On the Gravitation Produced by the Earth on Different Substances

Loránd Eötvös

The presentation held at the Hungarian Academy of Sciences
on January 20, 1889

Abstract: This is a translation of the celebrated presentation held by Loránd Eötvös at the Hungarian Academy of Sciences on January 20, 1889. Here Eötvös discusses the historical foundations of his claim about the universal equality of inertial and passive-gravitational mass, and gives a survey of his own many-year experimental geophysical studies verifying the equivalence principle with high precision. The famous Eötvös experiment verifying the equivalence principle, first given in this short presentation, was cited many times by Albert Einstein as one of the basics to his General Theory of Relativity. Later the Eötvös experiment became a key point for all following experimental research verifying the equivalence principle, which are still continuing till now, with much increased measuerement precision. This short presentation was originally published in 1890, in the *Mathematical and Natural Science Proceedings of Hungary*, which were issued in German (the official language of the Austro-Hungarian Empire): Roland von Eötvös. Über die Anziehung der Erde auf verschiedene Substanzen. *Mathematische und Naturwissenschaftliche Berichte aus Ungarn*, 1890, Bd. 8, S. 65–68. In this translation we use the original Hungarian transcription of the name of the author instead the German version, Roland von Eötvös, printed in that journal. Translated from the German in 2008 by Larissa Borissova and Dmitri Rabounski. The translators thank Péter Király and Istvánné (Kati) Szalay of the Research Institute for Particle and Nuclear Physics, the Hungarian Academy of Sciences, for assistance with the original Eötvös paper.

Of the suppositions used by Newton as the foundations of his theory of gravitation, the most important is the one which claims that the gravitation produced by the Earth on an Earth-bound body is proportional to the mass of the body, and is independent of the structure of the substance composing it.

Newton has already verified this supposition of him by experiment. He was unsatisfied with the scholarly experiments, well-known to him, which revealed the fact that a feather and a coin fell equally fast in emptiness. Targeting this purpose, he used motions of a pendulum which could be registered with much precision. Once he made a pendulum, where the same-weight-bodies consisting of different substances such as gold, silver, lead, glass, sand, table salt, water, corn, and wood, were moving along the arcs of circle, each of which possessing the same radius, and where he registered the duration of the oscillation, he was able to conclude that there was no difference between them.

No doubt, those experiments produced by Newton were much more precise than the aforementioned scholarly experiments; on the other hand, the measurement precision of those experiments was only $^1/_{1,000}$, so they, strictly speaking, proved only the fact that the difference between the accelerations did not exceed $^1/_{1,000}$ of their numerical value. This measurement precision which he used in such an important problem could not be deemed satisfactory. Bessel therefore concluded that repetitions of such a classical experiment on a pendulum were necessary.

Proceeding from his measurements produced from the oscillation losses in gold, silver, lead, iron, zinc, brass, marble, clay, quartz, and meteorite substance, he had unambiguously proved that the gravitational accelerations of these bodies did not possess deviations larger than $^1/_{50,000}$ from each other. This however was insufficient as well. Bessel pointed out very well that it would always be very interesting to check the validity of this assumption with increasing precision provided by the permanently developing instruments of each of the future generations.

Such a research is desirable due to two reasons. First, this is due to the fact that Newton's supposition led to such a foundation, according to which we can find the mass of a body through its weight measured by a balance. It is required by the logic that the truth of this supposition should be proven upto at least such a precision, which can be reached in the weight, and this is much higher than $^1/_{50,000}$ part, even more than than $^1/_{1,000,000}$ part. Second, this is due to the fact that the research produced by Newton and Bessel covered only bodies whose material structure was similar to each other, and manifested a small difference, while this problem is still remaining open for many liquid and gaseous bodies. Proceeding from Bessel's experiments, we can conclude at most that the gravity of the air differs from that of a solid body no greater than $^1/_{50}$ part.*

Since in the process of my research of the gravity of mass my attention was turned towards this problem, and since I resolved it in an absolutely different way than Newton and Bessel did, and since I reached

*In the original manuscript in German here is a typing mistake "Tein fünfzigtausendstelt", i.e. 1/50,000, while it should obvious be "Tein fünfzigstelt", i.e. 1/50. It is doubtful that, on the most lightweight body of those in this research, the clay ground, the mass of the ousted air is more than almost 1/2,000 part. Thus, we obtain the measurement precision for the air much lesser than the mentioned due to the typing mistake, namely: $2{,}000 \times 1/50{,}000 = 1/25$. — Comment due to Pál Selényi, the corresponding member of the Hungarian Academy of Sciences, Budapest, who studied the original Eötvös papers in 1953.

much higher measurement precision than they had, I found the way of my considerations and the results of my experiment to be worthy of presentation to the respected Academy.

The force due to which the bodies located in the empty space fall onto the Earth, and which is known as gravity, is a sum of two components, namely — the gravitation of the Earth and the centrifugal force, which is due to the rotation of the Earth. These two components, in general, are neither equal to each other nor oppositely directed at each other; they create an angle with respect to each other, which is approximately the same as the angle of the geographical latitude. The direction of the resulting sum depends on these components; it is also clear that, at the same point on the Earth, since the centrifugal force of the same-mass-bodies is the same, the gravity of these bodies should be different if the force of gravitation attracting each of these bodies is different.

At Budapest the centrifugal force results in a deviation towards the South for approximately $5'56''$, i.e. $356''$ from the direction of the attraction of the Earth. We obtain by calculation that, if the attraction from the side of the Earth on two bodies of the same mass, but consisting of different substances, would differ as $^1/_{1,000}$ part, these two gravities were directed at an angle of $0.365''$ (that is approximately $^1/_{3}''$) with respect to each other, while if the difference in the force of gravity would be $^1/_{20,000,000}$ part, the angle was $^{356''}/_{20,000,000}$ that results a little more than $^1/_{60,000}''$.

The lead lot and the libelle* of the torsion balance are not enough sensitive to the very small deviation in the direction of the force of gravity, which is expected in this observation. However this torsion balance as a whole is applicable to such an observation very well, because I already registered small deviations in the direction of the force of gravity in other observations with it.

I fixed a body, the weight of which was approximately 30 g, at the end of the shoulder of the balance. The shoulder, the length of which varied from 25 to 50 cm, was suspended through a platinum thread. Once the shoulder was directed orthogonally towards the meridian, I registered its position relative to the box of the whole instrument precisely by a system

*Consider a mirror fixed to the torsion thread. The light beam falling onto it, then reflected, may swivel around the zero point of the scale. Specialists call this *die Libelle*, in German, that means a *dragon-fly* in English, because such two light beams, being swivelling, seems like the large wings of a dragon fly in flight. Relative to technics in general, *die Libelle* is the decisive part of a water-level. It is a small glass container filled with liquid and a gas bubble. The gas bubble indicates whether the water-level is exactly horizontal or not. — Editor's comment. D.R. (The editor is thankful to Ulrich Neumann, Germany, for discussion.)

of two mirrors, one of which was moved in common with the shoulder, while another one was fixed on the box. Then I turned out the whole instrument, in common with the box, at $180°$ in such a way that the body, located initially at the Eastern end of the shoulder, arrived at the Western end of it. Then I registered this new position of the shoulder relative to the instrument. If the gravity of the body at both sides was differently directed, a twist of the suspending thread appeared. At the same time, such an effect was not registered in the case where a brass ball was fixed at one end of the shoulder, while the other end was equipped with a glass, corkwood, or antimonite crystal; meanwhile the deviation of $1/60{,}000''$ in the direction of the force of gravity should yield a twist of $1'$, which is surely accessed.

Later I also studied, especially, this situation in the case of the air. A body moving in the air was acted by the force, caused by the ousted air. The force was equal to the gravity of the ousted air, but directed oppositely towards it. If the gravity of the air was directed similarly to that produced on the other bodies, this circumstance manifested itself as a twist of the thread in the aforementioned experiments. Of course, this twist was proportional to the weight of the ousted air, not the weight of the body in the air. In order to increase the aforementioned twist as much as possible, I fixed, at one end of the shoulder, an empty glass ball, whose volume was $120\,\mathrm{cm}^3$ volume, while its weight was $30\,\mathrm{g}$, so the drift of the air was approximately $1/200$ of the last one. All these had required much accuracy: the deviating effect of the air stream on the body of so large volume should be removed so that the shoulder was in the state of sure equilibrium. This task was realized only in the resting underground floor of the Institute of Physics of the Budapest University, at night and only due to the fact that I had registered the state of equilibrium by a photo camera.

I was unable to also consider the twisting in the fall. So my experiments, which are still 400 times more precise than those produced by Bessel, showed no difference from Newton's supposition.

I therefore have to claim by right that, in general, the difference between the gravity of the bodies, which have equal masses but consist of different substances, is lesser than $1/20{,}000{,}000$ in the case of brass, glass, antimonite, and corkwood, but it is undoubtedly less than $1/100{,}000$ in the case of air.

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