THE EÖTVÖS EXPERIMENT
IN ITS HISTORICAL CONTEXT

Edited by
Éva Kilényi

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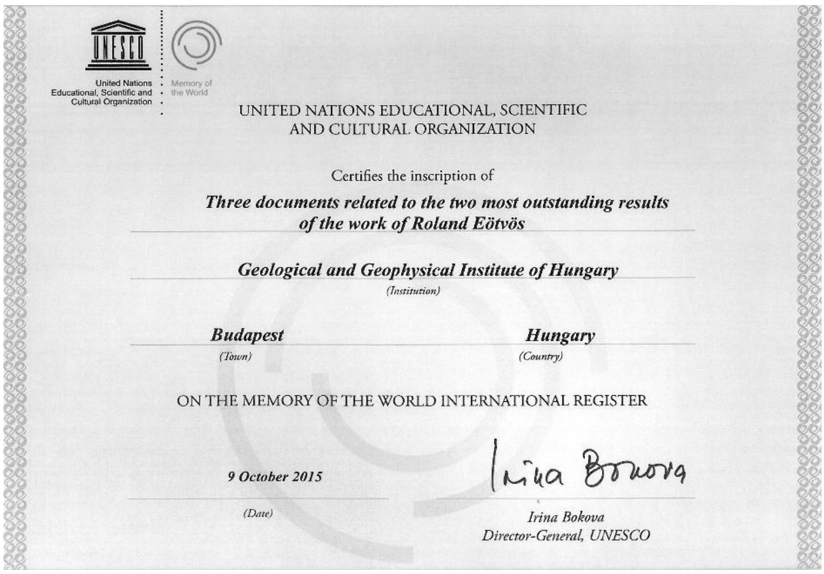
Commemorating the 100th anniversary of Loránd Eötvös' passing away, the Eötvös Loránd[1] Geophysical Foundation decided to dedicate a volume to him, the caretaking of whose heritage is its mission. The events of the near past helped us to choose one topic of his wide-spread activity: UNESCO has inscribed his hand-written draft of his famous treaty: *Contributions to the law of proportionality of inertia and gravity* – thought lost for a long time – on the Memory of the World International Register in 2015. The copy of this document is enclosed herewith.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Memory of the World

UNITED NATIONS EDUCATIONAL, SCIENTIFIC
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Certifies the inscription of

Three documents related to the two most outstanding results of the work of Roland Eötvös

Geological and Geophysical Institute of Hungary
(Institution)

Budapest *(Town)* ***Hungary*** *(Country)*

ON THE MEMORY OF THE WORLD INTERNATIONAL REGISTER

9 October 2015
(Date)

Irina Bokova
Director-General, UNESCO

Fig. 1.

Before starting to discuss the story of this study – being relevant to even present-day physics – a short appraisal of Eötvös is appropriate here. A former student of his, Károly Novobátzky, an eminent physicist himself near 80, wrote the following lines in 1963: "The feeling of deep reverence is arising in my mind as I try to give a portrait of Loránd Eötvös by force of personal commemoration. On and on

[1] The Hungarian usage of names is the contrary to English: first comes the family name and after it the personal names. It is also necessary to mention that in foreign-language publications Eötvös and his co-authors used the Latinized forms of their first names: Loránd → Roland, Dezső → Desiderius and Jenő → Eugen (Editor's note).

lessens the number of those who still saw Loránd Eötvös with their own eyes and heard him with their own ears. They participated in the fortunate experience to obtain an idea about strict morals and scientific notability on a living example."

Viewing from the present, when specialisation is inevitable, Eötvös seems to be the last member of classic scientists, who began by pondering over basic problems, like the figure of the Earth, and then continued by constructing a tool for solving the problem (the torsion balance named after him), then going into technical details to improve their invention, and finally using it on such a basic problem as the proportionality of inertia and gravity.

Eötvös reported on his results at the Hungarian Academy of Sciences in January 1889, with the title: *On the Gravitational Attraction of the Earth on Different Materials*, published by the Academy both in Hungarian and German, in 1890. The English translation of this paper is the first document in our volume. He attached no figures, simply stating that: *"I herewith assert that, if there is any difference between gravity of bodies of equal mass but of different composition, it is less than one part in twenty millionth in the case of brass, glass, antimonite and corkwood and it is undoubtedly less than one part in one hundred thousandth in the case of air."*

The importance of this short report can be evaluated by the fact that the 1906 invitation for scientific competition for 1909 of the Beneke-prize Foundation of the Royal Scientific Society of Göttingen proposed a topic based on Eötvös' results. Unfortunately, this announcement could not be found in the archives of the Göttingen Karl August University, but the evaluation announcement of the competition – enclosed in our volume both in reprint form in German and its English translation – evaluating the only paper arriving, under the motto: "Ars longa, vita brevis", quotes the definition of the task, along with the proposal of C. Runge, Dean of the Faculty of Philosophy.

This announcement motivated Eötvös to start a long series of observations between 1906 and 1908 with his torsion balance, significantly improved since 1889. The observations were carried out mainly by his assistants, Dezső Pekár and Jenő Fekete, under Eötvös' guidance. The anonymous report, submitted to the Beneke-prize Foundation, bearing the above cited motto, was drafted by Eötvös. In his meditation over the Latin proverb he is expressing his dissatisfaction with the precision of his results. One can ponder over why he did not continue his experiments to improve the results? He had ten more years from his life to do it! Relying on the fact that he never submitted this paper for publication, one can suppose that he intended to continue them.

As we discuss below, some of Eötvös' results exhibited deviations from the expected null results at a level that might have made him uncomfortable. The water-Cu comparison, for example, was a five-standard deviation (5 *sigma)* effect, which by itself would be significant even by today's rigorous standards.

We can surmise that the advent of General Relativity (GR) by Einstein in 1915 may have provided additional motivation for Eötvös to re-examine or repeat his earlier experiments. As is well known, GR rests on the assumption of the equality of gravitational and inertial mass (the Equivalence Principle), which is exactly what EPF were testing. Although the famous Eddington test of GR (measuring the deflection of starlight during a solar eclipse) took place only following Eötvös' death, GR had already achieved a significant confirmation: the correct prediction of the anomalous precession of the perihelion of Mercury. Moreover, as we note below, Einstein actually sent Eötvös a booklet about GR, so that there can be little doubt that Eötvös would have been fully aware of the implications of a non-null result in his experiment.

Whatever Eötvös' motivation for not publishing his results in an international journal, this decision deprived Eötvös of some of the credit he justly deserved from early workers in the field. There appear to be no references in contemporaneous publications to Eötvös' results published in a Hungarian journal in 1890, when he was the first to use a torsion balance for these purposes, nor to his results published in the journal of the Göttingen University in 1909. By using a torsion balance, he could overcome the problem of increasing the accuracy of time measurement which he could not achieve given the technical level of his time. With the torsion balance the quantity to be measured is an angle of deflection which he could increase by multiplying mirrors. The world had to wait several decades for physicists using modern electronics to surpass the sensitivity achieved by Eötvös.

Eötvös' first objective in experimenting with a tool for measuring local gravity, was the crucial question of his time: determination of the figure of planet Earth. As early as 1878, at the board meeting of the Royal Hungarian Association of Natural Sciences, Eötvös spoke of the necessity of gravity measurements in Hungary. After a short time, he realized that with the Sterneck-type invariable pendulum, the only tool available at that time, the sensitivity necessary for the task would not be achievable. Pondering over the problem, he turned toward the use of the torsion balance of Cavendish (or Coulomb), first only as a spectacular demonstration tool for his university lectures, but soon realizing the possibilities that could be achieved with it. Setting up the equation for a case when there is no extra mass in the vicinity of the balance, he found that if the equipotential surface deviates from a sphere, there are small horizontal forces turning the beam into the direction of the smallest curvature. From the equation it also became clear that if one of the masses at the end of the beam is lowered, the force acting on the lower mass can be resolved into a vertical and a horizontal component. The latter component exerts a torque against the resistance of the torsion wire resulting in turning the beam in the direction of the increase of gravity. Accordingly, it is measuring not only the direction of the curvature, but the horizontal gradient of gravity as well. Eötvös realized as soon as his instrument proved capable of being used outside the laboratory, that it harboured immense possibilities in geological investigations.

The first occasion at which Eötvös presented his results with his torsion balance at an international scientific forum, was the International Congress of Physicists in Paris (1900). The audience responded to his data about the sensitivity of his instrument with scepticism.

Between 20–28th September, 1906, the International Erdmessung (the predecessor of IUGS), held its XVth Conference in Budapest, providing a possibility for Eötvös to not only present a lecture on his latest results with his balance, but also to invite the best specialists of his time to visit his field crew and decide for themselves what to accept. A 10-member delegation headed by Sir George Darwin (Charles Darwin's son) actually did so, and what they saw not only convinced them to accept Eötvös' figures of accuracy, but upon returning to Budapest, the delegation forwarded an application to the Hungarian government to sponsor Eötvös' research with his torsion balance, regarding its exceptional importance [Szabó 2016].

The government accepted the proposal and from 1907 on an annual grant of 60,000 Crowns was allocated for the research work with Eötvös' torsion balance. The value of this sum can be appreciated by the fact that the annual material expenditure of the University Physical Department was 4000 Crowns. This grant, which had to be administered separately from the University Department's books, rendered all of Eötvös' later research possible, including his experiments on the proportionality of inertial and gravitational mass, as well as the founding of a Geophysical Institute. Following Eötvös' death this institute was named after him by D. Pekár, as director. With world-wide propagation of Eötvös balances in petroleum exploration in the 1920s, this institute became the cradle of training of geophysicists, coming to Budapest from all over the world.[2]

In 1907, Albert Einstein put forward his equivalence principle which led to his theory of general relativity and the geometric interpretation of gravity. To explain the fact that non-gravity experiments, carried out in a free-falling lift and in gravity-free space led – with some constrains – to similar results, requires the assumption of the equivalence of gravity and inertia, which affects an even larger sphere of phenomena. According to his memoirs, Einstein had no information about Eötvös' results of 1890 at the time of formulating the theorem of equivalence, it rather came to him as evident; an intuitive perception.

Einstein's interest turned towards its experimental verification later, when in the debates over the relativistic interpretation of gravity the question turned up as to whether the equivalence of gravity and inertia is valid for radioactive energy too. In 1912, Einstein turned to the 1911 Nobel-prize-winner Willy Wien, suggesting measurements to compare swing-times of pendula with uranium and lead samples, and asked Wien's opinion whether the necessary accuracy could be reached. As his own idea, Einstein suggested the use of an Eötvös-type torsion balance, and the conception of the Eötvös experiment, together with a sketch of the curvature variometer [J. Illy, 1989]. He even proposed to Wien to have these important experiments (experimentum crucis) carried out in Wien's laboratory. Wien's answer did not turn up in the Einstein papers, but we may be sure that he provided full information about Eötvös' results. In his 1913 paper, co-authored with Marcel Grossmann, Einstein refers to Eötvös' 1890 results, citing their accuracy. There is no other explanation for his proposing Eötvös' brilliant method as his own other than to suppose that someone had informed him and – as a real absent-minded scientist – he forgot about this method, but the idea remained. He had a high esteem for Eötvös, as his earlier paper proves, writing about the Eötvös Law of Capillarity.

After the death of F. R. Helmert, director of the Prussian Geodetical Institute (Potsdam), the committee representing the Institute, the Academy, and the

[2] Editor's note: In the 1970s I had the opportunity of studying British geophysical organizations, thanks to the British Council. In one of them, a bearded, middle-aged gentleman inquired kindly about my affiliation. On my answering: Loránd Eötvös Geophysical Institute, he re-questioned: the *baron* Roland Eötvös Institute? On my affirmative answer he said: „My father had been studying there in the 1920s". He was James C. Templeton who, as a geologist with the Anglo-Persian Oil Company, spent several months in the Eötvös Institute in 1923. Following his visit, he established the International Prospecting Company and later the British Geophysical Agency. Both companies were instrumental in popularising Hungarian-manufactured Eötvös balances in the British Empire.

government responsible for nominating the successor, could not agree on one name. Therefore, Einstein – representing the Academy – turned to Eötvös, asking his advice for the successor. Following Eötvös' suggestion, Einstein thanked him for his detailed considerations relating to the personal abilities of the candidates, and for his experiments proving the equivalence of gravity and inertia. Einstein also sent to Eötvös a small booklet about general relativity, containing "the theoretical aspects of the question". In his letter to professor A. Krüss, representing the government in the committee, forwarding Eötvös' proposal, Einstein wrote about Eötvös: *This report of a man of such unquestionable objectivity and expertise one cannot – in my opinion – give enough serious consideration.*

This Einstein – Eötvös correspondence is also included in our volume, as it helps to understand the atmosphere of the scientific world before the Great War.

Eötvös died on the 8th of April 1919, in the turmoil following a lost war, the collapse of the Hapsburg monarchy, a bourgeois revolution, enemy forces on three sides occupying big chunks of the country, and a communist take-over. His burial was organized with great splendour, the orator, the later eminent Marxist philosopher G. Lukács, spoke of him as "the great deceased of proletarian power". A born aristocrat, a real liberal democrat all his life, but sticking to his title of nobility, became a proletarian hero in his death by the joke of history.

Eötvös did not appreciate politics, his real interest lay in science. Even on his death bed he wanted to discuss the latest achievements of physics about atoms and electrons with his visitors. He dictated his last study – "*Experimenteller Nachweis der Schwere-änderung, die ein auf normal geformter Erdoberfläche in östlicher oder westlicher Richtung bewegter Körper durch diese Bewegung erleidet*" (*Experimental demonstration of gravity variations on eastward or westward moving objects caused by this movement on the surface of a perfectly spherical Earth*) – to his assistants, who posted it to Annalen der Physik on 13th March 1919. This topic is associated with O. Hecker's offshore gravity observations on board, resolving again a basic problem of physics, that of gravity changes of a moving object on the surface of the Earth. This phenomenon was named the Eötvös effect, and the correction proposed by him was named the Eötvös correction by the scientific community.

The description of the experiments carried out between 1906 and 1909 was published by his assistants in Annalen der Physik as: *Beiträge zum Gesetze der Proportionalität von Trägheit und Gravität; von Roland v. Eötvös†, Desiderus Pekár und Eugen Fekete,* in 1922. In the Abstract the (living) authors wrote: "…*The original size of this work was about 10 printed sheets in length, which is why a considerable abridgement was necessary, but without touching the originality of the work. …*" One point in our motivation to publish the original Eötvös draft is to address just this question: how much information on the techniques of the experiments has been lost by its abbreviation.

The publication in 1986 of a paper entitled "Reanalysis of the Eötvös Experiment" [Fischbach et al. 1986], focused world-wide attention on the classic experiment of Eötvös, Pekár and Fekete [EPF 1922]. According to this paper, a new force is present in nature (now called the 5th Force) whose source was baryon number, the total number of protons and neutrons in samples that were interacting. Plotting the $\Delta\kappa$ data of the Eötvös experiment as a function of B/M (baryon number/mass), a positive correlation could be recognized (Fig. 2). Fischbach and coworkers concluded that the slope of the resulting line was (5.65±0.71)·10^{-6}, which differs from the expected value of zero by several standard deviations. If the 5th Force really exists with a range of 100–1000 m, say, the composition-dependence must be due to the action of the nearby mass distribution [Király 1987].

As the smallest details of the original experiments became important for the authors [Fischbach et al. 1986], they turned to ELGI (Eötvös Loránd Geophysical Institute, Budapest) asking for the original observational data. This task seemed simple – largely thanks to D. Pekár, Eötvös' first assistant, who preserved all documents in rigorous order: in stacked boxes with the lids at the front – however, no documents have been found, relating to the proportionality between gravitational and inertial mass.

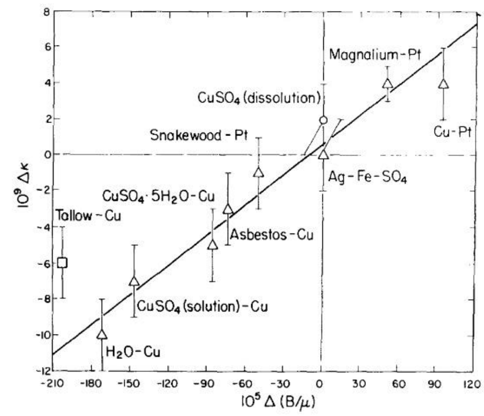

Fig. 2. Plot of $\Delta\kappa$ versus $\Delta(B/\mu)$ from Fig. 2. of Fischbach et al (1988). This is an expanded version of Fig. 1. from Fischbach et al. (1986). For each pair of materials, $\Delta\kappa$ denotes the fractional acceleration differences of the samples measured by EPF, and $\Delta(B/\mu)$ are the corresponding calculated ratios of baryon number-to-mass, where μ denotes the mass of each sample in units of the mass m_H of hydrogen. Additional details can be found in the above references.

To understand the background to this saga, it is necessary to give a short summary of the history of ELGI. In 1907 a new team was established within the framework of the Physical Institute of University of Budapest (now ELTE) under the name of "Eötvös' torsion balance measurements" which, after Eötvös' death is known world-wide as ELGI. Its personnel, until 1948, never exceeded 15–20 people. When the communist regime gained power, they declared that Hungary must become the "country of iron and steel" and, consequently, the importance and headcount of ELGI started increasing dramatically. In the mid-1960s the various departments of the Institute were scattered all over Budapest in rented premises, which made the coordination of research projects increasingly difficult. Finally, in 1965 the government decision was made to finance the building of a new centre for the Institute. Five years had elapsed between the planning and finishing of the building during which the headcount increased from 280 to approximately 610. When the time came to move into the new facility yet again there was no room for the proper storage of the archived material. Therefore, the boxes holding archived material were deposited in far from ideal rented storage facilities. During transport of the hundreds of boxes, Eötvös' autograph for the Beneke Prize must have slid out of its box, due to careless handling by the workers, and was scattered on the wet ground and trampled on. A conscientious worker must have picked up the scattered papers and stuffed them into another box containing field observations.

At the beginning of the 2000s geodesists proposed to use torsion-balance field data in detailed geoid studies, since significant parts of Hungary had been covered by 1–3 km station interval surveys. The project started with creating a digitised data bank from all field observations. In the course of handling the archived data, the long-lost Beneke autograph was discovered. The poor condition of the papers (fungal growths and wet footprints) required their complete conservation and restoration. This task was financed by the Eötvös Loránd Geophysical Foundation and carried out by the experts of the National Széchenyi Library. One can appraise their work by comparing the same page before and after cleaning (Fig. 3).

If we consider that generally after the publication of scientific papers the original manuscripts lose their further value, we can thank Pekár's extreme care in preserving all documents, and to pure luck, that the original autograph and data – although in a somewhat unorthodox manner – were preserved.

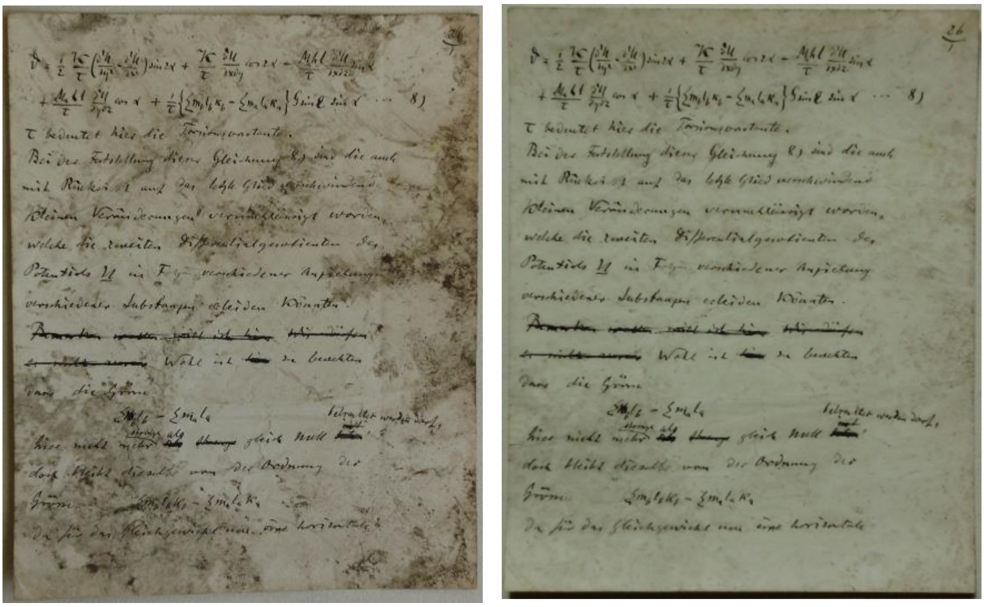

Fig. 3. One page of the Autograph before and after cleaning

Returning to the "5th Force" problem: up to the present, a generation of such experiments has failed to find compelling evidence for deviations from the predictions of Newtonian gravity that would be expected from the presence of a 5th force. Detailed discussions of these experiments, and of the phenomenology behind them, can be found in Fischbach et al. 1988 and Fischbach et al. 1999. Many physicists planned new, more sensitive versions of old experiments, and designed new ones to test for the presence of the 5th Force. It is thus possible that there exist other 5*th* force models capable of explaining the EPF data, while at the same time accommodating the null results obtained to date from modern experiments. Entertaining this possibility leads naturally to the question of whether some seemingly incidental features of the EPF experiment could be important in explaining their results.

The discovery of a hand-written draft (autograph) by Eötvös himself of what would become the published EPF paper sheds light on a number of questions and is thus of great historical importance. Although some pages of the autograph are missing, the overlap between the text we have and the published paper is quite large, so that it becomes both interesting and meaningful to compare the two. Among the differences there are two types: either the autograph contains more details or fewer. From the first type:

- In the autograph Eötvös presents a detailed discussion of the 1836 Guyòt experiment carried out at the Pantheon in Paris, which is completely missing from the published version. This experiment, which is described in some detail in Ref. [Fischbach et al. 1999, p. 127], clearly played a significant role for Eötvös if we are to judge by the space he devotes to it in his draft. Although Guyòt obtained what appeared to be a non-null result when comparing the direction of a plumb line to that of the normal to the surface of mercury, Eötvös eventually convinced himself that this resulted from "...the unevenly warmed and moving air." We can conjecture that Eötvös' analysis of the Guyòt experiment played a significant role in motivating the Eötvös design of his own experiment as discussed in the autograph. We note in passing that Eötvös' conclusion is supported by the observation that even if a new force arising from baryon number does exist, an idealized Guyòt experiment should still have obtained a null result. This follows from the observation that the test masses he was using, lead and mercury, are so close to each other in the periodic table that the difference in their B/μ values would have been so small as to be undetectable in his experiment.

- In Section 2. following Eqs. (9) and (10), the Eötvös draft contains a more extensive discussion of tidal effects than is present in the published version.
- In Section 3. Eötvös presents in his autograph a much more detailed description of his apparatus than is present in the published version. As noted above, of particular interest is his concern about the effects of temperature variations, an issue which became more prominent following the 1986 publication of Fischbach et al. Interestingly, neither the autograph nor the published version refers to the thermometers which were attached to their apparatus, presumably to monitor the ambient temperature.
- In the same discussion Eötvös notes that "*windowless chambers in basements*" would be the best, but none were available to them at the time. Thus "..*we had to be content with an observation room located at the entry hall of the laboratory available to us*…" We discuss the location problem in detail later.

- This section of the autograph contains additional information of potential historical interest relating to construction underway at the time, and the vibrations they produced. His concluding comments are quite interesting:

"*Although the results of observations show no significant influence of these disturbances, still we are very much aware that the observations presented here were not made under the most favourable conditions, also, they are not the best we believe are achievable with our instrument. But: 'Ars longa, vita brevis' – we have to content ourselves with having made a step forward*".

- The theme of time constraints appears several times. In Sec. 8. Eötvös writes: "*We did not have enough time to perform experiments that would fully satisfy ourselves, namely to build more perfect instruments*". The recurring references to time constraints – most probably referring to the deadline of the Beneke competition – and to the desire by EPF to build more perfect instruments, may explain the delay in submitting their work for publication cited by the authors in their introduction to the published paper. However, Eötvös himself states that his experimental results already improve on the previous results of Bessel by a factor more than 300. This leaves open the question of why this improvement was not sufficient to justify publication of his results at the time of completion of his experiment in 1909.
- It is also worth mentioning that in Section *9. Some experiments with radioactive substances*, the details of the observations are described by Eötvös himself, in contrast to the former ones. This reflects his deep interest in the new results of contemporary physics. The activity of their sample, 60 milliCuries, is sufficiently large that by today's stringent standards some care would be called for in handling this sample. No mention is made of any special steps taken in carrying out this phase of their experiment. This is not entirely surprising given that radioactivity had only been discovered a decade earlier, and its potentially harmful long-term effects were yet to be fully appreciated and understood. Maybe his fatal cancer a few years later originated from these experiments.

The second type of differences are those parts of the published version which do not appear in the Autograph. There are two types of these differences: a) Some Autograph pages have been lost. These pages are easily recognizable by both Eötvös' page numbering and the bulk of the text. b) There are long sections missing from the Autograph starting in Section *4. Observations and their analysis using the first method,* and cover three complete printed pages, containing the description of observations and their results. Section *5. Observations and their analysis using a second method* (with a longer title) starts in the Autograph without page numbering by Eötvös. After a short description of the mathematical-physical basis of this second method it stops at arriving to the description of the observations and their results covering more than three pages in the printed version. This pattern repeats itself in Section 6, with eight printed pages. We can conclude that Eötvös had been writing his text before the observations were completed (at one point he even used future tense), and these parts were written by Pekár and Fekete. As the original manuscript submitted to the Beneke Foundation cannot be found in either archive, we can only suppose that it contained long tables with all of the observation data which were abbreviated for the printed version, as they have written in the summary of the EPF paper.

The missing complete Section 7*. Observations along the meridian to determine the difference κ – κ' with regard to the attraction of the Sun*, raises quite a different question. In Section 2. we find: *Such experiments as these with the method of Eötvös,* *however, only give us information about the attraction of one single body, namely the Earth. Certainly, it is of interest to investigate whether or not the attraction of the Sun and the Moon, which do become perceptible in the phenomena of tide and direction variations of the plumb line, could also contribute to the clarification of the problem. In the following approximate treatise of the extremely complicated phenomena of tides we will answer this question.* (Autograph p. 27/23). Analysing the acting forces Eötvös concludes: *Let us assume that from the tidal phenomena one could determine the magnitude of the force −Z to about 1/100 of its value, then observations of the solar tide could reveal values of the coefficient κ that are larger than 10^{-6}, i.e. one millionth of unity. However, such a precise observation of an eventual 24-hour tidal wave corresponding to the attraction of the Sun is hard to imagine, if for no other reason than because it would be hard to separate it from the effects of solar radiation that occur with the same periodicity* (Autograph p. 32/28). It is not quite clear what he means, but probably he refers to gravity effects caused by temperature-change-induced deformations.

From the above text one can deduce that Eötvös thought that the method of determining the attraction of the Sun was not promising the necessary accuracy. There must have been a contradiction between Eötvös and Pekár on this question which casts some light on the relationship between them. In spite of being convinced that the method is not acceptable, Eötvös allowed his assistant to write a section about it independently of him.

The Eötvös experiment was followed in 1934 by an experiment undertaken by his student J. Renner [1935], who claimed to have achieved greater sensitivity than had been achieved earlier by EPF. Since Renner found no evidence for the composition-dependent effects reported by EPF, his results could have represented a serious challenge to the reanalysis of the EPF experiment in [Fischbach et al. 1986]. However, a subsequent analysis by RKD [Roll, Krotkov and Dicke 1964, Dicke 1961] of the Renner experiment found several inconsistencies in his methodology, which Renner himself acknowledged to RKD. The more recent experiments [Dicke 1961, Roll et al. 1964, Braginskii–Panov 1972], gave null results for acceleration differences to the Sun.

We turn next to the conclusion of the published paper which contains text not in the Eötvös autograph, specifically the table in Sec. 10 summarizing the EPF results. The significance of this table has been addressed previously in several papers [Fischbach et al. 1986, Fischbach et al. 1988, Franklin and Fischbach 2016]. It was noted in these references that in the published table the acceleration differences actually measured by EPF were combined in such a way as to produce an effective comparison of each sample (e.g. water) against Pt, even though Cu rather than Pt was the actual reference in most cases. The water–Pt comparison, for example, was obtained by writing

$$(\kappa_{water} - \kappa_{Cu}) + (\kappa_{Cu} - \kappa_{Pt}) = \kappa_{water} - \kappa_{Pt}$$

$$(-10 \pm 2)\cdot 10^{-9} + (4 \pm 2)\cdot 10^{-9} = (-6 \pm \sqrt{2^2 + 2^2}\,)\cdot 10^{-9} = (-6 \pm 3)\cdot 10^{-9}$$

The content of the previous equation is that by combining their actual measured results for $(\kappa_{water} - \kappa_{Cu})$, which is a 5σ effect, with $(\kappa_{Cu} - \kappa_{Pt})$, the water datum was reduced in significance to a smaller 2σ effect. Since this table is not in the Eötvös autograph, we are led to speculate that perhaps his co-authors may have summarized their data in the manner they did in order to avoid any suggestions that their results would conflict with the equivalence principle, which is at the heart of Einstein's (then successful) General Relativity, as noted above. If this was in fact the case, not only was GR influenced by the Eötvös experiment, but that experiment was itself influenced in turn by GR. But when criticising the interpretation of the EPF results, let us keep in mind what Nieto Hughes and Goldman wrote (1988): "*…neither the concept of baryon number, nor the mass defect existed at that time. Without these concepts, Eötvös could have spent considerable time and effort in a fruitless attempt to find out why the scatter in his data points was larger than his error estimates. We can easily sympathize and imagine the gnawing feeling that something was wrong, or that something very important was being missed*." Maybe this is the answer to our question: why did Eötvös not publish his results so outstanding in his time?

Let us return to the question of the location of the experiments. On pages 45/40 – 48/43 of the Autograph Eötvös describes it the following way: "*Observations with such delicate instruments should be made in a vibration-free environment which is also protected as much as possible from temperature variations, and especially from the effects of unilateral irradiation. Windowless chambers in basements would fit those conditions best. Unfortunately, no such chambers were available to us. Time was pressing so we had to be content with an observation room located at the entry hall of the laboratory available to us and had two windows looking South. However, buildings on the opposite side cast their shadow on these windows during most of the day, also, they were obstructed by rolling curtains, thus the room was kept dark all the time. For even more complete protection even within the room a separate housing was built for each instrument, whose walls consisted of canvas sheets stretched on double frames, and the space between was filled with fine sawdust and sewn like stitched blankets*.

Since the room where we made our observations lay away from street traffic initially, we had no reason to be worried about stronger vibrations, but unfortunately the circumstances deteriorated when a new construction was started in close vicinity during the observations. Although the results of observations show no significant influence of these disturbances, still we are very much aware that the observations presented here were not made under the most favourable conditions, also, they are not the best that we believe are achievable with our instrument."

Intriguingly, both paragraphs are left out from the printed version. At the same time, on page Abs. 15/78 of the Autograph about the location of the 1902 Absorption experiment, Eötvös writes the following: "*During our experiments the firm positioning of the apparatus in a basement room of uniform temperature provided adequate protection,...*"

In his paper: On the Gravitational Attraction of the Earth on Different Materials, published in 1890, and enclosed as the first document in our volume, Eötvös writes: "*I succeeded in this task in the undisturbed basement laboratory of the Institute of Physics, carrying out observations during the night and registering the state of equilibrium photographically*."

It remains an unanswered question why did he give up his formerly ideal basement laboratory? He was the director of the Institute of Physics, a highly esteemed scientist, and at the time of our story he was the president of the Hungarian

Academy of Sciences. Striving for an ideal laboratory as early as 1895, he wrote a letter to the Prime Minister asking for the basement of the Parliament building under construction to be relinquished for laboratory purposes: "… *the basement under the dome … the thick concrete layer underneath, the enormous dimensions and symmetrical layout of its walls make it an ideal location for the most sensitive and accurate physical, geodetical and meteorological experiments*." It is unnecessary to mention that his application ended in the dust bin of bureaucracy.

Let us try to find out where the actual observations were carried out. Bod et al. [1991] discuss this topic and provide architectural drawings of the building in question. Referring to personal communication to G. Marx, they write: "J. Barnóthy joined the Institute 5 years after the departure of Eötvös, and he firmly locates the site of the Eötvös–Pekár–Fekete experiment in a small annex at the SW end of the building (marked E_1 in the ground plan of Fig. 4), which now houses neutron generators. At Eötvös' time there was no building to the West. To the SW there was a temporary hole that was dug for future construction, to the East there is the huge complex of the Physics Institute with a strong concrete tower, about 20 meters NE. Below the experimental room there was no cellar but only soil, above it there was no floor. The torsion balances used in the experiment were mounted on stone piers (approximately one meter on a side) which were sunk deep into the ground. The purpose of these piers was to provide a stable shock-free platform for the sensitive balances, and a number of these are still visible today at the Atomic Physics Institute."

To resolve the contradictions a personal visit of the premises became necessary. The university campus in downtown Budapest, which in Eötvös' time accommodated the whole university except the Faculty of Law, at present belongs to the Faculty of Humanities. But in the time of Bod et al. [1991] the Faculty of Natural Sciences occupied the whole campus. The first and most startling experience of the "personal investigation" by the editor was provided by the small annex which houses at present the students' organization (see Fig. 6., the white building on the left). The youngsters were kind enough to show me around the building which, from the outside, looks more like a storing shed at a building site than an architect-designed part of a university laboratory building as seen on Eötvös' photo (Fig. 5). It is not connected to the main building and it has no brick facing, no tent-roof, and even its ground plan differs from the original one. Its windows are looking East and West and from the second room stairs are leading into a spacious basement hall, with at least 3.5 m height. My guides proudly showed me that the air extractor of their predecessors (the neutron generators) is still working with great noise. How could Bod et al. state that the building had no basement, unless it was excavated especially for the neutron generators?! It remains a mystery, as none of the Hungarian authors

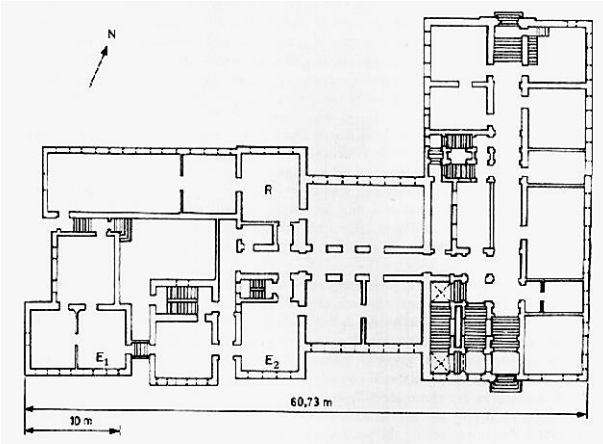

Fig. 4.
Ground plan of the Physics Departmen building built in 188

Fig. 5.
Eötvös' photo of the Physics Department building presumab taken from the rooftop of the main building. The windows o Eötvös' laboratory are partly screened by the opposite buildin The basement of the small anne in the front housed presumabl Eötvös's early experiments.

Fig. 6.
Present-day photo of the same building with the fou windows of Eötvös' laboratory in the front an the shed-like white annex its end. The supposed „ent hall" is behind the spruce The 4-story building on th left was built in the late 1930s.

of the cited paper are alive now. If Barnóthy was right, it is thus most probable that Eötvös' experiments of 1889 and his absorption experiments of 1902 were carried out in this basement laboratory.

The next and most important question that remains unanswered, is where the actual observations of 1907–08 were carried out? G. Barta, as retired professor of Geophysics still active at the time of the paper by Bod et al., told G. Marx – who enquired about the location of the Eötvös experiment – that Renner's laboratory, where he repeated the Eötvös experiment in 1934, was on the ground floor of the Physics building, on the northern side (marked by R in Fig 4). Renner complains in his paper [1935] that below the laboratory there was a cellar with a varying quantity of coal. Barta was not a university student at the time of Renner's experiment, and thus his recollections must have been based on hearsay. Still, we must suppose that between 1909 and 1934 the torsion-balance group (ELGI) could have relocated their laboratories from the southern to the northern side of the building, and the actual observations of the historical Eötvös experiment were carried out in a room on the southern side, marked by E_2 in the ground plan.

Finally, we feel that an evaluation of the Eötvös experiment with an overview of 100 years is necessary here. Perhaps the most significant measure of the continuing influence of Eötvös on contemporary physics is the impact his most famous experiment is having on current research. The elegant one-page paper by Lee and Yang [Lee and Yang 1955], which established the first limits on new long-range forces coupling to baryon number, used the EPF data. Interestingly, Lee and Yang had to temporarily set aside their work on the possibility of parity-violation in the weak interactions for which they received the Nobel Prize in 1957 [see also Franklin 2016, p.180]. Since the Lee-Yang paper was the direct motivation for the subsequent work of Fischbach, et al [1986], which led to the concept of a "5th force," it follows that much of the current interest in new long-range forces can be traced to the original EPF paper. Moreover, current attempts to reproduce the EPF data using torsion balances clearly depend on the advances Eötvös made, particularly leading to improvements in measuring the angle of the deflection of the torsion balance. It is thus clear that however the current searches for a 5th force turn out, interest in Eötvös' work will long endure.

Closing the *Historical Background,* we reach the present, 2019, the 100th anniversary of Eötvös' death. Browsing among the numerous commemorative programmes we find many institutions and individuals studying different sides of one of the basic problems of physics, namely the nature of gravitation; and for all of them the starting point is the Eötvös Experiment.

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