DETERMINATION OF THE GRAVITATIONAL CONSTANT G AT AN EFFECTIVE DISTANCE OF 125 m

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Abstract

In the plumb-line shaft in the dam of the Gigerwald-See, a pumped-storage lake 80 km south-east of Zurich, an experiment to measure the gravitational constant G at an effective distance of more than 100 m was started. The weight difference of two masses placed one above and one below the varying water level is measured with a mass-comparator. The goal is to measure in a first phase G with an accuracy of $< 1 \times 10^{-3}$. Together with the G-determination using a Cavendish type balance, the experiment will test the $1/r^2$ term in the gravitational law in the range of about 1 cm to 1 km.

Introduction

In recent years a great effort has been done to test the gravitational law [1]. These experiments can be separated in two groups: tests of the material dependence and tests of the distance dependence (inverse square law). The $1/r^2$ dependence has been tested with high accuracy ($\sim 10^{-8}$) at distances of $r > 10^7$ m [2]. On the other hand the gravitational constant G was only measured within laboratory distances $r \sim 10$ cm with a relative accuracy of $\simeq 1 \times 10^{-3}$. In the intermediate range (1 m to 1 km) it is very difficult to measure G [3,4] or to test the inverse square law [5,6,7,8,9,10] and only a few experiments were made in this region.

The proposed determination of G to $< 1 \times 10^{-3}$ at an effective distance of $r > 10^2$ m has a double importance, firstly only a few experiments are known that determine G with an accuracy of $< 10^{-3}$ [11], secondly the comparison with laboratory values of G can test the inverse square law of gravitation. Possible deviations of Newton's law could be interpreted by the existence of a fifth force [12] in the other case an upper limit could be found.

In this paper the experimental ideas are presented.

Description of the experiment

The easily accessible concrete dam of the Gigerwald-See has an overall height of 147 m and its crown is 360 m long. In addition to the regular water household the lake forms part of a hydroelectric storage system and is usually filled during the night using surplus electricity and emptied during day-time. The experiment is installed in the 110 m deep plumb-line shaft in the dam which is accessible on various levels (see figure. 1). The balance compares alternately the weight of a 1 kg mass near the balance with a second mass suspended on a 100 μm diameter gold-plated tungsten wire. The separation of the two test-masses is 105 m. The balance, a mass-comparator compares the weight of the two test-masses in the measuring process with an internal mass. The mass-comparator is a prototype, developed, made and maintained by 'Mettler', the producer of essentially all high precision balances used by national bureau of standards. The balance has been improved by two essential factors: it is operating in vacuum and it is temperature stabilized to 1 mK. In the laboratory the balance allows a reproducible comparison of two 1 kg masses within 0.1 μg. The two test-masses are interchanged hydraulically in such a way, that the force on the balance stays constant within 1 g. For this the output of the balance controls the hydraulic system with stepping motors. The weights are interchanged every 5 minutes.

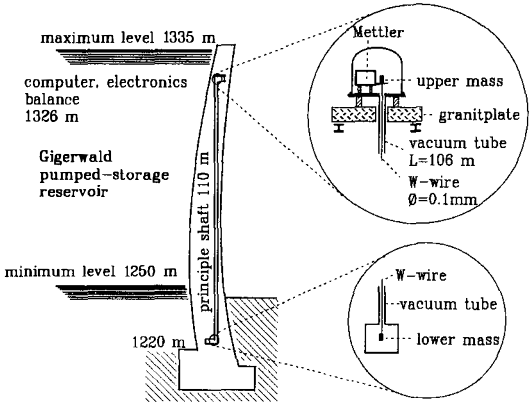

Figure 1: Cross-section through the dam. The mass-comparator and the 105 m long vacuum-system are indicated.

The oil free vacuum-system ($p \simeq 10^{-4}$ mbar) consist of a 105 m long 10 cm diameter stainless steel tube and the balance chamber.

The water level is measured with a pressure balance (resolution 2 cm). The distribution of the water is known as contour lines of the lake. The locations of the two weights in respect to the water were measured with an accuracy of 1 cm.

The expected weight changes as a function of the water level are shown in figure. 2. The

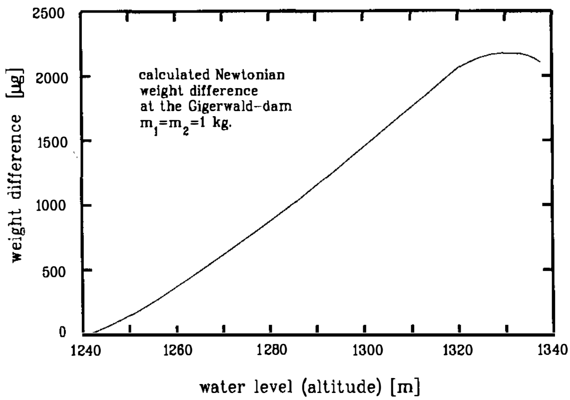

Figure 2: Calculated weight difference of the two 1 kg masses as a function of the water level above sea level.

weight difference is plotted as a function of the water level expressed in altitude of the water. The level variations of the Gigerwald lake are several meters per day and typically 10 m per week, the maximum variation is 85 m. The expected weight changes are about 1 mg. With the accuracy of the mass-comparator (< 1 μg) it should be possible to measure the gravitational constant at a level of 10^{-3}. This weight difference is only a function of geometrical data of the reservoir, every statical gravity anomalies and earth tides are cancelled. Only slow local variations of gravity due e.g. to snow are not completely eliminated in the measurements and must be taken into account.

The effective distance r_{eff} of the vertical force acting on one of the masses can be defined as:

$$r_{\text{eff}} = \frac{\int r dF_z}{\int dF_z} = \frac{\int z r^{-2} dm}{\int r^{-3} dm},$$

where r is the distance between one of the 1 kg masses and the mass of the water dm, the integrals are to be taken over the lake. The effective distance is a function of the water level, for the full lake r_{eff} is 136 m for the lower mass and 103 m for the upper one.

This experiment is to be compared with two other lake experiments: Splityard Creek [3] and Hornberg [4]. The Splityard Creek experiment was perfomed with a balance placed on a tower in the lake, they measured like us the weight difference between masses placed below and above the water. The measurements in the Hornberg experiment were made with 6 gravimeters, placed below and above the water level in a tower. These two lake experiments show measurements of G with an accuracy near 1 %. In both of them one limitation was the noise produced by the tower. In comparison the Gigerwald experiment is perfomed in a concrete dam, the entrance of the pressure-line is situated 300 m fom the mass-comparator, and the wind cannot cause serious vibrations of the dam. The limitation due to the calibration of the gravimeters (Hornberg) is eliminated by the use of a mass-comparator, which is regularly calibrated with a precision 1 g mass. The effective distance of more than 100 m is to be compared with the effective distance of 22 m for the Splityard Creek experiment and of 39 m and 68 m for the Hornberg experiment.

The experiment was started in autumn 1989, the installation will be terminated in early 1991, first results are expected in the second half of 1991.

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