

Letter from Eötvös

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The original Eötvös data, which had resulted from a measurement series completed in 1908, and which recently found renewed interest, were not formally published until 1922. Now a resuming letter, written by Eötvös eighty years ago, has been re-discovered. The letter throwing some additional light on his experiments is translated and briefly commented.

Recent geophysical measurements of G in mine shafts and bore holes [1] have stimulated renewed interest [2] in the specific gravitational attraction coefficients of materials of different chemical composition, which were determined between the years of 1889 and 1908 by Roland von Eötvös, who employed single and double torsion balances for that purpose. The data gathered around 1908 by him and his coworkers Pekár and Fekete were included in a prize essay which, in 1909, won for Eötvös the Beneke award of the faculty of philosophy of the University of Göttingen. Formal publication was delayed, however, until 1922, three years after Eötvös' death [3]. The reasons for this unusual publication delay seem not to be known [4].

There exists a letter from Eötvös, written around 1908 and reprinted with his permission in another author's booklet [5] published in 1914, where he comments on the measurement precision achieved. Since the letter has not been included in his collected works [6], it may probably be assumed that it is today forgotten or fairly unknown at least. The letter, which is written in German language and which should be of interest in the context mentioned, roughly translates as follows (with altered formula letters) [7].

"If we put the Earth's attraction on the unit of mass of a material equal to H_0 , on the unit of mass of a different material equal to H , then I write

$$H = H_0(1 + \Delta\kappa),$$

where H_0 and H are proportional to the gravitational constants accounting for the Earth's attraction on the two materials. As the substance of reference, represented by H_0 , I chose platinum. Now, your question refers to the point of how great the value of $\Delta\kappa$ is, which in my observations I still could detect?

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The first experiments, the results of which I published in 1890, were performed using extremely sensitive apparatuses. A rotation of the torsion setup by 180° out of an East-West position into a West-East position, if $\Delta\kappa = 1/10\,000\,000$ should hold, ought to have caused a rotation of the balance beam by 1 minute (corresponding to one scale division of the readout device). The mean error of an observation, however, amounted to only approximately one half of a minute, so that I took the limit of the detectable value of $\Delta\kappa$ to be $1/20\,000\,000$.

Today and at the time of my observations for the prize essay for Göttingen, things look even more favourably. During the course of two decades I succeeded in perfecting the torsion balance to a precision instrument which enables me to observe the ellipticity of the niveau surfaces and the curvature of the gravitational lines, even under the open sky. Such work caused me to utilize apparatuses of somewhat lower sensitivity, but of considerably higher precision. Employing these apparatuses, a rotation from East-West to West-East, in the case that $\Delta\kappa = 1/10\,000\,000$ should hold, ought to bring about a twist of 40 seconds of arc (half a scale division of the readout arrangement); yet the mean error of one observation always was smaller than one tenth of a scale division, which is smaller than 8 seconds of arc. The limiting value of the still detectable $\Delta\kappa$, therefore, can safely be assumed to lie below $1/50\,000\,000$. The results obtained according to this procedure were the following ones.

With platinum chosen as standard material, and with reference to the relation

$$H = H_{Pt} [1 + (\kappa - \kappa_{Pt})],$$

it was found that for

Magnesium
Snakewood
Copper
Water

$$\begin{aligned} \kappa - \kappa_{Pt} &= +4 \times 10^{-9} \pm 1 \times 10^{-9}, \\ \kappa - \kappa_{Pt} &= -1 \times 10^{-9} \pm 2 \times 10^{-9}, \\ \kappa - \kappa_{Pt} &= +4 \times 10^{-9} \pm 2 \times 10^{-9}, \\ \kappa - \kappa_{Pt} &= -6 \times 10^{-9} \pm 3 \times 10^{-9}. \end{aligned}$$

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Crystalline copper sulfate	$\kappa - \kappa_{\text{Pt}} = -1 \times 10^{-9} \pm 3 \times 10^{-9}$
Solution of copper sulfate	$\kappa - \kappa_{\text{Pt}} = -3 \times 10^{-9} \pm 3 \times 10^{-9}$
Asbestos	$\kappa - \kappa_{\text{Pt}} = +1 \times 10^{-9} \pm 3 \times 10^{-9}$
Tallow	$\kappa - \kappa_{\text{Pt}} = -2 \times 10^{-9} \pm 3 \times 10^{-9}$

The values stated are means values, each taken from hundred single values, with their mean errors. In three cases these mean values are slightly larger than their mean errors but do not entitle to the conclusion, however, that $\Delta\kappa$ is different from zero. In determining mean values, no rejection of anomalous measurement data has taken place, even not if external interference could be conjectured. I still have to mention that unfortunately just at the time of these observations a new building was erected in the immediate vicinity of the observatory (15 m away). In any case, today there does not yet exist any legitimation to say the last word in this question of paramount importance; the method I have put to test still allow for a multitudinously increasable precision of it reply. Yet already today I dare to say with certainty that, for the materials quoted above, $\Delta\kappa$ is smaller than $1/100\,000\,000$."

In the above Table I have corrected for a printing error, an erroneous plus sign, which appeared in front of the coefficient for crystalline copper sulfate, as a comparison with the otherwise identical summarizing table presented in section 10 of the 1922 paper of Eötvös, Pekár, and Fekete [3] reveals. As described in detail in the latter publication, during the measurements one arm of the torsion balance was continuously loaded with a platinum weight, and the substance under test was suspended on the end of the

opposite arm. For example, in order to determine the difference [8] $\kappa_{\text{H}_2\text{O}} - \kappa_{\text{Cu}}$, first a measurement series was carried out with the H_2O specimen being suspended on the opposite arm. Thereafter the H_2O test sample was replaced by a Cu specimen, and the measurements were repeated. The differential specific attraction coefficient was then determined by subtraction. Furthermore, in the Cu-Pt comparison, the second measurement series was performed with platinum weights on both arms. The number of sample measurements in different comparisons was not exactly hundred, but sometimes more and sometimes less. The material snakewood (*Piratinera guianensis* or *Brosium guianensis*) is a high-density wood which grows in tropical zones of South America, especially in Guyana and North Brasil [9].

The letter stresses that the idea of referencing all data to platinum was familiar to Eötvös, and not introduced after his death by Pekár and Fekete. In Sect. 3 of the paper of 1922, possible influence of man-made interference is also mentioned, yet the precise distance of the new building that was under construction during the measurement campaign, namely 15 m, is not stated. One is led to speculate that Eötvös planned new measurements under conditions of reduced man-made mechanical noise, an undertaking which eventually had been hampered by World War I.

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- [1] F. D. Stacey, G. J. Tuck, G. I. Moore, S. C. Holding, B. D. Goodwin, and R. Zhou, *Rev. Mod. Phys.* **59**, 157 (1987).
- [2] E. Fischbach, D. Sudarsky, A. Szafer, C. Talmadge, and S. H. Aronson, *Phys. Rev. Lett.* **56**, 3 (1986); – *Ann. Physics* (1988), to be published.
- [3] R. v. Eötvös, D. Pekár, and E. Fekete, *Ann. Physik* **68**, 11 (1922); for reviews on Eötvös' experiments see D. Pekár, *Naturwiss.* **7**, 149, 327 (1919); the second of these two review articles has been commented by W. Roth, *Naturwiss.* **7**, 416 (1919).
- [4] R. H. Dicke, *Sci. Amer.* **205**, 84 (December 1961).
- [5] M. B. Weinstein, *Kräfte und Spannungen, Das Gravitations- und Strahlungsfeld, Sammlung Vieweg, Tagesfragen aus den Gebieten der Naturwissenschaften und der Technik, Heft 8* (Vieweg, Braunschweig 1914), pp. 47–49.
- [6] R. v. Eötvös, *Gesammelte Arbeiten*, ed. P. Selényi, Akadémiai Kiadó, Budapest 1953).
- [7] Courtesy of Friedr. Vieweg & Sohn Verlagsgesellschaft mbH, Wiesbaden, April 1987.
- [8] When reconstructed from the original empirical data presented on pp. 34, 35, 37, 42, 44, 45, 47, and 48 of the 1922 paper, the table reads:

Magnesium	$\kappa - \kappa_{\text{Pt}} = + 4 \times 10^{-9} \pm 1 \times 10^{-9}$
Snakewood	$\kappa - \kappa_{\text{Pt}} = - 1 \times 10^{-9} \pm 2 \times 10^{-9}$

Copper	$\kappa - \kappa_{\text{Pt}} = + 4 \times 10^{-9} \pm 2 \times 10^{-9}$
Water	$\kappa - \kappa_{\text{Cu}} = -10 \times 10^{-9} \pm 2 \times 10^{-9}$
Crystalline copper sulfate	$\kappa - \kappa_{\text{Cu}} = - 5 \times 10^{-9} \pm 2 \times 10^{-9}$
Aqueous solution of copper sulfate	$\kappa - \kappa_{\text{Cu}} = - 7 \times 10^{-9} \pm 2 \times 10^{-9}$
Asbestos	$\kappa - \kappa_{\text{Cu}} = - 3 \times 10^{-9} \pm 2 \times 10^{-9}$
Tallow	$\kappa - \kappa_{\text{Cu}} = - 6 \times 10^{-9} \pm 2 \times 10^{-9}$

The platinum-referenced table presented in Eötvös' letter results from this table by adding to its mean values obtained for comparison with copper the mean value $\kappa_{\text{Cu}} - \kappa_{\text{Pt}} = 4 \times 10^{-9}$. The corresponding platinum-referenced standard deviations were obviously computed by combining the standard deviations of the comparisons with copper in quadrature with the value of 2×10^{-9} of the standard deviation of the Cu-Pt comparison. Such a calculation yields for each of the last five entries of the platinum-based table an unique worst-case type of standard deviation being on the order of 3×10^{-9} . For a discussion on the standard deviations of specific gravitational attraction coefficients see also P. G. Roll, R. Krotkov, and R. H. Dicke, *Ann. Physics* **26**, 442 (1964).

- [9] E. König, *Holz-Lexikon*, DRW-Verlags-GmbH, Stuttgart 1972, Vol. II, p. 220.