1 Measurement of the Gravitational Constant G

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The principle of our experiment is shown in Fig. 1.1. Two cylindrical stainless steel vessels, each filled with 6.75×10^3 kg mercury (labelled field masses), are used to change the weight difference of two test masses. The field masses are hollow cylinders, which can be moved vertically between two positions. The two test masses are copper cylinders coated with a thin gold layer to avoid oxidation. Each has a total mass of 1100 g. Both test masses are suspended by two tungsten wires (0.1 mm diameter) on a device called mass exchanger. This device allows to connect the test masses alternately to the balance. First, the field masses are at position I and the weight of each test mass is determined repeatedly. The weight difference, which we call the signal, is calculated. After a few hours we move the field masses in position II. Again the weight difference is determined. This cycle is repeated throughout the total measurement period (typically a few months). The signal is modulated by the gravitational forces of the two field masses. The gravitational constant G can be calculated from the amplitude of this modulation (approximately 0.8 mg) and the known mass distribution. In order to calibrate the balance two 100 mg standard masses are put on the balance. Together with the precisely known value of the local gravity one can convert the reading of the balance into a force.

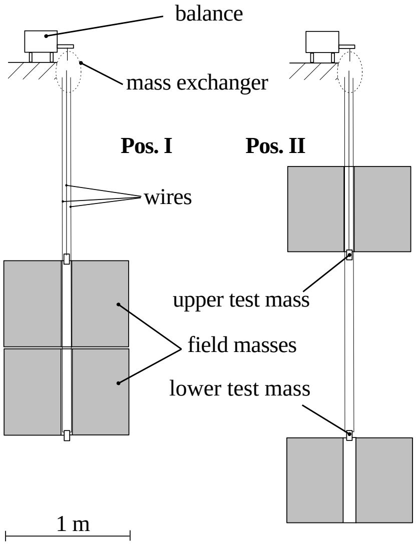

Figure 1.1: *The principle of the experiment. The two field masses are shown in the two positions I and II used for the measurements.*

The balance, a modified *Mettler-Toledo AT1006*, is a single pan beam balance. The total measuring range is 1.7 g with a resolution of 12.5 ng. To avoid disturbances caused by time delayed relaxation of mechanical stress in flexure strips of the balance, the load on the balance is kept constant during the exchange of the masses. The total load on the balance varies during the interchange by less than 100 mg. The whole weighing is performed in vacuum, to avoid errors due to buoyancy, convection and other gas pressure forces. For reasons of clarity the vacuum system is not shown in Fig. 1.1. A detailed description of our experiment is given in Ref.[1].

In 1998 a preliminary result of our measurements with a total relative uncertainty of 220×10^{-6} has been published[2]. The main problem of this measurement was a possible nonlinear response of the balance. For the required accuracy the calibration weights must

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[2] Deceased in the course of this work.

be much larger than our signal amplitude (0.8 mg). Considering a deviation from a strictly linear behaviour of the balance, a significant systematic error may result. To overcome this problem, we developed a method which can be used in situ and simultaneously. It is based on the fact that one only need to relate the average slope of the balance's response as determined by the calibration weights with the slope of the signal amplitude averaged over the calibration interval. This can be accomplished by placing a large number of small auxiliary masses on the balance while measuring G. These masses must be changed in approximately equal steps and over a range from zero to the value of the standard masses. Such a device operating in vacuum and under computer control has been built. It allows us to use two sets of 16 auxiliary masses each. By properly choosing the masses 256 steps are achieved.

A histogram of the signal amplitude is shown in Fig.1.2. The standard deviation of the measurements ranges between 200 ng and 400 ng, depending on the experimental conditions. This includes the noise of the balance and the nonlinearity. By averaging this 256 single measurements it is possible to reduce the effect of the nonlinearity to the ppm level.

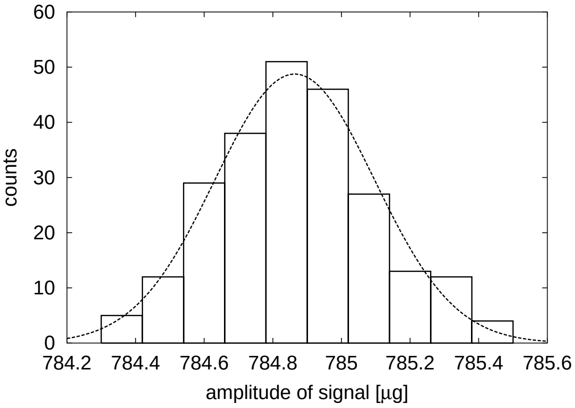

Figure 1.2: *Histogram of the signal amplitude measured over four days. For technical reasons only 237 of 256 possible operating points of the balance were included. The dashed line is a Gaussian distribution.*

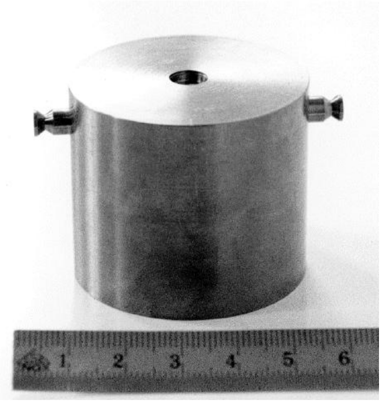

Figure 1.3: *The dimensions of the tantalum test mass are chosen such, that the gravitational quadrupole moment is minimised.*

We finished the measurements with the gold plated copper test masses and finally reached a statistical uncertainty of 7×10^{-6}. The calculation of the systematic uncertainty is still in progress. At present we are working on the mass integration and the estimation of the uncertainties. The integration of the test masses is relatively simple but has so far not been tested experimentally. In order to clarify this point, we install a second set of test masses made from tantalum ($\varrho = 16.6$ g/cm^3) (see Fig. 1.3). The high density allows us to choose a ratio between height and radius of the cylinders, such that the quadrupole moment of the test masses can be neglected.

We hope to have sufficient accurate measurements with the tantalum test masses during 2002. From the combined measurements of the tantalum and the copper test mass, the gravitational constant G will be calculated. This work is supported by the Swiss National Science Foundation and the Dr. Tomalla Foundation.

References

[1] J. Schurr *et al.*, Phys. Lett. A, **248** (1998), 295-308.

[2] F. Nolting, Dissertation, Uni. Zürich 1998.