The Newtonian Gravitational Constant G Interpreted as the Gravitational Inertia of Vacuum - G_0 . How to Arrange Twelve Precise Experimental Determinations of G_Z in their Spread 500 ppm? Unlocking of the Recommended Value of the Constant G – New Tests for Old Physics

Jiří Stávek

ABSTRACT

We have newly interpreted the Newtonian gravitational constant G as the gravitational inertia of vacuum G_0 . The source mass inserted into vacuum decreases this value G_0 to G_Z on the dependence of the atomic number Z of atoms in the source mass. This is the mechanism for the attraction of test masses through vacuum – the test mass follows the decrease of the gravitational inertia of vacuum towards the source mass. We have extracted the relationship $G_Z = G_0 (1 - k Z)$ where k is the experimental constant from ten actual precise experimental determinations of G_Z . This model was tested on two precise experimental values of G_Z determined for G_{EARTH} , and G_{BRASS} . This model enables to predict values G_Z for atoms, molecules and compositions of the studied source masses and to realize experimental verification with the existing experimental technology. The experimental G_Z values are thus arranged into a system and the spread in these data is explained as the influence of atoms of the source masses on their surrounding via the decrease of the gravitational inertia of vacuum. We might achieve the accuracy of experimental values G_Z with six significant figures for all configurations of source and test masses.

Keywords: Newtonian gravitational constant, gravitational inertia of vacuum, system for arrangement of experimental values G_Z , prediction of G_Z values, a road to G_Z with six significant figures.

Published Online: April 21, 2021

ISSN: 2684-4451

DOI : 10.24018/ejphysics.2021.3.2.65

Jiří Stávek*

Independent Researcher, Prague, Czech Republic.

(e-mail: stavek.jiri@seznam.cz)

*Corresponding Author

I. INTRODUCTION

The measurement of the Newtonian gravitational constant has a long tradition and during the past three centuries the researchers in this field developed the highest experimental skills in order to obtain reliable experimental values of G , e.g., [1]-[12].

During the last two decades about twelve new precise determinations of the gravitational constant G have been published. These experimental results declared uncertainties of about 20 ppm, but the total spread of the results is in the range about 500 ppm.

There are two possibilities how to resolve these discrepancies. One possibility is to discover some systematic errors in all of those data. The second possibility is to discover hidden rules of Nature governing those experimental values of G . However, it is very difficult to recognize the source of this problem. It is sometimes useful and important in science to look in another direction. To date, there is no quantitatively

theoretical relationship between the Newtonian gravitational constant and other fundamental constants.

The aim of this contribution is to propose a new way of looking on the Newtonian gravitational constant as a measure of the gravitational inertia of vacuum. This new concept opens a new road for the arrangement of the experimental values of G .

We have analyzed the set of twelve most precise experimental values of G and tried to discover a hidden order in those data. Each of those experimental values played a significant role as a part of their synergetic interplay and guided us on this very difficult journey.

At the end of this journey, we might get a set of rules how to analyze the existing experimental data, how to predict new G_Z values for any combination of atoms in the source mass. Moreover, we might newly interpret the gravitational attraction between the source mass and the test mass as a decrease of the gravitational inertia of vacuum between those two masses separated at a distance R . The source mass

decreases the gravitational inertia of vacuum and guides the test mass through this channel in vacuum to the surface of the source mass.

II. ACTIVE GRAVITATIONAL MASS AND PASSIVE GRAVITATIONAL MASS

In all experiments on the determination of the Newtonian gravitational constant the high attention is given to proper preparation of the source masses and test masses. The source masses play the role of the active gravitational mass while test masses play role of the passive gravitational mass.

It is very well-known experimental fact based on the Eötvös experiment that the passive gravitational mass plays the role of “inertial” mass and fulfills the Einstein’s Equivalence Principle as it was documented many times with very high accuracy, e.g., [13]-[14]. If the mass of the Earth M_{EARTH} plays the role of active gravitational mass, then all test masses on the surface of the Earth are passive gravitational masses in the Eötvös-type experiments.

Relatively little attention has been paid to an experiment by Lloyd B. Kreuzer in 1964 that tested the equality of the passive gravitational mass and active gravitational mass, [15]-[18]. However, the experimental technology at that time was not developed to observe those data below a certain observation limit.

In our model we assume that the source mass in the Cavendish-type experiments plays the role of the active gravitational mass and the smaller test mass plays the role of the passive gravitational mass. We expect that atoms of the active gravitational mass should decrease the value of the gravitational inertia vacuum G_0 and we could observe values for individual atoms G_Z where Z is the atomic number in the periodic system of chemical elements.

III. THE ARRANGEMENT OF THE PRECISE DETERMINATIONS OF THE NEWTONIAN GRAVITATIONAL CONSTANT

Historical literature on the determination of G surveys many inspirative experiments with different compositions of source masses and test masses. A very good introduction to this topic can be found in [19] and [20].

Based on this inspiration we will describe the composition of source masses and test masses in the most precise twelve determinations of G realized during two last decades. All these data are given in Table I.

The situation for the data evaluation is rather more complicated and some other experimental parameters determine the proper arrangement of those data in our set. All details of experiments are given in original papers of these experiments.

1. The G data from the experiments BIPM-01 and BIPM-14 are interpreted as G_0 – the gravitational inertia of vacuum. See details of these two experiments in the original papers.
2. The G data from experiments UWash-00, HUST-TOS-18, HUST-AAF-18, MSL-03, UCI-14, JILA-10, L&T-82, LENS-14 are interpreted as G_Z for atoms of those source masses with their atomic number Z .

3. The G value in UZur-06 is interpreted as G_{EARTH} and its value will be later calculated based on the composition of the Earth’s core. This experiment is the beam balance measurement where the active gravitational mass is M_{EARTH} .
4. The G value in UWup-02 is interpreted as G_{BRASS} and can be calculated for the given source mass (Cu 90%, Zn 10%).

Fig. 1 shows the relationship of the G_Z data on the atomic number Z for those ten source masses given in Table I.

From the experimental data for G_Z given in Figure 1 we can extract a relationship for the calculation of G_Z as:

$$G_Z = G_0(1 - k \times Z) = 6.67547 \times (1 - 6.53072 \times 10^{-6} \times Z) \times 10^{-11} [m^3 kg^{-1} s^{-2}] \quad (1)$$

where k is the constant from the linear regression, and $G_0 = 6.67547 \times 10^{-11} m^3 kg^{-1} s^{-2}$ is the value for the gravitational inertia of vacuum.

Predictions for G_Z calculated from Equation 1 can be experimentally tested for source masses made from not yet used chemical elements in those big G experiments.

In some cases, the source mass is made from compositions of several chemical elements. For this situation we can predict the G_{COMPOUND} as:

$$G_{\text{COMPOUND}} = \sum_{i=1}^n x_i \times G_Z \quad (2)$$

where x_i is the mass ratio of those chemical elements present in the source mass.

Fig. 1. Eight experimental determinations of G_Z on dependence of atomic numbers of chemical elements used in the source masses, and two experimental values for the gravitational inertia of vacuum G_0 ($Z = 0$).

IV. THE COMPARISON OF PREDICTED G VALUES FOR COMPOSED SOURCE MASSES WITH THE PRECISE EXPERIMENTAL DETERMINATIONS OF G

We will calculate G values for source masses composed from several different chemical elements and compare them with the precise G experimental determinations for that material: Table II.

TABLE I: TWELVE EXPERIMENTAL DETERMINATIONS OF THE NEWTONIAN GRAVITATIONAL CONSTANT

Atomic number	Source mass	Test mass	G value $10^{-11}\text{m}^3\text{kg}^{-1}\text{s}^{-2}$	Relative uncertainty ppm	Code	Reference
Vacuum	Cu – Te	Cu – Te	6.67559	27	BIPM-01	[21]
G_0	12 kg	1.2 kg				
Vacuum	Cu – Te	Cu – Te	6.67554	27	BIPM-14	[22], [23]
G_0	12 kg	1.2 kg				
26	Fe	Pyrex	6.674255	14	UWash-00	[24]
	8.140 kg	0.011 kg				
26	Fe	Silica	6.674184	12	HUST-TOS-18	[25]
	0.778 kg	0.068 kg				
26	Fe	Silica	6.674484	12	HUST-AAF-18	[25]
	8.541 kg	0.040 kg				
29	Cu	Cu	6.67387	40	MSL-03	[26]
	27 kg	0.5 kg				
29	Cu	Silica	6.67435	19	UCI-14	[27]
	59 kg	0.011 kg				
74	W	Cu	6.67234	21	JILA-10	[28]
	580 kg	0.78 kg				
74	W	W	6.6726	75	L&T-82	[29]
	10.5 kg	0.005 kg				
74	W	Rb atoms	6.67191	150	LENS-14	[30]
	516 kg					
Beam balance measurement of G_{EARTH}						
EARTH	Earth's mass	Cu	6.67425	19	UZur-06	[31]
	5.972×10^{24} kg	1.1 kg				
Cavendish-type measurement with the brass (Cu 90%, Zn 10%) as the source mass						
BRASS	Brass	Cu	6.67422	73	UWup-02	[32]
	576 kg	1.0 kg				

TABLE II: COMPARISON OF PREDICTED G VALUES FOR COMPOSED SOURCE MASSES WITH THE PRECISE EXPERIMENTAL DETERMINATIONS OF G

Beam balance measurement of G_{EARTH}						
EARTH	Earth's mass 5.972*10 ²⁴ kg	Cu 1.1 kg	6.67425	19 ppm	UZur-06	[31]
Cavendish-type measurement with the brass (Cu 90%, Zn 10%) as the source mass						
BRASS	Brass 576 kg	Glass 3.0 kg	6.67422	73 ppm	UWup-02	[32]
Earth's core composition and G_{EARTH} prediction						
Atomic number	Chemical element	Mass ratio	G_z for the element	G_z contribution		
26	Fe	0.888	6.674336	5.926811		
28	Ni	0.058	6.674249	0.387106		
30	S	0.045	6.674162	0.300337		
57	La (for other elements)	0.009	6.672985	0.060056		
G_{EARTH} calculated				6.674311		
CODATA 2018 G_{EARTH}				6.67430(15)		
G_{BRASS} prediction						
29	Cu	0.90	6.674205	6.006785		
30	Zn	0.10	6.674162	0.667416		
G_{BRASS} calculated				6.674201		
G_{WATER} prediction						
1	H	2/18	6.675426	0.741714		
8	O	16/18	6.675121	5.933441		
G_{WATER} calculated				6.675155		
G_{WATER} measurement						
H ₂ O	H ₂ O 500 kg	Cu 1.1 kg	6.67540	220 ppm	UZur-00	[33]

We propose to further develop new generations of techniques for the measurement of the Newtonian gravitational constant with the attention given to the source and test masses – their composition and amounts in individual experiments. Gilvarry and Müller in 1972 [34] tried to experimentally to find such a relationship but the technology at that time was not yet ready for these precise experiments.

We have now a very good opportunity to experimentally test if the source mass decreases the gravitational inertia of vacuum G_0 . We know from literature that the most successful description of gravitational processes was interpreted by Albert Einstein as [35]: “Gravity is not a foreign and physical force transmitted through space and time. It is manifestation of the curvature of spacetime.” There is one famous quote of Issac Newton [36]: “We must learn from Phænomena of Nature what Bodies attract one another, and what are the

Laws and Properties of the Attraction, before we enquire the Cause by which the Attraction is perform'd”.

In 1986 Ephraim Fischbach et al. [37], [38] stimulated an attention to a possible existence of the so-called fifth force. Though, it was soon found that this model is in error [39], [40] this concept started a new renaissance of gravity experiments at universities worldwide. Several teams collected during last three decades very precise experimental values of the Newtonian gravitational constant. Based on these experimental data we might open a question: “What is the physical meaning of the Newtonian gravitational constant G ?”

We can achieve the accuracy of G_z – the Newtonian gravitational constant – for different chemical elements constant with six significant figures and thus document that the spread in these G data has a deep reason hidden in Nature.

The fixing of G and SI constants might mask the real effects [41]-[43].

V. CONCLUSION

All experimental data used in this study document the masterpiece of all teams in this experimentally very complicated field of physics. One single value of G cannot discover the physical meaning of G – only synergetic cooperation of all teams might guide us to a better understanding of gravitational processes: [44]-[46].

ACKNOWLEDGMENT

We were supported by the contract number 0110/2020.

REFERENCES

- [1] M. U. Sagitov, "Current status of determinations of the gravitational constant and the mass of the Earth," *Soviet Astronomy*, vol. 13, pp. 712–718, (1970).
- [2] G. T. Gillies, "The Newtonian gravitational constant: an index of measurement," Bureau International des Poids et Mesures, France, 1982.
- [3] G. T. Gillies, "The Newtonian gravitational constant: recent measurements and related studies," *Rep. Prog. Phys.*, vol. 60, pp. 151–225, (1997).
- [4] J. Luo, and Z. K. Hu, "Status of measurement of the Newtonian gravitational constant," *Class. Quantum Grav.*, vol. 17, pp. 2351–2363, (2000).
- [5] V. K. Milyukov, J. Luo, Ch. Tao, and A. P. Mironov, "Status of the experiments on measurement of the Newtonian gravitational constant," *Gravitation and Cosmology*, vol. 14, pp. 368–375, (2008).
- [6] V. Milyukov, and S. H. Fan, "The Newtonian gravitational constant: modern status of measurement and the new CODATA value," *Gravitation and Cosmology*, vol. 18, pp. 216–224, (2012).
- [7] T. Quinn, and C. Speake, "The Newtonian constant of gravitation, a constant too difficult to measure?" 13 contributions to a Theo Murphy Meeting Issue, *Phil. Trans. R Soc.*, vol. A 372, (2014).
- [8] S. Schlamminger, J. H. Gundlach, and R. D. Newman, "Recent measurements of the gravitational constant as a function of time," *Phys. Rev. D*, vol. 91, 121101(R), (2015).
- [9] C. Rothleitner, and S. Schlamminger, "Invited review article: measurement of the Newtonian constant of gravitation, G," *Rev. Sci. Instrum.*, vol. 88, pp. 11110-1–111101-27, (2017).
- [10] J. Wu et al., "Progress in precise measurements of the gravitational constant," *Annalen der Physik*, vol. 531, pp. 1900013 (1–14), (2019).
- [11] Ch. Merkatos, B. Toman, A. Possolo, and S. Schlamminger, "Shades of dark uncertainty and consensus value for the Newtonian constant of gravitation," *Metrologia*, vol. 56, pp. 054001 (1–16), (2019).
- [12] Ch. Xue et al., "Precision measurement of the Newtonian gravitational constant," *National Science Review*, vol. 7, pp. 1803–1817, (2020).
- [13] P. G. Roll, R. Krotkov, and R. H. Dicke, "The equivalence of inertial and passive gravitational mass," *Annals of Physics*, vol. 26, pp. 442–517, (1964).
- [14] S. Schlamminger, K. Y. Choi, T. A. Wagner, J. H. Gundlach, and E. G. Adelberger, "Test of equivalence principle using a rotating torsion balance," *Phys. Rev. Lett.*, vol. 100, 041101, (2008).
- [15] L. B. Kreuzer, "Experimental measurement of the equivalence of active and passive gravitational mass," *Phys. Rev.*, vol. 169, 1007, (1968).
- [16] C. M. Will, "Active mass in relativistic gravity: theoretical interpretation of the Kreuzer experiment," *The Astronomical Journal*, vol. 204, pp. 224–234, (1976).
- [17] C. M. Will, "Theory and Experiment in Gravitational Physics," Second Edition, Cambridge University Press, Cambridge, Chapter 2, (2018).
- [18] C. Lämmerzahl, "Testing the Foundations of the Foundations of General Relativity," *AIP Conference Proceedings*, vol. 1256, pp. 51–65, (2010).
- [19] H. de Boer, "Experiments relating to the Newtonian gravitational constant," In *Precision Measurement and Fundamental Constants II*, Ed. B. N. Taylor and W. D. Phillips, National Bureau of Standards, (1981), pp. 561–572, Table 2.
- [20] G. T. Gillies, and C. S. Unnikrishnan, "The attracting masses in measurements of G: an overview of physical characteristics and performance," *Phil. Trans. R. Soc. A*, vol. 372, 0022, Table 1, (2014).
- [21] T. J. Quinn, C. C. Speake, S. J. Richman, R. S. Davis, and A. Picard, "A new determination of G using two independent methods," *Phys. Rev. Lett.*, vol. 87, 111101, (2001).
- [22] T. Quinn, H. Parks, C. Speake, and R. Davis, "Improved determination of G using two methods," *Phys. Rev. Lett.*, vol. 111, 101102, (2013).
- [23] T. Quinn, C. Speake, H. Parks, and R. Davis, "The BIPM measurements of the Newtonian constant of gravitation," *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, vol. 372, pp. 2026, (2014).
- [24] J. H. Gundlach, and S. M. Merkowitz, "Measurement of Newton's constant using a torsion balance with angular acceleration feedback," *Phys. Rev. Lett.*, vol. 85, pp. 2869–2872, (2000).
- [25] Q. Li et al., "Measurements of the gravitational constant using two independent methods," *Nature*, vol. 560, pp. 582–588, (2018).
- [26] T. R. Armstrong, and M. P. Fitzgerald, "New measurements of G using the measurements standards laboratory torsion balance," *Phys. Rev. Lett.*, vol. 91, pp. 201101, (2003).
- [27] R. Newman, M. Bantel, E. Berg, and W. Cross, "A measurement of G with a cryogenic torsion pendulum," *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, vol. 372, pp. 2026, (2014).
- [28] H. V. Parks, and J. E. Faller, "Simple pendulum determination of the gravitational constant," *Phys. Rev. Lett.*, vol. 105, pp. 110801, (2010).
- [29] G. G. Luther, and W. R. Towler, "Redetermination of the Newtonian gravitational constant," *Phys. Rev. Lett.*, vol. 48, p. 121, (1982).
- [30] G. Rosi, F. Sorrentino, L. Cacciapuoti, M. Prevendelli, and G. M. Tino, "Precision measurement of the Newtonian gravitational constant using cold atoms," *Nature*, vol. 510, pp. 518–521, (2014).
- [31] S. Schlamminger, E. Holzschuh, W. Kündig, F. Nolting, R. E. Pixley, J. Schurr, and U. Straumann, "Measurement of Newton's gravitational constant," *Phys. Rev. D*, vol. 74, pp. 082001, (2006).
- [32] U. Kleinevoß, "Bestimmung der Newtonschen Gravitationskonstanten G," PhD. Thesis, Bergische Universität Wuppertal, Wuppertal, Germany, (2002).
- [33] F. Nolting, J. Schurr, S. Schlamminger, and W. Kündig, "Determination of the gravitational constant G by means of a beam balance," *Europhysics News*, (2000). <http://dx.doi.org/10.1051/epn:2000406>.
- [34] J. J. Gilvarry, and P. M. Müller, "Possible variation of the gravitational constant over the elements," *Phys. Rev. Lett.*, vol. 28, pp. 1665–1669, (1972).
- [35] A. Einstein, "Die Grundlage der allgemeinen Relativitätstheorie," *Annalen der Physik*, vol. 49, pp. 769–822, (1916).
- [36] I. Newton, "Optics", Dover Publications, reissued in 2012, ISBN-10: 0-486-60205-2, Query 31, p. 376.
- [37] E. Fischbach, D. Sudarsky, A. Szafer, C. Talmadge, and S. H. Aronson, "Reanalysis of the Eötvös experiment," *Phys. Rev. Lett.*, vol. 56, pp. 3–6, (1986).
- [38] E. Fischbach, J. T. Gruenwald, D. E. Krause, M. H. McDuffie, M. J. Muetherthies, and C. Y. Scarlett, "Significance of composition-dependent effects in fifth-force searches," *Arxiv*: 2012.02862v2.
- [39] C. W. Stubbs, E. G. Adelberger, F. J. Raab, J. H. Gundlach, B. R. Heckel, K. D. McMurry, H. E. Swanson, and R. Watanabe, "Search for intermediate-range interaction," *Phys. Rev. Lett.*, vol. 58, pp. 1070–1073, (1987).
- [40] G. M. Tino, L. Cacciapuoti, S. Capozziello, G. Lambiase, and F. Sorrentino, "Precision gravity tests and the Einstein equivalence principle," *Progress in Particle and Nuclear Physics*, vol. 112, pp. 103772, (2020).
- [41] J. Stávek, "Spin interpreted as the angular momentum curvature, electron g-factor interpreted as the ratio of toroidal torsion and curvature, unlocking of the fixed Planck constant h – new tests for old physics," *European Journal of Applied Physics*, vol. 3, pp. 61–66, Issue 1, (2021).
- [42] J. Stávek, "Rydberg constant interpreted as the Gaussian curvature, Gauss-Bohr-de Broglie model – two shadow projections of the helix, unlocking of the fixed constant c of the speed of light – new tests for old physics," *European Journal of Applied Physics*, vol. 3, pp., Issue 2, (2021).
- [43] J. J. Mareš, P. Hubík, V. Špička, J. Stávek, J. Šesták, and J. Křištofik, "Shadows over the speed of light," *Physica Scripta*, vol. 2012, 014080, 2012.
- [44] C. Speake, and T. Quinn, "The search for Newton's constant," *Physics Today*, vol. 67, pp. 27 – 33, (2014).
- [45] T. Quinn, "Don't stop the quest to measure Big G," *Nature*, vol. 505, p. 455, (2014).
- [46] S. Schlamminger, "Gravity measured with record precision," *Nature*, vol. 560, pp. 562–563, (2018).