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On the abnormal 1996 German G-experiment

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Abstract. The 1996 experiment performed at the Physico-Technical Federal Board (Physikalisch-Technische Bundesanstalt, PTB) provided a value of the Newtonian gravitational constant that exceeds the standard value by ~ 0.6 %. In this paper, it is shown that this anomaly does not result from neglecting the Earth's shielding effect.

In 1992–1993, a precise measurement of the Newtonian gravitational constant G was made in PTB [1]. The following abnormal value was obtained:

$$G_{\mathrm{PTB}} = 6.71540 \cdot (1 \pm 83 \cdot 10^{-6})\theta,$$

where $\theta = 10^{-11}\ \mathrm{m}^3\mathrm{kg}^{-1}\mathrm{s}^{-2}$. Currently, the Committee on Data for Science and Technology (CODATA) gives a much smaller (by 0.6 %) value:

$$G_{\mathrm{COD}} = 6.67259 \cdot (1 \pm 128 \cdot 10^{-6})\theta.$$

An original non-thread torsion balance was used as a measuring tool in the experiment [1]. The beam rested on a float submerged in a bath filled with mercury. The beam was kept on a natural rotation axis by means of the mercury surface tension forces. The balance was kept using the compensation principle. Under the action of gravitational forces generated in the system of masses of attraction, the beam departing from the given azimuth. A laser interferometer detected this deflection and exercised a command to return the beam to the zero-mark. This command was treated by an electrostatic compensator based on a standard electrometer. The compensating voltage was the gravitational moment measure.

Masses of attraction had the form of cylinders. Their parameters are listed in Table 1.

Table 1. Geometrical and mass characteristics of attracted and attracting cylinders

Name	Attracted cylinder	Attracting cylinder
Material	Zerodur	Tungsten
Radius	$R_0 = 25$ mm	$R = 20$ mm
Length (height)	$H_0 = 24$ mm	$H = 37$ mm
Density	$\rho_0 = 2.5$ g/cm^3	$\rho = 19.3$ g/cm^3
Mass	118 g	897 g
Number	2	4

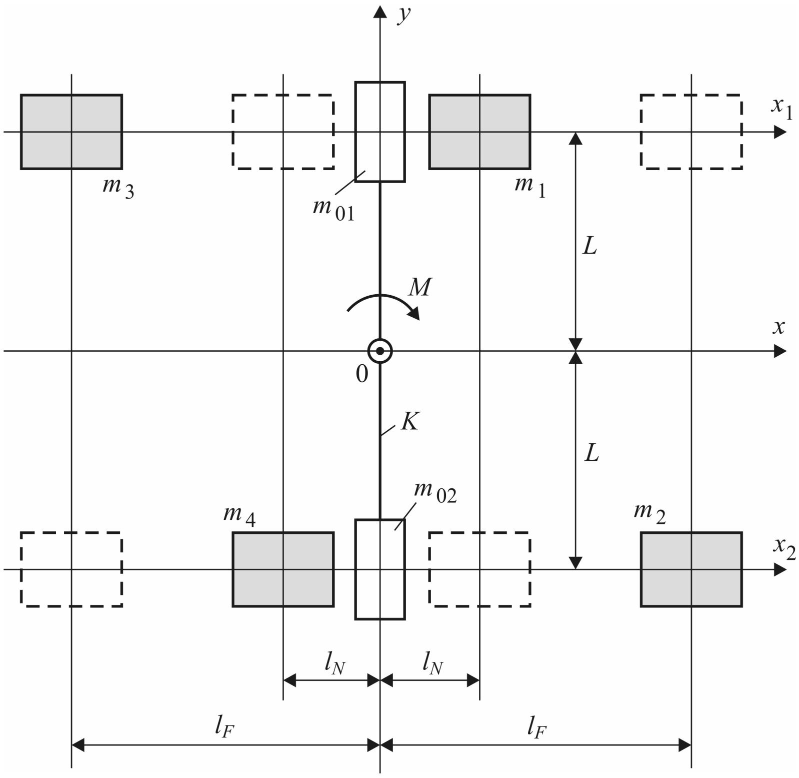

Figure 1. Location of test masses in the G-experiment [1]: $\{x, y, z, 0\}$ is a reference system of coordinates, whose Z-axis is directed down to the Earth's center; x_1 is a joint axis of the cylinders m_{01}, m_1, and m_3; x_2 is a joint axis of the cylinders m_{02}, m_2, and m_4; the attracted cylinders m_{01} and m_{02} are rigidly connected to the beam K of the balance; $l_N = 0.037$ m and $l_F = 0.142$ m are coordinates of the attracting cylinders in the "near" and the "far" positions, respectively; $L \approx 0.167$ m is a balance arm

In Figure 1, a geometrical scheme of the experiment is presented. Identical attracted cylinders, m_{01} and m_{02}, and other functional elements were rigidly connected to the beam K of the balance. (The latter, together with the beam, made a noticeable but minor contribution to the gravitational signal being measured.) Each of the equal-sized attracting cylinders, $\{m_1, m_3\}$ and $\{m_2, m_4\}$, was placed in an individual guide tube and adjusted with respect to the axes x_1 and x_2 of the cylinders m_{01} and m_{02}. The attracting cylinders could be moved with compressed air from the "near" to the "far" position and back.

The pneumatic transportation, in contrast to a conventional mechanical one, when changing positions, does not lead to distortions in the gravitational background, which are difficult to overcome. This is a very important methodological finding [1].

The measurement procedure was as follows. The system was positioned into the first geometrical configuration when the attracting masses m_1 and m_4 take the "near" position and the masses m_2 and m_3 — the "far" position. Then, the torque M_* of this configuration was measured. Next, the attracting masses were placed into the opposite positions shown by a dotted line in Figure 1. The torque in this configuration had a negative value M_{**}. Then, the difference moment was determined:

$$M = M_* - M_{**}, \tag{1}$$

which did not contain an unknown component of the background masses.

Mathematical interpretation of the experiment was made using a finite element method. The attracting and the attracted cylinders, their suspension rods, the beam, and the interferometer prisms were divided into small elements. The gravitational interaction of elements was assumed to obey the Newton law:

$$\Delta T = G\frac{\Delta m\,\Delta m_0}{l^2}, \tag{2}$$

where Δm is an elementary mass of a given attracting cylinder; Δm_0 is an elementary mass of an attracted body (a cylinder, a beam, etc.); l is a center-to-center distance of the masses of the elements Δm and Δm_0.

By carrying out calculations, the authors found a theoretical expression for the difference moment in the following form:

$$M_{\text{th}} = GE, \tag{3}$$

where G is the sought-for gravitational constant; E is the calculated integral factor of dimensionality kg^2/m. The non-ordinary value of G_{PTB}, which has been still not fully explained, has been obtained by comparing (1) and (3).

The authors of this paper tried to find out whether the abnormal value of G_{PTB} not taken into account in [1] is explained by a non-Newtonian phenomenon in gravitation denoted now by the term "gravitational shielding effect" (GShE).

Note that this effect was discovered in 1919 by Prof. K. Majorana, (academician and President of the Association of Italian Physicists). In a unique special experiment [2], which was repeated many times, K. Majorana discovered that the weight Q of a test lead sphere with a mass of 1274 g definitely decreases by $\Delta Q = (0.98 \pm 0.16)$ μg if this sphere is surrounded by a symmetric mercury shield of thickness of ~ 8.4 cm. According to K. Majorana's approximate calculations, a universal shielding index $h_0 = 6.7 \cdot 10^{-12}$ cm^2/g corresponds to the observed weight defect ΔQ.

The fact is, K. Majorana's discovery has still not been universally recognized as a scientific achievement, although his opponents could not find any shortcomings in the experiments [2]. By now, nobody could repeat these experiments using a similar scheme of solution. Even K. Majorana's second experiment [3] that was performed with a large shielding mass (10 tons of lead), was essentially successful, although it had a GShE of the same order ($h_0 \approx 2.8 \cdot 10^{-12}$ cm^2/g). The opponents focused not on the experiment itself [2] but on K. Majorana's working hypothesis (which seems to be rather crude and vulnerable), and, as indicated in [4, 5], improper and even erroneous extrapolations are admitted.

The authors of [4] chose another, very laborious but objective, way to verify the experiments [2]. They decided to search for traces of Majorana's GShE in independent gravitational experiments performed at different times by different researchers to determine the Newtonian gravitational constant G. A quantitative analysis of the most reliable G-experiments has shown the following:

1. The experiment [2] had no error. K. Majorana observed the weight defect ($\Delta Q \approx 1$ µg) to be observed in his experiments.
2. According to a more precise calculation, the shielding index is $h_0 = 6.2 \cdot 10^{-12}$ cm^2/g.
3. The long-known dramatic disagreement between G-values obtained in non-identical G-experiments is a logical consequence of neglecting the Earth's shielding effect.

The latter follows from Le Sage's theory of gravitation briefly described in [4]. According to this theory, the elementary attracted mass Δm_0, with addition of the elementary attracting mass Δm, has in the Earth's presence an increment of gravitational forces equal to

$$\Delta \vec{T}_0 = f \frac{\Delta m_0 \Delta m}{l^3} \vec{l} [1 - P(\beta)], \tag{4}$$

where $\vec{l}$ is the vector starting in the center of the mass m_0 and ending in the center of the mass Δm; β is the angle between $\vec{l}$ and the direction $\vec{z}$ to the Earth's center; $P(\beta)$ is the probability of absorption of Le Sage's graviton by the Earth; $f = 6.765\,\theta$ is the "true" constant of gravitation to be distinguished from its Newtonian substitutes G obtained with a conventional assumption $P = 0$.

The experiment [1], as any other one of a similar kind, when interpreted from law (4), has, instead of (3), the following general expression for a theoretical output moment:

$$M_{\text{th}} = fE \cdot (1 - \varepsilon). \tag{5}$$

A dimensionless value ε is found by integrating the moments generated by forces (4) with respect to the volumes of attracted and attracting bodies.

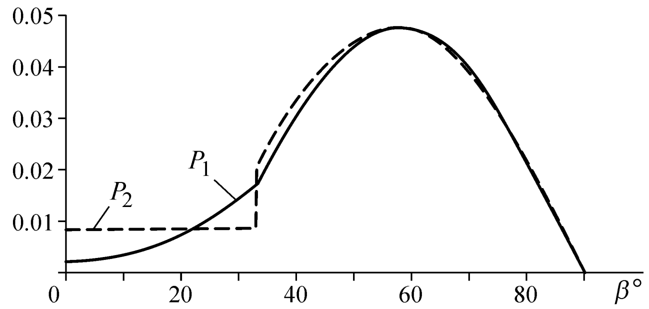

Figure 2. Graphs of the functions P_1 and P_2 used in the analysis of the abnormal G-experiment [1]

The ε-value obviously depends not only on the Earth's shielding function $P(\beta)$ but also on the geometry of this experiment. From a comparison of (5) and (3) follows a relation which is characteristic of each experiment:

$$G = f \cdot (1 - \varepsilon). \tag{6}$$

The parameter ε for an experiment tested [1] was calculated with two most reliable versions of the function $P(\beta)$. In [4], they are denoted $P_1(\beta, W_2)$ and $P_2(\beta, W_2)$ and specified by the following expressions:

$$P_1 = \begin{cases} -0.096\cos\beta + 0.098 & \text{at } 0 \le \beta \le 33°, \\ 0.136\cos\beta - 0.164\cos^3\beta & \text{at } 33° < \beta \le 90°, \\ 0 & \text{at } 90° < \beta \le 180°; \end{cases} \tag{7}$$

$$P_2 = \begin{cases} -0.002\cos\beta + 0.01 & \text{at } 0 \le \beta \le 33°, \\ 0.134\cos\beta - 0.157\cos^3\beta & \text{at } 33° < \beta \le 90°, \\ 0 & \text{at } 90° < \beta \le 180°. \end{cases} \tag{8}$$

The version P_2, in contrast to the version P_1, admits a discontinuity at $\beta = 33°$ (Figure 2). (The angle $\beta = 33°$ corresponds to the Earth's core boundary.)

The non-Newtonian law (4) was included only into the interaction of the attracting and the attracted cylinders. However, law (4) did not hold

Table 2. Quantization of attracted and attracting cylinders

Quantization	Attracted cylinder	Attracting cylinder
By radius	$\Delta R_0 = \frac{R_0}{15} \approx 1.667$ mm	$\Delta R = \frac{R}{12} \approx 1.667$ mm
By height	$\Delta H_0 = \frac{H_0}{18} \approx 1.333$ mm	$\Delta H = \frac{H}{27} \approx 1.370$ mm
By angle	$\Delta\varphi_0 = \Delta\varphi = \frac{\pi}{54} \approx 3.333°$	

Table 3. G-values to be expected in experiment [1] with a purely Newtonian interpretation ($\theta = 10^{-11}$ m^{3}kg^{-1}s^{-2})

Version	f	ε	G
$P_1(\beta)$	$6.765\,\theta$	$1.5383 \cdot 10^{-2}$	$6.6609\,\theta$
$P_2(\beta)$	$6.765\,\theta$	$1.5344 \cdot 10^{-2}$	$6.6612\,\theta$

true for minor attracted masses (the beam and other parts). The attracted and the attracting cylinders were divided into 29160 and 34992 elements, respectively. In this case, the cylindrical quantization system (Table 2) was used.

The results of the calculations are presented in Table 3.

Conclusion

1. According to the calculations, neglecting the Earth's shielding effect in the experiment [1], if this effect is treated from law (4) in versions (7) or (8), must result in $G \approx 6.661\,\theta$.
2. An abnormally large value of $G_{\mathrm{PTB}} = 6.7154\,\theta$ obtained in [1] is most likely the result of some hidden causes of a non-gravitational nature.
3. Nevertheless, the Earth's shielding effect, in principle, cannot be ruled out, although to verify the value G_{PTB}, an essential deformation of parameters included in law (4) is necessary. For instance, at $f = 6.82\,\theta$ in the same versions, (7) and (8), we have $G \approx G_{\mathrm{PTB}}$. However, escalation of f up to a specified level seems to be rather problematic.

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