# Universal Gravitation Constant: Measurement using a electronic version of the Cavendish torsion pendulum balance (draft)

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## I. Introduction:

Gravitational forces are of course quite familiar with their large magnitude as a consequence of the large mass of the Earth. In order to learn the proportionality factor between gravitational force and the masses of objects as proposed by Newton in 1687, it was necessary to measure the “universal” gravitational constant **G**. To determine this constant we must directly measure both the masses of the objects as well as the gravitational forces. Hence we need masses that are manageable in size and an apparatus that enables us to apply a force with them. Coulomb first constructed the torsion balance in 1784 for electrostatic measurements. Cavendish modified the apparatus in 1798 and used it for the first accurate measurement of the gravitational constant **G** using lead spheres. When Cavendish succeeded, obviously many years after Newton’s description of the theory of gravitation, he said he had “weighed the Earth”, since with **G** and the Earth’s radius makes it possible to estimate the mass of the earth. The order of magnitude of the Earth’s mass had been estimated by Newton, based on his estimate of the Earth’s density, so that Cavendish had a rough idea of the value and therefore knew how sensitive his instrument would have to be.

In this experiment you will use a modern recreation of the Cavendish apparatus to measure the universal gravitational constant. The apparatus is based on a “torsional pendulum”. A pair of weights on a hanger is hung on a slender wire; if the hanger is twisted slightly, it oscillates slowly back and forth. This same device can be used as a very sensitive “balance” and in the experiment the balance will be used to detect the small gravitational force due to two larger lead balls placed close to the weights on the hanger.

***To do this experiment you need to be extremely careful, be very calm and patient.***

## II. Configuration of the instrument

First read the Gravitational Torsion Balance Lab Manual and then these notes.

A Cavendish balance apparatus to generate small rotations, which create an electrical signal.
An interface to change and transfer the signals recorded in the balance into a computer
A computer with software to record and handle the data or a digital multimeter and notepad to record the data.

Since the measurement of G is sensitive to the environment you must be very careful during the whole experiment to minimize external influences. To get a sensible number of G, you’d better be prepared to repeat the experiment several times.

## III. NOTICE

- Two plastic plates are used to cut off the airflow and protect the tungsten wire from breaking. So do not remove them. If you have to do it, please consult an instructor.
- Do not take away the two big balls. If necessary, please take away or put the two balls at the same time, tenderly.

- Touch the table and the Cavendish set as little as possible and do not cause any vibrations on the table because even small vibrations will cause a large error or even ruin your experiment. Make sure the apparatus is placed on a rubber mat.
- Rotate the spindle very delicately to make small angle oscillations. Avoid having anything touch the plastic plates, especially the big balls when you rotate them.

In brief, you must be very careful when moving or adjusting the instrument.

**IV Objectives:**

- Learn the theory of damped simple harmonic oscillation and measure the motion of a damped torsional oscillator.
- Learn the theory of damped simple harmonic oscillation.
- Measure a gravitational torque using the balance, and estimate the universal gravitational constant G based on these measurements.

**V Operations:**

(a) Plug in the power of CAVENDISH SET.

(b) Calibration (please see instruction on the manual)
You must be very careful when you insert the pin into the hole.

(c) After calibration you can begin the process of measurement of G. Do the static and dynamic methods to measure the gravitational constant. Static way maybe is easier to realize, but the dynamic way can give you more accurate result.

<u>Static Method</u>:

Suppose the balance is at rest and there is no torque on the tungsten that means that there is no force on the balance so the balance is free of any force. Now the indicator on the computer (or digital voltmeter) is V= 0.0 Volt. Then you move the two big balls quickly to one extreme position. (Initially the two big balls are perpendicular to the glass and we assume there is no force acting on the two small balls.)
In this case the most serious problem is obtaining the equilibrium position; you have to allow the balance to oscillate freely and wait until it stops completely. It has a long time constant, so please be very patient.

<u>Dynamic method</u>:

There are detailed instructions in the manual about how to perform a dynamic measurement. Here as a reminder:
Notice the reaction of the wire is very slow so must be patient. For instance, if you adjust the spindle and want a rotation of the bar, you must wait after you adjust it, which will take several minutes. Carefully rotate the spindle so the wire twists and then the balance will rotate under the drive of this torque.

Before you rotate the big balls make sure to identify the direction of the oscillation because you must find the right direction so you can add the gravitational force on the oscillation. Maybe it is hard to observe the oscillation direction of the balance but this is important.

Hints:

Determine the oscillation period T of the balance. A good oscillation should have a relative stable period and stable change of the amplitude.

When the amplitude of the damped oscillation becomes very small (this means the gravitation force between the small and big balls can have a obvious effect on the oscillation) then you move the big balls just as the manual described.  Notice the measurement of the damping factor and the change in the amplitude due to the gravitational force should be noticeable in one oscillation.

Use the parameters provided in the manual to calculate the torque constant K.

You will get the free damped oscillation curve and the curve when the gravitational force has is acting. Calculate the damped factor x, the angle $\theta_D$.

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**When you leave, please do not forget to turn off the power and unplug the power.**