of mutation and others also play a role.

The string theoretic equations that determine which particles can exist and what values the universal constants have yield many possibilities. The stuff of spacetime could have many geometries and each of these is likened to a genetic configuration. Each configuration is an island (kosmos) in the Landscape (kosmoi.)

String theory has been accused of being little more than a mathematical fiction that is incapable of being put to the test of experiment. While this may be a valid criticism, it might be that the real problem is a lack of context or frame of reference. An interesting hint in this direction was given by Roger Penrose at a recent talk at the Perimeter Institute. [11] Penrose asks a question, that he readily admits to be crazy: what happened before the big bang? He discusses thermodynamics and entropy, black holes, the nature of clocks and time and the geometry of spacetime. All the considerations he presents lead to the idea that there may be a context in which the big bang occurred.

His next step was to seek some evidence for his ideas. He reasoned his way to some consequences of his hypotheses. One consequence is that certain structures should be seen in the WMAP data. These structures are like a fossil record for the context of the big bang. When the data was analyzed structures similar to what he expected were seen. Is this evidence for another kosmos? The results of the analysis could well be a chimera; a statistical ghost rising from the mass of information. The importance of Penrose's ideas is that it may be possible to provide a context for big bang physics. His ideas will almost certainly require redaction, but his incessant probing shows us what may be the way forward.

Penrose is as much a mathematician (a geometer) as a physicist. In physics, mathematics is a guide, a tool and a language, but it can also confound and mislead when used inappropriately. In this regard, I recently read a definition of kinematics and was struck by something. The definition goes something like the following. Kinematics is the study of motion using mathematics and the concepts of space and time, without regard to causes. Although kinematics is an essential part of physics, it is nearly a completely mathematical subject. Essentially all physical content can be removed from kinematics and it can be presented as just mathematics. Additional assumptions base on physical insight are required to order to pass to dynamics. These days what we hear about, string theory, the Landscape, supersymmetry, brane theory and so on. These are largely mathematical in nature rather than physical. I wonder if these things are the kinematics of a new physics. All that seems to be lacking, in a manner of speaking, is a passage to dynamics. What are the insights? What would be the corresponding hypotheses?

Immanuel Kant (1724-1804), a German philosopher, had many things to say about science and mathematics. [12] He felt that the opinions of empiricist, e.g., David Hume (1711-1776), concerning the ultimate nature of reality, the noumenon, were nonsensical. In Kant's view, chemistry would never amount to more than a "cookbook" and should not be regarded as a true science. Apparently, he was not aware of the work of Lavoisier, Priestley, Scheele and many others. He also asserted that mathematics was drivable from pure logic alone. In other word, that mathematics has no additional content beyond that of logic.

In formal logic, we start out with a collection of symbols, called an alphabet, and then we give a prescription for using these to form a collection of correctly made formulae. Each of which is called a well-formed formula or a wff. A wff stands for a declarative statement and we suppose that there is some way to establish the truth of each of these, i.e., an interpretation. We are then given a collection of methods of reasoning, called syllogysisms, e.g., modus tollens. These methods, when give true statements allow us to gather new true statements. We are also given a set of rules that allow us to use tautologies. In mathematics, say Euclidean geometry, we can see how this works. We have undefined terms, point, line, plane and the like. We are expected to understand what these are. We are then given a set of statements, axioms, the truth of which seems plausible. These things form the basis of how we decide the truth of any geometric statement. They are assumed true in the physical world. All other geometric statements are then deduced by syllogistic arguments so they are just as true as the axioms. There are, of course, many more details, but this captures the essence of it.

In Kant's view, the axioms of Euclid's geometry should be deducible from pure logic rather than from an intuition base on physical experience . If that were the case then all of geometry would be reduced to pure logic. Is this a reasonable idea? Is it true? In fact, it is not true even if philosophically reasonable. It was shown that Kant's ideas are not true by Bertrand Russell (1872-1970) and his teacher Alfred Whitehead (1861-1947). [13] In short mathematics has to assume something beyond logic; something that is not part of logic. This something is now taken to be set theory, usually some variation of the Zermelo-Fraenkel system. This basis is sufficient to cover most of what we normally call mathematics.

Physics has content above that of mathematics, just as mathematics has content beyond that of logic. Without this content, it would be nothing more than mathematics. New content appears frequently in physics. Investigators working with microcircuits, single atom systems and the like are gaining experience and intuition at the quantum level. At the same time, astronomers and cosmologist are gathering new and often surprising information about the wider universe. Physical insight requires experience and these areas are where it will continue to come from.

This is not to say that we should ignore or de-value mathematics. Mathematicians, in their work, strip away all that is irrelevant and strive to include all that is necessary to the understanding of their chosen topics. The mathematician in concerned with logical consistency and aesthetics, while the physicist is more concerned with content. The mathematical approach has great value for the physicist when placed in the proper context. This is seen in the mathematical concept of infinity.

To a mathematician a set is infinite if it can be placed into bijective correspondence with one of its proper subsets. The notion of bijective correspondence comes from logic and is simply a two-place predicate with certain characteristics. Correspondence is neither spatial nor temporal, but rather conceptual in nature. However, while mathematical infinity is atemporal and aspatial, it may include these and many other possibilities. Indeed, the infinities of mathematics have characteristics that have little to do with space and time.

So what? The size of the universe, whether finite or infinite, is a question of long standing. Opinion has always been divided between these two. This dichotomy also appears in science. Aristotle in his meteorology declared that the world is eternal, i.e. temporally infinite, but spherically symmetric and finite. William Herschel (1738-1822) originally assumed in his star gaging (gauging) that the universe is spatially finite. [14] In Christian dogma, the universe was created by God in the distant past and it will end at some point in the future. There was also Olber's paradox that seemed to indicate that the universe is neither spatially nor temporally infinite. In Herschel's day, assuming a finite universe seemed to be a reasonable hypothesis. Nevertheless, Herschel had to modify his ideas on the size and extent of the universe as he gained more knowledge. Subsequent investigations further enlarged the universe. By the beginning of the twentieth century, we see the young Einstein believing in a universe that is both spatially and temporally infinite. Einstein held this belief until he was confronted with Hubble's findings.

The mathematics of infinity allows us to consider temporal, spatial, atemporal, aspatial and other kinds of infinities. Suppose that the universe is infinite and that the character of this infinity is neither spatial nor temporal. We, of course, can say little about the character of this kind of infinity. However, one thing that can be said is that it will contain endless sub-universes that may be finite or infinite. It may be the case that some of these are combinations, being finite in some respects and infinite in others. This idea begins to sound like the Landscape, i.e., an enormous collection of kosmoi.

A question that occurs has to do with the logical consistency of this. It has always been assumed, usually tacitly, that Nature is consistent. A theory that is inconsistent, be it mathematical or physical, is rejected out of hand. The reason is simple, if a theory is inconsistent statements of the form "*A* and not *A*" can be produced. This is considered irrational because of what has been called the explosion principle, i.e., contradictions entail everything. In a Multiverse composed of many kosmoi we would expect that many statements of contradictory form would be interpreted as true.

However, we need not abandon all hope of rationality and forsake reason. Modal logic with Kripke semantics or something similar may be the appropriate logic that provides rationality for the Multiverse. [15] Another form of logic, called paraconsistent logic, developed in the twentieth century offers another foundation for rationality. Paraconsistent logic allows the formal treatment of inconsistencies in a reasonable way. [16] This kind of logic, which does not include an explosion principle, has motivated recent interest in the computer science circle. It has been proposed as a way to deal with inconsistent databases, documentation, multi-system interfaces and so on. There have even been developments of paraconsistent mathematics. Could there be paraconsistent physics?

What is ultimately possible in physics? Honestly, I just don't know. All I can do is speculate and have done so here. I am left with the impression that physics is headed in new and unexpected directions. Physics will change in the future and the resulting discipline may not be recognizable as such. This, nevertheless, does not entail the end of the rational understanding of nature. As discussed above many brilliant scientists are already probing the limits of rational understanding and this will certainly continue. New methods of reasoning might well be expected. In the final wash, we take our satisfaction in the process rather than the imagined goal.

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