What is ultimately possible in physics depends on foundations and philosophy

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ABSTRACT: I argue that what is ultimately possible in physics will ultimately depend on the willingness and ability of individual physicists to seriously concern themselves with the question of whether a theory's physical foundations and assumptions actually correspond to Nature or not. Several examples in modern physics related to the topics of time and space-time are discussed where I feel this issue to be especially pertinent, including the existence of space-time, the theory of cosmic inflation, the standard interpretation of the "block" view of time provided by relativity, the theory that time and space are quantized, and thermodynamic time reversal. I conclude with some comments about Albert Einstein, a physicist I believe physics can today still learn much from, not just for his theories and ideas, but also from his approach to physics.

What is ultimately possible in physics depends on the future emphasis of physics on foundations and philosophy. Perhaps not the most popular statement one could make, and given that I believe philosophers give philosophy a bad name, it is an unpopularity I can sympathise with. Nevertheless, it is a statement I believe to be true. Not philosophy in the sense of earnest academics inventing new 'isms' and 'ists', saying something in 10 pages that could be said in a single sentence, or pontificating endlessly about the whys and wherefores of a question but never actually addressing it, but philosophy in its real, wider sense; put very broadly, the investigation of the nature of reality. It would seem obvious that investigating the nature of physical reality, and trying to correctly assert what physically is and isn't, would be the main goal of physics. With the likes of Michael Faraday, Ludwig Boltzmann, Ernst Mach, Erwin Schrödinger, and Albert Einstein—all heavyweights of physics with a strongly philosophical approach to science, being deeply concerned with the foundations, assumptions, and logical and ontological underpinnings of physical theory—it seems that until midway through the 20th century, it largely was. Since this time, however, this has tended to be less and less the case. Following on from logical positivism and then Karl Popper, physical theories are often claimed to not have truth-values (in the sense of being definitely right of wrong), and science not to be a question of whether a theory correctly corresponds to Nature or not. Essentially, as long as a theory makes predictions that can falsified empirically, and ideally, those predictions match the results of observation and experiment, this is all that matters.

> I don't demand that a theory correspond to reality because I don't know what it is. Reality is not a quality you can test with litmus paper. All I'm concerned with is that the theory should predict the results of measurements.
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> Stephen Hawking, *The Nature of Space and Time*, Princeton University Press, 2000.

While not denying the tremendous worth of experimental falsifiability and confirmation, such an ideology is deeply problematic for two reasons. If a theory or simple physically based assertion cannot be said to correctly correspond to Nature in some way or not, and science isn't a case of an assertion being right or wrong (even though deciding between ourselves which one it is in any objective way is impossible, hence the great and unique worth of the scientific method), what value is it? The whole idea of physically based truth goes out the window, and science can have nothing to say about physical reality and make no claim to. After all, with a question of truth and reality, a proposition is either absolutely true of false, either absolutely corresponds to Nature or it doesn't, and there is no middle ground, no 50% true, no half

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correspondence. Furthermore, as is sometimes done, possibly claiming that science is concerned with facts rather than truth is circular, as a fact must be true to be a fact.

> You could say people didn't really think the theory was true because they had rejected the idea of truth in science. Truth in science must mean correspondence to reality, or it means nothing.
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> David Deutsch, *New Scientist*, Lone Voices Special, Issue 2581, 9 December, 2006.

Secondly, if science isn't a question of truth and correspondence to Nature, there is not necessarily a need that science be accountable to them. No matter how much a theory's foundations may differ from that suggested by observation, logic, or physical intuition and insight, as long as a theory makes predictions that, in principle, can be falsified, there can be no physical grounds to even remotely discount that theory unless its predictions can be falsified. This then renders claims that a particular untested theory is more persuasive than another, or is more "likely" to be true, as also being physically baseless. One cannot deny a cake is there (i.e. deny that science is a question of right or wrong, which a question of correspondence always is), and then try to take a bite from it (look to correspondence to Nature to justify a theory's greater persuasiveness). Of course, all of a theory's physical foundations and assumptions might, in principle, also be falsified or confirmed, but if little attention is paid to such foundations in the first place—something that is highly possible if one isn't concerned with the question of their actual correspondence to Nature—this is unlikely to happen. In light of such a situation, it become much more likely that the foundations of a theory can be entirely at odds with the way Nature actually is. If so, any conclusions derived from these foundations, or further theories derived from them, will be too. As parts of modern theoretical physics move farther and farther from the realms of realistic observability, and parts become more and more motivated by mathematical novelty over that suggested by observation, physical insight, or physical intuition, the chances of this happening only increase.

> How does it happen that a properly endowed natural scientist comes to concern himself with epistemology? Is there no more valuable work in his specialty? I hear many of my colleagues saying, and I sense it from many more, that they feel this way. I cannot share this sentiment...Concepts that have proven useful in ordering things easily achieve such an authority over us that we forget their earthly origins and accept them as unalterable givens. Thus they come to be stamped as 'necessities of thought,' '*a priori* givens,' etc. The path of scientific advance is often made impassable for a long time through such errors. For that reason, it is by no means an idle game if we become practiced in analyzing the long common place concepts and exhibiting those circumstances upon which their justification and usefulness depend, how they have grown up, individually, out of the givens of experience. By this means, their all-too-great authority will be broken.
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> Albert Einstein, 1916, Memorial notice for Ernst Mach, *Physikalische Zeitschrift,* 17: 101-02

In this essay I argue that what is ultimately possible in physics will ultimately depend on the willingness and ability of individual physicists to seriously concern themselves with the question of whether a particular theory's physical foundations and assumptions do indeed correspond to reality or not. While leaving more obvious contenders such as quantum mechanics, string theory, and extra dimensions, all topics where, very pleasingly, there has recently been a steady increase in attention to foundations, several examples in modern physics are discussed where I feel this issue to be especially pertinent. All of them, in way or another, relate to the subjects of time and space-time—topics that, somewhat uniquely, seem to equally bridge physics, mathematics and philosophy.[2]

1. THE NON-EXISTENCE OF SPACE-TIME

[2] Such a situation has proved very fruitful for individuals who have been able to effectively (and penetratingly) bridge all three of these subjects. I see Albert Einstein as being the perfect example of this. Carlo Rovelli might be a more modern example.

I have argued elsewhere that, despite being assumed to in physics, zero-duration instants of time and instantaneous magnitudes do not actually exist [1, 2]. Further, that if instants of time did really exist, as is the very nature of this ethereal notion—a static, durationless "snap-shot" of a physical process—motion and change would be impossible. As it represents the present tense version of an instant, this also applies to a present moment or 'now', while the same arguments apply to spatial points, with the difference simply being that a spatial point has zero extent rather than zero duration.

In many cases whether or not instants exist is of no consequence to physics. The non-existence of instants and instantaneous magnitudes does not mean that instantaneous values, limits, and real numbers suddenly stop being useful in physics. The real problem arises when the assumption of their physical existence is not recognized and then leads to contradiction and paradox (as with Zeno's motion paradoxes), or these faulty assumptions are unknowingly built into theories whose possible validity is dependent on them. Two examples of this—the theory that time and space are quantized, and the idea that the block view of time provided by relativity precludes change—will be discussed shortly.

An upshot of the conclusion that instants and spatial points do not exist is that because they are without the things—points—that would constitute their respective building blocks, not only can time and space also not exist, but neither can space-time. As they assume instants and spatial points in order to bound and determine their contributing temporal and spatial values as intervals, time and spatial coordinates in special and general relativity can also have no physical existence. This then means that the same can be said for space-time points (which consist of one time and three spatial coordinates), space-time intervals (the distance between two space-time points on a space-time manifold), and as such, the space-time continuum itself.[3]

The statement that space-time doesn't actually exist would no doubt seem outrageous to many physicists, including to many of the world's most esteemed relativity experts. Yet, late in his life, Einstein himself held this view.[4] Space-time does not actually bend or warp, stretch, or expand, as there is nothing *there* to do these things. When boiled down, all that exists is matter and motion, the remainder of physics, such as energy and force, deriving from this. Furthermore, it is the existence of motion that enables the hands of a clock to rotate and a progression along the length of a meter (which in turn provides intervals to use for space-time coordinates and enables one to derive a space-time manifold in relativity), rather the existence of time, space, or space-time enabling motion. This is not to stay that, as a model, space-time isn't very valuable. As a way of modeling the motion of a body in light of relativistic and gravitational effects such as time dilation and length contraction, it has proved to be extremely effective. However, as with instants, that space-time is a construct must be kept mind, least its existence be assumed and be treated as a fundamental component of another theory. With the reality of space-time being viewed by many physicists and mathematicians as being more of a philosophical question—a distraction to the real business of solving equations—the threat of this happening is very real.[5] Although there are several examples, including relativistic time travel [3], and Hawking and Hartle's "No boundary proposal" employing imaginary time [4], perhaps the most striking example of this threat actually being realized is the theory of cosmological inflation [5].

2. COSMIC INFLATION

With inflation, the universe is said to expand at an exponential rate many times the speed of light at the end of the grand unification epoch 10^{-36} seconds after the big bang. Although

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[3] I am far from alone in the view that space-time does not exist. See, for example, H. R. Brown & O. Pooley, Minkowski space-time: a glorious non-entity, in D. Dieks, (ed.), *The ontology of spacetime,* The philosophy and foundations of physics, Volume 1, pp. 67—89. Elsevier, (2006).

[4] "Space-time does not claim-existence in its own right, but only as a structural quality of the [gravitational] field." Einstein, A. *Relativity: The special and general theory,* Appendix V, (1952), p. 155. Methuen & Co Ltd, 1920.

special relativity precludes any object accelerating through the light-speed barrier, general relativity does not restrict the structure of space-time itself doing this. With inflation, this is exactly what is said to happen, with a scalar field called the "inflation field" generating a repulsive force when the field settles into its lowest energy state. This repulsive force is then said to drive the exponential expansion of the fabric of space-time (a de Sitter space). A helpful analogy to help picture this is to imagine a balloon (representing space-time) with small dots on it (representing particles). As the balloon inflates and stretches, the distance between the dots increases, but relative to the balloon's surface, the dots remain motionless. That is, during inflation the expansion takes place so rapidly that matter has no time to move and the process "freezes in" the original configuration of the quantum bubble that is said to have become our universe.

However, if space-time doesn't exist and there isn't actually anything there to expand, the fundamental premise of inflation can only be wrong. Considering that inflation is so well regarded as a theory, a number of its predictions very accurately matching observation [6], I realise that this a bold statement and will go down with some like a lead balloon. Yet, if one grants that inflation is reliant on space-time itself expanding, and one also grants that space-time does not exist, there is no escape from this conclusion. It should be noted that there is also a very well thought-out alternative to inflation, the variable speed of light theory (VSL) of John Moffat [7], and Andreas Albrecht and Joäo Magueijo [8], respectively, that addresses the same problems and makes similar predictions [9, 10]. Indeed, if space-time does not exist, inflation essentially becomes a variable speed of light theory.

3. RELATIVITY AND BLOCK TIME

The standard interpretation of block time provided by relativity is another example where I believe had more attention been paid to the underlying physical assumptions and their correspondence to Nature, a very different conclusion would have been reached—and in this case, a big paradox avoided. Relativity tells us that all times in the universe, past, present and future, are all laid out together in a fixed, four-dimensional space-time block. This follows as a natural consequence of the lack of a preferred present moment in relativity, with judgements of simultaneity being relative. However, this "block" view of time seems to be very much at odds with how we as people seem to experience the world, where, subjectively, time seems to flow. Indeed, a number of physicists view this seeming incompatibility as representing a real problem, because with all events and times already laid out together, they do not see that this allows for motion and change. In an effort to remedy this, some have gone as far to assert that time does indeed flow in relativity, positing that proper time evolves along families of world-lines. It is argued that this then allows for the existence of the present, the past, and for physical evolution, and thus, an "Evolving block universe" [11]. More often, however, people just accept that motion and change are illusions (even though such a view is also incompatible with the need for the continuity and associated motion of neural processes that an observer would require in order to subjectively perceive such an illusion).

However, as long as one recognizes that instants, the instantaneous, and space-time points—all static, discontinuous entities—do not actually exist, motion can still take place with such a "block" view. One must solely focus on the matter and motion in the universe, and except for the interval as represented by a clock being used as the reference, completely forget about time, the past, present and future, while recognizing that instants and space-time points are simply constructs. Furthermore, one can still assign an order to events in Nature, in the same way one can say that 2 follows 1, and 3 follows 2, without making reference to tense, before and after, past and future.[6] This also naturally applies to the readings of a clock. If interpreted in this way, the paradox of block time disappears, and motion and change can be seen to be entirely compatible with a timeless view of reality in which there is no preferred present moment. That is, while the lack of differentiation between past, present and future in relativity negates a flow of time, it by no means negates motion and change. The only thing

[6] In this same way, the thermodynamic arrow of time becomes a question of the relative order of events (i.e. 1, 2, 3 or 3, 2, 1), rather than of the direction of time.

that does this is the assumption that the instantaneous is real, or the presumption that without time, motion is not possible.

4. TIME AND SPACE'S QUANTIZATION

Another relevant example, I would contend, relates to the question of whether time and space may be quantized and come as discrete atoms, particles of time and space. As such particles would represent a smallest possible interval—not just the smallest that we are able to operationally define as per Planck time ($\sqrt{\hbar G/c^5}$ = 5.39124(27) x 10^{-44} seconds) and Planck length ($\sqrt{\hbar G/c^3}$ = 1.616252(81) x 10^{-35} meters), but which actually physically *exist*—such intervals would require starting and stopping points to bound and determine them as intervals. As I have argued elsewhere [1, 2], if such stops—instants and spatial points—really did exist, however, motion and change would be impossible. The existence of a so-called non-zero duration instant is precluded for this same reason. This is not to say that the readings of clocks and meters cannot be quantized. With any clock and meter being constituted of matter, they should be. But this has nothing to do with "time" and "space" being quantized; rather, matter.

5. THERMODYNAMIC TIME REVERSAL

The way thermodynamic time reversal has historically often been treated is another case that I believe illustrates the problem of not questioning physical assumptions carefully enough. It is often said that if the entropy of an isolated system began to decrease after a period of entropy increase, this representing a breach of the second law of thermodynamics, events leading up to this point would evolve backwards. For example, if this happened as the universe began to contract in a closed universe, as Stephen Hawking once argued [12], events would then evolve, backwards, back to the big bang. Effects would precede causes, a person would grow younger as time passed, and one would be dead before they were born. Nevertheless, as the same thermodynamic processes would underlie our physiology and brain processes, people living during this time would also *think* in the direction in which entropy was decreasing. Because this would mean that their mental processes, memory and sense of causality would also be reversed, everything would seem quite normal to such back-to-front people.

However, such a scenario has a fatal flaw. Irrespective of our sense of causality also being reversed in such a situation, this does not change the fact that events would still be causeless. A ball that was hit with a bat and rolled along the ground before coming to a stop (with entropy increasing), would still somehow be expected to begin rolling back to the bat without a force acting upon it (with entropy decreasing). With the laws of physics being time reversible, one might argue that the ball would now instead be pulled by some force, but what would *cause* this pull? The bat? The whole scenario clearly falls over. Thus, in any isolated system in which entropy decreased after a period of entropy increase, physical process would be causeless, this rendering entropy decease in any such system a firm no go. As this includes our universe, this also demands that the second law of thermodynamics can never be breached in it.[7] If, in another universe, entropy decreased and never increased, there would be so such issue, but I think a strong case can be made that the upholding of causality in general would only be possible in a system with entropy increasing. For example, in a universe with entropy decreasing, heat would be expected to transfer to a rolling ball's kinetic energy through friction, this increasing its velocity and increasing the usable energy. Friction would impart energy to the ball. However, without an additional source of energy to enable this transfer, the process could not work, even in principle. Although it has only been briefly outlined, please note that the 'lack of cause' argument detailed above also represents a solution to the

[7] This is not to say that I believe thermodynamic time reversal is not possible. Rather, that it can only take place within the context of increasing entropy. Please see http://arxiv.org/abs/physics/0612053 for more details. In this model, heat is forced to flow to hotter under the immense and increasing density just prior to a big crunch or black hole singularity. However, rather than this *actually* happen, the order of (future) events reverse, so that heat can continue to flow to cold. With the laws of physics, with the exception of thermodynamic processes, being time reversible, this would not appear to pose any problem or paradox, while it would also avoid some.

reversibility or 'Loschmidt's' paradox [13]—the mystery of how it can be possible to derive a irreversible process from entirely time-symmetric dynamics.

6. CONCLUSION

Theoretical physics currently finds itself in something of a crisis. With theories such as string theory, extra dimensions, and the multiverse holding such prominence, never before has the gap between theory and observation been so large. With physics generally assuming the existence of instants, time, space, and space-time, the divide between reality and these assumptions (and theories whose validity rely upon them) is similarly sizable. Meanwhile, and although the gap has lately reduced, over recent decades, never before has the disjoint between physics and philosophy also been so big. I do not think that these things are unrelated.

> It has often been said, and certainly not without justification, that the man of science is a poor philosopher. Why then, should it not be the right thing for the physicist to let the philosopher do the philosophizing? Such might indeed be the right thing at a time when the physicist believes he has at his disposal a rigid system of fundamental concepts and fundamental laws which are so well established that waves of doubt cannot reach them; but, it cannot be right at a time when the very foundations of physics itself have become problematic as they are now.
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> Albert Einstein
> Physics and reality, *Journal of the Franklin Institute*, Volume 221, Issue 3, 349-382, 1936.

A number of references to Albert Einstein have appeared in this essay. Considering Einstein's immense impact on 20th (and now 21st) century physics, this is probably to be expected. Yet, I view the combination of Einstein's acute physical insight and intuition, concern for foundations, and 'reality mindedness', at the same time being coupled with a very high proficiency with mathematics, as the main thing that contributed to his being so successful as a physicist. All too often these two features seem to be mutually exclusive in a physicist, and I see this lack of meeting as being at the very root of the gap between theoretical physics and reality currently being so large. If theory is to bridge this gap in the future, I am convinced that modern theoretical physics will need to concern itself more with foundations and the question of whether such foundations really do correspond to Nature or not. Pleasingly, I see the establishment of the Foundational Questions in Physics and Cosmology Institute as being a big step towards this

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