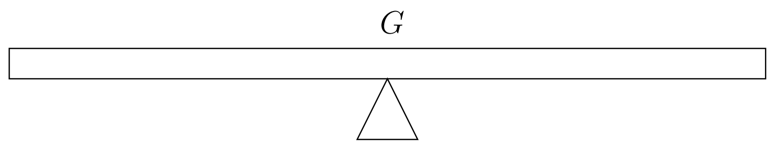
Rotational Equilibrium

In this laboratory, we study the conditions for static equilibrium.

1 Axis Through the Center of Gravity

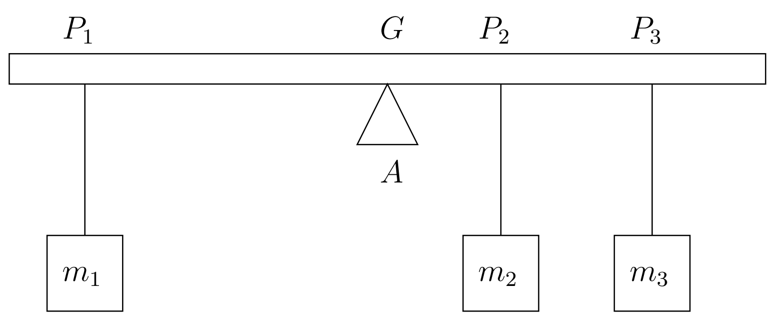
Suspend the meter stick at its center of gravity, with its numbers increasing from left to right. The meter stick should balance in a horizontal position.



Let the point at which the center of gravity is located be designated as G, and record its position in the table below.

G (cm)	m_1 (g)	P_1 (cm)	m_2 (g)	P_2 (cm)	m_3 (g)	P_3 (cm)
	350	10.0	550	65.0	150	

Hang the masses m_1 and m_2 at the positions P_1 and P_2 given in the table, using the figure below as a guide.



Then adjust the position of mass m_3 until a horizontal balance is obtained, and record this as P_3 in the table. Remember that the weight hanger itself has a mass of 50 grams.

Before we proceed, the mass of the clamp must be added to each mass to obtain the total mass that exerts a force at each point. The average mass of a clamp is 21 grams. Add this to each mass and record the total mass in the table below.

	Mass (kg)	Force (N)	Moment arm (m)	Torque (N m)
1				
2				
3				
Net Torque				

The moment arms of the forces about the axis A are obtained by finding the distance from each position P to the axis A. For this setup, the axis of rotation A is the same as the center of gravity G. Calculate these and enter them in the table provided.

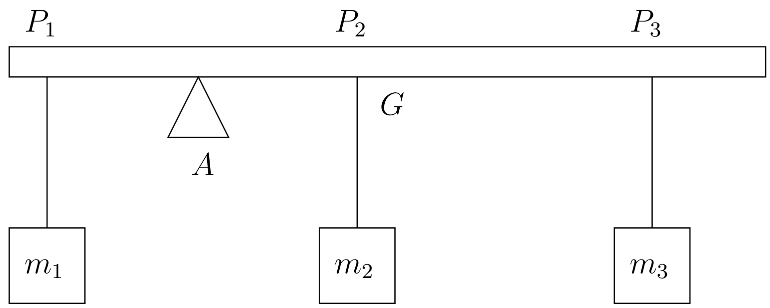
Calculate the torques, using the appropriate forces and moment arms. Take counterclockwise torques to be positive and clockwise torques to be negative. Finally, add all the torques to determine whether the net torque is zero.

2 Axis Not Through the Center of Gravity

Determine the mass of the meter stick (without any clamps).

Mass of meter stick (kg)	

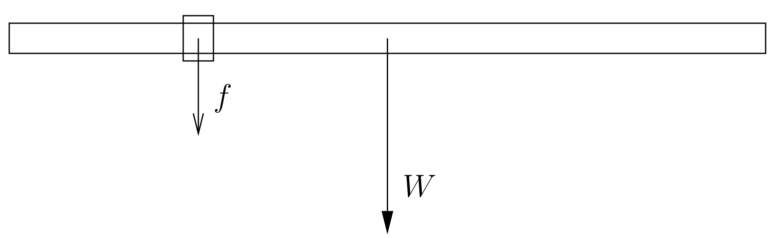
Suspend the meter stick on the axis A at the 25 cm mark. Add masses m_1 and m_2 at positions P_1 and P_2, as indicated in the table below, using the figure below as a guide.



A (cm)	m_1 (g)	P_1 (cm)	m_2 (g)	P_2 (cm)	m_3 (g)	P_3 (cm)
25.0	550	5.0	150	45.0	100	

Add m_3, and move it until the stick balances horizontally, and record its position as P_3 in the table. (The masses listed include the weight hangers, but not the clamp masses.)

Let us consider the meter stick plus the one clamp located at the axis of rotation to be a single object. Below is the beginning of a free-body diagram for this object.



We have included the weight W of the meter stick and the weight f of the clamp on the free-body diagram. Complete the diagram by drawing the rest of the forces that act on the object. There are three downward forces and one upward force that you need to add.

Complete the table below. The row labeled W is for the force of gravity that acts on the meter stick. As before, include the mass of the clamp in obtaining the total mass in rows 1, 2, and 3. Do not add the mass of the clamp to the mass of the meter stick in row W. As before, the moment arm is the distance from the force to the axis A.

	Mass (kg)	Force (N)	Moment arm (m)	Torque (N m)
1				
2				
3				
W				
Net Torque				

3 Arbitrary Axis Through One End

The equilibrium achieved above involved an actual axis of rotation A. The sum of the torques of an object in rotational equilibrium should be zero when calculated about *any* axis. In other words, we can choose any point at all to serve as our axis for the purpose of calculating torques, *whether or not it is the actual axis of rotation*. In this part, we will analyze the previous setup using an axis at the left end of the meter stick (the zero of the meter stick). Now, we need to take into consideration the torques produced by the forces at the 25 cm mark. (We did not need to do this before because that was our axis of rotation.) All of the forces now will have different moment arms, because of the new axis.

Now we need to measure or calculate the upward force F exerted on the meter stick clamp at the 25 cm mark by the knife-edge support. (This is the upward force on your free-body diagram above.) To measure the force

F, use a spring scale to lift the meter stick, together with all the hanging weights, off the knife-edge support. While the stick is thus suspended, and still in equilibrium, read the total weight, as shown by the scale, and record this in the table below.

Spring scale reading (g)	

Convert this measurement to a force in Newtons.

Measurement of upward force F (N)	

This is the force that the knife-edge support must exert on the clamp when the meter stick is supported on it, and it is the only upward force exerted on the meter stick.

Since the meter stick is in equilibrium when it rests on the knife-edge support, we know that the sum of all the forces is zero, and this allows us to calculate F from all of the downward forces. Calculate F in this way and compare it to the measured value you just obtained for F.

Calculation of upward force F (N)	

Complete the table below. The row labeled W is for the force of gravity that acts on the meter stick. As before, include the mass of the clamp in obtaining the total mass in rows 1, 2, and 3. The row labeled F is for the upward force of the knife-edge support on the meter stick. For best results, I suggest using your calculated value of F rather than your measured value. (The spring scales are not that accurate.) The row labeled f is for the weight of the clamp that sits on the knife-edge support.

	Mass (kg)	Force (N)	Moment arm (m)	Torque (N m)
1				
2				
3				
W				
F				
f				
Net Torque				

4 Questions

1. In section 3, our torque table contains rows for forces F and f. Those forces were present in the situation in section 2, but they are not listed in the torque table in section 2. Is that ok? Why?

5 Acknowledgments

This document was originally written by J. R. O'Donnell. It was modified by B. L. Hurst in 2000, and further modified by S. N. Walck in 2001 and 2007.