

Instruction Manual and Experiment Guide 012-10381A

Tension Protractor

ME-6855



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Figure 1: Front view

Included Parts

- Tension Protractor
- String, 15 cm
- Wire hook

Other Parts Recommended

- 90 cm Steel Rod (PASCO part ME-8738)
- Large Table Clamp (ME-9472)
- Additional string (SE-8050)
- Hooked Mass Set (SE-8759)

Introduction

The Tension Protractor is used to measure string tension and angle simultaneously. It eliminates the need for separate spring scales and protractors in equilibrium experiments.

About the Apparatus

The Tension Protractor consists of a torsion spring scale and a protractor.

The string is attached to the rotating part of the protractor and wrapped twice around a small pulley (see Figure 1). When the string is pulled, the torsion spring stretches and the red pointer rotates. The string tension is read on the



The string can be pulled at any angle in the plane of the protractor. The string angle is read where the string crosses the outer degree scale. The angle scale is marked from 0° to 90° in each of four quadrants. Horizontal (to the left or right) is 0° and vertical (straight up or straight down) is 90°. Note that the angle markings are slightly offset in order to align with the string, which does not originate from the center of the circle but rather from a point tangent to the pulley.

Set-up

Mounting the Tension Protractor on a Rod

Mount the Tension Protractor on a horizontal or a vertical rod using the attached rod clamp as shown in Figure 2.

Zeroing the Force Scale:

After attaching the Tension Protractor to a rod, follow these steps to ensure that the red pointer indicates 0 N when no force is applied.

- 1. Allow the string to hang freely with no force applied.
- Loosen the thumb screw on the back of the Tension Protractor (Figure 2). 2.
- 3. Move the screw up or down to set the red pointer to zero on the face of the Tension Protractor.
- Tighten the thumb screw. 4.

Zeroing the Angle Scale

After attaching the Tension Protractor to a rod, follow these steps to ensure that the string crosses 90° when it is hanging vertically.

- Hang a small mass on the string to act as a plumb bob (Figure 3). 1.
- 2. Turn the outer ring or the protractor to rotate the angle scale (it is held in place by friction). Align the 90° mark with the string.

Measuring Force and Angle

- 1. Ensure that the string is wrapped around the pulley *twice* so that the string is always tangent to the pulley regardless of the string angle or tension.
- 2. Hang a mass from the wire hook (as in Figure 1), or set up an arrangement of string, masses and other objects to apply tension. See the experiments on the following pages for examples.
- 3. Read the magnitude of force on the inner red scale as indicated by the red pointer.
- 4. Read the angle on the outer scale where the string crosses it.

Figure 2: Back view

Figure 3: Zero the angle scale





String Replacement

The Tension Protractor is designed for use with Braided Physics String (PASCO part SE-8050). Using string of a different diameter will cause error in the force reading. Follow these steps to replace the string.

- **1.** Use a #0 or #1 phillips screwdriver to remove the screw on the face of the Tension Protractor.
- 2. Remove the old string.
- **3.** Tie a loop at the end of the new string.
- 4. Put the screw through the loop and replace the screw in the face of the protractor.
- 5. Wrap the string *twice* around the pulley in the clockwise direction.
- 6. Tie the wire clip to the end of the new string. If the wire clip is lost, it can be replaced with a small paper clip.

About the Experiments

The experiments in this manual use one or two Tension Protractors and other equipment, such as rods, clamps, and masses that are commonly found in introductory labs.

- **1. Static Equilibrium with Unequal Angles** (page 4): Examine the forces required to hang a weight in static equilibrium using two strings at different angles.
- **2.** Boom in Static Equilibrium (page 7): Examine the two requirements for a boom in equilibrium. The boom is pivoted at one end and a string suspends the other end.

Experiment 1: Static Equilibrium with Unequal Angles

Equipment Needed

Eq	uipment Needed	Suggested Part
•	(2) Tension Protractors	ME-6855
•	(2) Large Table Clamps	ME-9472
•	(3) 90 cm Steel Rods	ME-8738
•	(2) Multi Clamps	SE-9442
•	Hooked Mass Set	SE-8759
•	Braided Physics String	SE-8050
•	Balance	SE-8723

Purpose

The purpose of this experiment is to verify that the vector sum of the forces acting on an object in equilibrium is zero.

Pre-lab Question

If an object is suspended by two strings at two different angles, as shown in Figure 1.1, which string will have the greater tension?

Theory

The vector sum of the forces acting on an object in equilibrium is zero:

$$(eq. 1-1) \qquad \qquad \sum_i \vec{F}_i = 0$$

This requires that the sum of the force components in the x- and y-directions must each separately be zero:

$$(eq. 1-2) \qquad \qquad \sum_{i} \vec{F}_{ix} = 0$$

$$(eq. 1-3) \qquad \qquad \sum_{i} \vec{F}_{iy} = 0$$

For example, if three forces are acting on an object (as shown in Figure 1.2), Equation 1-2 vields

$$(eq. 1-4) F_{2x} - F_{1x} = 0$$

$$(eq. 1-5) F_2 \cos \theta_2 - F_1 \cos \theta_1 = 0$$

This can also be interpreted as requiring the magnitudes of the x-components of the forces to be equal and opposite:

(eq. 1-6)
$$F_{2x} = F_{1x}$$

$$(eq. 1-7) F_2 \cos \theta_2 = F_1 \cos \theta_1$$









Similarly, Equation 1-3 yields

 $(eq. 1-8) F_{1y} + F_{2y} - F_{3y} = 0$

(eq. 1-9)
$$F_1 \sin \theta_1 + F_2 \sin \theta_2 - F_3 = 0$$

Or, the sum of the magnitudes of the forces up must equal the sum of the magnitudes of the forces down:

$$(eq. 1-10) F_{1y} + F_{2y} = F_{3y}$$

$$(eq. 1-11) F_1 \sin \theta_1 + F_2 \sin \theta_2 = F_3$$

Procedure

1. Clamp two rods (90 cm long) vertically to the table, approximately 80 cm apart. Attach two Tension Protractors (oriented with zero degrees horizontal) to a cross rod, and clamp this rod between the vertical rods as shown in the Figure 1.3 (but don't attach the mass yet).





- **2.** Zero the force scale of each Tension Protractor: Without anything attached to the Tension Protractor string, adjust the thumb screw in the back until the force scale reads zero.
- 3. Zero the angle scale of each Tension Protractor: Hang a small mass (10 g) from the hook. Rotate the outer ring to align the 90° mark with the string (Figure 1.4).
- **4.** Cut a string about 60 cm long. Tie a loop about 25 cm from one end so that the string length on one side of the loop is about 20 cm and the string length on the other side of the loop is 35 cm. Tie one end of the string to the wire hook on one of the Tension Protractors and tie the other end of the string to the wire hook of the other Tension Protractor. Hang a 500 g mass from the string loop (Figure 1.3).
- 5. Read the magnitude of force and the angle for each string and record them in Table 1.1.



Figure 1.4: Zero the angle scale



6. Remove the hooked mass and use a balance to find its exact mass. Record it in Table 1.1.

Table 1.1: Data

	Magnitude of Force (N)	Angle (°)	Hanging Mass (kg)
Tension 1			
Tension 2			

Analysis

- 1. Calculate the weight of the hanging mass and record it in Table 1.2.
- 2. Calculate the x- and y-components of the tension of each string. Record them in Table 1.2.

Table 1.2: Calculations

Weight of Hanging Mass	
x-component of Tension 1	
x-component of Tension 2	
y-component of Tension 1	
y-component of Tension 2	

- **3.** Calculate the sum of the forces to the left and the sum of forces to the right. Calculate the percent difference between them. Record these values in Table 1.3.
- **4.** Calculate the sum of the upward forces and the sum of the downward forces. Calculate the percent difference between them. Record these values in Table 1.3.

Table 1.3: Results

		Percent Difference
Sum of x-components	Left	
Sum of x-components	Right	
	Upward	
Sum of y-components	Downward	

5. Estimate the precision of the tension and angle measurements. Are the resulting forces being compared the same within the range of the precision?

Experiment 2: Boom in Static Equilibrium

<u>Eq</u>	uipment Needed	Suggested Part
•	Tension Protractor	ME-6855
•	Large Table Clamp	ME-9472
•	Multi Clamp	SE-9442
•	Hooked Mass Set	SE-8759
•	Braided Physics String	SE-8050
•	Level	SE-8729
•	(2) 90 cm Steel Rods	ME-8738
•	Balance	SE-8723
•	Meter Stick with a hole in each end (requires drilling 8 mm or 5/16 inch holes)	SE-8729

 short rod, about 6 mm (1/4 inch) in diameter and 15 cm (6 inches) long

Purpose

The purpose of this experiment is to examine the two requirements for a boom to be in equilibrium and use them to determine the forces acting on the boom at the pivot.

Pre-lab Questions

- 1. What are the two requirements for an extended object to be in equilibrium?
- **2.** Does the tension of the string shown in Figure 2.1 cause a clockwise or counterclockwise torque about the pivot?
- **3.** Does the hanging mass shown in Figure 2.1 cause a clockwise or counterclockwise torque about the pivot point?
- 4. Where does the weight of the boom (in this case, the meter stick) act?
- 5. Which angle will you measure with the Tension Protractor (in Figure 2.1)?

Theory

There are two requirements for an object in equilibrium:

1. The vector sum of the forces acting on the object in equilibrium is zero:

$$(eq. 2-1) \qquad \qquad \sum_i \vec{F}_i = 0$$

2. The vector sum of the torques acting on the object in equilibrium is zero:

$$(eq. 2-2) \qquad \qquad \sum_i \dot{\tau}_i = 0$$

Counterclockwise torques are defined to be positive and clockwise torques are negative. Torque is calculated using $\tau = r(\sin\theta)F$, where *r* is the lever arm distance measured from the pivot to the point where the force (*F*) is applied, and θ is the angle between the lever arm (*r*) and the applied force (*F*). Requirement #1 also implies that the sum of the force components in the x- and y-directions must each separately be zero:

$$(eq. 2-3) \qquad \qquad \sum_{i} \vec{F}_{ix} = 0$$

$$(eq. 2-4) \qquad \qquad \sum_{i} \vec{F}_{iy} = 0$$

Another way of stating Requirement #2 is that the sum of all the clockwise torques equals the sum of all the counterclockwise torques:

(eq. 2-5)
$$\sum \tau_{\text{clockwise}} = \sum \tau_{\text{counterclockwise}}$$

Procedure

- 1. Measure the masses of the meter stick and a hooked mass (use the mass marked 500 g). Record these masses in Table 2.1.
- 2. Balance the meter stick on a sharp edge, such as the edge of a table, to find the center of mass of the meter stick. Record the position of the center of mass in Table 2.1. This is the point at which it is assumed that the total weight of the meter stick acts.
- **3.** Clamp one of the long rods (90 cm long) vertically to the table (see Figure 2.1). Attach a right-angle clamp to the rod near the table. Clamp the short rod to the vertical rod to act as a pivot.
- 4. Slide the hole at one end of the meter stick over the short rod. The meter stick should pivot freely on the rod.



5. Tie a loop of string loosely around the meter stick. This will be used to hang the hooked mass.

- 6. Clamp the Tension Protractor near the top of the vertical rod.
- **7.** Zero the force scale of the Tension Protractor: Without anything attached to the Tension Protractor string, adjust the thumb screw in the back until the force scale reads zero.
- **8.** Zero the angle scale of the Tension Protractor: Hang a small mass (10 g) from the hook. Rotate the outer ring to align the 90° mark with the string (Figure 2.2).
- **9.** Tie a string to the hook of the Tension Protractor. Use a piece of string that is long enough to reach the free end of the meter stick with the stick being approximately horizontal. Tie the other end of the string to the end of the meter stick, keeping the meter stick approximately horizontal. Keep the meter stick and the face of the Tension Protractor in the same plane, and keep the pivot rod perpendicular to that plane.
- **10.** Hang the 500 g mass from the loop of string around the meter stick at about the 60 cm mark.
- **11.** Use the level to determine if the meter stick is horizontal. Make the stick level (horizontal) by changing the height of the pivot clamp or the height of the Tension Protractor. Or, for small adjustments, move the hanging mass, but keep it between the 55 cm and 65 cm marks.
- **12.** Record the angle of the string in Table 2.1.
- **13.** Record the tension in the string in Table 2.1.
- **14.** Record the distance from the pivot to the point where the string is attached to the meter stick in Table 2.1.
- 15. Record the distance from the pivot to the hanging mass in Table 2.1.
- **16.** Record the distance from the pivot to the center of mass of the meter stick in Table 2.1.

Table 2.1: Data

Mass of meter stick	
Mass of hooked mass	
Center of mass of meter stick	
Angle of string	
Tension	
Distance from pivot to string	
Distance from pivot to hanging mass	
Distance from pivot to center of mass of meter stick	

Analysis

- 1. Calculate the clockwise torques about the pivot caused by the hanging mass and the stick and record them in Table 2.2. Calculate the total clockwise torque and record it in Table 2.2.
- 2. Calculate the counterclockwise torque about the pivot caused by the tension in the string and record it in Table 2.2. (Don't forget to account for the angle!) Calculate the total counterclockwise torque and record it in Table 2.2.



Figure 2.2: Zero the angle scale



3. Compare the total clockwise torque to the total counterclockwise torque by calculating the percent difference. Record the percent difference in Table 2.2. Are they the same? Should they be the same?

Table 2.2: Calculations and Results

Torque caused by hanging weight	
Torque caused by meter stick	
Total clockwise torque	
Torque caused by string	
Total counterclockwise torque	
Percent difference	

- **4.** Calculate the known horizontal forces. Use Equation 2-3 to determine the unknown horizontal force at the pivot and record it in Table 2.3.
- **5.** Calculate the known vertical forces. Use Equation 2-4 to determine the unknown vertical force at the pivot and record it in Table 2.3.
- 6. Calculate the magnitude and direction of the force at the pivot. Specify whether you are measuring the angle from the horizontal or the vertical. Draw a diagram showing the angle of the force. Record the magnitude and angle in Table 2.3.

Table 2.3: Forces at the Pivot

Horizontal pivot force	
Vertical pivot force	
Magnitude of pivot force	
Angle of pivot force	

Questions

- 1. How do the clockwise torques compare to the counterclockwise torques?
- 2. Is the direction of the pivot force parallel to the meter stick?
- **3.** Using the convention that counterclockwise torques are positive and clockwise torques are negative, sum the torques about the center of mass of the meter stick. What do you expect the sum to be?

Additional Experiment Suggestion: Hanging a Level Sign

Using a set-up similar to that of Experiment 1, hang a rectangular sign board from two different-length strings. Attach the strings to the sign as shown. Adjust the positions of the Tension Protractors to make the sign is level. Confirm that the two requirements for equilibrium are satisfied. Predict what would happen if the two unequal length strings were attached to the upper corners of the sign.



Technical Support

For assistance with any PASCO product, contact PASCO at:

Address:	PASCO scientific
	10101 Foothills Blvd.
	Roseville, CA 95747-7100
Phone:	916-786-3800 (worldwide)
	800-772-8700 (U.S.)
Fax:	(916) 786-7565
Web:	www.pasco.com
Email:	support@pasco.com

For more information about the Tension Protractor and the latest revision of this Instruction Manual, visit:

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Author: Ann Hanks

