

Lab 10: Statics and Torque Lab

Objectives:

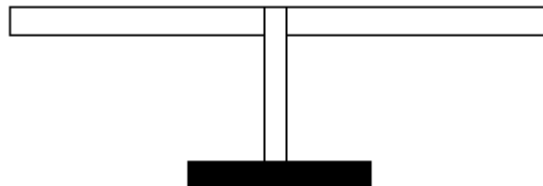
- To understand torque
- To be able to calculate the torque created by a force and the net torque on an object
- To understand the conditions for static equilibrium

Equipment:

- Meter stick balance
- Mass hangers
- Masses
- Spring scale
- Meter stick for measurement
- Two bathroom scales

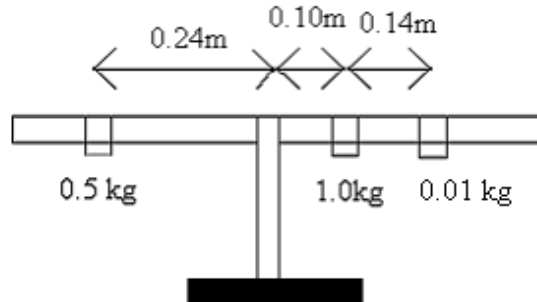
Exploration 1 Balance

At your lab table is a meter stick to which masses can be added. Balance the meter stick (parallel to the table) on the pivot without any mass hangers or masses on either side of the pivot. The meter stick may not balance at the exact middle of the meter stick. However, when it is balanced, there is an equal amount of mass on each side of the meter stick. This will be our starting position.



Exploration 1.1 Add masses to each side of the rod so that the rod does not rotate, but is balanced (parallel to the table). In particular, add two masses to one side and one mass to the other side. Is there more than one arrangement that will balance the rod? Explain.

Exploration 1.2 Consider a meter stick balance that is free to rotate, as in the picture below. If the following arrangement of masses were placed on the meter stick while someone was holding it level, then the meter stick was released, would the meter stick remain balanced? Show any calculations and explain.

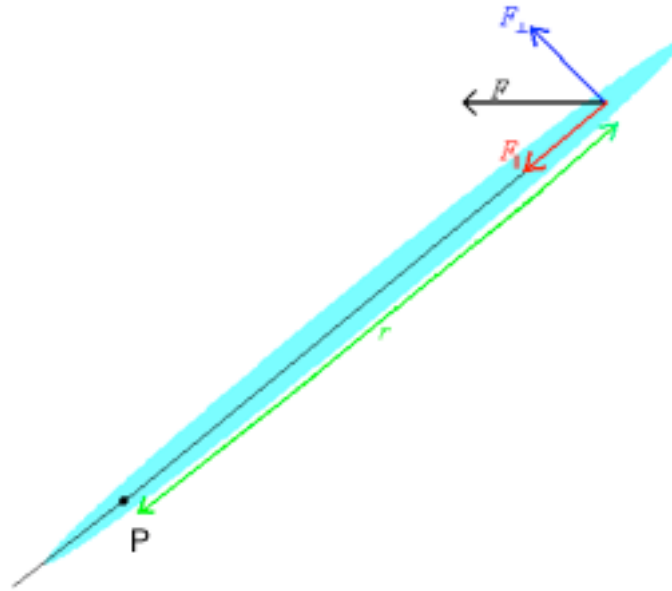


Exploration 1.3 For the case in Exploration 1.2, determine the total force upwards and the total force downwards. Draw a force diagram for the rod. Does the net force explain why the rod does or does not remain balanced? Explain.

Exploration 1.4 If the arrangement in Exploration 1.2 does rotate, where could another mass be placed so that it doesn't rotate? Is there more than one place? Determine a mass and position necessary to balance the meter stick.

Exploration 2 Torque

For an object free to rotate about a point, P, label r as the distance between the pivot point and the point of application of a force, F , as in the picture below. The component of the force that is perpendicular to a line through the pivot point and the point of application of the force will be labeled F_{\perp} and the component of the force that is parallel to a line through the pivot point and the point of application of the force will be labeled F_{\parallel} .



Exploration 2.1 Do both F_{\perp} and F_{\parallel} cause the object to rotate about the pivot point? Explain.

Exploration 2.2 On a meter stick balance, hang a mass at a distance of about 0.20m from the pivot point on one side of the meter stick. Use a spring scale to apply a force at a point on the other side of the meter stick to make it balance. First apply the force perpendicular to a line through the pivot point and the point of application. Then apply the force at an angle. Is the same force needed each time? Try applying a force parallel to a line through the pivot point and the point of application. Can you balance the meter stick in each case?

Investigation 1 Torque

Investigation 1.1 Take some data for the situation in Exploration 2.2. with the force applied at different angles. Record the angle, the applied force and the parallel and perpendicular components of the force in the table below for five different angles.

Angle	Applied Force, F	F_{\perp}	F_{\parallel}

The cross product of the force and the distance from the pivot is called the torque, τ . Torque is a vector measured in units mN (meter Newtons). Mathematically,

$$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$$

The magnitude of the torque is

$$\tau = rF\sin\theta = r F_{\perp}$$

where θ is the angle between \mathbf{r} , a vector drawn from the pivot point to the point of application of the force, and \mathbf{F} .

Calculate the torque for each angle in the table above and report it in the table below. Estimate the uncertainty in your torque calculation. Show mathematically and explain how you estimate the uncertainty.

Angle	Torque, τ

Is the table above consistent with your expectations? Why?

If you are taking a calculus-based course, you can determine the direction of the torque from the right-hand rule applied to the cross product.

If you are taking an algebra-based course, you can think of the rotation as either clockwise or counter clockwise. In this case, it is often convenient to label one direction of torque positive and the other direction of torque negative.

Exploration 3 Static Equilibrium

The sum of all the torques on an object is the net torque.

When an object is not rotating, the net torque on the object is zero. If the net torque on an object is not zero, the object will rotate.

Mathematically, the net torque is written as

$$\tau_{net} = \tau_1 + \tau_2 + \tau_3 + \dots$$

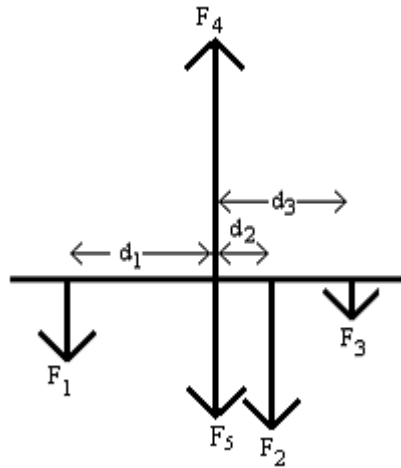
$$\tau_{net} = r_1 F_{1\perp} + r_2 F_{2\perp} + r_3 F_{3\perp} + \dots$$

where a torque is positive if it causes a clockwise rotation and negative if it causes a counterclockwise rotation.

Exploration 3.1 Calculate the net torque on the meter stick in Exploration 1.2 and the additional torque need to make the meter stick balance. Show your work below.

If the net torque on an object equals zero, the object will not rotate. If the net force on an object equals zero, then the object will not move. If both the net force and the net torque are zero, then the object is said to be in static equilibrium.

When working problems involving torque and forces, it is useful to draw the force diagram with the forces drawn at the point they are exerted. For example, the situation in Exploration 1.2, the force diagram would be drawn like this:



where F_1 is force of the 0.5 kg mass on the rod, F_2 is the force of the 1.0kg mass on the rod, F_3 is the force of the 0.01kg mass on the rod, F_4 is the upward force of the pivot on the rod and F_5 is the mass of the rod. d_1 , d_2 and d_3 are the distances of the masses from the pivot. Forces F_4 and F_5 are at the pivot.

If the rod is not moving, the net force on the rod is zero and this can be written mathematically as

$$F_1 + F_2 + F_3 + F_4 + F_5 = 0$$

If the rod is not rotating, the net torque on the rod is zero. You may choose to calculate the torque about any point on the object. In some cases, like this one, it is natural to take the torque about the pivot point. In this case the torque due to forces F_4 and F_5 are zero, because the distance between the force and the pivot point is zero. This can be written mathematically as

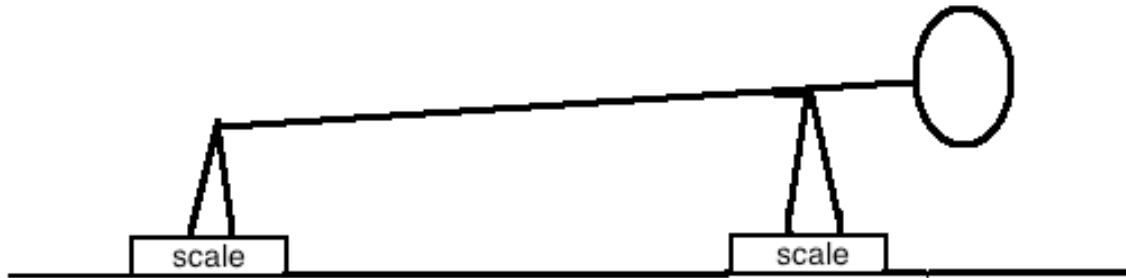
$$\tau_1 + \tau_2 + \tau_3 = 0$$

or

$$F_1 d_1 - F_2 d_2 - F_3 d_3 = 0$$

The point about which you take the torque may depend on the problem and which quantities are known and unknown.

Exploration 3.2 If you were to place yourself in a pushup position, but with your hands on a (bathroom) scale and your feet on another (bathroom) scale, you could measure the upward force of the scale on your hands and on your feet. The mass in your body is not uniformly distributed, but all of your weight can be considered to act at your center of gravity.



Carry out the experiment. Measure your weight, the force of the floor on your hands, the force of the floor on your feet and any relevant distances. Use the fact that you are in equilibrium and the net force and the net torque must be zero, draw a force diagram for the situation and calculate the location of your center of gravity. Show your work.