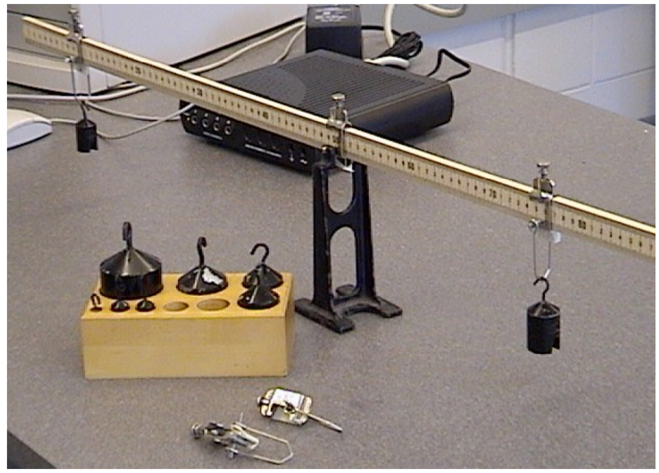
Torque

Object:

Today we will apply the conditions of linear and rotational equilibrium to a balance loaded with various masses.



Reference: Chapter 9 in Cutnell & Johnson.

Apparatus:

1. Meter Stick
2. Mass Hangers
3. Set of Masses
4. Pan Balance

Introduction:

The pan balance is a common piece of laboratory equipment to physicists, chemists, biologists, and any experimental scientist. The equal arm balance dates back to the times of the ancient Egyptians. Their initial design consisted of a beam balanced at the center with pans hanging form either end. As grains or pebbles were placed in the pans, the gravitational force acting at a distance from the axis of rotation produced a torque, which resulted in the rotation of the beam. Recall that torque is the product of force and moment arm:

$$\tau = rF\sin\theta$$

$$\tau = I\alpha$$

Thus, an equal *force* is not necessary to balance the beam. In order to stop the rotation, an equal but opposite *torque* needed to be applied to the beam. This is really nothing more than an application of Newton's Second law for rotational motion.

This is the design we will be using to examine torques and rotational equilibrium. We will use a meter stick, hanging masses and a fulcrum to apply torques to the meter stick and to achieve rotational equilibrium.

Procedure:

1. Using the pan balance, find the mass of the meter stick, the meter stick support clamp, and each of the mass hangers.

2. With the knife-edge clamp on the meter stick near its center, support the meter stick on the support stand. Adjust the meter stick through the clamp until the stick is balanced, and then tighten the clamp screw.

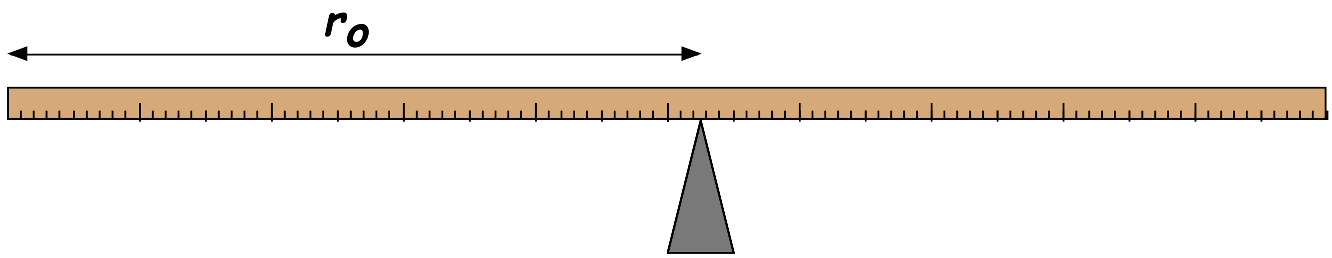


Figure 1: Finding the balancing point of a meter stick

Record the distance of the balancing point, r_o, from the zero end of the meter stick as indicated in figure 1. Note that the support will not necessarily be centered at the 50 cm mark on the meter stick.

CASE I: TWO KNOWN MASSES

1. With the meter stick on the support stand at r_o, suspend a mass m_1=200 gm at the 15 cm position.

2. Suspend a second mass m_2=200 gm on the other side of the support and adjust its moment arm, r_2, until rotational equilibrium is achieved. Record the moment arm, r_2, as indicated in figure 2.

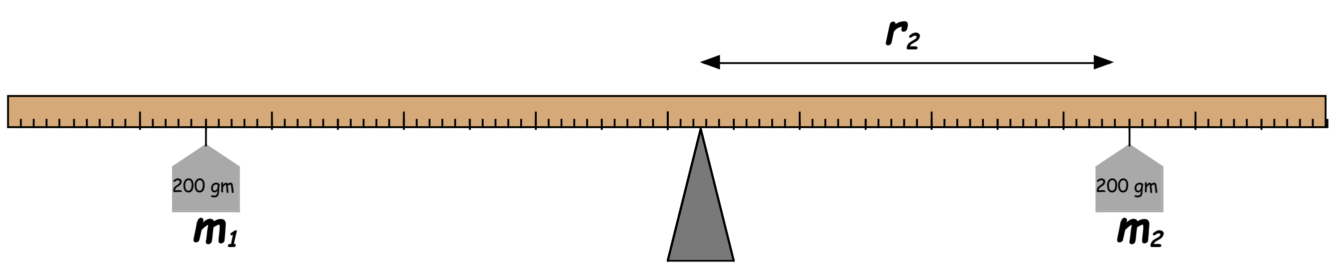


Figure 2: Balancing two known masses

3. Calculate the clockwise and counter-clockwise torques about the balancing point, r_o. How do they compare? What is the % difference between them? (Be sue to take into account the masses of the hangers!!)

CASE II: THREE KNOWN MASSES

1. Remove all the masses from the previous part such that the meter stick is again balanced at its fulcrum.

2. With the meter stick supported at r_o, suspend m_1=100 gm at the 30 cm mark, and m_2=200 gm at the 70 cm mark. Now suspend m_3=150 gm and adjust its moment arm until the system is

in rotational equilibrium as shown in figure 3. Record r_3. Again, calculate the clockwise and counter-clockwise torques and compare.

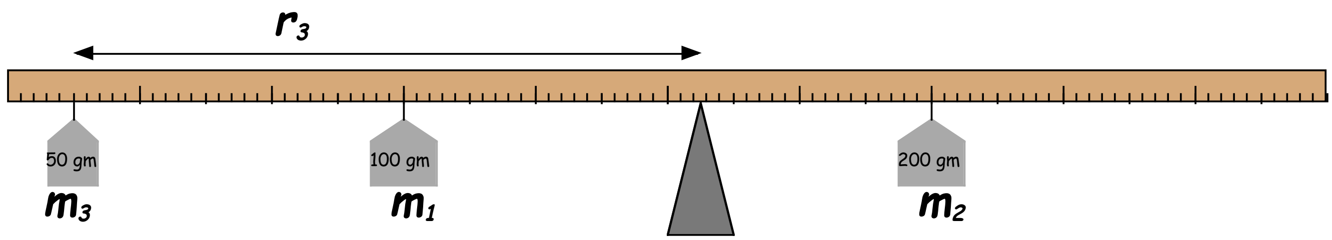


Figure 3: Balancing three known masses.

3. With m_1=100 gm at the 20 cm mark, and m_2=200 gm at the 60 cm mark, calculate the theoretical value of the moment arm r_3 for m_3=50 gm. Find the value experimentally and compare the theoretical and experimental values. Record their % difference.

CASE III: AN UNKNOWN MASS

1. Again, remove all the masses from the previous part such that the meter stick is again balanced at its fulcrum.

2. With the meter stick supported at r_o, suspend the unknown mass, m_1, near one end of the meter stick, say at about the 10 cm mark or so. Suspend from the other end of the meter stick an appropriate known mass and adjust its position until rotational equilibrium is achieved. Compute the value of the unknown mass by calculating clockwise and counter-clockwise torques, etc.

3. Use the pan balance to measure the unknown mass and compare to the calculated value. Compute the % difference.

CASE IV: METER STICK WITH ONE MASS

In the previous cases, the mass of the meter stick was not explicitly taken into account. This was because the weight of the meter stick acted through the fulcrum, which we were using as our center of rotation. Recall that when the moment arm is zero, the corresponding torque is also zero. Thus, the weight of the meter stick contributed no clockwise or counter-clockwise rotation and was ignored.

If we change the support position, we can no longer ignore the mass of the meter stick and its contribution to the torque about the center of rotation.

1. Loosen the support clamp and reposition it at the 30 cm mark on the meter stick.

2. Suspend a mass m_1=100 gm near the end of the meter stick and adjust its position until the system is in rotational equilibrium as shown in figure 4.

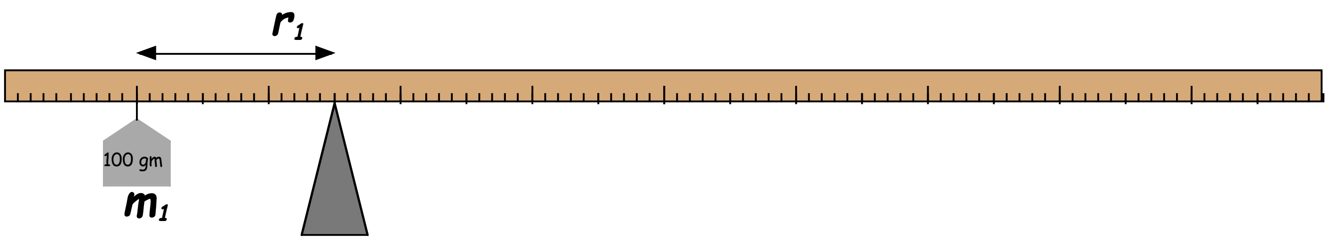


Figure 4: One mass with the meter stick

3. Calculate the clockwise and counter-clockwise torques about the point of support. The weight of the meter stick acts at the point r_o as if a mass equal to the mass of the meter stick, m_{ms} were suspended there.

4. Using the new support position as the center of rotation, calculate the mass of the meter stick, m_{ms}. Now use the pan balance to measure the mass of the meter stick and compare. Find the % difference between these values.

CASE V: METER STICK WITH TWO MASSES

1. Support the meter stick at the 20 cm mark. Suspend m_1=500 gm at the 10 cm mark. Calculate the moment arm for a mass m_2=100 gm such that the system will be in rotational equilibrium.

2. Adjust the position of mass m_2=100 gm until rotational equilibrium is achieved and record the moment arm.

3. Compare the theoretical (calculated) and experimental (experimentally determined) moment arms and find the % difference.

4. How does this final experimental set-up compare to the pan balance you have been using throughout the experiment? Sketch this final set-up and explain the similarities to the conventional pan balance.