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Planck Units Measured Totally Independently of Big *G*

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Abstract

In this paper, we show how one can find the Planck units without any knowledge of Newton's gravitational constant, by mainly focusing on the use of a Cavendish apparatus to accomplish this. This is in strong contrast to the assumption that one needs to know G in order to find the Planck units. The work strongly supports the idea that gravity is directly linked to the Planck scale, as suggested by several quantum gravity theories. We further demonstrate that there is no need for the Planck constant in observable gravity phenomena despite quantization, and we also suggest that standard physics uses two different mass definitions without acknowledging them directly. The quantization in gravity is linked to the Planck length and Planck time, which again is linked to what we can call the number of Planck mass events. That is, quantization in gravity is not only a hypothesis, but something we can currently and actually detect and measure.

Keywords

Planck Mass, Newton's Gravitational Constant, Cavendish Apparatus, Quantum Gravity

1. Background

In 1899, Max Planck [1] [2] introduced what is known today as the Planck units. He did this by assuming there were three universal constants; namely, the speed of light c, the Planck constant $\hbar$, and Newton's gravitational constant. Using dimensional analysis, he derived a mass, time, length, and temperature (energy), which he thought were important, even fundamental units. These were given mathematically by $m_p=\sqrt{\frac{\hbar c}{G}}$, $l_p=\sqrt{\frac{G\hbar}{c^3}}$, $t_p=\sqrt{\frac{G\hbar}{c^5}}$, $E_p=\sqrt{\frac{\hbar c^5}{G}}$ (or actually the Planck temperature $T=\sqrt{\frac{\hbar c^5}{G k_b^2}}$ which is directly linked to the Planck energy).

Haug [3] [4] has recently suggested that G is a universal composite constant of the form $G=\frac{l_p^2 c^3}{\hbar}$, and that it is the Planck units that are even more fundamental. Naturally, we can find $G=\frac{l_p^2 c^3}{\hbar}$ mathematically by solving Planck's formula for the Planck length with respect to G. Similarly, we can solve the Planck mass formula, the Planck time formula, or the Planck energy formula with respect to G; this gives $G=\frac{\hbar c}{m_p^2}$, $G=\frac{t_p^2 c^5}{\hbar}$, and $G=\frac{\hbar c^5}{E_p^2}$, respectively. To suggest that the gravitational constant is a composite constant related to the Planck units was already suggested in 1984 by Cahill [5] [6]. His suggested formula was based on solving the Planck mass formula for G, so his formula was $G=\frac{\hbar c}{m_p^2}$. However, modern physics relies on G to find the Planck units, so claiming that G is a universal composite constant seems to lead to a circular problem. This circular problem was likely first pointed out in 1987 by Cohen [7]. For example, McCulloch [8] [9], as late as 2016, suggested the same composite formula (re-discovery) for G as Cahill, that is; $G=\frac{\hbar c}{m_p^2}$ (unaware of the Cahill formula, as it was more or less forgotten), and McCulloch repeated the standard physics assumption that one needs to know G in order to find the Planck mass. In his own words:

In the above gravitational derivation, the correct value for the gravitational constant G can only be obtained when it is assumed that the gravitational interaction occurs between whole multiples of the Planck mass, but this last part of the derivation involves some circular reasoning, since the Planck mass is defined using the value for G.—M. McCulloch, 2016.

This is a common assumption in modern physics, but here we will prove that the Planck mass and the other Planck units can be extracted from gravity observations with no knowledge of G, and we will also discuss some possible implications of this method. There also exist suggestions to link the gravitational constant to electromagnetic parameters or constants such as the fine structure constant; see Kallinski [10] and Sánchez [11], or to cosmological constants as likely first suggested by Bleksley [12] in 1951. However, this is outside the scope of this paper as the focus here is on the Planck units. Still, there are also likely to be direct links between, for example, the cosmological constants, such as the Hubble constant, and the Planck units, as described recently by Haug [13] [14] [15].

2. A Short History of the Gravitational Constant

Newton did not measure the gravitational constant himself, nor did he introduce it in his work. His formula was actually $F = \frac{Mm}{R^2}$, which he only described in words in *Principia* [16]. Even without any gravitational constant, he was able to measure and predict the mass of planets relative to each other quite accurately; see Cohen [17] for a more detailed description. In 1798, Cavendish [18] produced his famous paper on finding the density of the Earth and he did not measure, describe, or use a gravitational constant either. The Cavendish apparatus was needed to compare the density of the Earth with a mass of a known uniform material, such as water, iron, mercury, or lead. If one knew of a planet or moon in our solar system that consisted of a uniform amount of matter, and also knew the amount of that matter, then a Cavendish apparatus would not be needed to find the density of that celestial object—the Earth, for example. However, this is obviously not the case. Therefore, the Cavendish apparatus is very useful because then one has full control over the choice of the material of the gravitational objects; they can be made of lead, for example. Then one can compare the weight of such an object with whatever clump of matter one has decided on as a standard weight, such as the kg.

The Cavendish apparatus is also well suited for measuring the gravitational constant. What is known today as Newton's gravitational constant was actually first mentioned by Cornu and Baille [19] in 1873, which introduced the formula $F = f\frac{Mm}{R^2}$. In any case, in 1894, the notation G for the gravitational constant was introduced by Boys [20]. It took many years before G became the standard notation; as late as 1928, Max Planck [21] was still using the notation f and Einstein [22] used the notation k in 1916, for example. Naturally, whether the gravitational constant is called f, k or G is merely cosmetic, what is interesting here is that for hundreds of years, scientists were able to perform a large number of gravity calculations, measurements, and predictions with no knowledge of G; see Haug [23] for an in-depth study of the history of the gravitational constant. One can argue that Cavendish used G indirectly, but we can just as well argue that he was relying on the Planck units indirectly, which, like the gravitational constant, had not been introduced at the time of Cavendish. The Planck units were introduced in 1899, while Newton's gravitational constant was introduced in 1873. Of course, the fact that one constant was introduced before another one does not necessarily make it more fundamental, and the frontiers of understanding may change over time; something we will also look at in this paper.

3. The Planck Mass Measured Directly with a Cavendish Apparatus

Remarkably, using a Cavendish apparatus, we can measure the Planck units without any knowledge of Newton's gravitational constant. Here we will demonstrate this first for the Planck mass. A Cavendish apparatus consists of two small balls and two larger balls, all made of lead, for example. The torque (moment of force) is given by:

$$\kappa\theta \tag{1}$$

where κ is the torsion coefficient of the suspending wire and θ is the deflection angle of the balance. We then have the following well-known relationship:

$$\kappa\theta = LF \tag{2}$$

where L is the length between the two small balls in the apparatus. Further, F can be set equal to the gravitational force given by:

$$F = \frac{l_p^2 c^3}{\hbar}\frac{Mm}{R^2} = \frac{t_p^2 c^5}{\hbar}\frac{Mm}{R^2} = \frac{\hbar c^5}{E_p^2}\frac{Mm}{R^2} = \frac{\hbar c}{m_p^2}\frac{Mm}{R^2} \tag{3}$$

This means we have:

$$\kappa\theta = L\frac{\hbar c}{m_p^2}\frac{Mm}{R^2} \tag{4}$$

We also have the natural resonant oscillation period of a torsion balance given by:

$$T = 2\pi\sqrt{\frac{I}{\kappa}} \tag{5}$$

Further, the moment of inertia I of the balance is given by:

$$I = m\left(\frac{L}{2}\right)^2 + m\left(\frac{L}{2}\right)^2 = \frac{mL^2}{2} \tag{6}$$

This means we have

$$T = 2\pi\sqrt{\frac{mL^2}{2\kappa}} \tag{7}$$

And when solved with respect to κ, this gives

$$\frac{T^2}{2^2\pi^2} = \frac{mL^2}{2\kappa}$$

$$\kappa = \frac{mL^2 2\pi^2}{T^2} \tag{8}$$

Next in Equation (4), we are replacing κ with this expression, and solving with respect to the Planck mass:

$$\frac{mL^2 2\pi^2}{T^2}\theta = L\frac{\hbar c}{m_p^2}\frac{Mm}{R^2}$$

$$\frac{L^2 2\pi^2 R^2}{\hbar cLMT^2}\theta = \frac{1}{m_p^2}$$

$$m_p^2 = \frac{\hbar cMT^2}{L2\pi^2 R^2\theta}$$

$$m_p = \sqrt{\frac{\hbar cMT^2}{L2\pi^2 R^2\theta}} \tag{9}$$

The mass M is the mass of each of the two large lead balls in the Cavendish apparatus, not the mass of the Earth. All we need in order to find the mass of the large balls is an accurate measurement of weight. Such a measurement of weight should be independent of knowledge of Newton's law of gravitation, but since weight is an effect of gravity, they are still related. For example, the act of choosing an arbitrary clump of matter and using that as the standardized weight unit can be applied here. If we work with the kg definition of mass, we can weigh the large balls in the Cavendish apparatus with the one kg mass on the other side. Keep in mind that in addition to measurements done in relation to the Cavendish apparatus, we need the Planck's constant. Planck's constant can be found from the Watt balance [24] [25] [26] [27], or more traditionally from the black body spectrum [28]. That we need the Planck constant is related to the fact that we are operating with masses in the form of kg. The new kg definition[1] is directly linked to the Planck constant.

The angle θ and the oscillation time period T are what we measure with the Cavendish apparatus. The length L is the distance between the small lead balls and R is the distance between the large lead ball's centre to the centre to the small lead ball, when the arm is in equilibrium position (mid-position).

Today, there even exists a small, ready-to-use Cavendish apparatus, which measures the angle of the arm and the time very accurately by fine electronics and is plugged directly into a computer with a USB cable; see **Figure 1**. Using this low-budget apparatus, we can measure the Planck mass with about only 5% error without any knowledge of Newton's gravitational constant.

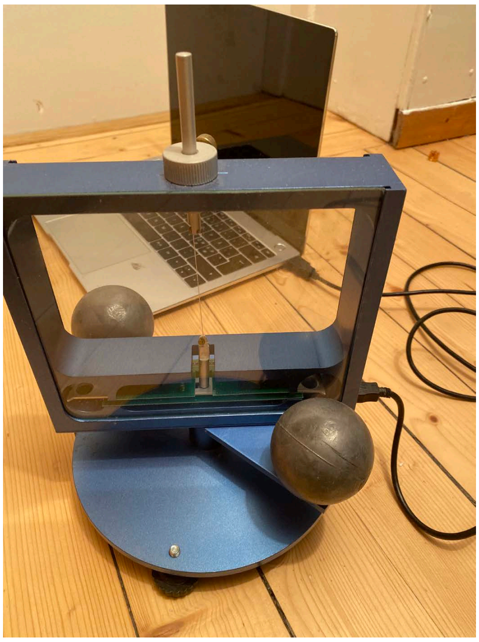

Figure 1. Low budget modern Cavendish apparatus combining old mechanics with modern electronics that feed directly to your computer through a USB cable. It is remarkable that using such an instrument, we can measure the Planck mass with only about 5% error.

[1]The 2018 definition decided upon at the General Conference on Weights and Measures (CGPM).

As soon as we know the Planck mass, we have the input needed to perform gravitational predictions, such as predictions on the orbital velocity of planets and satellites, for example; see Table 1. Looking at several places in Table 1, we find the parameter N, which is the number of Planck masses in the gravitational object, e.g. the Earth. The number of Planck masses in the Earth can be found first by finding the Planck mass from a Cavendish apparatus as described in this section. Second, one measures the gravitational acceleration on the surface of the Earth; to do this we simply need an object we can drop, a brass ball, for example, and two time-gates[2]. Next we have from the table that:

$$g = N\frac{\hbar c}{R^2 m_p}$$

$$N = g\frac{R^2 m_p}{\hbar c} \tag{10}$$

Now we have N (the number of Planck masses in the Earth, $N = 9.81\times\frac{6371000^2\times m_p}{\hbar c}\approx 2.74^{32}$), and again we had no need for G to find it; we now have the input we need to complete all other gravity predictions in the table.

Haug [29] [30] [31] has, in a similar way, shown how the Planck units can be found independent of big G using a Newton force spring as well as a pendulum clock and a ball clock, but here the focus is on using a Cavendish apparatus. We have looked at this briefly before [32], but this paper goes into the topic in much more depth. See also Appendix A, on how we can extend the derivation above to find the Planck length and Planck time "directly" from a Cavendish apparatus without knowledge of both G and $\hbar$.

Table 1 shows a series of outputs we can get from a Cavendish apparatus. All of the Planck units in this table require that we know the Planck constant as well, and some also require the speed of light to find them.

4. Why Newton's Gravitational Constant Likely Is a Universal Composite Constant

In our analysis, the first strong indication that the gravitational constant is a composite constant is given by its output units, which are $m^3 \cdot kg^{-1} \cdot s^{-2}$. It would be very strange if something concerning the fundamental nature of reality would be found in metres cubed, divided by kg and seconds squared. The Planck mass, the Planck length, and the Planck time are somewhat easier to relate to. The speed of light is also something we can relate to logically; it is the distance light travels in a vacuum during a pre-specified time interval. The Planck constant is more complex (and its interpretation is outside the scope of this paper), but it is related to the view that energy seems to come in quanta; see also [33]. In sum, the Planck mass, the Planck time, the Planck length, and even the speed of light seem to be more intuitive than does the gravitational constant.

[2]Or alternatively a ball with a built-in stop-watch; such balls are sold for this particular purpose, and are known as g-balls.

Table 1. The table shows a series of gravity formulas when using the standard Newton gravitational constant and the alternative when arguing that Newton's gravitational constant is a composite constant. Note that N is the number of Planck masses in the gravitational object; this can be found by measuring the Planck mass indirectly first.

	Standard form/way	Planck form	Observed
Gravitational constant	$G \approx 6.67 \times 10^{-11}$	$G = \frac{\hbar c}{m_p^2} = \frac{l_p^2 c^3}{\hbar} \approx 6.67 \times 10^{-11}$	indirectly only
Cavendish: Gravitational constant	$G = \frac{L 2\pi^2 R^2 \theta}{M T^2}$		indirectly only
Cavendish: Planck mass	Only derived from G	$m_p = \sqrt{\frac{\hbar c M T^2}{L 2\pi^2 R^2 \theta}}$	indirectly only
Cavendish: Planck length	Only derived from G	$l_p = \sqrt{\frac{\hbar L 2\pi^2 R^2 \theta}{M T^2 c^3}}$	indirectly only
Cavendish: Planck time	Only derived from G	$t_p = \sqrt{\frac{\hbar L 2\pi^2 R^2 \theta}{M T^2 c^5}}$	indirectly only
Cavendish: Schwarzschild radius	Normally dependent on G	$r_s = \frac{L 4\pi^2 R^2 \theta}{c^2 T^2}$	indirectly onlyo
Newton's gravity force	$F = G\frac{mM}{R^2}$	$F = n_1 n_2 \frac{\hbar c}{R^2}$	indirectly only[3]
Gravitational acceleration field	$g = \frac{GM}{R^2}$	$g = N\frac{l_p}{R^2}c^2$ or $g = N\frac{\hbar c}{R^2 m_p}$	Yes
Mass from acceleration field	$M = \frac{gR^2}{G}$	$M = \frac{gR^2\hbar}{l_p^2 c^3}$	indirectly only
Orbital velocity	$v_o = \sqrt{G\frac{M}{r}}$	$v_o = c\sqrt{N\frac{l_p}{r}}$	Yes
Escape velocity	$v_e = \sqrt{2G\frac{M}{r}}$	$v_e = c\sqrt{N2\frac{l_p}{r}}$	indirectly only[4]
Time dilation	$t_2 = t_1\sqrt{1-\frac{2GM}{rc^2}}$	$t_2 = t_1\sqrt{1-N2\frac{l_p}{r}}$	Yes
Newton's gravitational bending of light	$\delta = \frac{2GM}{rc^2}$	$\delta = N2\frac{l_p}{r}$	Twice of that
GR gravitational bending of light	$\delta = \frac{4GM}{rc^2}$	$\delta = N4\frac{l_p}{r}$	Yes
Gravitational red-shift	$\lim_{r\to+\infty} z(r) = \frac{GM}{R^2}$	$\lim_{r\to+\infty} z(r) = N\frac{l_p}{r}$	Yes
Schwarzschild radius	$r_s = \frac{2GM}{rc^2}$	$r_s = N2l_p$	indirectly only
Einstein's field equation	$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = \frac{8\pi G}{c^4}T_{\mu\nu}$	$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = \frac{8\pi l_p}{m_p c^2}T_{\mu\nu}$	indirectly only

[3]Actually, Newton's gravitational force has never been observed directly, only indirectly through the predictions that come from mathematically rearranging this formula to develop other predictions, such as orbital velocity.

[4]To my knowledge the escape velocity has not been tested empirically.

Continued

Einstein's constant	$\kappa = \frac{8\pi G}{c^2}$	$\kappa = \frac{8\pi l_p}{m_p}$	Indirectly only
Einstein's cosmological constant	$\Lambda = \kappa\rho_{vac}$	$\Lambda = \frac{8\pi l_p}{m_p}\rho_{vac}$	indirectly only
Hawking temperature	$\frac{c^3}{8\pi GM}\frac{\hbar}{k_b}$	$T = \frac{1}{N8\pi}\frac{m_p c^2}{k_b}$	indirectly only[5]
Hawking dissipation time	$t_{ev} = \frac{15360\pi G^2 M^3}{\hbar c^4}$	$T = N^3 15360\pi t_p$	indirectly only[6]
Bekenstein-Hawking luminosity	$P = \frac{\hbar c^6}{15360\pi G^2 M^2}$	$P = \frac{1}{N^2 15360\pi}\frac{\hbar c^2}{l_p^2}$	indirectly only[7]

Haug [3] has shown that assuming the gravitational constant is a composite will help make all of the Planck units more intuitive. For example, the Planck time is given by $t_p = \sqrt{\frac{G\hbar}{c^5}}$; when rewritten based on the idea that the gravitational constant is a composite, this simply gives the (known) $t_p = \frac{l_p}{c}$. The latter form is well known, but the view that Newton's gravitational constant is a composite constant renders the form $t_p = \sqrt{\frac{G\hbar}{c^5}}$ unnecessary. We might then ask, what is the intuition on c^5 and G? The answer may not be so clear. Yet, the intuition behind $\frac{l_p}{c}$ is simple; it is a very short distance divided by the speed of light, so it comprises a very short time interval. The gravitational constant composite formula has the same challenge, in that we could end up with a circular problem again because modern physics typically assumes that we need to know big G before we can find the Planck units. However, as we have demonstrated clearly in this paper and other papers using other approaches, this is not the case. This does not mean that big G is wrong; it is just likely to be a composite universal constant rather than a fundamental constant.

We find that many gravitational formulas may be seen from a new perspective when rewritten based on the idea that Newton's gravitational constant is a composite constant; we summarize a selection of such gravitational formulas in Table 1.

5. Relative Standard Uncertainty

Assume we have measured the Planck mass (with a standard uncertainty of 1%) on the kitchen table with Cavendish apparatus plugged into our computer. The relative uncertainty in the gravitational constant must then be:

[5] At least not directly.

[6] At least not directly.

[7] At least not directly.

$$\frac{\partial G}{\partial m_p} \times \frac{\frac{m_p}{100}}{G} = \frac{2\hbar c}{m_p^3} \times \frac{m_p}{G \times 100} = \frac{1}{50} = 2\% \tag{11}$$

That is to say, the standard uncertainty in the Newton gravitational constant will always be twice that of the standard uncertainty in the Planck mass measurements. This is in line with what is found in NIST (2018) CODATA, which reports a relative standard uncertainty for the gravitational constant of 2.2×10^{-5} and 1.1×10^{-5} for the Planck mass.

Considerable experimental efforts have been going into, and are still going into, improving the measurement of accuracy in G; see, for example, [34] [35] [36] [37] [38]. Our claims in this paper that the gravitation constant is not needed to find the Planck units, nor to predict gravitational phenomena, do not reduce the significance of this effort. It is just that these researchers are, in reality, measuring the Planck length indirectly, or actually l_p^2 since we have $G = \frac{l_p^2 c^3}{\hbar}$ and c and $\hbar$ are today defined as exact constants. The only uncertainty then comes from l_p. This explains why it is so hard to measure G precisely and why it has a bigger uncertainty than other constants, such as the fine structure constant. This is because G is just an indirect measure of the smallest length that exists.

6. Finding the Planck Length and Planck Time without Knowledge of *G* and *h*

We can actually find the Planck length and the Planck time without knowing the Planck constant, in addition to not knowing G. To do this, we also need to know the Compton wavelength of the mass (the gravitational object). Here we will show how the Compton wavelength from any mass can be found with no knowledge of $\hbar$; for a discussion of the Compton wavelength and its relation to the de Broglie wavelength, see Appendix A. We can write any kg mass as:

$$m = \frac{h}{\lambda}\frac{1}{c} = \frac{\hbar}{\bar{\lambda}}\frac{1}{c} \tag{12}$$

where $\bar{\lambda}$ is the reduced Compton wavelength of the mass in question. This is simply the well-known Compton [39] wavelength formula, $\bar{\lambda} = \frac{\hbar}{mc}$ solved with respect to the mass[8]. Equation (12) actually holds for any mass, including composite masses such as protons and even cosmological size objects. A mass consisting of many fundamental particles does not have one Compton wavelength, but rather it has one for each fundamental particle it consists of. However, these wavelengths from each elementary particle can be aggregated in the following way:

[8]Compton gave this formula indirectly in his 1923 paper and it assumes the electron initially stands still. The relativistic version of the reduced Compton wavelength would be $\bar{\lambda} = \frac{\hbar}{mc\gamma}$, see [40].

$$\bar{\lambda} = \sum_{i=1}^{n} = \frac{1}{\frac{1}{\bar{\lambda}_1} + \frac{1}{\bar{\lambda}_2} + \frac{1}{\bar{\lambda}_3} + \cdots + \frac{1}{\bar{\lambda}_n}} \tag{13}$$

This is then what we will call a reduced Compton equivalent mathematical wavelength for the mass in question. This is because a composite mass consists of many elementary particles that likely all have their own reduced Compton wavelengths. We will soon get back to how the Compton wavelength may be related to the de Broglie wavelength. In this framework, c and $\hbar$ are constants; the only thing that distinguishes different size rest-masses is the Compton wavelength. We think there is no simpler way to express the kg mass from assumed fundamental constants, and naturally we also need one variable to distinguish between different mass sizes, and this variable is the Compton wavelength. This does not alter the basic standard addition of mass rule since we must have[9]:

$$m = m_1 + m_2 + m_3$$

$$\frac{\hbar}{\bar{\lambda}}\frac{1}{c} = \frac{\hbar}{\bar{\lambda}_1}\frac{1}{c} + \frac{\hbar}{\bar{\lambda}_1}\frac{1}{c} + \frac{\hbar}{\bar{\lambda}_1}\frac{1}{c}$$

$$\frac{\hbar}{\frac{1}{\frac{1}{\bar{\lambda}_1} + \frac{1}{\bar{\lambda}_2} + \frac{1}{\bar{\lambda}_3}}}\frac{1}{c} = \frac{\hbar}{\bar{\lambda}_1}\frac{1}{c} + \frac{\hbar}{\bar{\lambda}_1}\frac{1}{c} + \frac{\hbar}{\bar{\lambda}_1}\frac{1}{c} \tag{14}$$

In this case, all we need to compare the relative size of masses will be their Compton wavelengths. One can find the Compton wavelength of an electron, for example, by Compton scattering[10]. This does not require that one first knows the mass in kg or the Planck constant. One is simply shooting a photon with wavelength λ_1 before it hits the electron. Then one measures the photon wavelength, λ_2, of the photon after it hits the electron, and in addition one measures the angle, θ, between the incoming photon and the outgoing photon; from this alone we know the Compton wavelength of the electron, and mathematically we have:

$$\lambda_1 - \lambda_2 = \frac{h}{mc}(1 - \cos\theta)$$

$$\lambda_1 - \lambda_2 = \frac{h}{\frac{h}{\lambda_e}\frac{1}{c}c}(1 - \cos\theta)$$

$$\lambda_1 - \lambda_2 = \lambda_e(1 - \cos\theta)$$

[9]In addition, comes binding energy, but we can always do a correction for this as energy can be treated as a mass equivalent. Ignoring binding energy will maximum give a extra error of approximately 1% in the Compton wavelength.

[10]Or from the hydrogen spectrum based on the Rydberg formula [41]. The reduced Compton wavelength of an electron, as derived from the Rydberg formula, is $\bar{\lambda}_e = \frac{\lambda}{2\pi} Z^2 \left(\frac{1}{2}\frac{\alpha^2}{n_1^2} - \frac{1}{2}\frac{\alpha^2}{n_2^2} \right)$, where Z is the atomic number, and n_1 is the principal quantum number of an energy level, and n_2 is the principal quantum number of an energy level for the electron transition. In this formula, λ is the observed electromagnetic radiation wavelength in a vacuum. See Appendix A for the Rydberg formula approach.

$$\lambda_e = \frac{\lambda_1 - \lambda_2}{1 - \cos\theta} \tag{15}$$

What is important here is that $\hbar$ not exist in the end result, nor the mass size, all we need is the two wavelengths of the photon and the angle between the ingoing and outgoing photon to find the Compton wavelength. The reduced Compton wavelength $\bar{\lambda}_e$, is simply the Compton wavelength divided by 2π.

Next, the cyclotron frequency is given by:

$$f = \frac{qB}{2\pi m} \tag{16}$$

Because the electrons and protons have the same charge, the cyclotron ratio is equal to their mass ratio, and their mass ratio is equal to their reduced Compton wavelength ratio:

$$\frac{f_P}{f_e} = \frac{\frac{qB}{2\pi m_P}}{\frac{qB}{2\pi m_e}} = \frac{m_e}{m_P} = \frac{\bar{\lambda}_P}{\bar{\lambda}_e} \tag{17}$$

This means if we know the Compton wavelength of the electron and the cyclotron frequency of the electron and the proton, then we also know the Compton wavelength of the proton. Next we can simply count the number of protons in the gravity object. We can count the number of protons used as the gravity object (the large mass) in the Cavendish apparatus. This is naturally a challenge, but not impossible. For example, in recent years one has used very uniform silicon crystal balls that have been turned into almost perfect spheres, and has basically counted the number of atoms[11], see [43] [44]. So, this is more than pure theory.

As soon as we know the Compton wavelength of the gravity object in the Cavendish apparatus, we can easily find the Compton wavelength from the Earth, for example. This is because we must have the following relation:

$$\frac{g_1 R_1^2}{g_2 R_2^2} = \frac{\frac{GM_1}{R_1^2} R_1^2}{\frac{GM_2}{R_2^2} R_2^2} = \frac{M_1}{M_2} = \frac{\frac{\hbar}{\bar{\lambda}_1}\frac{1}{c}}{\frac{\hbar}{\bar{\lambda}_2}\frac{1}{c}} = \frac{\bar{\lambda}_2}{\bar{\lambda}_1} \tag{18}$$

We can measure the gravitational acceleration field from the large ball in the Cavendish apparatus without knowledge of any constants; it is given by:

$$g = \frac{L 4\pi^2 \theta}{T^2} \tag{19}$$

Further, the gravitational acceleration field of the Earth can be measured without knowledge of any physical constant. This also means that we can find the Compton wavelength of small and large objects without knowledge of any gravitational constant. In Appendix A, we show, similar to our derivation for the Planck mass in Section 3, that the Planck length from a Cavendish apparatus is given by:

[11]Other methods also exist to count the number of atoms, see [42], for example.

$$l_p = \sqrt{\frac{\hbar L 2\pi^2 R^2 \theta}{M T^2 c^3}} \tag{20}$$

If we now replace M with $M = \frac{\hbar}{\bar{\lambda}_M}\frac{1}{c}$, where $\bar{\lambda}_M$ is still the reduced Compton wavelength, but we have just added a subscript symbol, so one can later easily see when the reduced Compton wavelength comes from the larger or smaller mass; then the Planck constant cancels out, and we are left with:

$$l_p = \sqrt{\frac{\bar{\lambda}_M L 2\pi^2 R^2 \theta}{T^2 c^2}} = \frac{\pi R}{Tc}\sqrt{\bar{\lambda}_M L 2\theta} \tag{21}$$

and since we can find the reduced Compton wavelength without knowledge of the kg mass or the Planck constant, we can find the Planck length also without any knowledge of G or $\hbar$. The same is the case for the Planck time, which is just the Planck length divided by the speed of light, so it is given by:

$$t_p = \sqrt{\frac{\bar{\lambda}_M L 2\pi^2 R^2 \theta}{T^2 c^4}} = \frac{\pi R}{Tc^2}\sqrt{\bar{\lambda}_M L 2\theta} \tag{22}$$

Clearly, the Planck length and the Planck time can be found without knowledge of the Planck constant or the gravitational constant, but also the Planck mass; see **Table 2** for a summary of the Planck units. Other gravitational predictions can be found by using a Cavendish apparatus.

7. Is Newton's Gravitational Constant Even Needed?

At the beginning of this paper, we pointed out that Newton's original gravitational formula was $F = \frac{Mm}{R^2}$, and not the "modern" (1873) version of $F = G\frac{Mm}{R^2}$. The characteristic of Newtonian mechanics, which appears at this point, is that the force depends on the product of the masses and on the inverse of the relative distance squared. By dimensional analysis, it at first seems that a multiplicative dimensional constant with dimensions equal to the Newton gravitational constant must appear in this expression to get the right dimensions of Newton force, which in modern physics is given by $\text{m}\cdot\text{kg}\cdot\text{s}^{-2}$. Based on this, any of the following constants will do, as they are dimensionally equivalent and will give exactly the same output values $G = \frac{\hbar c}{m_p^2} = \frac{l_p^2 c^3}{\hbar} = \frac{t_p^2 c^5}{\hbar} = \text{m}^3\cdot\text{kg}^{-1}\cdot\text{s}^{-2}$. However, the need for these dimensions in the gravitational constant, as we will demonstrate, is simply due to our modern kilogram mass definition, which we have reason to think is incomplete. We will claim that all observable gravity phenomena need GM and not GMm. One of the masses always cancels out in the derivation for any observable gravity phenomena, something we will soon show more clearly. So, the dimensions that are input for any gravity phenomena are linked to $GM = \text{m}^3\cdot\text{s}^{-2}$. That is, there is no kg in any directly observable gravitational observation, only in the gravitational force formula itself and in the current mass

Table 2. The table highlights the Planck units and other gravitational phenomena that can be found with a Cavendish apparatus. The table also shows what constants we will need to find those units and phenomena when using this method.

	From Cavendish Apparatus:	Constants needed:
Planck mass	$m_p=\sqrt{\frac{\hbar cMT^2}{L2\pi^2R^2\theta}}=\frac{T\hbar}{\pi R}\sqrt{\frac{1}{2\bar{\lambda}_M L\theta}}$	Needs $\hbar$
Planck mass	$m_p=\sqrt{\frac{\bar{\lambda}c^2M^2T^2}{L2\pi^2R^2\theta}}=\frac{TMc}{\pi R}\sqrt{\frac{\bar{\lambda}_M}{2L\theta}}$	Needs c
Planck energy	$E_p=\sqrt{\frac{\hbar c^5MT^2}{L2\pi^2R^2\theta}}=\frac{Tc^2\hbar}{\pi R}\sqrt{\frac{1}{2\bar{\lambda}_M L\theta}}$	Needs $\hbar$ and c
Planck energy	$E_p=\sqrt{\frac{\bar{\lambda}c^6M^2T^2}{L2\pi^2R^2\theta}}=\frac{TMc^3}{\pi R}\sqrt{\frac{\bar{\lambda}_M}{2L\theta}}$	Needs c
Planck length	$l_p=\sqrt{\frac{\hbar L2\pi^2R^2\theta}{c^3MT^2}}=\frac{\pi R}{cT}\sqrt{2\bar{\lambda}_M L\theta}$	Needs c
Planck time	$t_p=\sqrt{\frac{\hbar L2\pi^2R^2\theta}{c^5MT^2}}=\frac{\pi R}{c^2T}\sqrt{2\bar{\lambda}_M L\theta}$	Needs c
Schwarzschild radius	$r_s=\frac{L4\pi^2R^2\theta}{c^2T^2}$	Needs c
Gravitational acceleration	$g=\frac{L2\pi^2\theta}{T^2}$	Constant free
Orbital velocity	$v_o=\sqrt{\frac{RL4\pi^2\theta}{T^2}}$	Constant free
Newton gravitational constant	$G=\frac{L2\pi^2R^2\theta}{MT^2}=\frac{2L\pi R^2\theta\bar{\lambda}_M c}{\hbar T^2}$	Needs $\hbar$ and c

definition. Actually $GM=\frac{l_p^2c^3}{\hbar}\frac{\hbar}{\bar{\lambda}_M}\frac{1}{c}=c^2\frac{l_p^2}{\bar{\lambda}_M}$. We see that the Planck constant embedded in G always cancels with the Planck constant embedded in the kg mass. We will claim the Newton gravitational constant is needed to get the Planck constant out of the kg mass definition and to get the Planck length into the mass. Prof. Jammer [45] has, in his work on mass, made it clear that we still are searching for an adequate definition of mass and, to put it edgily, he has stated "*mass is a mess*". Even if one knows much about mass today, we think one should be open to new suggestions of mass definitions as long as they seem to lead to a consistent theory, in particular if the suggestions can add a deeper understanding. Haug [29] has recently suggested a new mass definition where any mass is given by:

$$\bar{m}=\frac{l_p}{c}\frac{l_p}{\bar{\lambda}} \tag{23}$$

That is, mass should be seen as the Planck time multiplied by $\frac{l_p}{\bar{\lambda}}$, which we have coined collision-time. Our new mass definition assumes that any mass is quantized and observations can only exist in whole Planck times; something we will get back to in Section 8. What is interesting here is that when one uses that mass definition instead, one will get a Newtonian gravity formula equal to:

$$\bar{F} = c^3 \frac{\bar{M}\bar{m}}{R^2} \tag{24}$$

and when we use the unit of length equal to the unit of time connected through the speed of light, we get Newton's original formula $F = \frac{\bar{M}\bar{m}}{R^2}$. Even if we set $c = 1$, this is not the same as setting also $h = 1$ and $G = 1$, so this is not why we do not need h and G. The dimensions of this gravity formula are different than in standard gravity. But then we will claim the Newton force itself cannot be observed. This formula still gives identical predictions for any observable gravity phenomena as does the "modern" 1873 version of the Newton formula. This can be clearly seen in **Table 3**. Even if the gravity force formulas are different, all the formulas for predictable phenomena end up being identical, both in numerical outputs and dimensions. However, our new approach contains one less physical constant. In the Newtonian formula, we need to know G and M. When we break down the mass to the simplest way for expressing it in terms of kg based on fundamental constants, we have $M = \frac{\hbar}{\bar{\lambda}_M}\frac{1}{c}$. So, to know G and M, we need to know three constants: G, $\hbar$, and c; these are the three constants that Planck suggested were the fundamental universal constants. In addition, we need to know one variable that is dependent on the mass size, namely the Compton wavelength. However, to know the gravitational constant multiplied by the kg mass, GM, we only need to know the Planck length, the speed of light, and the Compton wavelength. That is, if we know that G is a composite constant and we can only assume G is a composite constant, if (and only if) we can find the Planck units without knowing G first hand. Here, we have demonstrated that this is indeed the case.

In our alternative mass and gravity formula, we have: $c^3\bar{M} = GM = c^2\frac{l_p^2}{\bar{\lambda}_M}$. However, when using $c^3\bar{M}$ rather than GM, we do not need more information to know our gravitational constant, c^3, in addition to our mass $\bar{M}$, compared in order to find the product of the two $c^3\bar{M}$. To know both G and M, we need information that is not necessary for predicting gravity phenomena, namely the Planck constant. Indirectly, we will claim standard physics uses two different masses without being aware of it, or at least not acknowledging it directly. The convention is to use the kg mass definition, which is linked to the Planck constant that contains enough information to be used in all non-gravity physics. In addition, modern physics indirectly uses our new mass definition $\bar{M} = \frac{l_p}{c}\frac{l_p}{\bar{\lambda}_M}$ that is obtained by multiplying G with M, which gives $GM = c^3\bar{M}$, where c^3

Table 3. The table shows that any gravity observations we can make contain GM and not GMm; GM contains and needs less information than is required to find G and M. We can, therefore, set up an alternative Newton-like gravity that only requires knowledge of the speed of light (gravity) and the Planck length; this alternative theory gives exactly the same predictions for anything that can be observed.

	Modern Newton:	**Alternative:**
Mass	$M=\frac{\hbar}{\bar{\lambda}_M}\frac{1}{c}(\text{kg})$	$\bar{M}=\frac{l_p}{c}\frac{l_p}{\bar{\lambda}_M}$ (collision-time, see [29])
Non observable (contains GMm)		
Gravitational constant	$G,\left(G=\frac{l_p^2c^3}{\hbar}\right)$	c^3
Gravity force	$F=G\frac{Mm}{R^2}\left(\text{kg}\cdot\text{m}\cdot\text{s}^{-2}\right)$	$F=c^3\frac{\bar{M}\bar{m}}{R^2}\left(\text{m}\cdot\text{s}^{-1}\right)$
Observable predictions, identical for the two methods: (contains only GM)		
Gravity acceleration	$g=\frac{GM}{R^2}=\frac{c^2}{R^2}\frac{l_p^2}{\bar{\lambda}_M}$	$g=\frac{c^3\bar{M}}{R^2}=\frac{c^2}{R^2}\frac{l_p^2}{\bar{\lambda}_M}$
Orbital velocity	$v_o=\sqrt{\frac{GM}{R}}=c\sqrt{\frac{l_p^2}{R\bar{\lambda}_M}}$	$v_o=\sqrt{\frac{c^3\bar{M}}{R}}=c\sqrt{\frac{l_p^2}{R\bar{\lambda}_M}}$
Time dilation	$T_R=T_f\sqrt{1-\sqrt{\frac{2GM}{R}}^2\Big/c^2}=T_f\sqrt{1-\frac{2l_p^2}{R\bar{\lambda}_M}}$	$T_R=T_f\sqrt{1-\sqrt{\frac{2c^3\bar{M}}{R}}^2\Big/c^2}=T_f\sqrt{1-\frac{2l_p^2}{R\bar{\lambda}_M}}$
Gravitational red-shift	$z=\frac{\sqrt{1-\frac{2GM}{R_1c^2}}}{\sqrt{1-\frac{2GM}{R_2c^2}}}-1=\frac{\sqrt{1-\frac{2l_p^2}{R_1\bar{\lambda}_M}}}{\sqrt{1-\frac{2l_p^2}{R_2\bar{\lambda}_M}}}-1$	$z=\frac{\sqrt{1-\frac{2c^3\bar{M}}{R_1c^2}}}{\sqrt{1-\frac{2c^3\bar{M}}{R_2c^2}}}-1=\frac{\sqrt{1-\frac{2l_p^2}{R_1\bar{\lambda}_M}}}{\sqrt{1-\frac{2l_p^2}{R_2\bar{\lambda}_M}}}-1$
Gravitational red-shift	$z_\infty(r)\approx\frac{GM}{c^2R}=\frac{l_p^2}{R\bar{\lambda}_M}$	$z_\infty(r)\approx\frac{c^3\bar{M}}{c^2R}=\frac{l_p^2}{R\bar{\lambda}_M}$
Gravitational deflection (GR)	$\delta=\frac{4GM}{c^2R}=\frac{4}{R}\frac{l_p^2}{\bar{\lambda}_M}$	$\delta=\frac{4c^3\bar{M}}{c^2R}=\frac{4}{R}\frac{l_p^2}{\bar{\lambda}_M}$
Advance of perihelion	$\frac{6\pi GM}{a(1-e^2)c^2}=\frac{6\pi}{a(1-e^2)}\frac{l_p^2}{\bar{\lambda}_M}$	$\frac{6\pi c^3\bar{M}}{a(1-e^2)c^2}=\frac{6\pi}{a(1-e^2)}\frac{l_p^2}{\bar{\lambda}_M}$
Indirectly/"hypothetical" observable predictions: (contains only GM)		
Escape velocity	$v_e=\sqrt{\frac{2GM}{R}}=c\sqrt{2\frac{l_p^2}{R\bar{\lambda}_M}}$	$v_e=\sqrt{\frac{2c^3\bar{M}}{R}}=c\sqrt{2\frac{l_p^2}{R\bar{\lambda}_M}}$
Schwarzschild radius	$r_s=\frac{2GM}{c^2}=2\frac{l_p^2}{\bar{\lambda}_M}$	$r_s=\frac{2c^3\bar{M}}{c^2}=2\frac{l_p^2}{\bar{\lambda}_M}$

Continued

Gravitational parameter	$\mu = GM = c^2 \frac{l_p^2}{\bar{\lambda}_M}$	$\mu = c^3 \bar{M} = c^2 \frac{l_p^2}{\bar{\lambda}_M}$
Two body problem	$\mu = G(M_1 + M_2) = c^2 \frac{l_p^2}{\bar{\lambda}_1} + c^2 \frac{l_p^2}{\bar{\lambda}_1}$	$c^3(\bar{M}_1 + \bar{M}_2) = c^2 \frac{l_p^2}{\bar{\lambda}_1} + c^2 \frac{l_p^2}{\bar{\lambda}_2}$
Quantum analysis:		
Constants needed	G, $\hbar$, and c or l_p, $\hbar$, and c	l_p and c
Variable needed	one for mass size	one for mass size

is a gravitational constant. In a recent publication [4] [29], we have claimed that incorporating our mass definition $\bar{M} = \frac{G}{c^3} M$ into physics could be useful for unifying gravity with other parts of physics, but that is outside the scope of this paper; see [46]. The fact that we can find all of the Planck units without knowledge of G, and also the Planck length and Planck time without knowledge of $\hbar$, and further, that we can predict observable gravity phenomena only using two constants, the Planck length and the speed of light, rather than three constants, is the essence of this paper.

8. Interpretation of the Alternative Mass Definition and Its Link to Standard Mass

Our new mass definition is rooted in ideas similar to those of Newton's. Newton was clear that mass was the quantity of matter ("*quantities materiae*"). Less known among many researchers today is that Newton [16] also clearly claimed all matter ultimately consisted of indivisible particles with spatial dimension and, further, that the smallest time interval was also indivisible. In other words, the mass should somehow be related to the quantity of these indivisible particles. In Principia [16], in the third part of his book, which was about gravity, Newton even claimed that the indivisible particles were the foundation of his entire philosophy. Newton held on to this view, as he repeated much of it in his book *Opticks* [47], published in 1704.

Naturally, Newton had not yet figured out the size of these indivisible particles, nor the time interval of the indivisible moment of time, as he called it, nor had he made any observations that could directly back his hypothesis. Almost 300 years later, in 1899, Max Planck first linked the Newton gravity theory indirectly to the Planck units by deriving the Planck units from dimensional analysis, relying also on the gravity constant G combined with h and c. At that time, there was considerable disagreement about the importance of the Planck units. Einstein was likely the first, in 1916, to suggest that a quantum gravity theory was the next step, after he finished his general relativity theory; in his own words:

"*Because of the intra-atomic movement of electrons, the atom must radiate not only electromagnetic but also gravitational energy, if only in minute* *amounts. Since, in reality, this cannot be the case in nature, then it appears that the quantum theory must modify not only Maxwell's electrodynamics but also the new theory of gravitation*".

In 1918, Eddington [48] suggested the Planck length had to play a central role in a quantum gravity theory and stated: "*But it is evident that this length* (*the Planck length*) *must be the key to some essential structure. It may not be an unattainable hope that someday a clearer knowledge of the process of gravitation may be reached.*" However, other prominent physicists at that time, such as Bridgman [49] ridiculed the idea that the Planck units could play a role of any importance, and that they were more like mathematical artefacts coming out of dimensional analyses [50]. Even to this day, the physics community is split in its opinions on the Planck units. The majority of researchers seem to think the Planck length and the Planck time are the shortest possible even hypothetical observable length and time interval; see, for example, [51] [52], while others are still claiming that the Planck length is more or less a mathematical artefact [53]. If the Planck length can only be calculated from G, h, and c as believed by most researchers today, then why not simply assume the Planck units have no significance, just as Einstein abandoned the ether? If it cannot be detected then why not simply abandon it? However, since we have now demonstrated that we can measure the Planck length and the Planck time independent of G and $\hbar$, and also that all observable gravity predictions we have looked at can be made using only two constants, l_p and c, this gives strong support to the idea that the Planck length is indeed central in gravity, and represents something very fundamental.

Returning to our new mass definition, in our model, we will postulate that both energy and matter ultimately consist of indivisible particles, somewhat similar to the Newton corpuscular theory, which again was rooted in ideas from ancient atomism, see [54]. Even if several researchers were clearly interested in this path, maybe mostly from a historical perspective, for example Schrödinger [55], little or nothing seemed to come out of this line of thought in recent times. Most researchers have assumed this path leads to a dead end and have stopped investigating it, but we will challenge that view here; see also Whyte [56]. Today we know much more about mass and energy than was known in Newton's time, and we can, therefore, combine some new insights with the corpuscular view of Newton. We will assume the indivisible particles always move at the speed of light, except when they collide. The collision itself lasts the Planck time. Actually, we do not need to assume that the diameter of this particle is the Planck length, or that it moves at the speed of light or that the collision lasts the Planck time. All we need to do is assume it has a diameter, and that it has extension in space as Newton explicitly pointed out in Principia. Further we must assume that such indivisible particles move at a constant speed when not colliding. Both the diameter of this indivisible particle and its speed can be extracted from gravity phenomena with no prior knowledge of G, $\hbar$, or c; see Appendix C. Next, we can use these two constants (the Planck length and the speed of light) to predict any observable gravity phenomena as shown in Table 3.

In our model, indivisible particles that do not collide will be what we call pure energy and are massless (and they move at c, not by assumption, but from what we find from observable gravity phenomena). It is easy to think this is automatically in conflict with the wave-particle duality, but this is not necessarily the case, as the wavelength in this theory will be the distance between two indivisible particles travelling in the same direction and after each other. Further, in this model, it is the collision between indivisible particles that corresponds to what we call mass, so the quantity of matter is linked to the quantity of collisions (number of collisions). However, there are two aspects of these collisions: first, how many collisions one has in an observational time-window, but also the duration of these collisions. We will show that the current mass definition contains information about the number of collisions. That is, the quantity of mass can be counted as the number of collisions, but this would be an incomplete definition of mass, as it does not tell anything about the duration of these collisions. We will assume the duration of each collision is the Planck time.

Let us first go back to the standard mass definition to show why we mean the standard mass definition contains the number of collisions in a mass. An electron has a mass of approximately 9.1×10^{-31} kg. That is, it is basically a fraction of one kg. Therefore, we will always get the same value for mass if we write $\frac{m_e}{m_{1\text{kg}}} = \frac{m_e}{1\ \text{kg}}$ since $m_{1\text{kg}} = 1\ \text{kg}$; this ratio, we could claim, is dimensionless, but still one could claim this is actually what we call the kg mass of an object as, if we always linked it to one kg; that is, if we always keep one kg in the denominator, which is needed if we want to get the kg mass. One could try to object here, as kg is also related to weight, but Newton pointed out in Principia that mass is a word for the quantity of matter, and he also stated "*I have always found that the quantity of matter to be proportional to their weight.*" This should not be misunderstood, but if we move one kg from the Earth to the moon and also an object of 100 grams, the mass and the weight of the 100 grams will still be the same as found from weighing it on the moon relative to the one kg clump of matter we also brought there. The weight of the 100 g or the one kg moved to the moon is only lower compared to similar masses as measured in the Earth's gravitational field. As long as the one kg and the 100 grams are in the same gravitational field, and both are relative to each other at rest, they will have the same weight relative to each other no matter what gravity field we measure them in (except in a zero gravity field). That is, the weights in kg are directly proportional to the quantity of matter in each object for masses that are in the same gravitational field, as first pointed out by Newton.

The mass ratio of an electron relative to one kg can be written:

$$\frac{m_e}{m_{1\text{kg}}} = \frac{\frac{\hbar}{\bar{\lambda}_e}\frac{1}{c}}{\frac{\hbar}{\bar{\lambda}_{1\text{kg}}}\frac{1}{c}} = \frac{\frac{c}{\bar{\lambda}_e}}{\frac{c}{\bar{\lambda}_{1\text{kg}}}} = \frac{f_e}{f_{1\text{kg}}} \tag{25}$$

The reduced Compton frequency of one kg is:

$$f_{1\text{kg}} = \frac{c}{\bar{\lambda}_{1\text{kg}}} = \frac{c}{\frac{\hbar}{1\text{ kg} \times c}} = \frac{c^2 \times 1\text{ kg}}{\hbar} \approx 8.52 \times 10^{50} \text{ times per second} \tag{26}$$

And the electron's reduced Compton frequency is:

$$f_e = \frac{c}{\bar{\lambda}_e} \approx 7.76 \times 10^{20} \text{ times per second} \tag{27}$$

Interestingly, this is also very close to the trembling motion by the electron predicted by Schörodinger [57], that has not actually been observed. However, what if it is an internal "trembling motion", or more precisely the numbers of collisions that happen at the Compton periodicity inside the electron? That is, matter is ticking at the Compton frequency, something that has been more or less verified by recent research; see [29] [58] [59]. In any case, the kg mass of the electron, based on the view that the kg definition of mass from a deeper perspective actually is a frequency ratio, is given by:

$$m_e = \frac{7.76 \times 10^{20}}{8.52 \times 10^{50}} \approx 9.1 \times 10^{-31} \text{ fraction of one kg} \tag{28}$$

which is the well-known electron mass.

Similar frequencies (collisions-ratios) can be found for any mass, small or large. The Compton frequency ratio will always give the correct mass as expressed in kg. That is, we will claim the kg mass of an object is closely related to the ratio of Compton frequency in the mass is question when divided by Compton frequency in a one-kg mass. This is not really a surprise, as it is in line with existing knowledge because it is well known that we have: $\frac{m_2}{m_1} = \frac{\bar{\lambda}_1}{\bar{\lambda}_1} = \frac{\frac{c}{\bar{\lambda}_2}}{\frac{c}{\bar{\lambda}_1}}$.

However, if one always uses one kg as the reference mass $m_1 = m_{1\text{kg}}$, then this always presents a frequency ratio that gives the mass relative to one kg; in other words, the kg mass of an object. In our view, any mass expressed as kg (or pound) or relative to any human chosen reference mass (such as a pond) is, from a deeper perspective, best understood as a frequency ratio, that again we claim represents a collision ratio. It is important to see that such a mass definition in general is independent of the observational time window; if we cut the observational time window to half a second, then the frequency ratio of both the electron and the one-kg reference mass drops in half, so the electron mass is still the same 9.1×10^{-31} kg. An exception is when we get to observational time windows close to the Compton time of the elementary particle in question. If, for example, the observational time window is equal to one-and-a-half times the Compton time of the particle in question, then the observed mass is suddenly time-dependent. If we are studying an electron, then one-and-a-half Compton time is $1.5\frac{\bar{\lambda}_e}{c}$.

The number of collisions in the electron in this time interval can only be one, as we assume one collision happens every Compton time. However, the numbers of collisions in one kg will be $1.5\frac{\bar{\lambda}_e}{c}\times 8.52\times 10^{50}\approx 1.65\times 10^{30}$ collisions, and the observed mass of the electron will then be $\frac{f_e}{f_{1\text{kg}}}=\frac{1}{1.65\times 10^{30}}\approx 6.07\times 10^{-31}$ fraction of a kg. This is lower than the known electron mass. This is a considerably shorter time interval than we can measure with today's best atomic or optical clocks, which is about 10^{-19} of a second (see Campbell *et al.* [60] and Zanon-Willette *et al.* [61]), so our predictions above are not in conflict with what has been observed. If we had an observational window of an electron over just a random Planck time, then there would only be a probability for the electron to be in a collision state, but we could not calculate this probability without knowing the duration of the collision itself, something we soon will get back to.

In our model, a collision happens between two indivisible particles at the Compton periodicity in matter. Still, it is clear that the kg definition of matter does not contain any information about the duration of these collisions, only the number of collisions in a given time interval as well as the ratio relative to the numbers of collisions in a kg. An analogy would be that you have a clock that rings every hour; we know the time between each time it rings, that is one hour, but the clock does not tell us how long the ring lasts. If the duration of collisions is what is important for gravity, then one cannot use such a mass definition for gravity predictions without adding this aspect to the mass. If the Planck length and the speed of light are linked to the duration of the collision, in form of Planck time, then the Planck time must appear directly or somehow embedded in the mass definition for it to be of any use for gravity calculations. And this is what we claim the current gravity theory unknowingly does when multiplying G with M. Then we are getting the Planck length into the mass, and the Planck constant out of the mass. This is to get also the duration of each collision into the mass definition/model. Again, no one knew about the Planck length when suggesting a gravity constant G in 1873, but it could very well be that the gravity constant contains what is missing in the rest of the gravity formula, which is found by calibrating it to gravity observations. That G was introduced a few years before the Planck units does not make it more fundamental. On the contrary, one most often understands things at a surface level first.

Actually, it looks like any mass definition that is relative to a humanly-constructed reference mass will indirectly be a collision (frequency) ratio that does not contain information about the duration of the collisions. Even if we take the ratio of two masses based on our new collision-time mass definition, where we choose the reference mass to be the collision-time of a one kg mass, $\bar{m}_{1\text{kg}}=\frac{l_p}{c}\frac{l_p}{\bar{\lambda}_{1\text{kg}}}$, then the end result is that this mass ratio is identical to the kg mass ratio:

$$\frac{\bar{m}_e}{\bar{m}_{1\text{kg}}} = \frac{\frac{l_p}{c}\frac{l_p}{\bar{\lambda}}}{\frac{l_p}{c}\frac{l_p}{\bar{\lambda}_{1\text{kg}}}} = \frac{\frac{c}{\bar{\lambda}_e}}{\frac{c}{\bar{\lambda}_{1\text{kg}}}} = \frac{f_e}{f_{1\text{kg}}} \approx 9.1\times 10^{31} \text{ fraction of one kg} \tag{29}$$

We see here that when we define the mass as a ratio relative to a human-selected reference mass (collision time of a kg mass or just the kg mass or for example pound) then the Planck length cancels out in such a mass ratio definition. If the Planck time is related to the duration of the collision itself, then the standard mass definition (a ratio relative to a human constructed mass) has no information about this part. We have reason to think gravity is directly related by the duration of these collisions. This is more than a loose opinion; we have demonstrated how the Planck length and Planck time can be extracted from gravity phenomena with no knowledge of G or $\hbar$. We have shown how a long series of observable gravity phenomenon are only dependent on two constants, namely the Planck length and the speed of light (speed of gravity). So, to describe any gravity phenomena, one needs to get the Planck time into the mass. Standard physics has been able to do this by calibrating a constant G to gravity observations. This gravity constant is, in all observable gravity phenomena, multiplied by the gravitational mass, *GM*, and this is equal to $GM = \frac{l_p^2 c^3}{\hbar}\frac{\hbar}{\bar{\lambda}}\frac{1}{c} = c^3\frac{l_p}{c}\frac{l_p}{\bar{\lambda}} = c^3\bar{m}$. Thus, standard physics is getting indirectly the mass we have suggested and standard gravity needs to do this (and do this by multiplying G with M), as we need the duration of the internal collisions that happen inside matter. This is partly a hypothesis, but it is more than that, as it gives an explanatory model of why and how we can measure the Planck length and the Planck time without any knowledge of G and $\hbar$.

Returning to our new mass definition $\bar{m} = \frac{l_p}{c}\frac{l_p}{\bar{\lambda}}$. The first part of this equation $\frac{l_p}{c} = t_p$ represents the duration of a collision between two indivisible particles. The second part, $\frac{l_p}{\bar{\lambda}}$, presents the percentage of the observational time window when the mass is in a collision state; that is, for how much of the observational time window two indivisible particles are in collision. For example, assume we observe an electron in a one-second observational time window. According to our model, it then has $f_e = \frac{c}{\bar{\lambda}_e} \approx 7.76\times 10^{20}$ collisions in that time window. The duration of the sum of the collisions is

$7.76\times 10^{20}\times t_p \approx 4.19\times 10^{-23}$ second, which is identical to $\frac{l_p}{\bar{\lambda}} \approx 4.19\times 10^{-23}\%$ of the observational time (in this case one second). That is, for any observed elementary particle, such as an electron, we see that this fraction is very small.

When we are observing (even hypothetically) the particle at time windows as short as one Planck time then $\frac{l_p}{\bar{\lambda}}$ represents the probability for the particle to be in a collision state. Assume an electron has a collision every Compton time: $t_c = \frac{\bar{\lambda}_e}{c} \approx 1.29 \times 10^{-21}$ seconds. However, the one collision we will have in this observational time window only lasts the Planck time. If we take a randomly-selected Planck time observational window, then we do not know if the particle is in collision state or not, but we know the probability, which must be:

$$\frac{\frac{l_p}{c}}{\frac{\bar{\lambda}}{c}} = \frac{l_p}{\bar{\lambda}} \text{ (for a Planck time observational time-window).}$$

If the reduced Compton wavelength of the particle is less than the Planck length, then $\frac{l_p}{\bar{\lambda}} > 1$, then the integer part will be identical to the number of collisions (quantization) during a Planck time observational time window, and the remaining fraction (if any) can be seen as a probability for an additional collision to happen in the observational time window of the Planck time. This also means that if we hypothetically observe masses in an observational time window of one Planck time, then particles considerably smaller than a Planck mass are dominated by probability, while masses equal to or above the Planck mass size are dominated by determinism. It is also important to be aware that if the mass has a Compton wavelength shorter than the Planck length, then it must be a composite mass. That is, it must consist of more than one elementary particle; see section 6 for further details.

9. Consistency

We have introduced a new mass definition, so a natural question to ask is: "*Does this lead to a consistent theory, or does it lead to inconsistencies when the consensus theory today is already proven to work well*?" We have completed extensive research to ensure that it leads to a consistent theory. We can always go between this mass and the standard mass simply by multiplying the new mass with $\frac{\hbar}{l_p^2}$, or by multiplying the standard kg mass with $\frac{l_p^2}{\hbar}$ to go back and forth between them. This is identical to multiplying the standard mass with $\frac{G}{c^3}$ (since $\frac{G}{c^3} = \frac{l_p^2}{\hbar}$), which makes it easy to see why we have $GM = c^3 \bar{M}$.

One might suspect that, since our new mass definition and the standard mass definition only differ by a ratio of two known physical constants, and $GM = c^3 \bar{M}$, that this is a trivial change of units without any important implications. One could come up with an almost infinite number of unit changes that lead to no new insights and that might only make the formulas and the output dimensions less intuitive than the established framework. For example, we could multiply all masses and all energies by $\sqrt{c}$; this would alter no rules of physics, but would make the existing formulas look more complex, and the output and dimensions would be less intuitive than they are in the existing framework, but it would not lead to any new insight. As a minimum, a change of units should lead to some simplification and hopefully some new insight. We will claim that our change of mass definition both simplifies the formulas and leads to new important insights in physics.

Our multiplication of the existing kilogram mass with a ratio of two constants is more than just a change of units because our new mass definition contains the two constants needed for predicting all observable gravitational phenomena, namely the Planck length and *c*, while the standard mass contains the Planck constant and *c*, but has no information about the Planck length. However, as carefully explained in the previous sections, one is indirectly doing the same already in standard physics, but by multiplying *G* with *M*, one is getting the Planck length into the mass and, at the same time, removing the Planck constant. Our new mass definition simply makes Newtonian gravity and other parts of gravity simpler; we can now work with two constants rather than three. Taking up a popular theme of the day, superstring theory, for example, suggests that the speed of light *c* and the Planck length are the two fundamental constants [62], but superstring theory still has not led to the breakthrough once hoped for, and thus it is time to look at existing formulas in a new and fresh way. This new view gives us an idea that we may have been using two different mass definitions all along without being aware of it, or explicitly noting it, as explained in the section above.

10. Conclusion

We have shown that the Planck mass (and Planck energy) can be measured with a Cavendish apparatus without any prior knowledge of *G*. Further, we have shown how the Planck length and Planck time can be found with no knowledge of *G* and $\hbar$ using a Cavendish apparatus. This no longer posits the Planck units as simply being a derived constant from big *G*, but possibly makes the Planck units even more important than big *G*, since the gravitational constant can be written as a composite constant $G=\frac{\hbar c}{m_p^2}=\frac{\hbar c^5}{E_p^2}=\frac{t_p^2 c^5}{\hbar}=\frac{l_p^2 c^3}{\hbar}$. In addition, we have shown that the standard mass definition is possibly incomplete, since all gravity phenomena can be calculated by only knowing the Planck length and the speed of light, plus one variable describing the mass size, which is the Compton wavelength. All of these elements can be found without any knowledge of *G* or the Planck constant. We claim that the embedded gravitational constant contains the Planck constant to get the Planck constant out of the standard mass definition, since all predictable gravity phenomena have $GM=c^2\frac{l_p^2}{\bar{\lambda}_M}$.

It seems that standard physics indirectly uses two different mass definitions: one for all other areas of physics, the standard kg mass definition, but in gravity, we think one is indirectly using a more complete mass definition that one gets by always multiplying M with G. Using the same mass definition in non-gravity physics as well could be the key to unifying gravity with other areas of physics. We do not need the Planck constant for quantization in gravity, as we get that from the Planck length, the Planck time, and the embedded Compton frequency embedded in matter.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Appendix A: The Planck Time and the Planck Length

We can also find the Planck time directly without any knowledge of G in a Cavendish experiment by utilizing the derivation below:

$$\kappa\theta = LF$$

$$\frac{mL^2 2\pi^2}{T^2}\theta = L\frac{t_p^2 c^5}{\hbar}\frac{Mm}{R^2}$$

$$t_p = \sqrt{\frac{\hbar L 2\pi^2 R^2 \theta}{MT^2 c^5}} \tag{30}$$

And, since we can express M as $M = \frac{\hbar}{\bar{\lambda}}\frac{1}{c}$, we get:

$$t_p = \frac{\pi R}{c^2 T}\sqrt{2\bar{\lambda}_M L\theta} \tag{31}$$

Similarly, we can also find the Planck length without knowledge of G and $\hbar$ by taking into account that the mass of an elementary particle can be written as:

$$m = \frac{\hbar}{\bar{\lambda}}\frac{1}{c} \tag{32}$$

In this case, we know the mass is the Planck mass, so the reduced Compton wavelength is related to the Planck length that we can find directly using a Cavendish apparatus:

$$\kappa\theta = LF$$

$$\frac{mL^2 2\pi^2}{T^2}\theta = L\frac{l_p^2 c^3}{\hbar}\frac{Mm}{R^2}$$

$$l_p = \sqrt{\frac{\hbar L 2\pi^2 R^2 \theta}{MT^2 c^3}}$$

$$l_p = \frac{\pi R}{cT}\sqrt{2\bar{\lambda}_M L\theta} \tag{33}$$

In other words, all of the natural Planck units can be found directly from a Cavendish apparatus, with no knowledge of G. The Planck time, or the Planck length can also be found without knowledge of the Planck constant in addition to no knowledge of G.

Appendix B: The De Broglie Wavelength versus the Compton Wavelength

In 1924, de Broglie [63] suggested that there was likely a matter wavelength. He perhaps came up with this suggestion since it had been shown that light had a wave-particle duality, so why not matter also? He indicated that the matter wavelength was given by the formula (see also [64]):

$$\lambda_b = \frac{h}{p} = \frac{h}{mv} \tag{34}$$

where λ_b is the de Broglie matter wavelength. Solved with respect to *m*, this gives

$$m = \frac{h}{\lambda_b v} \tag{35}$$

This formula is valid when $v \ll c$ (the non-relativistic approximation). A drawback in describing the mass as a function of the de Broglie wavelength instead of the Compton wavelength is that the mass is then not defined for a rest-mass, since this would mean $v = 0$. And dividing by zero is undefined, or infinity [65] [66], neither of which make much sense. The relativistic form of the de Broglie wavelength is $\lambda_b = \frac{h}{mv\gamma}$ and the relativistic form of the Compton wavelength is $\lambda = \frac{h}{mc\gamma}$, where $\gamma = 1\big/\sqrt{1 - v^2/c^2}$ is the Lorentz factor. This means that the de Broglie wavelength is always equal to the Compton wavelength times $\frac{c}{v}$. And we can again see that the de Broglie wavelength is not defined for a rest-mass particle, while the Compton wavelength is.

From this, we also have $m = \frac{h}{\lambda_b v}\gamma = \frac{h}{\lambda \frac{c}{v} v}\gamma = \frac{\hbar}{\bar{\lambda}}\frac{1}{c}\gamma$, where again λ_b is the de Broglie wavelength, and λ and $\bar{\lambda}$ are respectively the Compton wavelength and the reduced Compton wavelength. As a particle velocity is close to zero, the de Broglie wavelength approaches infinity, something that has led to a series of strange assumptions.

Haug [29] has even suggested that the Compton wavelength is the true matter wavelength and that the de Broglie wavelength is just a mathematical derivative of this. As the de Broglie wavelength always contains the Compton wavelength, one can naturally get to most of the same results from using the de Broglie wavelength. However, in the case of a rest-mass particle, in general we cannot use the de Broglie wavelength, but an in-depth discussion of this is outside the scope of this paper. When wave-like properties in electrons were observed [67] [68], it was assumed the de Broglie hypothesis was correct. It was correct in the sense that matter does indeed have wave-like (and particle-like) properties; still, this does not mean that the de Broglie wavelength was actually measured. The Compton wavelength, on the other hand, has been measured in a long series of experiments.

Another drawback in using the mass as calculated from the de Broglie wavelength is that we need to know the velocity of the particle. When using the Compton wavelength for a rest-mass, we eliminate *v*. Further, the mass from the Compton formula is the rest-mass. The mass formula linked to the Compton wavelength can easily be extended to a relativistic form [40]; this is $\bar{\lambda} = \frac{\hbar}{mc\gamma}$, but that is not needed here.

Appendix C

We assume the diameter of the indivisible particle is x and that this massless particle moves at an unknown speed y. We have the following Newtonian "equivalent" gravity formula (see also Table 3):

$$F = x^3 \frac{\bar{M}\bar{m}}{R^2} = x^3 \frac{\frac{y}{x}\frac{y}{\bar{\lambda}_M}\frac{y}{x}\frac{y}{\bar{\lambda}_m}}{R^2} \tag{36}$$

This equation we discussed in Section 7, but we then assumed $x = l_p$ and $y = c$. Here, we assume the diameter of the indivisible particle and the speed of it is totally unknown but, as we will demonstrate, they can be extracted from gravity phenomena and can then be used to predict any other gravity phenomena with no prior knowledge of G, $\hbar$, or c.

This means we have:

$$\kappa\theta = LF = Lx^3 \frac{\bar{M}\bar{m}}{R^2} = Lx^3 \frac{\frac{y}{x}\frac{y}{\bar{\lambda}_M}\frac{y}{x}\frac{y}{\bar{\lambda}_m}}{R^2} \tag{37}$$

where κ is the torsion coefficient of the suspending wire and θ is the deflection angle of the balance.

We also have that the natural resonant oscillation period of a torsion balance is given by:

$$T = 2\pi\sqrt{\frac{I}{\kappa}} \tag{38}$$

Further, the moment of inertia I of the balance is given by:

$$I = \bar{m}\left(\frac{L}{2}\right)^2 + \bar{m}\left(\frac{L}{2}\right)^2 = \frac{\bar{m}L^2}{2} \tag{39}$$

This means we have

$$T = 2\pi\sqrt{\frac{\bar{m}L^2}{2\kappa}} \tag{10}$$

And when solved with respect to κ, this gives:

$$\frac{T^2}{2^2\pi^2} = \frac{\bar{m}L^2}{2\kappa}$$

$$\kappa = \frac{\bar{m}L^2 2\pi^2}{T^2} \tag{41}$$

Next in the equation 4, we are replacing κ with this expression, and solving with respect to the Planck mass:

$$\frac{\bar{m}L^2 2\pi^2}{T^2}\theta = Lx^3 \frac{\frac{y}{x}\frac{y}{\bar{\lambda}_M}\frac{y}{x}\frac{y}{\bar{\lambda}_m}}{R^2}$$

$$xy = \sqrt{\frac{\bar{\lambda}_M L 2\pi^2 R^2}{T^2}\theta} \tag{42}$$

As we have shown before in this paper, the reduced Compton wavelength can be found independent of any prior knowledge of any physical constants. This means only x and y are unknowns. From this equation alone we cannot find their separate values, but observations show $xy \approx l_p c$, and we will claim we must have xy exactly equal to $l_p c$ if one looks away from any measurement error. Since x is the diameter of the indivisible particle, then it makes sense that this diameter is the Planck length. And we know y is the speed of the indivisible massless particle, so then the speed of the particle is c.

We can, however, also find their separate values without any speculation. What we have measured with a Cavendish apparatus could be classified as a Newtonian gravity phenomenon. All Newtonian phenomena contain l_p and c, that is x and y, so from Newtonian phenomena alone we can only extract the combination of them. We can naturally measure the speed of light from electromagnetic phenomena and then divide xy by c and find that $x = l_p$, but then we assume the speed in gravity formulas (the speed of gravity?) is identical to the speed of light. This is not needed, as we can separate the value of y and x only from gravity observations with no prior knowledge of G, $\hbar$, and c.

For example, from gravitational deflection we have:

$\delta = \frac{4y^3 \bar{M}}{y^2 R} = \frac{4y^3 \frac{x}{y}\frac{x}{\bar{\lambda}}}{y^2 R} = \frac{4}{R}\frac{x^2}{\bar{\lambda}_M}$. Solved with respect to x, we have $x = \sqrt{\frac{\delta \bar{\lambda}_M R}{4}}$. The sun's deflection has been measured to be approximately 1.75 arcseconds. This gives a value of $x \approx l_p$

($x = \sqrt{\frac{1.75 \times \pi/648000 \times 1.77 \times 10^{-46} \times 696340000}{4}} \approx 1.616 \times 10^{-35}\,\text{m}$). This is no coincidence. This is because the Planck length is the only physical constant that the deflection of light is dependent on. The same is true with gravitational red-shift, and gravitational time dilation. So, from these, we can find the Planck length independent of knowledge of any other constant. Next we can measure any Newtonian gravity phenomena, which will give us yl_p; by dividing by the Planck length we then find the $y \approx c$. This is also no coincidence. All observable gravity phenomena are only dependent on c and l_p and they can be extracted from gravity phenomena with no prior knowledge of any physical constant. Again, superstring theory has suggested that only the same two constants are needed, but there do not seem to have been any real breakthroughs with it. The path we are proposing is thus revolutionary. It means G is a composite that contains c, $\hbar$, and l_p; it contains $\hbar$ to get this out of our incomplete mass definition and it gets l_p into the mass definition, and c is needed in some but not all gravity phenomena.