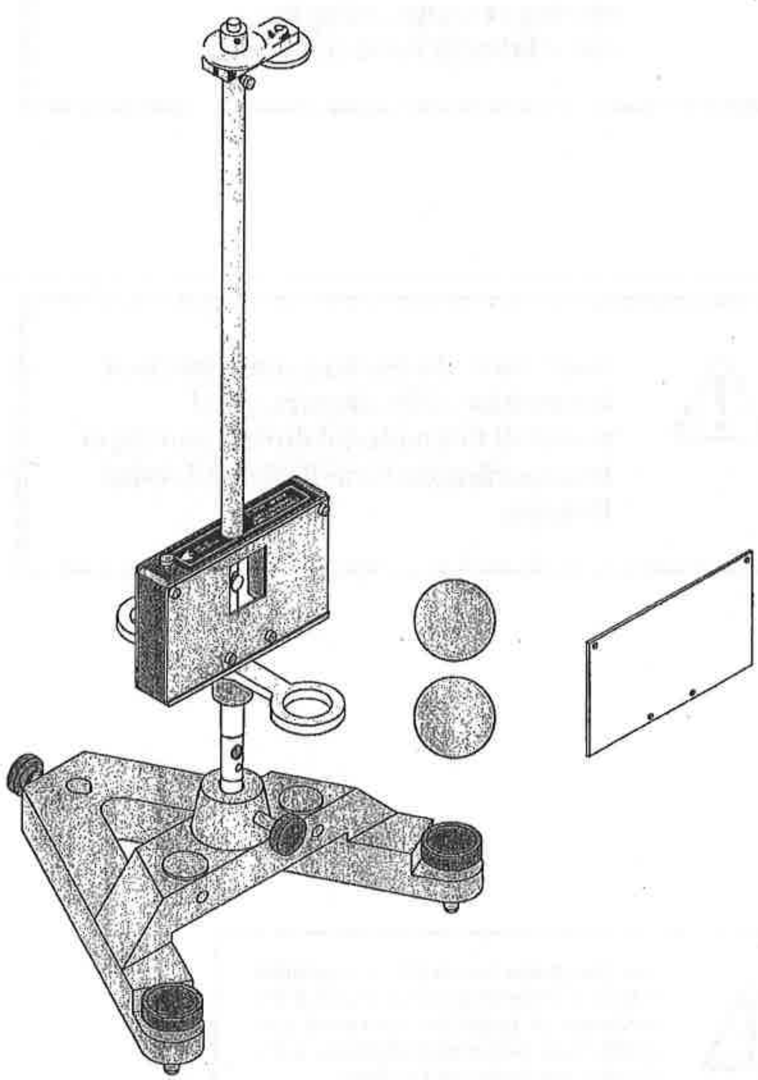
Student copy of PASCO manual. Pages 8-16 have been removed because they give detailed instructions about how to do the experiment and solve the theory - we want you to make your own experimental design and theory calculations.

Instruction Manual and Experiment Guide for the PASCO scientific Model AP-8215

012-06802B
11/98

GRAVITATIONAL TORSION BALANCE



$7.50

PASCO scientific
10101 Foothills Blvd. • Roseville, CA 95747-7100
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better ways to teach science

Note: To avoid breaking the torsion ribbon, the locking mechanism must be fully raised on both sides during moving or transporting the Gravitational Torsion Balance.

Note: Save the packing material from the interior of the chamber, and re-install this material during moving or transporting the Gravitational Torsion Balance.

The exclamation point within an equilateral triangle is intended to alert the user of the presence of important operating and maintenance (servicing) instructions in the literature accompanying the device.

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Copyright, Warranty, and Equipment Return

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Copyright Notice

Limited Warranty

PASCO scientific warrants the product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace at its option any part of the product which is deemed to be defective in material or workmanship. The warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by PASCO scientific. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment after repair will be paid by PASCO scientific.

Equipment Return

Should the product have to be returned to PASCO scientific for any reason, notify PASCO scientific by letter, phone, or fax BEFORE returning the product. Upon notification, the return authorization and shipping instructions will be promptly issued.

➤ **NOTE:** NO EQUIPMENT WILL BE ACCEPTED FOR RETURN WITHOUT AN AUTHORIZATION FROM PASCO.

When returning equipment for repair, the units must be packed properly. Carriers will not accept responsibility for damage caused by improper packing. To be certain the unit will not be damaged in shipment, observe the following rules:

① The packing carton must be strong enough for the item shipped.

② Make certain there are at least two inches of packing material between any point on the apparatus and the inside walls of the carton.

③ Make certain that the packing material cannot shift in the box or become compressed, allowing the instrument come in contact with the packing carton.

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Introduction

The PASCO scientific AP-8215 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 Gravitational Torsion Balance consists of two 38.3 gram masses suspended from a highly sensitive torsion ribbon and two 1.5 kilogram masses that can be positioned as required. The Gravitational Torsion Balance is oriented so the force of gravity between the small balls and the earth is negated (the pendulum is nearly perfectly aligned vertically and horizontally). The large masses are brought near the smaller masses, and the gravitational force between the large and small masses is measured by observing the twist of the torsion ribbon.

An optical lever, produced by a laser light source and a mirror affixed to the torsion pendulum, is used to accurately measure the small twist of the ribbon. Three methods of measurement are possible: the final deflection method, the equilibrium method, and the acceleration method.

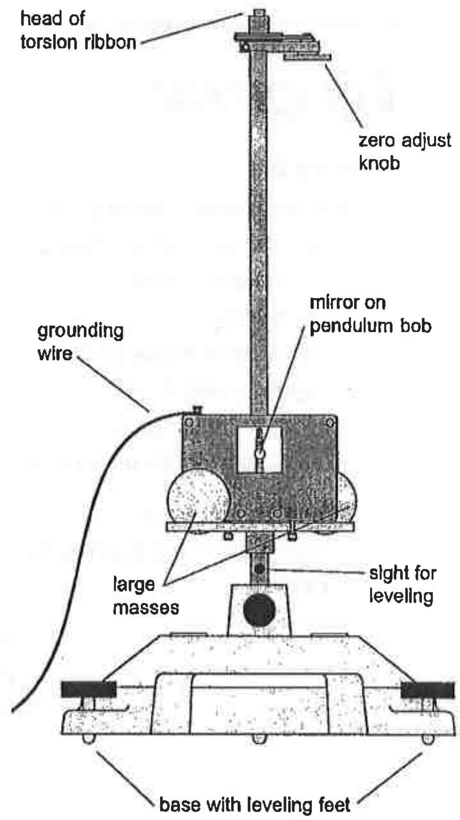

Figure 1
Assembled Gravitational Torsion Balance, ready to begin Henry Cavendish's classic experiment to determine the gravitational constant

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.

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.

Newton's law of universal gravitation:

$$F = G\frac{m_1 m_2}{r^2}$$

where m_1 and m_2 are the masses of the objects, r is the distance between them, and $G = 6.67 \times 10^{-11}\ \mathrm{Nm^2/kg^2}$

Equipment

Included:

- Gravitational Torsion Balance
- support base with leveling feet
- 1.5 kg lead balls (2)
- plastic plate
- replacement torsion ribbon (part no. 004-06788)
- 2-56 x 1/8 Phillips head screws (4)
- Phillips screwdriver (not shown)

Additional Required:

- laser light source (such as the PASCO OS-9171 He-Ne Laser)
- meter stick

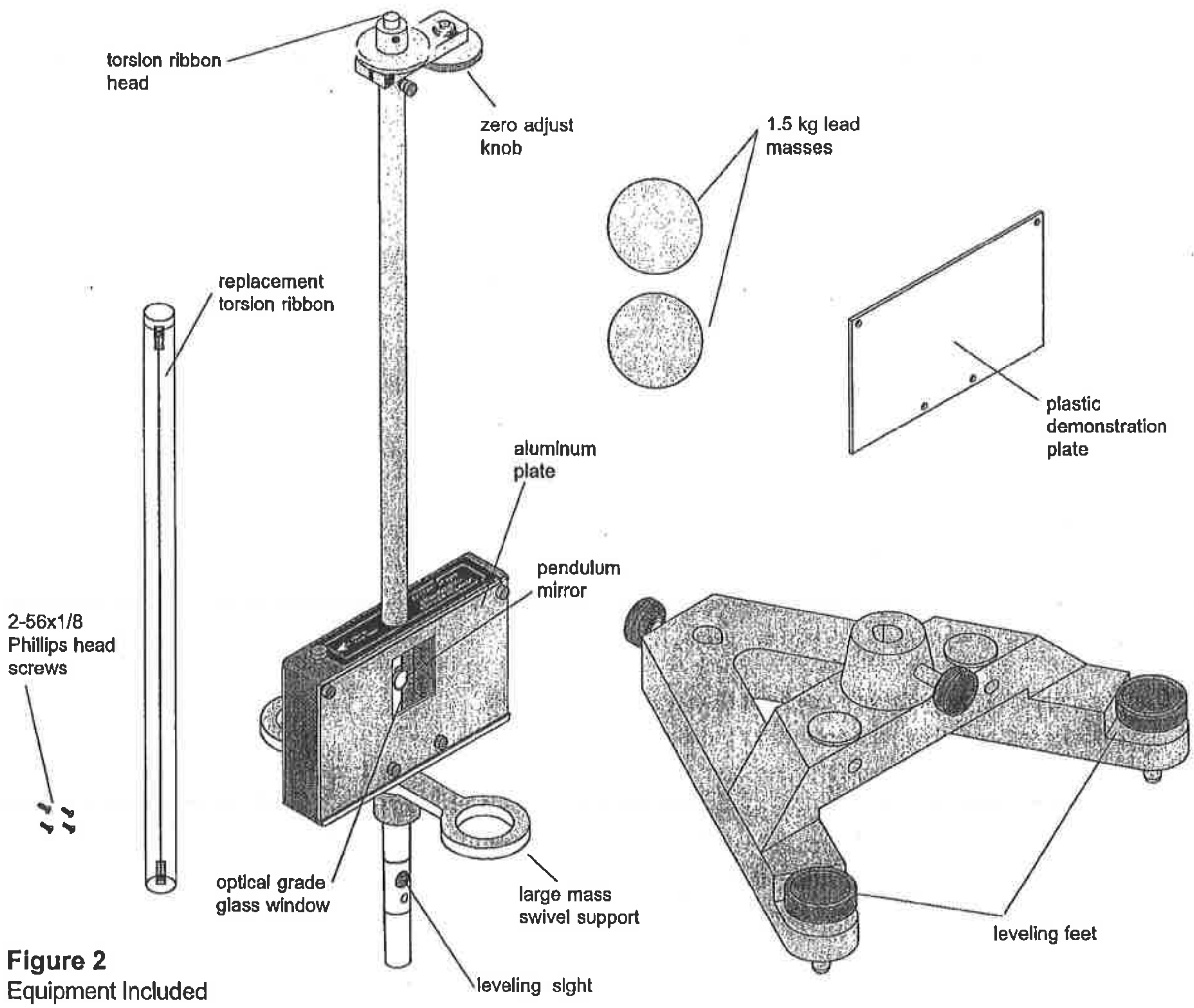

Figure 2
Equipment Included

Equipment Parameters

- Small lead balls
  Mass: 38.3 g ± 0.2 g (m_2)
  Radius: 9.53 mm
  Distance from ball center to torsion axis: d = 50 .0 mm
- Large lead balls
  Mass: 1500 g ± 10 g (m_1)
  Radius: 31.9 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 aluminum plate and the small ball is in the center position within the case: b = 46.5 mm (Tolerances will vary depending on the accuracy of the horizontal alignment of the pendulum.)
- Distance from the surface of the mirror to the outer surface of the glass window: 11.4 mm
- Torsion Ribbon Material: Beryllium Copper
  Length: approx. 260 mm
  Cross-section: .017 x .150 mm

IMPORTANT NOTES

➤ **The Gravitational Torsion Balance is a delicate instrument. We recommend that 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, allowing time for the slight elongation of the torsion band that will occur initially.**

➤ **Keep the pendulum bob secured in the locking mechanisms at all times, except while setting up and conducting experiments.**

Equipment Setup

Initial Setup

1. Place the support base on a flat, stable table that is located such that the Gravitational Torsion Balance will be at least 5 meters away from a wall or screen.

Note: For best results, use a very sturdy table, such as an optics table.

2. Carefully remove the Gravitational Torsion Balance from the box, and secure it in the base.

3. Remove the front plate by removing the thumbscrews (Figure 3), and carefully remove the packing foam from the pendulum chamber.

Note: Save the packing foam, and reinstall it each time the Gravitational Torsion Balance is transported.

4. Fasten the clear plastic plate to the case with the thumbscrews.

➤ ***Do not touch the mirror on the pendulum.***

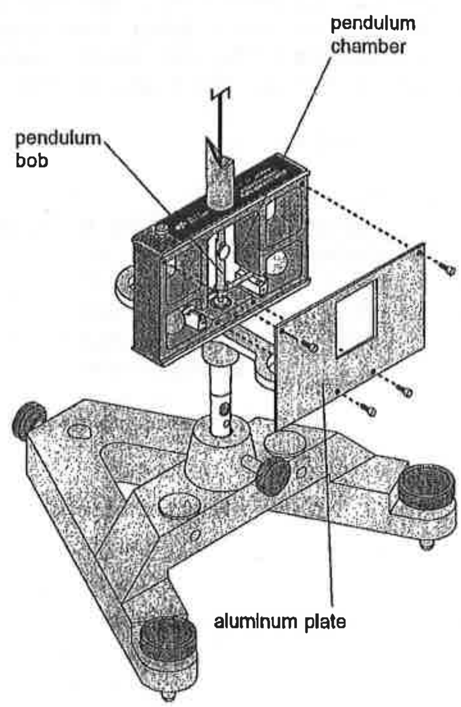

Figure 3
Removing a plate from the chamber box

Date: Fri, 17 Feb 2006 13:50:31 -0800
From: Steve Pon <pon@pasco.com>
Subject: re: Question about Torsion Balance
To: Martin Ligare <mligare@bucknell.edu>
cc: Ned Ladd <ladd@bucknell.edu>

02/17/06

To Martin Ligare:

Thank you for contacting PASCO scientific Teacher & Technical Support.
The small shaft connecting the two small masses is constructed of aluminum 2024-T4. It is 3.735 inches in length and 0.125 inches in diameter.

I hope this information is helpful for you.

Steven Pon

PASCO scientific Teacher & Technical Support
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DataStudio version 1.9.7r8 is available for download from:
http://store.pasco.com/forms/DSdownload.cfm

>> To whom it may concern:

>> I have a question about the Pasco Model AP-8215 Gravitational Torsion
>> Balance. We are using two of these balances in our advanced lab
>> course at Bucknell, and our students are getting very nice data.
>> We are curious about the mass of the pendulum bob arms, i.e., the rod
>> connecting the two small masses. Do you know the mass, or perhaps
>> the material from which the rod is constructed?

>> Thanks,
>>
>> Martin Ligare
>> Department of Physics & Astronomy
>> Bucknell University
>> Lewisburg, PA 17837
>> voice: (570) 577-1207
>> fax: (570) 577-3153
>> mligare@bucknell.edu

Leveling the Gravitational Torsion Balance

1. Release the pendulum from the locking mechanism by unscrewing the locking screws on the case, lowering the locking mechanisms to their lowest positions (Figure 4).

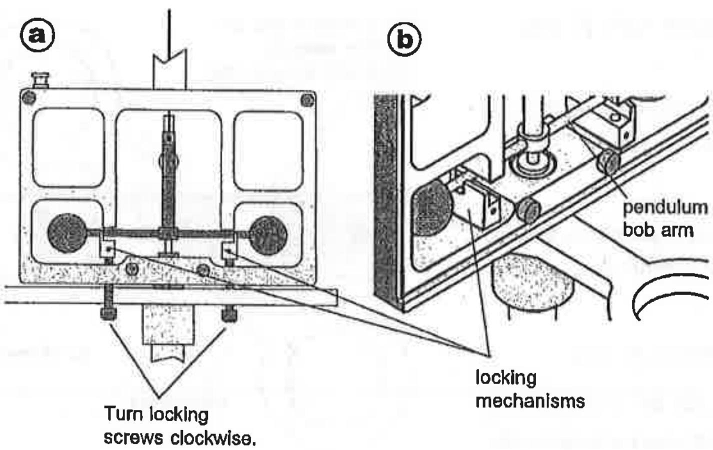


Figure 4
Lowering the locking mechanism to release the pendulum bob arms

2. Adjust the feet of the base until the pendulum is centered in the leveling sight (Figure 5). (The base of the pendulum will appear as a dark circle surrounded by a ring of light).

3. Orient the Gravitational Torsion Balance so the mirror on the pendulum bob faces a screen or wall that is at least 5 meters away.

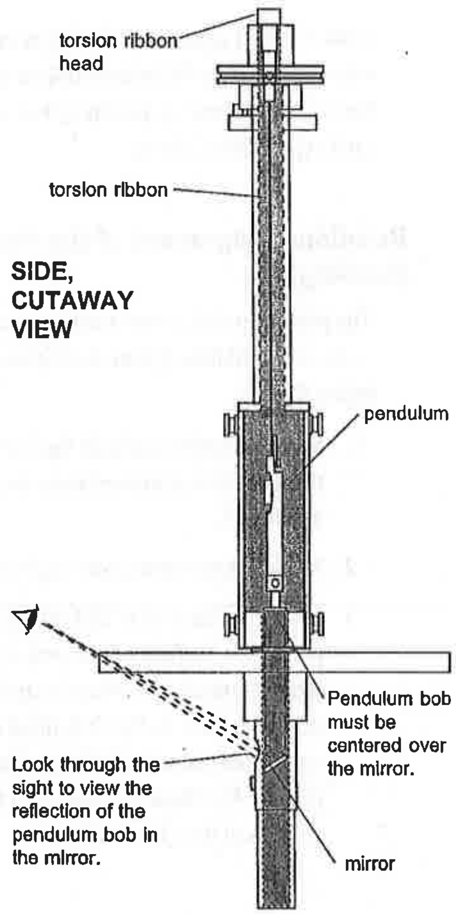


Figure 5
Using the leveling sight to level the Gravitational Torsion Balance.

Vertical Adjustment of the Pendulum

The base of the pendulum should be flush with the floor of the pendulum chamber. If it is not, adjust the height of the pendulum:

1. Grasp the torsion ribbon head and loosen the Phillips retaining screw (Figure 6a).

2. Adjust the height of the pendulum by moving the torsion ribbon head up or down so the base of the pendulum is flush with the floor of the pendulum chamber (Figure 6b).

3. Tighten the retaining (Phillips head) screw.

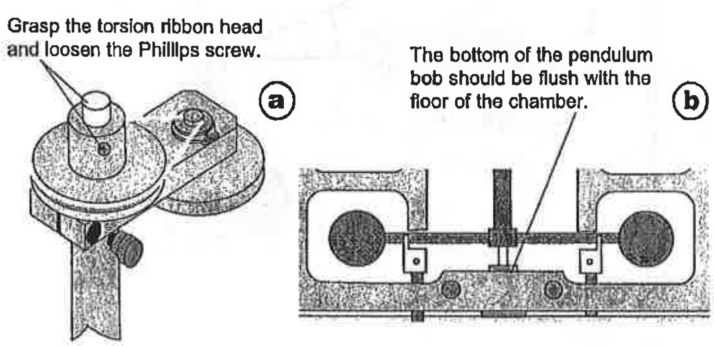


Figure 6
Adjusting the height of the pendulum bob

Note: Vertical adjustment is only necessary at initial setup and when you change the torsion ribbon or if someone has loosened the retaining screw by mistake; it is not normally done during each experimental setup.

TOP, CUTAWAY VIEW

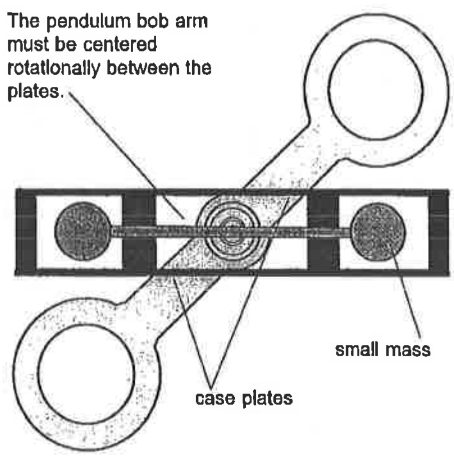


Figure 7
Aligning the pendulum bob rotationally

Rotational Alignment of the Pendulum Bob Arms (Zeroing)

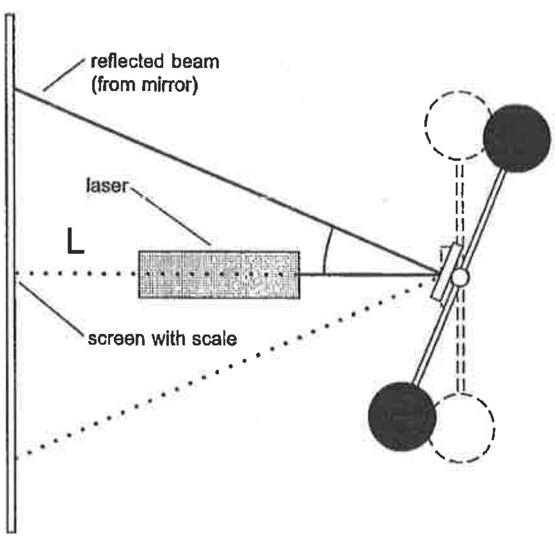
The pendulum bob arms must be centered rotationally in the case — that is, equidistant from each side of the case (Figure 7). To adjust them:

1. Mount a metric scale on the wall or other projection surface that is at least 5 meters away from the mirror of the pendulum.

2. Replace the plastic cover with the aluminum cover.

3. Set up the laser so it will reflect from the mirror to the projection surface where you will take your measurements (approximately 5 meters from the mirror). You will need to point the laser so that it is tilted upward toward the mirror and so the reflected beam projects onto the projection surface (Figure 8). There will also be a fainter beam projected off the surface of the glass window.

TOP VIEW



SIDE VIEW

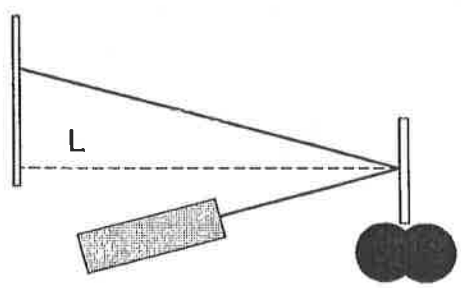


Figure 8
Setting up the optical lever

3. Rotationally align the case by rotating it until the laser beam projected from the glass window is centered on the metric scale (Figure 9).

4. Rotationally align the pendulum arm:

   a. Raise the locking mechanisms by turning the locking screws until both of the locking mechanisms barely touch the pendulum arm. Maintain this position for a few moments until the oscillating energy of the pendulum is dampened.

   b. Carefully lower the locking mechanisms slightly so the pendulum can swing freely. If necessary, repeat the dampening exercise to calm any wild oscillations of the pendulum bob.

   c. Observe the laser beam reflected from the mirror. In the optimally aligned system, the equilibrium point of the oscillations of the beam reflected from the mirror will be vertically aligned below the beam reflected from the glass surface of the case (Figure 9).

   d. If the spots on the projection surface (the laser beam reflections) are not aligned vertically, loosen the zero adjust thumbscrew, turn the zero adjust knob slightly to refine the rotational alignment of the pendulum bob arms (Figure 10), and wait until the movement of the pendulum stops or nearly stops.

   e. Repeat steps 4a – 4c as necessary until the spots are aligned vertically on the projection surface.

5. When the rotational alignment is complete, carefully tighten the zero adjust thumbscrew, being careful to avoid jarring the system.

Hints for speedier rotational alignments:

- Dampen any wild oscillations of the pendulum bob with the locking mechanisms, as described;
- Adjust the rotational alignment of the pendulum bob using small, smooth adjustments of the zero adjust knob;
- Exercise patience and finesse in your movements.

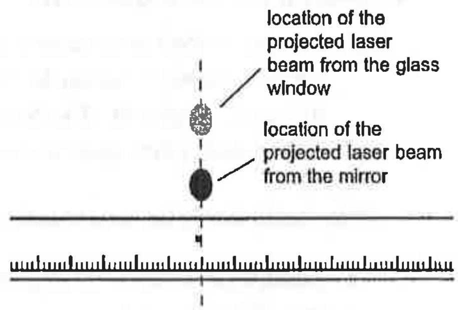


Figure 9
Ideal rotational alignment (zeroing) of the pendulum

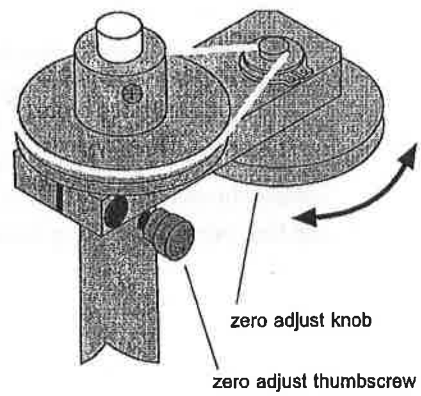


Figure 10
Refining the rotational alignment of the pendulum bob

Setting up for the Experiment

1. Take an accurate measurement of the distance from the mirror to the zero point on the scale on the projection surface (L) (Figure 8). (The distance from the mirror surface to the outside of the glass window is 11.4 mm.)

Note: Avoid jarring the apparatus during this setup procedure.

2. Attach copper wire to the grounding screw (Figure 11), and ground it to the earth.

3. Place the large lead masses on the support arm, and rotate the arm to Position I (Figure 12), taking care to avoid bumping the case with the masses.

4. Allow the pendulum to come to resting equilibrium.

5. You are now ready to make a measurement using one of three methods: the final deflection method, the equilibrium method, or the acceleration method.

Note: The pendulum may require several hours to reach resting equilibrium. To shorten the time required, dampen the oscillation of the pendulum by smoothly raising the locking mechanisms up (by turning the locking screws) until they just touch the crossbar, holding for several seconds until the oscillations are dampened, and then carefully lowering the locking mechanisms slightly.

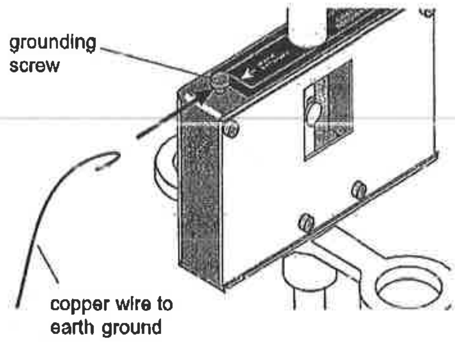


Figure 11
Attaching the grounding strap to the grounding screw

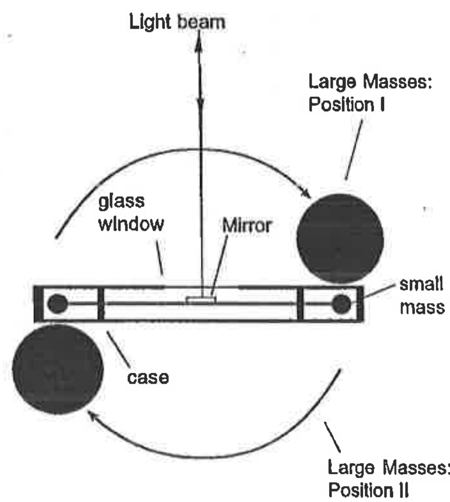


Figure 12
Moving the large masses into Position I

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 (a situation similar to that of the Gravitational Torsion Balance) is about 7×10^{-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.

Maintenance

Replacing the Torsion Ribbon Assembly

If the torsion ribbon breaks, replace it as follows:

1. Remove the plates, and raise the locking mechanism using the locking screws until the pendulum arms are securely anchored (Figure 21a).
2. Grasp the pendulum bob near the bottom ribbon tab to stabilize it.
3. Loosen the Phillips screw on the bottom tab of the torsion ribbon assembly (Figure 21a), and remove the bottom half of the broken ribbon assembly.
4. Loosen the Phillips screw at the top of the balance assembly (Figure 21b).
5. Grasp the torsion ribbon head and remove the top portion of the broken torsion ribbon assembly.
6. Attach the top tab of the new torsion ribbon to the torsion ribbon head using the Phillips screw, being sure the copper disc on the tab is in contact with the torsion ribbon head (Figure 22). Align the tab with the face of the torsion ribbon head.

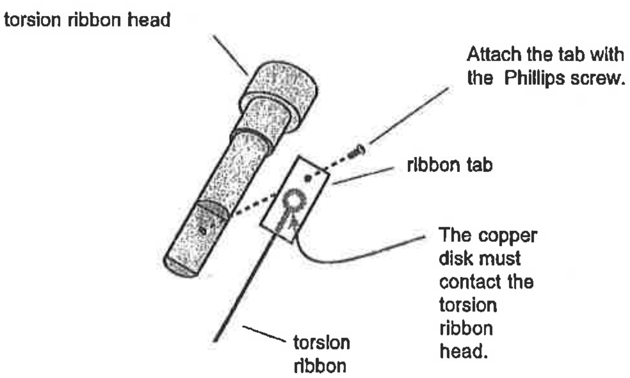


Figure 22
Attaching the top tab of the torsion ribbon assembly to the torsion ribbon head

7. Thread the ribbon through the shaft.
8. Using the zero adjust knob, align the bottom tab with the face of the pendulum bob.

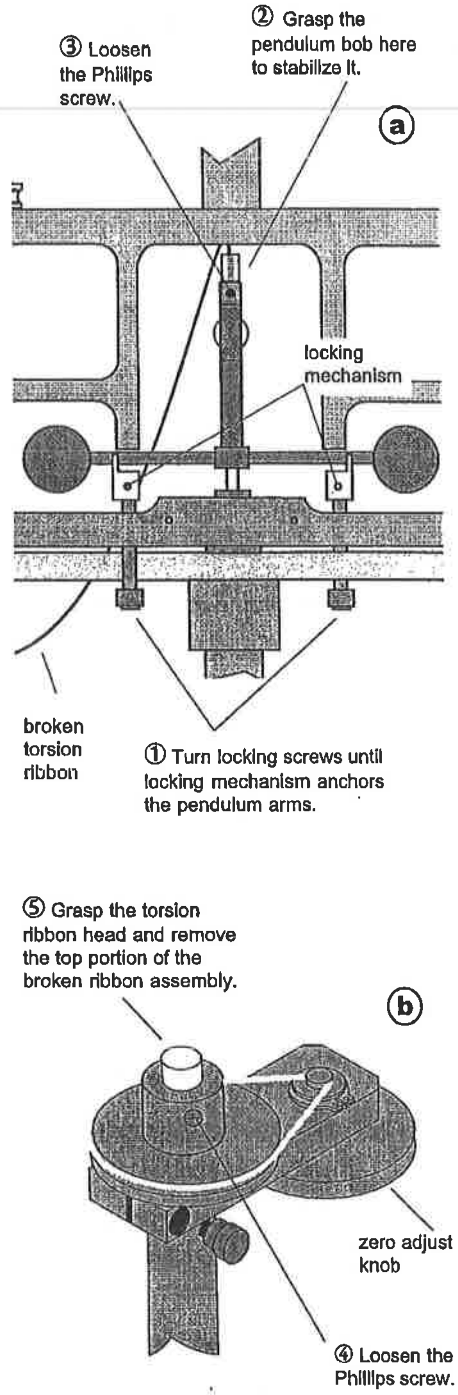


Figure 21
Securing the pendulum bob before removing a broken torsion ribbon, and loosening the torsion ribbon head

⚠ *Note:* **Be sure the ribbon is not twisted.**

9. Tighten the Phillips screw on the top of the balance to secure the torsion ribbon head.
10. Attach the bottom tab of the ribbon to the pendulum bob using the Phillips screw.
11. Replace the back plate.
12. Level and align the pendulum according to the instructions in the *Equipment Setup* section of this manual.

⚠ *Note:* **To avoid breaking the torsion ribbon, the locking mechanism must be fully raised on both sides during any moving or transporting of the Gravitational Torsion Balance.**

Transporting and Storing

1. To prepare the Gravitational Torsion Balance for transporting or storing:
   a. Remove the front plate.
   b. Raise the locking mechanism to securely anchor the pendulum bob.
   c. Check to be sure that the torsion ribbon is hanging straight down the center of the tube. If it is not, lower the locking mechanisms, be sure the torsion wire is centered, and raise the locking mechanisms again. Repeat as necessary until the ribbon is centered in the tube.
   d. Reinstall the packing foam into the chamber to secure the pendulum bob.
   e. Replace the plate.
2. The Gravitational Torsion Balance may be stored flat in its shipping container.
3. Store in a cool, dry place, and protect the device from any jarring or rough handling.

Safety Precaution

The small and large masses are made of lead, which is toxic if ingested. Use appropriate precautions for handling lead, including hand washing after handling the masses.

Technical Support

Feedback

If you have any comments about the product or 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 feedback. 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.

fax: (916) 786-3292

e-mail: techsupp@pasco.com

web: www.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 to facilitate description of individual parts.

➤ 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.