

Testable Criterion Establishes the Three Inherent Universal Constants

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Abstract

Since the late 19th century, differing views have appeared on the nature of fundamental constants, how to identify them, and their total number. This concept has been broadly and variously interpreted by physicists ever since with no clear consensus. There is no analysis in the literature, based on specific criteria, for establishing what is or is not an inherent universal constant. The primary focus here is on constants describing a relation between at least two of the base quantities mass, length and time. This paper presents a testable criterion to identify these unique constants of our local universe. The value of a constant meeting these criteria can only be obtained from experimental measurement. Such constants set the scales of these base quantities that describe, in combination, the observable phenomena of our universe. The analysis predicts three such constants, uses the criterion to identify them, while ruling out Planck's constant and introducing a new physical constant.

Keywords: fundamental constant, inherent universal constant, new inherent constant, Planck's constant

1. Introduction

The analysis presented here is conceptually and mathematically simple, while going directly to the foundations of physics. It focuses on the inherent physical relationships among mass, length and time. These act as fundamental constraints on the physical properties of the local universe (Burrows & Ostriker, 2014).

The first suggestion that potential "fundamental constants" might exist as the natural units of theoretical physics came in the late 19th century (Johnstone-Stoney, 1881). Subsequently, others suggested zero to seven such constants (Uzan, 2011; Cohen-Tannoudji, 2011; Matsas et al., 2013). Weinberg (1983) described them as "... a list of the constants that appear in the laws of nature at the deepest level that we yet understand, constants whose value we cannot calculate with precision in terms of more fundamental constants ... because we do not know of anything more fundamental." Their values are obtained only by experimental measurement.

The term "fundamental physical constant" is broadly inclusive and imprecise. Various categories and sub-categories have been suggested from time to time. One such classification, recently presented in Applied Physics Research (Suto, 2015), is convenient for the analysis presented here. It distinguishes between universal constants, such as c (velocity of light), and micro material constants consisting of *either* physical quantities (such as m_0 , electron rest mass; e , unit of electrical charge; λ_C , Compton wavelength; R_∞ , Rydberg constant) *or* physical constants (such as k_B , Boltzmann's constant; N_A , Avogadro's constant).

Although this concept has been the subject of debate for over a century, no consensus has emerged (Johnstone-Stoney, 1881; Uzan, 2011; Cohen-Tannoudji, 2009; Matsas, Pleitez, Saa, & Venzella, 2013; Weinberg, 1983; Karshenboim, 2005; Karshenboim & Peik, 2004; Jeckelmann, 2012). Until now no systematic analysis, based on empirical criteria, has appeared in the literature that attempts to identify those few physical constants describing a relation between the base quantities mass, length and time. These are the inherent physical constants of the local universe, the "universal constants" — labeled here as U . They are inherent to that part of physical reality we can in principle observe, which is expected to have three dimensions of space and one of time (Tegmark, 2014). Certainly, the U are essential parts of the foundations of physics at both the quantum and universe scales.

This analysis proposes a testable criterion and uses it to identify the U residing among the known physical constants. Such an approach also provides a firmer basis for evaluating whether or not Planck's constant, h , is one of the inherent universal constants (Suto, 2015), where it is suggested that h is a micro material constant in the physical quantities sub-category.

2. Methodology

Any testable criterion must be able to identify every physical constant combining at least two of the base quantities that is a **U**, while specifically excluding all other such physical constants, without contradiction. The criterion proposed here is this — the experimental measurement of the value of the base quantities that define the **U** cannot depend on any physical constants other than the reference units of measurement for those base quantities.

The International System of Units (SI) identifies seven base quantities. Those of particular interest here are:

length (l) in meters (m).

mass (m) in kilograms (kg).

time (t) in seconds (s).

The analysis focuses on those physical constants that can be expressed as a combination of at least two of these base quantities. There are four combinations: (m, l), (m, t), (l, t), (m, l, t). Constants of measurement involving just one base quantity represent a different category of fundamental constants — the experimentally measured value of a base physical quantity is expressed as a number times a unit, which is a particular example of the base quantity that is currently being used as a reference. There is no inherent fundamental unit for mass, length or time.

Throughout this paper, reference is made to the extensive lists of fundamental physical constants provided by Cohen and Taylor (1987) and by Mohr, Taylor and Newell (2012). They include numerous constants dependent on the measurement of one base quantity, such as the mass of a particle. This analysis focuses on identifying those physical constants (combinations of the base quantities m , l and t) that meet the criterion developed here for identifying a **U**.

In a relationship involving three independently established physical constants (each containing at least two of the base quantities — mass, length, time), such as $A \times B = C$, there are exactly four possible outcomes regarding the presence of **U**:

- 1) none is a **U**, which is allowed.
- 2) one is a **U**, not allowed because it could be derived from the other two non-**U**.
- 3) two are **U**, allowed and the relevant case for this analysis.
- 4) three are **U**, not allowed.

3. Results and Discussion

3.1 Predicted Number of **U**

- 1) Any combination of the base quantities needs at most one **U**, otherwise redundancy or contradiction.
- 2) All **U** must have one and only one base quantity in common, a unifying principle for the **U**.

This predicts three **U** for the four combinations of the base quantities (m, l, t).

3.2 Analysis of the Four Combinations

For (l, t), let $l / t = \text{length} / \text{time} = \mathbf{c} = \text{the velocity of electromagnetic radiation (E.M.) in vacuo} = 3 \times 10^{10} \text{ cm/s}$. Thus, \mathbf{c} describes a relation between the two base quantities, length and time, that are measured directly. It requires no other physical constants. Therefore, \mathbf{c} meets the criteria for a **U**. There is no other known example of a fundamental physical constant in the lists used here for (l, t).

For (m, t), there is no known example of a fundamental physical constant in the lists used here for (m, t).

For (m, l), consider the rest mass of a particle, m_0 , and its Compton wavelength, λ_C . The ratio $[m_0 / \lambda_C]_{\text{particle}}$ is not constant because as m_0 increases λ_C decreases, whereas their product $[m_0 \times \lambda_C]_{\text{particle}} = m \cdot l$ is constant. Both m (particle mass, m_0) and l (Compton wavelength, λ_C) are measured directly. The values of λ_C for the proton and neutron have not been measured experimentally. For the electron, use the values of λ_C (Compton, 1923; van Assche et al., 1971) and m_0 to give $(9.11 \times 10^{-28} \text{ g}) \times (2.43 \times 10^{-10} \text{ cm}) = 2.21 \times 10^{-37} \text{ g} \cdot \text{cm} = \mathbf{\kappa}$. It requires no other physical constants. Therefore, $\mathbf{\kappa}$ meets the criteria for a **U**. There is no other known example of a fundamental physical constant in the lists used here for (m, l).

For (m, l, t), set $\mathbf{G} = (d^2x / dt^2) \cdot x^2 / \text{mass} = (l_1 / t^2) \cdot (l_2)^2 / m = \text{the universal gravitation constant} = 6.67 \times 10^{-8} \text{ cm}^3/\text{g} \cdot \text{s}^2 = l^3 / m \cdot t^2$. Thus, \mathbf{G} describes a relation involving all three of these base quantities. Both l_1 and t are measured directly so l_1 / t^2 gives the acceleration of the test mass. The distance, l_2 , between reference mass and test mass is measured directly. The reference mass, m , is measured directly. It requires no other physical

constants. Thus, **G** meets the criteria for a **U**. There is no other known candidate for a **U** using (m, l, t) that meets the testable criteria in the lists used here for (m, l, t) .

3.3 Analysis of h

Consider the quantum of action, h , which leads to $h = [m_0 \times \lambda_C]_{\text{particle}} \times c = \kappa \times c$. The previous analysis showed that κ and c satisfied the testable criterion for a **U**. Now apply it to evaluate $h (m \cdot l^2 / t)$.

1) What specific physical relationship among the base quantities (m, l, t) does h define:

- a) what mass, m , what distance, l^2 , what time, t ?
- b) what mass, m , what distance, l_2 , what velocity, (l_1 / t) ?

Using $\kappa = [m_0 \times \lambda_C]_{\text{particle}}$ for m and l_2 , along with $c = (l_1 / t)$, simply employs the values of two already established **U** to create h .

2) There is, as yet, no direct experimental measurement of h in terms of just m, l and t . Current experimental approaches to measuring h employ the values of other physical constants, such as the von Klitzing and Josephson constants. Thus, h does not satisfy the empirical criteria for a **U**.

As discussed in Methodology, using $h = \kappa \times c$ can only satisfy either none is a **U** or two are **U** (κ and c , the case here). The results of this analysis show there are just three **U** (c, κ and **G**), as predicted. To-date, no alternative set of empirical criteria has been proposed in the literature that identifies h, c and **G** as the only **U** while excluding all others, including κ , without contradiction?

3.4 Other Candidate Physical Constants

There are four additional (SI) base quantities:

electric current (i , ampere = Coul/s)

thermodynamic temperature (T , kelvin K)

amount of substance (n , mole)

luminous intensity (I_v , candela)

No known combination of the seven base quantities that includes any of these four can be shown to meet the criteria for a **U** (Uzan, 2011; Karshenboim, 2005; Karshenboim & Peik, 2004; Jeckelmann, 2012).

Take the example, $k_B \times N_A = R_0$, with Boltzmann's constant, $k_B = m \cdot l^2 / t^2 \cdot K$, Avogadro's constant, $N_A = \text{Number} / \text{mole}$, the Gas constant, $R_0 = (m \cdot l^2 / t^2) / \text{mol} \cdot K$. None of them meets the criteria for a **U**. This result is supported by the analyses of other researchers using different approaches (Uzan, 2011; Karshenboim, 2005; Karshenboim & Peik, 2004; Jeckelmann, 2012).

Another example involves the relationship $c = 1 / (\epsilon_0 \times \mu_0)^{1/2}$, where μ_0 is the magnetic constant and ϵ_0 is the electric constant, which emerges from Maxwell's equations for the classical vacuum. Stratton (1941) offers a detailed analysis of the nature of ϵ_0 and μ_0 , noting that, "No experiment has yet been imagined by means of which dimensions may be attributed to either ϵ_0 or μ_0 as an independent physical entity." He points out that it is a requirement of the field equations that $c = 1 / (\epsilon_0 \times \mu_0)^{1/2}$ and c must be a velocity, which cannot be calculated *a priori*. The parameter μ_0 is a measurement system constant. It is not a physical system constant that can be measured and so the value of μ_0 is defined, which then defines ϵ_0 , by using $\epsilon_0 = (1 / \mu_0 \times c^2)$, (Uzan, 2011; Karshenboim & Peik, 2004; Jeckelmann, 2012; Stratton, 1941). Neither meets the criteria for a **U**.

3.5 Unit of Electric Charge

As pointed out by Stratton (1941), it is convenient to recognize electric charge, e , as a fundamental *unit* related to (m, l, t) , via the ampere (Coul/s) and $\mu_0 = g \cdot \text{cm} / \text{Coul}^2$. It is the only known example of an inherent universal unit.

Define $Q_{\text{Planck}} = (4\pi \times \epsilon_0 \times c \times h / 2\pi)^{1/2} = (2 \times \kappa / \mu_0)^{1/2}$ and $\mu_0 = 4\pi \times 10^{-7} (\text{N} / \text{A}^2) = (0.1257) g \cdot \text{cm} / \text{Coul}^2$. For $\kappa = 2.214 \times 10^{-37} g \cdot \text{cm}$ and $e = 1.602 \times 10^{-19} \text{Coul}$, then $Q_{\text{Planck}} = 18.772 \times 10^{-19} \text{Coul} = (11.718) \times e \text{Coul}$. Thus, $e = (0.1207) \times [\kappa (g \cdot \text{cm}) / \mu_0 (g \cdot \text{cm} / \text{Coul}^2)]^{1/2} = (0.1207) \times (\kappa / \mu_0)^{1/2} \text{Coul}$ and so the value of e depends on $\sqrt{\kappa}$.

4. Conclusions

The testable criterion established κ, c and **G** as inherent universal constants of the local universe. They are foundation constants establishing the most fundamental relationships among the base quantities of mass, length and time — the "givens" of our local universe on both the quantum and universe scales. The three **U** are sufficient to uniquely define these basic relationships, having the common base quantity length, l .

The analysis produced a U for (m, l) , κ , a fundamental constant not previously identified as such. It related two energy states of matter — localized energy in the particle state and dispersed energy in the wave state. It is also related to the unit of electric charge via the equation $e = (0.1207) \times (\kappa / \mu_0)^{1/2}$ Coul.

The fact that h does not meet the testable criterion for a U challenges the common opinion that h has equal status with c and G . This opinion has *never* been supported in the literature by a set of testable criteria that can be used to define an inherent universal constant. These criteria would have to identify h , c and G uniquely and exclude all others. Replacing h with the equation $\kappa \times c = h$ introduces a new perspective on theories incorporating h .

The empirical criterion developed here provides an effective tool for understanding what qualifies as an inherent universal constant of the local universe, U . Many experimental measurements depend on a well-defined understanding of the nature of these U . The theories and equations of physics that describe basic physical relationships and phenomena in terms of the base quantities (m, l, t) require them.

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