***Instruction Manual and Experiment Guide for the PASCO scientific Model SE-9633B***

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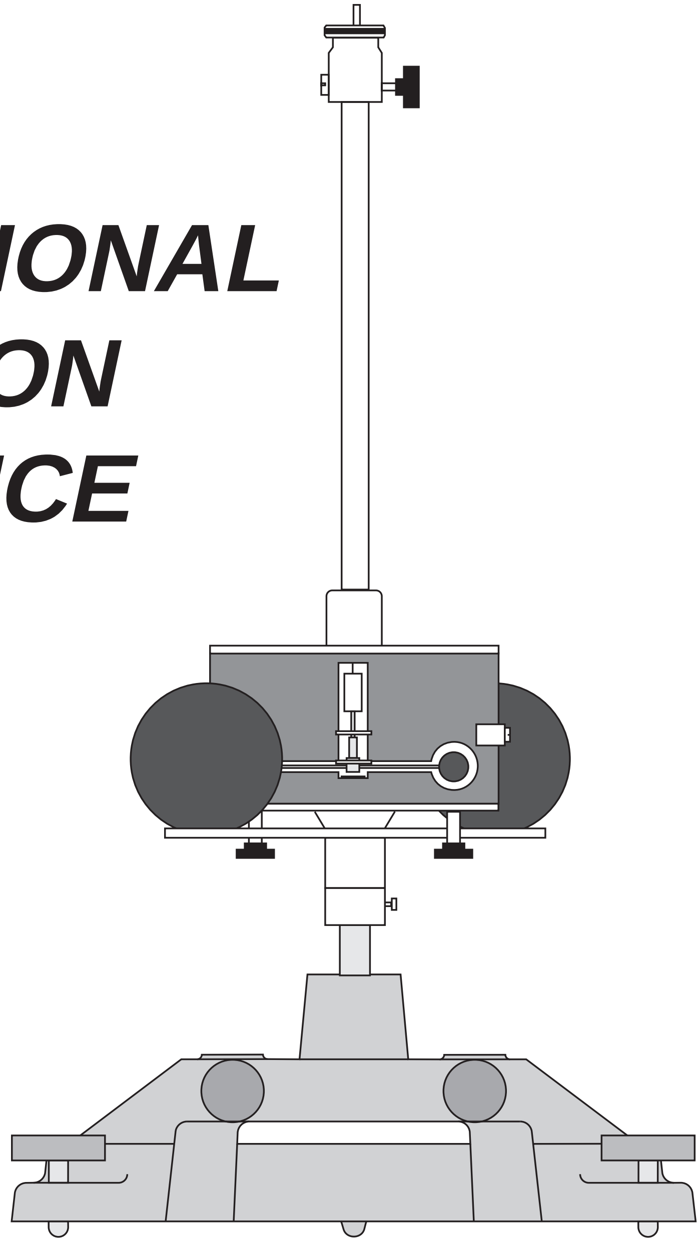
# GRAVITATIONAL TORSION BALANCE





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# Table of Contents

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# Introduction

The PASCO scientific SE-9633B Gravitational Torsion Balance reprises one of the great experiments in the history of physics—the measurement of the gravitational constant, as performed by Henry Cavendish in 1798.

The torsion balance (see Figure 1) consists of two 15 gram masses suspended from a highly sensitive torsion band, and two 1.5 kilogram masses that can be positioned as required. The torsion constant of the band is determined by observing the period of oscillation of the torsion balance, which is approximately 10 minutes. The large masses are then brought near the smaller masses and the gravitational force is measured by observing the twist of the torsion band.

To accurately measure the small twist of the band, an optical lever is used, consisting of a laser or other light source (not included) and a mirror affixed to the torsion band. Three methods of measurement are possible. The acceleration method requires only about 5 minutes of observation, and produces results accurate to within 15%. With an observation time of up to 45 minutes, the final-deflection method can be used, producing results that are accurate to within 10%. The method of equilibrium position requires the longest time of 90 plus minutes, but the results are accurate to within 5%.

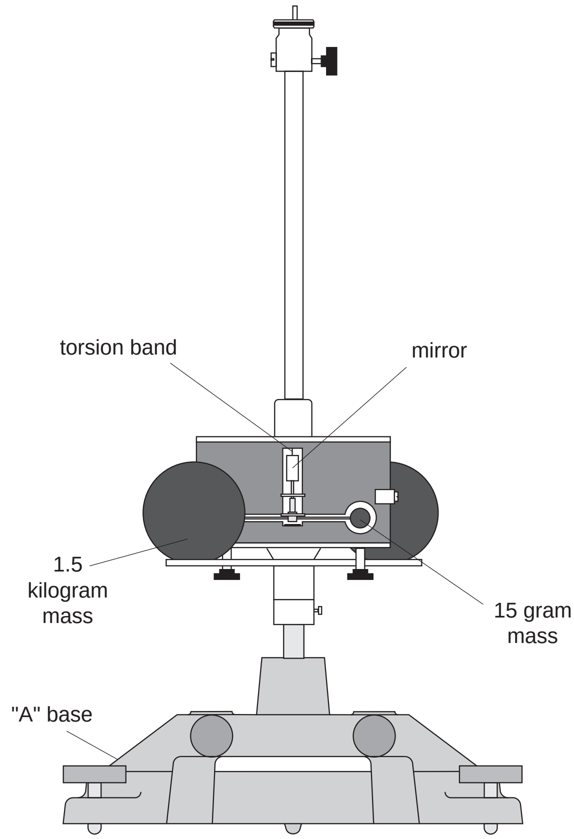



**Figure 1: The Gravitational Torsion Balance**

# A Little Background

The gravitational attraction of all objects toward the Earth is obvious. The gravitational attraction of every object to every other object, however, is anything but obvious. Despite the lack of direct evidence for any such attraction between everyday objects, Isaac Newton was able to deduce his law of universal gravitation:

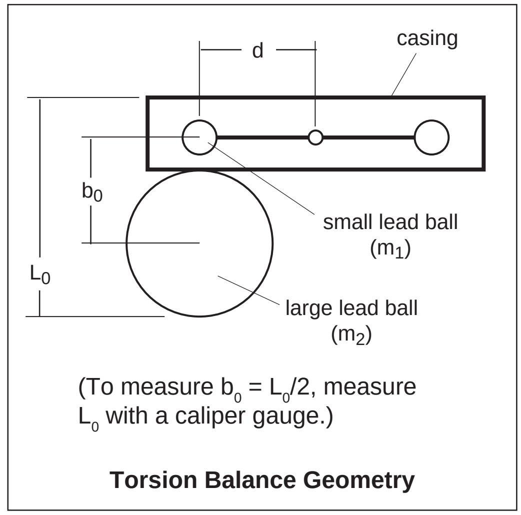
$$F = \frac{Gm_1m_2}{R^2}$$

where $m_1$ and $m_2$ are the masses of the objects, R is the distance between them, and G is a constant.

However, in Newton's time every measurable example of this gravitational force included the Earth as one of the masses. It was therefore impossible to measure the constant, G, without first knowing the mass of the Earth (or vice versa).

The answer to this problem came from Henry Cavendish in 1798, when he performed experiments with a torsion balance, measuring the gravitational attraction between relatively small objects in the laboratory. The value he determined for **G** allowed the mass and density of the Earth to be determined. Cavendish's experiment was so well constructed that it was a hundred years before more accurate measurements were made.

# Equipment



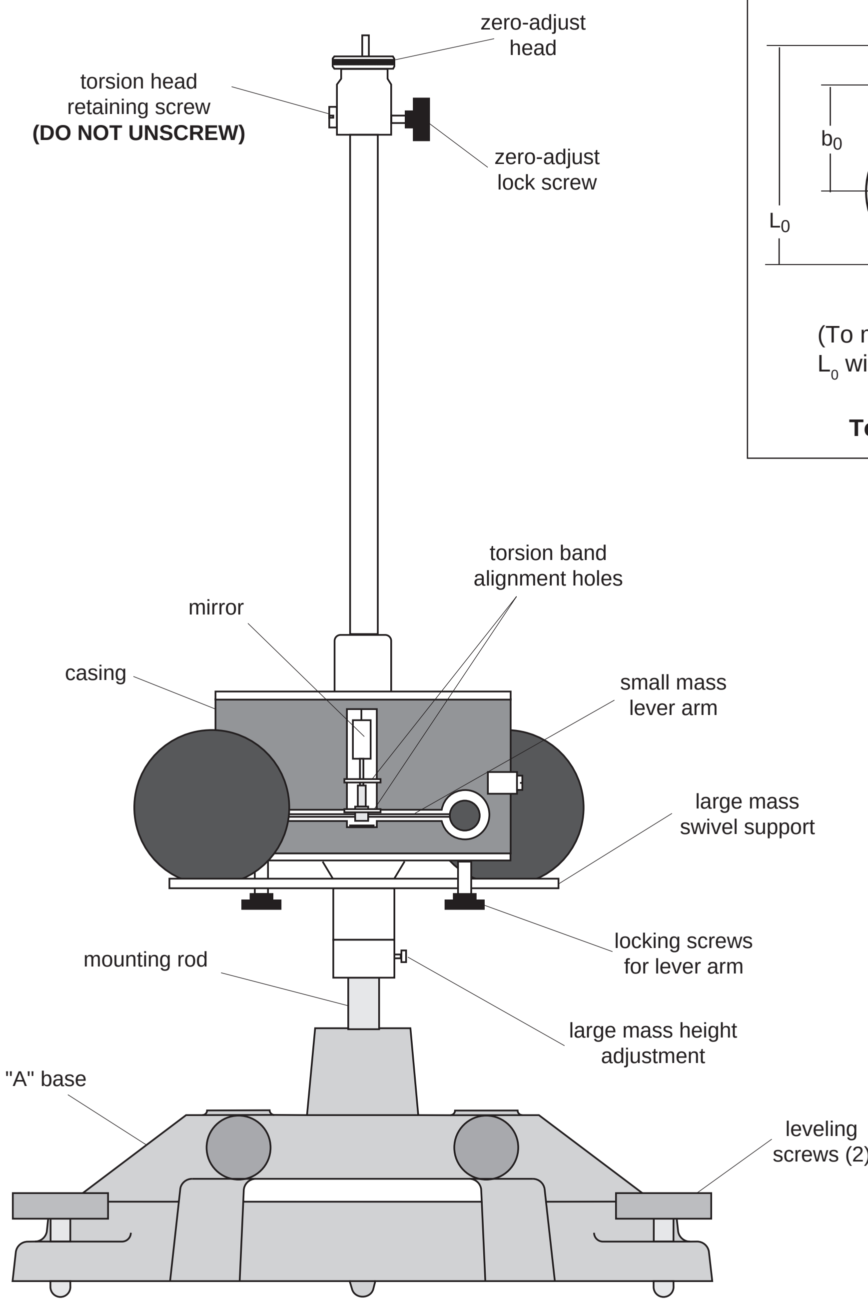




**Figure 2: Setting Up the Gravitational Torsion Balance**

## Equipment Parameters

**(see Figure 2 insert—Torsion Balance Geometry)**

- Small lead balls
  Mass: 0.015 kg ($m_2$)
  Radius: 7.5 mm
  Distance to torsion axis: d = 50 mm
- Large lead balls
  Mass: 1.5 kg ($m_1$)
  Radius: 32 mm
- Distance from the center of mass of the large ball to the center of mass of the small ball when the large ball is against the casing glass and the small ball is in the center position within the casing:
  b = 46.5 mm
- Period of Oscillation of System:
  T = approximately 10 minutes
- Logarithmic damping decrement:
  D = approximately 0.7
- Torsion Band
  Material: Bronze
  Length: 26 cm
  Cross-section: 0.01 mm x 0.15 mm
  Torsion Constant $8.5 * 10^{-9}$ N*m/rad

# Setup

**➤ IMPORTANT NOTES**

- The Gravitational Torsion Balance is a delicate instrument. We recommend you set it up in a relatively secure area where it is safe from accidents and from those who don’t fully appreciate delicate instruments.
- The first time you set up the torsion balance, do so in a place where you can leave it for at least one day before attempting measurements. This allows time for the slight elongation of the torsion band which will occur initially.
- Mount the torsion balance in a position so that the mirror on the torsion wire faces a wall or screen at least 5 meters away.

## Initial Setup

① Remove the "A" base from its box. Place the "A" base on a flat, stable table, and adjust the leveling screws until the tripod is approximately level.

② Carefully remove the torsion balance, the large mass swivel support and the height adjust collar from the box. Slide the swivel support on the mounting rod. Then slide the height adjust collar against the swivel support and secure it with the phillips head screw.

③ Insert the assembled mounting rod into the tripod and secure it in place with the other hinge-handled bolt.

④ Place the two 1.5 kg lead balls on the swivel support, as shown.

## Leveling the Torsion Balance

① Unlock the small mass lever arm by loosening the locking screws that are located at the bottom of the casing.

② Adjust the leveling screws of the "A" base until the torsion band is suspended precisely in the center axis of the torsion band alignment holes.

## Setting Up the Light Source

An optical lever is used to accurately measure the small angle of twist of the torsion band. The torsion balance is designed to be used with an incandescent light source, as the mirror mounted to the torsion wire is a spherical mirror with a 30 cm focal length. However, a laser can also be used.

To set up the light source and scale (see Figure 3):

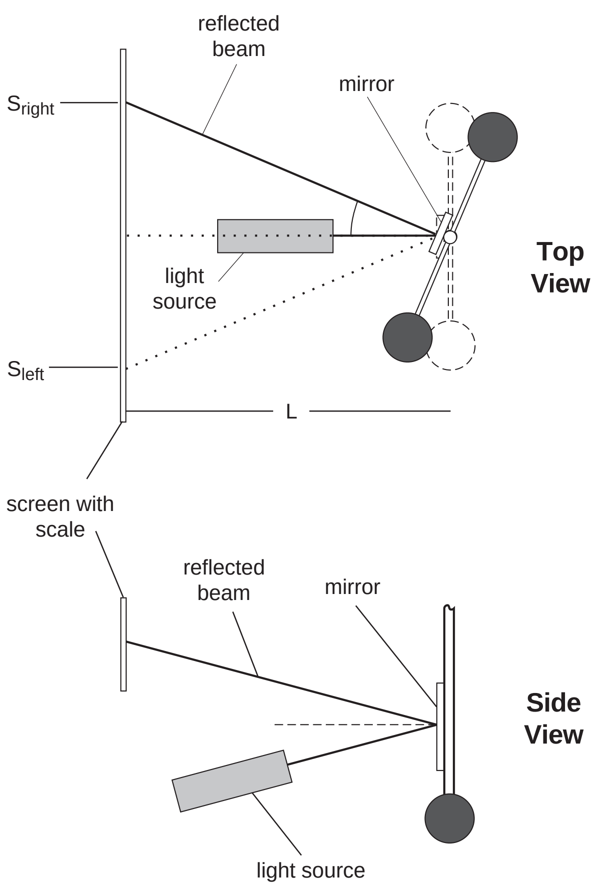



**Figure 3: Setting Up the Optical Lever**

**Using an Incandescent Light Source**

① Mount a metric scale on a wall at least 5 meters away from the torsion balance, facing the mirror.

② Stretch a thin thread over the aperture of your light source, to use as a focusing aid (a piece of tape half covering the aperture will also work).

③ Place the light source so the aperture is approximately 30 cm away from the mirror and so the light source is tilted up at an angle and pointing toward the mirror.

④ Adjust the distance and angle of the light source until you get a sharp image of the thread on the scale that you mounted on the wall.

**Using a Laser**

① Mount a metric scale on a wall at least 5 meters away from the torsion balance, facing the mirror.

② Point the laser so that it is tilted upward toward the mirror and so the spot is reflected onto your scale that is opposite the mirror. This will give good results, but the light spot will be enlarged by the spherical mirror. This will make accurate measurements somewhat more difficult then with a well focused spot.

OR

③ Use a convex lens to converge the laser beam to a point at the focal point of the suspended mirror. Shine the laser through the lens onto the mirror and adjust the distance of the lens from the mirror until the light spot is sharply focused on the scale.

## Zeroing the Torsion Band

After the torsion balance has been leveled:

① After setting up and leveling the torsion balance, and before zeroing the torsion band, leave the apparatus standing for at least one day with the small mass lever arm unlocked. The torsion band will elongate slightly during this period. If you zero the band before this elongation, you will probably have to rezero the band after a day or two.

② Remove the large lead balls.

③ First lock the small mass lever arm in place with the two locking thumbscrews, then unscrew the thumbscrews to release the lever arm and start the torsion balance oscillating.

④ Turn on the light source and watch the movement of the light spot. Note and mark the maximum points of deflection of the spot ($S_{right}$ and $S_{left}$). These limits of the motion are determined by the small lead balls striking the glass in the casing. The effective measuring range lies between $S_{right}$ and $S_{left}$.

⑤ Let the balance oscillate for several more minutes and observe the rest position the light spot tends toward as the system moves toward equilibrium. If this position deviates significantly from the midpoint of $S_{left}$ and $S_{right}$, loosen the zero-adjust lock screw, and turn the zero-adjust head through a small angle toward the desired zero point. Then retighten the zero-adjust lock screw.

⑥ Repeat step 5 until the equilibrium position of the light spot is near the midpoint between $S_{left}$ and $S_{right}$.

## Preparing for a Measurement

After setup, leveling, and zero adjustment, place the large lead balls on the swivel support. Move the support carefully until the large balls touch the casing wall. Leave the apparatus undisturbed with the small mass lever arm unlocked. In time, the light spot will come to rest. Leave the apparatus in this position. You're now ready to make a measurement using either the acceleration method, final-deflection method, or the equilibrium position method.

# Measuring the Gravitational Constant

## Overview of the Experiment

The gravitational attraction between a 15 gram mass and a 1.5 kg mass when their centers are separated by a distance of approximately 46.5 mm—this is the situation you will be investigating with the torsion balance—is about $7 \times 10^{-10}$ newtons. If this doesn't seem like a small quantity to measure, consider that the weight of the small mass is more than two hundred million times this amount.

The enormous strength of the Earth's attraction for the small masses, in comparison with their attraction for the large masses, is what originally made the measurement of the gravitational constant such a difficult task. The torsion balance (invented by Charles Coulomb) provides a means of negating the otherwise overwhelming effects of the Earth's attraction in this experiment. It also provides a force delicate enough to balance the tiny gravitational force that exists between the large and small masses. This force is provided by twisting a very thin bronze wire.

The large masses are first arranged in Position I, as shown in Figure 4, and the balance is allowed to come to equilibrium. The swivel support that holds the large masses is then rotated, so the large masses are moved to Position II. This forces the system into disequilibrium. The resulting oscillatory rotation of the system is then observed by watching the movement of the light spot on the scale, as the light beam is deflected by the mirror.

Any of three methods can be used to determine the gravitational constant, G, from the motion of the small masses. Using Method I, the final deflection method, the motion is observed for about 45 minutes, and the result is accurate to within approximately 10%. In method II the experiment takes 90 minutes or more and produces an accuracy of 5%. Using Method III, the acceleration method, the motion is observed for only 5 minutes, and the result is accurate only to within approximately 15%.

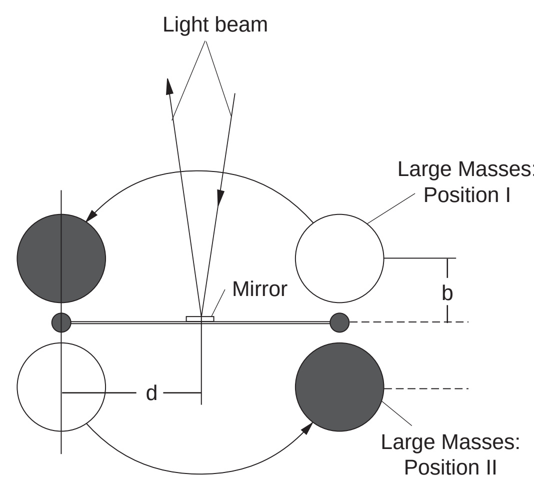



**Figure 4: Diagram of the Setup**

## *METHOD I: Measurement by Final Deflection*

Observation Time ≈ 45 minutes

Accuracy ≈ 10%

➤ **IMPORTANT—Pre-Lab Preparation:**

① Before performing this experiment, the torsion balance should be set up, leveled, and zeroed, as described in the previous section.

② At least a few hours before the experiment, the large masses should be placed on the swivel support, and the support should be rotated so the masses are in Position I (Figure 4), with the large masses touching the glass walls of the casing. The small mass lever arm should be unlocked, so that the torsion balance can freely come to equilibrium.

### Theory

With the large masses in Position I (Figure 4), the gravitational attraction, **F**, between each small mass ($m_2$) and its neighboring large mass ($m_1$) is given by the law of universal gravitation:

$$F = Gm_1m_2/b^2. \qquad (1.1)$$

This force exerts a torque ($\tau_{grav}$) on the system:

$$\tau_{grav} = 2Fd. \qquad (1.2)$$

Since the system is in equilibrium, the twisted torsion band must be supplying an equal and opposite torque. This torque ($\tau_{band}$) is equal to the torsion constant for the band ($\kappa$) times the angle through which it is twisted ($\theta$), or:

$$\tau_{band} = -\kappa\theta. \qquad (1.3)$$

Combining equations 1.1, 1.2, and 1.3, and taking into account that $\tau_{grav} = -\tau_{band}$, gives:

$$\kappa\theta = 2dGm_1m_2/b^2.$$

Rearranging this equation gives an expression for G:

$$G = \frac{\kappa\theta b^2}{2dm_1m_2} \qquad (1.4)$$

To determine the values of $\theta$ and $\kappa$ — the only unknowns in equation 1.4 — it is necessary to observe the oscillations of the small mass system when the equilibrium is disturbed. This is done by rotating the swivel support so the large masses are moved to Position II. The system will then oscillate until it finally slows down and comes to rest at a new equilibrium position. A graph of this motion is shown in Figure 5. The position of the small mass system is indicated by **S**, the position of the light beam on the scale.

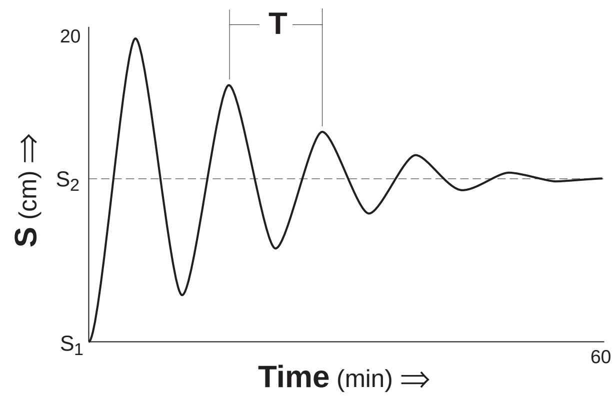



**Figure 5: Graph of Small Mass Oscillations**

At the new equilibrium position $S_2$, the torsion wire will still be twisted through an angle $\theta$, but in the opposite direction of its twist in Position I, so the total change in angle is equal to $2\theta$. Taking into account that the angle is also doubled upon reflection from the mirror (see Figure 6):

$$\Delta S = S_2 - S_1,$$

$$4\theta = \Delta S/L, \qquad \text{or}$$

$$\theta = \Delta S/4L. \qquad (1.5)$$

The torsion constant can be determined by observing the period (T) of the oscillations, and then using the equation:

$$T^2 = 4\pi^2 I/\kappa; \qquad (1.6)$$

where **I** is the moment of inertia of the small mass system. The moment of inertia for the mirror and support system for the small masses is negligibly small compared to that of the masses themselves, so the total inertia can be expressed as:

$$I = 2m_2d^2. \qquad (1.7)$$

Therefore:

$$\kappa = 8\pi^2m_2d^2/T^2. \qquad (1.8)$$

Substituting equations 1.5 and 1.8 into equation 1.4 gives:

$$G = \frac{\pi^2 \Delta S\, db^2}{T^2 m_1 L} \qquad (1.9)$$

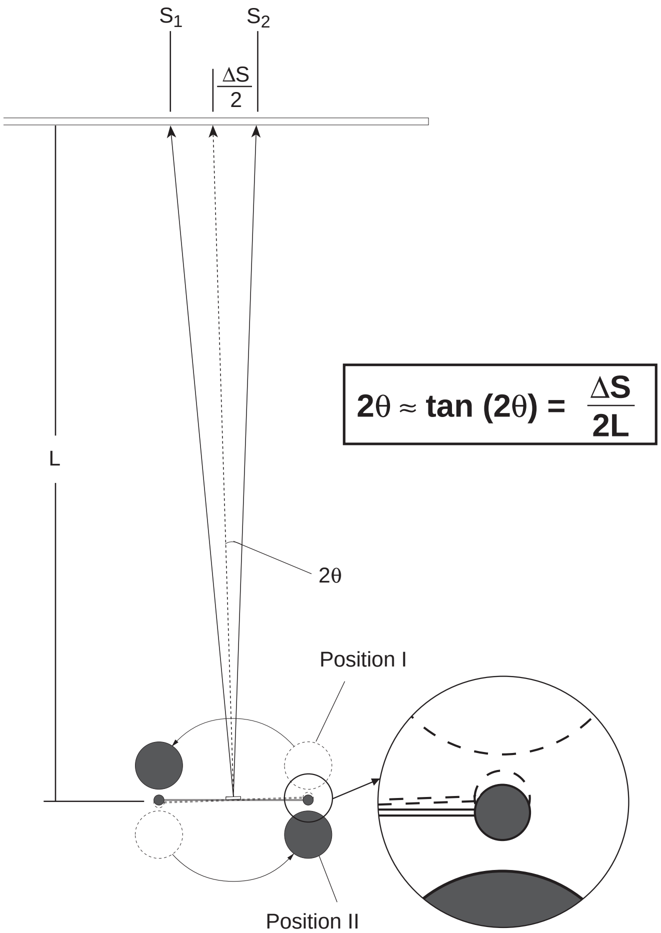



**Figure 6: Diagram of the Experiment**

All the variables on the right side of equation 1.9 are known or measurable.

$d = 50$ mm

$b = 46.5$ mm

$m_1 = 1.5$ kg

$L$ = (Measure as in Figure 6)

By measuring the total deflection of the light spot ($\Delta S$) and the period of oscillation (T), the value of G can therefore be determined.

## Procedure

① To begin, the masses should be arranged in Position I (Figure 4), the balance should be leveled and zeroed, and the small masses should be at equilibrium.

② Turn on the light source and observe the zero point of the balance for several minutes to be sure the system is at equilibrium. Record the zero point ($S_1$) as accurately as possible, and indicate any variation over time as part of your margin of error in the measurement.

③ Rotate the swivel support so that the large masses are moved to Position II. Move the support carefully. The spheres should be touching the glass case, but take care not to knock the case, which would disturb the system.

④ Immediately after rotating the swivel support, observe the light spot. Record the position of the light spot (S) and the time (t) every 15 seconds for the first few minutes and then every 30 or 60 seconds. Continue recording the position and time for about 45 minutes, or until the oscillations have stopped.

## Analysis

① Construct a graph of light spot position versus time, with time on the horizontal axis, as in Figure 5.

② From your data, measure $\Delta S$, the change in position of the light spot from its initial position ($S_1$) to its position ($S_2$).

③ From your graph, measure the period (T) of the oscillations of the small mass system. For best results, determine the average value of T over several oscillations.

④ Use your results and equation 1.9 to determine the value of G.

⑤ The value calculated in step 4 is subject to the following systematic error. The small sphere is attracted not only to its neighboring large sphere, but also to the more distant large sphere, though with a much smaller force. The geometry for this second force is shown in Figure 7 (the vector arrows shown are not proportional to the actual forces).

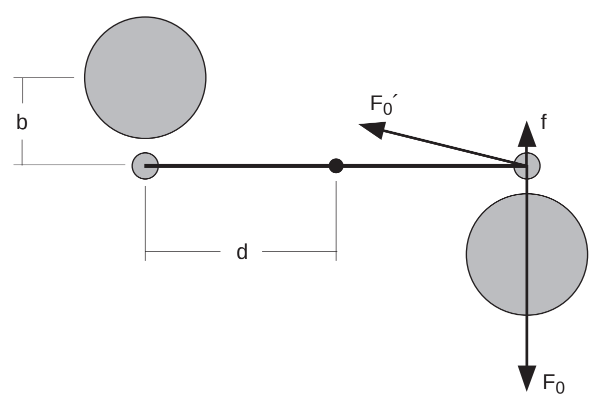



**Figure 7: Correcting the Measure Value of G**

The force, $\mathbf{F}_0$ is given by the gravitational law, which translates, in this case, to:

$$F_0 = \frac{Gm_2m_1}{(b^2+4d^2)}$$

and has a component $f$ that is opposite to the direction of the force $\mathbf{F}_0$:

$$f = \frac{Gm_2m_1b}{(b^2+4d^2)\,(b^2+4d^2)^{\frac{1}{2}}} = \beta F_0$$

This equation defines a dimensionless parameter, β, that is equal to the ratio of the magnitude of $f$ to that of $\mathbf{F_0}$. Using the equation $F_0 = Gm_1m_2/b^2$, it can be determined that:

$$\beta = b^3/(b^2 + 4d^2)^{3/2}. \qquad (1.10)$$

From Figure 7 ,

$$\boldsymbol{F = F_0 - f = F_0 - \beta F_0 = F_0(1 - \beta)},$$

where **F** is the value of the force acting on each small sphere from *both* large masses, and $\mathbf{F_0}$ is the force of attraction to the nearest large mass only. Similarly,

$$G = G_0(1 - \beta),$$

where G is your experimentally determined value for the gravitational constant, and $G_0$ is corrected to account for the systematic error. Finally,

$$G_0 = G/(1 - \beta).$$

Use this equation with equation 1.10 to adjust your measured value.

## METHOD II: Measurement by Equilibrium Positions

Observation Time = 90+ minutes

Accuracy = 5 %

➤ **IMPORTANT — Pre-Lab Preparation:**

① Before performing this experiment, the torsion balance should be set up, leveled, and zeroed, as described in the previous section.

② At least a few hours before the experiment, the large masses should be placed on the swivel support, and the support should be rotated so the masses are in Position I (Figure 4), with the large masses touching the glass walls of the casing. The small mass lever arm should be unlocked, so that the torsion balance can freely come to equilibrium.

## Theory

When the large masses are placed on the swivel support and moved to either Position I or Position II, the torsion balance oscillates for a time before coming to rest at a new equilibrium position. This oscillation can be described by a damped sine wave with an offset, where the value of the offset represents the equilibrium point for the balance. By finding the equilibrium point for both Position I and Position II and taking the difference, the value of ΔS can be obtained. This method of determining ΔS is more accurate than Method I because it does not rely on the assumption that the light spot is at rest when its initial position is recorded. The remainder of the theory is identical to that described in Method I.

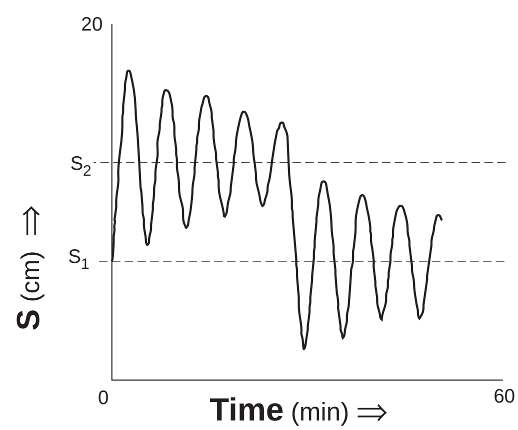



**Figure 8: Graph of Small Mass Oscillations**

## Procedure

① To begin, the masses should be arranged in Position I (Figure 4), the balance should be leveled and zeroed, and the small masses should be at equilibrium.

② Turn on the light source.

③ Rotate the swivel support so that the large masses are moved to Position II. Move the support carefully. The spheres should be touching the glass case, but take care not to knock the case, which would disturb the system.

④ Immediately after rotating the swivel support, observe the light spot. Record the position of the light spot (S) and the time (t) every 15 seconds. Continue recording the position and time for about 45 minutes.

⑤ Rotate the swivel support to Position I. Repeat the procedure described in Step 4. Although it is not imperative that this step be performed immediately after Step 4, it is a good idea to proceed with it as soon as possible in order to minimize the risk that the system will be disturbed between the two measurements. Waiting more than a day to perform Step 5 is not advised.

## Analysis

① Construct a graph of light spot position versus time for both Position I and Position II. You will now have two graphs similar to Figure 5, or one graph similar to Figure 8.

② Find the equilibrium point for each configuration by analyzing the corresponding graphs (the equilibrium point will be the center line about which the oscillation occurs). Find the difference between the two equilibrium positions and record the result as ΔS.

③ Determine the period of the oscillations of the small mass system by analyzing the two graphs. Each graph will produce a slightly different result. Average these results and record the answer as T.

④ Use your results and equation 1.9 to determine the value of G.

⑤ The value calculated in Step 4 is subject to the same systematic error as described in Method I. Perform the correction procedure described in that section to find the value of $G_0$

## *METHOD III: Measurement by Acceleration*

Observation Time ≈ 5 minutes

Accuracy ≈ 15%

➤ **IMPORTANT—Pre-Lab Preparation:**

① Before performing this experiment, the torsion balance should be set up, leveled, and zeroed, as described in the previous section.

② At least a few hours before the experiment, the large masses should be placed on the swivel support, and arranged in Position I (see Figure 4). The large masses should be touching the glass walls of the casing, and the small mass lever arm should be unlocked, so that the torsion balance can freely come to equilibrium.

### Theory

With the large masses in Position I (see Figure 4), the gravitational attraction, **F**, between each small mass ($m_2$) and its neighboring large mass ($m_1$) is given by the law of universal gravitation:

$$\boldsymbol{F} = Gm_1m_2/b^2. \qquad (3.1)$$

This force is balanced by a torque from the twisted torsion band, so that the system is in equilibrium. The angle of twist, θ, is measured by noting the position of the light spot where the reflected beam strikes the scale. This position is carefully noted, then the large spheres are moved to Position II, as shown in the figure. This disturbs the equilibrium of the system, which will now oscillate until friction slows it down and a new equilibrium position is found.

Since the period of oscillation of the small masses is long (approximately 10 minutes), they do not move significantly when the large masses are first moved from Position I to Position II. Because of the symmetry of the setup, the large masses exert the same gravitational force on the small masses as they did in Position I, but now in the opposite direction. Since the equilibrating force from the torsion band has not changed, the total force ($\mathbf{F}_{total}$) that is now acting to accelerate the small masses is equal to twice the original gravitational force from the large masses, or:

$$\boldsymbol{F}_{total} = 2\boldsymbol{F} = 2Gm_1m_2/b^2. \qquad (3.2)$$

Each small sphere is therefore accelerated toward its neighboring large sphere, with an initial acceleration ($a_0$) that is expressed in the equation:

$$m_2\mathbf{a}_0 = 2Gm_1m_2/b^2. \qquad (3.3)$$

Of course, as the masses begin to move, the torsion wire becomes more and more relaxed so that the force decreases and this acceleration is reduced. If the system is observed over a relatively long period of time, as in Method I, it will be seen to oscillate. If, however, the acceleration of the small masses can be measured before the torque from the torsion band changes appreciably, equation 3.3 can be used to determine G. Given the nature of the motion—damped harmonic—the initial acceleration is constant to within about 5% in the first one tenth of an oscillation. Reasonably good results can therefore be obtained if the acceleration is measured in the first minute after rearranging the large masses, and:

$$G = b^2 a_0 / 2m_1 \qquad (3.4)$$

The acceleration is measured by observing the displacement of the light spot on the screen. If, as is shown in Figure 6:

- $\Delta s$ = the linear displacement of the small spheres,
- d = the distance from the center of mass of the small spheres to the axis of rotation of the torsion balance,
- $\Delta S$ = the displacement of the light spot on the screen, and
- L = the distance of the scale from the mirror of the balance,

then, taking into account the doubling of the angle on reflection,

$$\Delta S = \Delta s(2L/d). \qquad (3.5)$$

Using the equation of motion for an object with a constant acceleration ($x = 1/2\ at^2$), the acceleration can be calculated:

$$\boldsymbol{a}_0 = 2\Delta s/t^2 = \Delta Sd/t^2 L. \qquad (3.6)$$

By monitoring the motion of the light spot over time, the acceleration can be determined using equation 3.5 and 3.6, and the gravitational constant can then be determined using equation 3.4.

## Procedure

① To begin, the masses should be arranged in Position I (Figure 4) The balance should be leveled and zeroed, and the small masses should be at equilibrium.

② Turn on the light source and record the zero point of the light spot ($S_1$) as accurately as possible. Observe it for several minutes to see if there is any initial drift of the spot.

③ Rotate the swivel support so that the large masses are moved to Position II. Move the support carefully. The spheres should be touching the glass case, but take care not to knock the case, which could disturb the system.

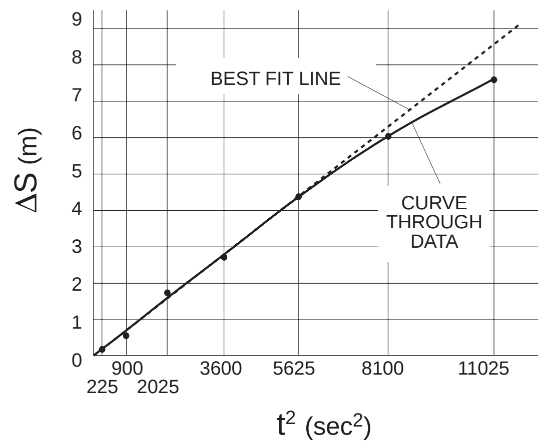



**Figure 9 Graph – Light Spot Displacement Vs Time Squared**

④ Immediately after rotating the swivel support, observe the light spot. Record the position of the light spot (S) and the time (t) every 15 seconds for about two minutes.

## Analysis

① Construct a graph of light spot displacement ($\Delta S = S - S_1$) versus time squared ($t^2$), with $t^2$ on the horizontal axis (see Figure 9). Draw a best-fit line through the observed data points over the first minute of observation.

② Determine the slope of your best-fit line.

③ Use equations 3.4, 3.5, and 3.6 to determine the gravitational constant.

④ The value calculated in step 3 is subject to a systematic error. The small sphere is attracted not only to its neighboring large sphere, but also to the more distant large sphere, although with a much smaller force. The geometry for this second force is shown in Figure 7 (the vector arrows are not proportional to the actual forces).

You can correct for this error using the procedure that is described in step ⑤ of the analysis for Method I.

# Replacing the Torsion Band

## Materials Needed

- Single-edged razor blade
- Scissors
- Forceps, curved tip preferred
- Needle nose pliers
- 2-lock jaw pliers (10")
- Plastic electrical tape
- Sticky-back aluminum tape, cut in 1/4" strips
- Jeweler's screwdriver
- Ruler
- Lens tissue
- Leybold part #68320 (or equivalent) bronze band (0.01 x 0.15 mm flat wire)

➧ **IMPORTANT NOTE:** If the torsion band on your gravitational balance breaks, we recommend that you call PASCO scientific and arrange to return the apparatus to us for repair. However, if you prefer to replace the band yourself, follow the following procedure.

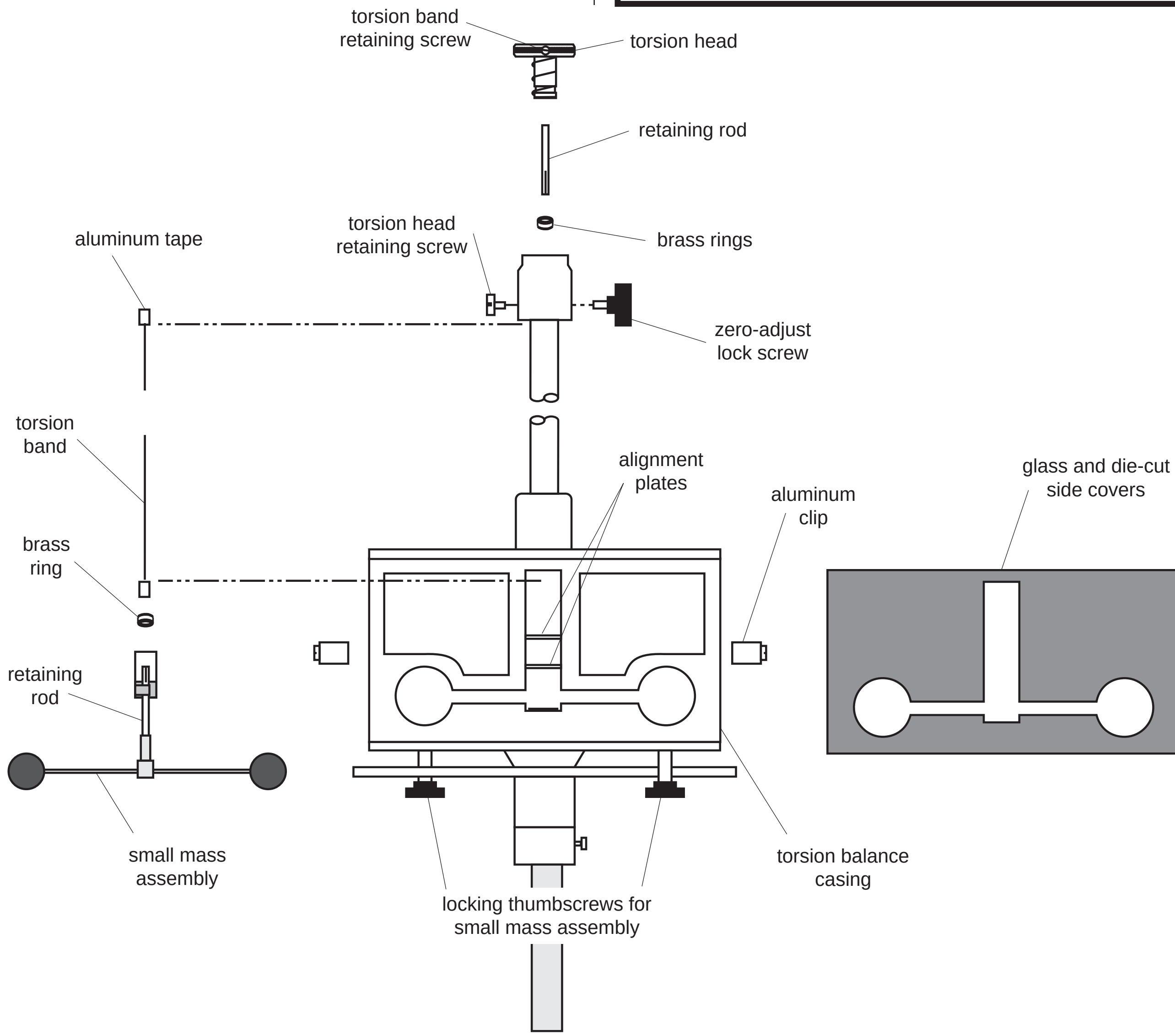



**Figure 10 Replacing the Torsion Band**

## Procedure

① Using the plastic electrical tape, tape the tips of the lock-jaw pliers so they won't mar the delicate brass rings used in the unit.

② Measure the approximate distance from the bottom of the torsion head casing to the top end of the retaining rod at the mirror end of the band (L, in Figure 9). Note this distance as the length of the new torsion band.

③ Remove the torsion balance from the "A" base and lay it carefully on its side.

④ Remove the torsion head as follows:

> ➧ **IMPORTANT:** If for some reason you are removing the torsion head and the torsion band is not broken, be careful. The delicate band is easily broken. Be sure that you perform step a, below, before step c. The torsion head is spring loaded with sufficient tension to break the torsion band when it is released.

a. Loosen the torsion band retaining screw, until the retaining rod slides freely (do not pull on it).

b. Loosen the zero-adjust lock screw.

c. Loosen the torsion head retaining screw.

(**CAUTION —** The torsion head is spring-loaded. Hold on to it carefully as you loosen the retaining screw.)

⑤ Using the taped pliers from step 1, carefully remove the brass ring from around the retaining rod. Be careful not to damage the ring.

⑥ Remove the aluminum clips on the side of the torsion balance casing and remove the glass sides.

⑦ Remove the small mass assembly (you will need to slide the two plastic alignment plates out of their slots to remove the assembly). Carefully remove the brass ring from the retaining rod, as in step 5.

⑧ Take one 1/4" strip of aluminum tape and adhere it to one end of the bronze band (with the band still on the spool). Fold the tape onto itself, sticky side to sticky side. Measure out the amount of bronze band needed (from step 2), stick another piece of aluminum tape to this end, and fold the aluminum tape over onto itself.

> ➧ **IMPORTANT:** Be very careful not to kink the torsion band.

⑨ Cut the torsion band so the aluminum tape is at both ends. Trim the tape ends so they are no wider than the inside diameter of the brass rings that you removed from the retaining rods. (The tape should be about 2 mm wide by 1 cm in length.)

⑩ Clean out the slots of the retaining rods with the single sided razor blade. The razor blade can also be used to widen the gap of the slot so the tape will fit in. Just be sure that the gap is not so wide that the brass ring will not fit over the rod. (Notice that the brass rings only fit over the rods in one direction.)

For both ends of the torsion band, insert the end of the band through the brass ring and into the slot in the retaining rod. Push down on the brass ring to clamp the taped end of the band into the slot.

Holding the torsion balance upside down, drop the retaining rod (torsion head end) through the tube. Place the small mass assembly into the casing, and clamp it in place with the locking thumbscrews on the bottom of the casing.

Place the torsion head back into the tube, so the retaining rod drops through the hole in the torsion head. Push the torsion head fully in and secure it in place by tightening the torsion head retaining screw and the zero-lock thumbscrew.

With the retaining rod hanging freely through the hole in the torsion head, retighten the band retaining screw.

Turn the torsion balance right side up and unlock the small mass assembly. Check that the small mass assembly hangs freely in the balance. If necessary, loosen the band retaining screw (while carefully holding onto the retaining rod) and adjust the retaining rod in the torsion head so that the small mass assembly hangs freely.

Lock the small mass assembly in place with the locking thumbscrews. If necessary, use the lens tissue to clean the mirror of fingerprints. Replace the glass sides of the casing, cleaning the glass if necessary, and the aluminum clips.

# Technical Support

## Feed-Back

If you have any comments about this product or this manual please let us know. If you have any suggestions on alternate experiments or find a problem in the manual please tell us. PASCO appreciates any customer feed-back. Your input helps us evaluate and improve our product.

## To Reach PASCO

For Technical Support call us at 1-800-772-8700 (toll-free within the U.S.) or (916) 786-3800.

Internet: techsupp@PASCO.com

## Contacting Technical Support

Before you call the PASCO Technical Support staff it would be helpful to prepare the following information:

- If your problem is with the PASCO apparatus, note:

  Title and Model number (usually listed on the label).

  Approximate age of apparatus.

  A detailed description of the problem/sequence of events. (In case you can't call PASCO right away, you won't lose valuable data.)

  If possible, have the apparatus within reach when calling. This makes descriptions of individual parts much easier.

- If your problem relates to the instruction manual, note:

  Part number and Revision (listed by month and year on the front cover).

  Have the manual at hand to discuss your questions.