The 2019 Convention, Quantum Gravity and the definition of Kilogram

Abhishek Majhi*
Indian Statistical Institute,
Plot No. 203, Barrackpore, Trunk Road,
Baranagar, Kolkata 700108, West Bengal, India

There appears to be a lack of general consensus among the BIPM and the quantum gravity community regarding the definition of kilogram, in light of the 2019 convention, concerning the role of the gravitational constant G as a defining constant. Unless a decision is reached, not only the task of the BIPM to "ensure worldwide unification of measurements" remains unfulfilled, but also the proposals of experimental tests of quantum gravity remain devoid of any scientific value.

According to the 2019 convention adopted by the BIPM[1, 2], the SI unit of mass, namely, kilogram(kg) is defined in terms of the Planck constant h, the velocity of light in vacuum c and the Cesium frequency standard $\Delta\nu_{cs}$, considering these quantities as exact by convention[2]. These are called defining constants because the base units like kg are defined in terms of these constants. According to the BIPM, the definition of kg is the following[1]:

$$1 \text{ kg} \approx 1.475 \times 10^{40} \, \frac{h\Delta\nu_{cs}}{c^2}. \tag{1}$$

The motivation behind adopting such a convention, according to the BIPM, is that "*the realizations are separated conceptually from the definitions so that the units can, as a matter of principle, be realized independently at any place and at any time.*"[2]. That is, instead of relying on a practically experienced prototype of unit, now we rely on logical definitions of the units in terms of the defining constants.

Now, the BIPM declare that the defining constants are among the "*fundamental constants of nature, such as the Planck constant and the speed of light, so that the definitions are based on and represent our present understanding of the laws of physics.*"[2]. However, the BIPM do not clarify why the gravitational constant G can not be considered as one of the defining constants, although "*our present understanding of the laws of physics*" do involve well established theories of gravity (like general relativity which the BIPM cite in ref.[2]) which are based on the assumption that G is a fundamental constant. We do not find any reason why kg can not be defined in terms of G, c and $\Delta\nu_{cs}$ as follows[2]:

$$1 \text{ kg} \approx 2.133 \times 10^{-26} \, \frac{c^3}{G\Delta\nu_{cs}}. \tag{2}$$

Consequently, a dilemma arises whether to choose the definition (1) or the definition (2) for kg. Even if any one definition among these two options is chosen over the other, some reason needs to be provided for this choice. Otherwise, the founding logic of the "*worldwide unification of measurements*" will depend on an arbitrary choice and not on reason.

Such shortcoming of the BIPM becomes more profound when we take into account any theory of "quantum gravity"[3, 4] and any proposed experimental tests of quantum gravity due to the explicit involvement of the three fundamental constants G, h, c (e.g. see refs.[6–9] and the relevant references therein). In order to "*ensure worldwide unification of measurements*", the BIPM necessarily need to resolve the dilemma concerning the definition of kg.

Now, as far as the quantum gravity community are concerned, none of the articles which have been published in and after 2019[6–10] show any glimpse of awareness regarding such logical dilemma that underlies the definition of kg in light of the 2019 convention adopted by the BIPM. Without the provision of a unique definition of kg, any proposal of experimental test of quantum gravity remains illogical at its foundation.

*Electronic address: abhishek.majhi@gmail.com

[1] We have considered the value only up to three places after the decimal. The precision is not the matter of concern in the present discussion.

[2] We have considered the value of G, up to three places of decimal, as given in the NIST website: https://physics.nist.gov/cgi-bin/cuu/Value?hbar—search_for=universal_in!

Hence, the scientific value of such research outputs come into question. Quite interestingly, in and after 2019, such questionable research outputs have been (i) published in prestigious journals[6, 9, 10] (ii) conceptualized by eminent scientists like Penrose among others[8] (iii) discussed without any concern in the quantum gravity community[5]. It appears as if the BIPM and the quantum gravity community are ignorant about each other's viewpoints concerning the logical foundations of measurements as far as the 2019 convention is concerned.

Therefore, we believe that a general consensus regarding the definition of kg and the associated role of the gravitational constant G needs to be achieved worldwide. Otherwise, in light of the 2019 convention, on one hand the BIPM's task of ensuring "*worldwide unification of measurements*" remains unfulfilled and on the other hand, any proposal of experimental tests of quantum gravity, in and after 2019, remain devoid of any scientific value. In view of this, we pose the following questions for both the BIPM and the quantum gravity community:

- *If the gravitational constant G is one of the fundamental constants according to our present day understanding of the laws of physics, then why can it not be considered as one of the defining constants (like Planck constant h, etc.)?*
- *Which one among (1) and (2) is the definition of kilogram if both h and G are in the BIPM's list of defining constants?*
- *Why any one among the definitions (1) and (2) shall be preferred over the other?*
- *Can the BIPM and the quantum gravity community reach a general consensus regarding the answers to the above questions?*

We hope that the BIPM and the quantum gravity community will soon come up with answers to the above questions in near future. However, at the moment, we find an explicit lack of harmony within the worldwide scientific community as far as the basic conventions of measurements are concerned.

Acknowledgment: The author has been supported by the Department of Science and Technology of India through the INSPIRE Faculty Fellowship, Grant no.- IFA18- PH208.

[1] International Committee for Weights and Measures (CIPM), https://www.bipm.org/en/committees/ci/cipm. 1
[2] *BIPM: The International System of Units (SI)*, Brochure, 9th Edition (2019), online link. 1
[3] Quantum Gravity, Stanford Encyclopedia of Philosophy, https://plato.stanford.edu/entries/quantum-gravity/. 1
[4] C. Rovelli, Quantum gravity, Scholarpedia, 3(5):7117 (2008), http://dx.doi.org/10.4249/scholarpedia.7117. 1
[5] Challenges for Witnessing Quantum Aspects of Gravity in a Lab, ICTP SAIFR (2021), https://www.ictp-saifr.org/qgem2021/. 2
[6] S. P. Kumar, M. B. Plenio, Nature Communications 11, 3900 (2020), https://doi.org/10.1038/s41467-020-17518-5. 1, 2
[7] J. Tilly et. al., Qudits for Witnessing Quantum Gravity Induced Entanglement of Masses Under Decoherence, https://arxiv.org/abs/2101.08086.
[8] R. Howl, R. Penrose, I. Fuentes, Exploring the unification of quantum theory and general relativity with a Bose-Einstein condensate, New J.Phys. 21 (2019) 4, 043047, https://iopscience.iop.org/article/10.1088/1367-2630/ab104a, arXiv link: https://arxiv.org/abs/1812.04630. 2
[9] M. Toros et. al., Relative acceleration noise mitigation for nanocrystal matter-wave interferometry: Applications to entangling masses via quantum gravity, Phys. Rev. Research 3, 023178 (2021), https://doi.org/10.1103/PhysRevResearch.3.023178. 1, 2
[10] D. Carney et al, Tabletop experiments for quantum gravity: a user's manual, Class. Quantum Grav. 36, 034001 (2019), arXiv link: https://arxiv.org/abs/1807.11494. 1, 2