On the Origin of the Constants c and h

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Abstract

It is argued that the speed of light c and Planck's quantum h are anomalies that undermine the basis of Newtonian physics, the existence of space and time. In a Kuhnian sense, c and h were unpredicted parameters, extraneous to Newton's physics. Relativity and quantum mechanics, despite their obvious success, can be seen modifications of Newtonian physics that hided the possibility that space and time were inappropriate concepts for describing reality. Rather than being fundamental, space and time might just be the most suitable frames for human perception. c indicates a failure of the Newtonian space-time paradigm on large scale, while h indicates a failure on small scale. At the same time, c and h are related to light and matter, two phenomenologies Newtonian physics cannot explain as such. There is no a priori reason why reality should present itself in this particular fashion, and there is no reason for the existence of 3+1 dimensions either.

It is further suggested that reality might be truly three-dimensional, the fourth dimension being an illusion created by navigating through a sequence of tangent spaces of a three-dimensional manifold. All physical laws would then be encdoded in a connection on this manifold. The most simple three-dimensional manifold, endowed with unique properties, is S^3. From the point of view of natural philosophy, there must be a reason for the existence of constants of nature. If S^3 is indeed a description of reality, then it should provide a reason for the existence of c and h. It is suggested that c is related to the fact that S^3 has a tangent space and h is related to the noncommutativity of $SU(2)$, the group acting on S^3.

A Kuhnian approach to physical reality

Space and time are the most enduring notions of our description of reality. These concepts were probably established long before science in its early forms had started and evidently dominate our perception. Isaac Newton postulated absolute space and absolute time as axioms of his classical mechanics and founded modern science when relating celestial phenomena to lab experiments on Earth. For him, the existence of space and time was obvious. What if he was wrong? What if space and time were phenomenologies that emerged from something deeper?

Though the idea of space and time being absolute has been considerably modified by relativity, the general belief that space and time were reasonable notions for describing reality persisted. Yet, that might be misleading. Space and time, unexplained in their nature, may be just the phenomenologies most compatible with human perception rather than the most appropriate terms for describing reality. Science proceeds at a peculiar pace, as outlined by Thomas Kuhn in his treatise *The Structure of Scientific Revolutions*. Long periods of 'normal science', dominated by the paradigm of the time, are interrupted by revolutions in which a large part of the existing knowledge becomes obsolete, and a new paradigm, often simpler and more insightful, is established.

The periods of normal science greatly differ on time scales, and often paradigms are nested inside one another. Since Newton, physics has undergone a series of paradigm shifts, but the superparadigm of reality presenting itself on the space-time stage subsisted. To those familiar with Kuhn's ideas it might leap to the eye that the contemporary standard models of physics show many signs of crisis. These models are extensively complicated, the most visible symptom being the large number of free parameters. Many unexpected phenomena, called anomalies by Kuhn, were described in an ad-hoc manner by introducing new parameters, leading to further complication. On the other hand, many 'established' concepts do not have an explanation derived from first principles.

While a general critique of the standard models is beyond the scope of this article, we will recall the litmus test of the quality of a theory, the number of free parameters. Strictly speaking, every 'constant of nature' is a free parameter we use to describe Nature, and often, such parameters hide a lack of deeper understanding. Revolutionary progress in physics has always been linked to a reduction of the number of constants.[1] If we apply this principle to the extreme, an ultimate theory of physics must get rid of all constants of Nature, including the most cherished ones, c and h. Regarding the role of constants of Nature, it is worth considering a comment given by Albert Einstein, the scientist who achieved much more than anyone else in revealing the significance of the constants c and h [1]:

> "I would like to formulate a law of nature, which is based in nothing but a belief in the simplicity, that is, the intelligibility of nature: There are no arbitrary constants. That means, nature is constructed in a way that allows strongly determined laws, in which only rationally deduced constants do occur.'

[1]For example, electrodynamics, by means of the formula $\frac{1}{c^2} = \epsilon_0 m u_0$, reduced three constants to two.

We should thus call into question the validity of the constants c and h. They might be anomalies that prove the failure of the Newtonian concepts of space and time.[2]

c, the large scale anomaly related to light. The speed of light, first measured by Römer in 1676, is a problem for classical physics. A finite speed of light, though advocated by Newton, had no relation to the theory of dynamics he developed in his *Principia*. For others, such as Descartes, a finite speed of light remained irritating. There is no reason whatsoever that justified its finiteness from Newton's theory. However, the fact that c was finite was viewed rather as a curiosity than as a serious contradiction to Newton. But strictly speaking, light was an anomaly with respect to Newtonian physics. Newtonian physics applied to matter, and light remained an extraneous concept, unexplained in its very nature. The fact that the velocity of light had a limited value was a problem for Newton's theory because velocity, a well-defined notion in Newton's dynamics, had no preferred numerical value.

The severity of the problem - though considered a discovery - turned out to be even more obvious at the beginning of the 20th century when the unexplainable velocity of light was shown to be a limiting velocity for matter as well. Bluntly speaking, the observation that masses cannot even reach the speed of light was a falsification of Newtonian dynamics. There is no reason whatsoever from Newton's laws why particles should not be accelerated beyond c.

Einstein (with important contributions by Poincare and Lorentz), in a stroke of genius, constructed a dynamics for massive particles that incorporated c as a limiting velocity for matter: special relativity. Special relativity is a brilliant theory because it is not only mathematically consistent but describes a variety of puzzling phenomena in a spectacular parsimonious way with just one free parameter, c. While this solution did little harm to Newton's theory, which remained a valid approximation for small velocities, there might be an unsettling possibility: that the very concepts of space and time were wrong and special relativity was just a workaround that helped a paradigm that otherwise was doomed to fail to survive.

All things considered, if we look at the period 1676-1905, c is a free parameter that was introduced ad-hoc (though it took more than 200 years in this case) to remedy an anomaly that contradicted an established model, the physics of space and time. In the aftermath of Einstein's special relativity, the space-time paradigm was much fortified by Minkowski's ambitious ideas, which were publicized aggressively at conferences around 1908. Minkowski's point of view was that the newly postulated conglomerate, 3+1 dimensional spacetime, was truly something four-dimensional. But it is not. Space and time are simply not the same, if we do not depart from our senses.

[2]One might ask about the role of Newton's constant G which is considered a fundamental constant as well. We believe however that G may be expressed in terms of c and the mass distribution in the universe, as suggested by [2], [3]; see also [4] and [5].

Disregarding the different nature of space and time and postulating higher dimensional spaces as descriptions of reality is probably one of the most catastrophic deviations of modern physics. Back then c, the riddle of whose origin should have been subject to investigation, was baptized a 'scale factor' and deprived of its fundamental meaning. Surely, Erwin Schrödingers words apply here: 'Once the problem is remediated by an excuse, there is no need any more to reflect upon it.'

h, the small scale anomaly related to matter. The limiting velocity of light, or even the very existence of light, is a large-scale phenomenon predominantly present in astronomy, the field where science began. When scientists started to investigate small-scale phenomena more than two centuries later, another profound anomaly arose: Planck's quantum of action. The fact that h presents an anomaly of Newtonian physics is even more evident than in the case of c. There was no reason inherent to Newtonian dynamics that remotely suggested that small timescales and small length scales were a problem. Yet it is here where conventional physics broke down. Neither Newton nor anyone of his followers, literally nobody had foreseen that.

There is no need to repeat how much the picture of reality held by physicists at the beginning of the twentieth century was shattered by quantum phenomenology. And certainly, the emergence of quantum mechanics constituted a revolution in a Kuhnian sense, during which the concepts of determinism and causality evaporated. However quantum physics was also a revolutionary simplification in many aspects: The quantum h was discovered by Planck in blackbody radiation, ingenuously linked to the energy of light by Einstein and then, in a tantamount stroke of genius, applied to atomic physics by Bohr. All this presented a tremendous simplification and unification of phenomena that otherwise would have remained unrelated curiosities in a much more complicated picture of reality. As relativity, quantum physics was a great achievement because it constituted a widely consistent description of reality with just one constant, h. Yet, one constant may be one too many.

There is another unsettling aspect specific to quantum theory. Though a lot of mathematical techniques were developed alongside its development, two very basic notions (ironically related to Newton) were destroyed: continuity and differentiability. This is a serious problem. We still depict space-time as manifolds to which we apply a variety of sophisticated mathematical methods, although there is no way to do reasonable mathematics on manifolds (the very notion cannot even be defined) unless one uses continuity and differentiability. Physicists have gotten used to (and were allowed by mathematicians) to gloss over the problem by stating that one has to consider 'quantum effects' (whatever that means). This has become a universal excuse for a dramatic failure of Newtonian physics at the small scale: Rather that 'quantum corrections', it might be that the very notions of space and time do not make sense at a fundamental level.

The failure of the space-time concept. From a broader perspective, one must conclude here that c and h are anomalies of Newtonian physics. They are not only discoveries that founded modern physics but also unpredicted phenomena that suggest that the underlying concepts, space and time, are inappropriate. h indicates a failure of Newtonian physics at the small scale as c indicated a failure at the large scale. It is not that physics misses a unification of quantum physics and relativity, this is presumably an ill-posed problem. Quantum physics and relativity are both manifestations of the fact that space and time itself are wrong concepts.

On the other hand, a purely mathematical reason for the existence of a constant with physical units is missing. What precisely is a physical unit? Generally speaking, it transforms qualitatively different quantities into each other by multiplication. At first sight, mathematics seems to deal with the very same quantity, pure numbers. But this is not quite true. Particularly on manifolds, there are qualitatively different objects, such as numbers and angles, vectors and matrices (elements of $SO(3)$), tangent spaces and so on. Sometimes the differences are subtle and may not be visible on first approximation. Yet there is the possibility that physical constants emerge from purely mathematical concepts that, though qualitatively different, are improperly equated on first approximation.

The threedimensional world S^3

If c and h are really manifestations of poorly understood mathematics, they surely indicate that our usual picture of a 3+1 dimensional space-time is wrong. What could be a possible alternative that is consistent with the rich phenomenology? If we recall Occam's razor, it suggests that that fundamental physics is simple. Thus it might be a good idea to consider the most simple end elementary mathematical objects from swhich one can expect a sufficiently rich phenomenology.

S^3 and $SU(2)$. As far as manifolds are concerned, an obvious guess is that S^3, the unit sphere in three dimensions, has a close relation to reality. It is worth pointing out a few peculiar properties that are purely mathematical. Poincares conjecture, proven recently by Grigori Perelman, states that all simple connected three-dimensional manifolds are homeomorphic to S^3, highlighting its uniqueness. Then, S^3 is also isomorphic to the group $SU(2)$, so to speak, it can operate on itself (As S^1, but not S^2). To anticipate a little, elements of $SU(2)$ can be almost perfectly visualized by rotations.[3]

$SU(2)$ is a Lie group, which means a differentiable manifold, with the peculiarity that the derivative projects to the Lie algebra $su(2)$, not to $SU(2)$ itself. While $SU(2)$ is obviously compact, $su(2)$ is not. The Lie algebra can be visualized by vectors in

[3] 3-D computer animations use $SU(2)$ for describing spatial rotations.

R^3, which again corresponds to a rotation in three-dimensional space. The direction of the 'vector' is the rotation axis and its length the angle of rotation (which can indeed be infinite). However, there is an important caveat: a concatenation of finite rotations cannot be assigned to addition of vectors, since vector addition does commute, while finite rotations do not.[4]

Tangent spaces and c. But how can the perceived 3+1 dimensions be generated by a Lie group which has just three dimensions? A very natural concept when dealing with manifolds is the tangent space. Taking the two-dimensional analogy of the sphere, a tangent space can be easily visualized: a flat plane that consists of vectors (or 1-forms). The tangent space is a linear extrapolation of the local manifold, so to speak.

It is evident that though the tangent space at every point is different, each tangent space is a quite good approximation of the manifold. However, if one considers a sequence of tangent spaces, for example by moving around on the manifold, an interesting effect occurs: The sequence of three-dimensional tangent spaces, each one similar to its neighbor, may be perceived as 3+1 dimensional, almost flat manifold. Time would parametrize the path, though not in the usual sense (since time is directed). Could this similarity of adjacent tangent spaces manifest as something we perceive as continuous space-time? In this case, our perception of 3+1 dimensional reality would be an illusion in principle, generated by a sequence of tangent spaces along a path. All dynamical laws of Nature would then be encoded in a connection on this manifold, a well-known concept in differential geometry.

It seems natural to associate the tangent space with the light cone: a linearized picture of reality from which we deduce information about objects at a distance. Light is the only information available in a space-time point, the same thing can be said for the light cone. The greater the distance, the more insecure the extrapolation.

What happens if the result of differentiation is qualitatively different from the original object and what if one is as well tempted to equate it? Then a factor is needed that qualitatively transforms sone notion into the other one. Such a factor can manifest as a dimensionful constant of Nature, in this case c. c might be an anomaly that necessarily arises when we try to equate quantities that are different, such as elements of a Lie group and elementss of a Lie algebra. It is important to realize that such 'constants of nature' would arise almost as a mathematical necessity. c would be the constant that appears because we linearize.

S^3, h and spin. Aside from the obvious property of having a tangent space, which is quite common for a manifold, the most remarkable property of S^3 is that the action of the group ($SU(2)$ is homeomorphic to S^3) is noncommutative. As in the case of the

[4] Technically called the Lie bracket.

related $SO(3)$, finite elements do not commute:

$$a \circ b \neq b \circ as \tag{1}$$

in general. Suppose now that the elements of S^3 (or $SU(2)$, respectively) are physical quantities that are represented as vectors, which is quite a good approximation in most cases. The multiplication of elements of $SU(2)$ would then correspond to a vector addition, but not exactly. Thus a tiny effect would result when the sum of two vectors is equated to the product of the two elements of $SU(2)$. This manifestation might be Planck's quantum h. Here again, the appearance of a 'physical constant' becomes a purely mathematical necessity, when physical objects are assigned inappropriately to mathematical objects that are equivalent on first approximation only. One might put it in still another way: A commutator of two elements is not something one can compare to the elements themselves. Again, we are tempted to equate these commutators to the original elements, and this requires another factor that is different from a usual number: h seems to be the consequence of S^3 being noncommutative.

While this is a very general argument, the phenomenology of h is a clear hint that this constant of nature is related to rotations and their noncommutativity, for example the exchange relations for angular momentum in quantum mechanics, $[p_x, p_y] = \hbar p_z$ etc.

As a third indication, $SU(2)$ is the double cover of $SO(3)$, the group of rotations in threedimensional space. Ever since this mathematical property was discovered, it has been related to the existence of spin. Contrary to common wisdom, which considers spin to be a consequence of the Dirac equation, this description does not provide a reason for the existence of spin from first principles.

$SO(3)$ allows for an interpretation as rotations in an three-dimensional space. This is presumably the subtle way in which Nature created the illusions we believe to this day to exist: space and time. But time may just be a parameter that is needed for differentiation, and Euclidean three-dimensional space might be a misleading image of the three-dimensionality that is inherent in the Lie algebra of S^3. Whenever we do reasonable math on the simplest three-dimensional manifold, we differentiate and we concatenate elements. This might be the origin of the constants c and h, and the origin of light and matter.

Outlook

While these thoughts are certainly speculative, such an attempt to reformulate the space-time concept would have profound consequences for fundamental physics. There would be no need for a unification of quantum physics and relativity, just a replacement of c and h that correctly describes the mathematical objects and explains how the phenomenology of space and time arises. Waves and particles could lose their role as fundamental terms for describing reality, the more fundamental phenomenology we have to wonder about seems to be light and matter.

There would be no wave particle dualism, no measurement problem, no collapse of the wave function, no causality or violation of it, there would be just one big misunderstanding of what we falsely believe to be the stage of reality: space and time.

So why do the constants of nature c and h exist at all? This may be an unusual question. It is sometimes tempting to imagine how an extraterrestrial superintelligence would do physics. Is there a cogent reason why such a highly advanced civilization (a level that we might not have yet achieved) would be unable to describe the phenomenology in purely mathematical terms, without any 'physical' constants? We may assume that these intelligent beings measure the same constants *if they developed a paradigm similar to ours*, but they may as well have advanced further. Our belief in the existence of physical constants might be due to a limited understanding.

On the other hand, it makes sense to assume that before such a level of intelligence is reached, phenomenology is assigend to mathematical objects at a premature stage. If such inappropriate assignments reveal themselves by tiny effects only, one would expect that a considerable coevolution of science and technology is required until a civilization eventually arrives at the proper conclusions. In the end, this does not appear to be so very different from the story of homo sapiens.

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