

JoVE: Science Education
Torque
--Manuscript Draft--

Manuscript Number:	10345
Full Title:	Torque
Article Type:	Manuscript
Section/Category:	Manuscript Submission
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Science Education Title: Torque

Overview: The goal of this experiment ~~is will be~~ to understand the components of torque and to balance multiple torques on a system in order to achieve equilibrium.

Much like how a force causes a linear acceleration, a torque is a force that causes a rotational acceleration. It is defined as the product of a force and the distance the force is from the axis of rotation. If the sum of the torques on a system is equal to zero the system will not have any angular acceleration.

Principles of Torque: A torque is defined as the product of a force applied at some distance from the axis of rotation.

$$\vec{\tau} = \vec{F} \times \vec{r} \text{ (Equation 1)}$$

Where \vec{F} is the force applied and \vec{r} is the distance to the axis of rotation. Torque has units of force multiplied by distance and so is measured in Newton meters. Because torque is a vector, it has both magnitude and direction. The direction of the torque is perpendicular to the plane made by the force and distance components. Using one's right hand the direction can be determined. Extend the pointer finger in the direction of the first component. Then extend the middle finger in the direction of the second component. Once this is done, the direction of the extended thumb is the direction of the torque.

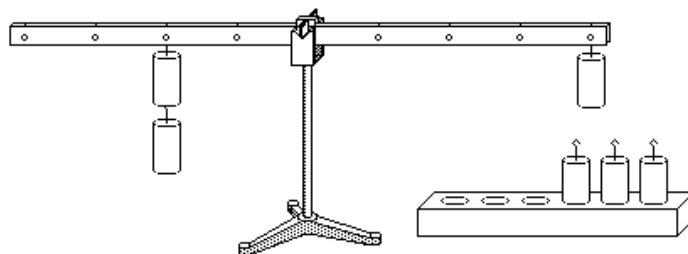
An example is a wrench tightening a bolt. A force is applied at the end of the wrench some distance from the bolt which provides a torque to rotate the bolt into place. The longer the distance \vec{r} the larger the torque as can be seen from Equation 1. The force needed to rotate an object can be reduced significantly by just increasing the length of the force to the axis of rotation.

A torque on a system will cause an angular acceleration on that system.

$$\vec{\tau} = \vec{\alpha} * I \text{ (Equation 2)}$$

Here $\vec{\alpha}$ is angular acceleration and I is the moment of inertia for that system. This is the rotational equivalent of Newton's second law $\vec{F} = m * \vec{a}$ with mass being replaced with the moment of inertia and acceleration being replaced with angular acceleration.

The experiment will consist of a meter stick which is able to rotate freely about its axis as shown in Figure 1.



(Figure 1)

Weights are attached at various lengths from the axis of rotation which will cause a torque on the system. If the torques on both sides are balanced the meter stick should not rotate from rest.

Procedure:

1. Using two weights to balance the beam

- 1.1) Start by connecting one 100 kg weight to the first hole on the right. Then connect a 100 kg weight to the first hole on the left. If released from rest the beam should not rotate.
- 1.2) Remove the 100 kg weight from the left side. Determine using Equation 1 where a 50 kg weight would need to be placed in order to balance the torque from the right side. Place the weight and confirm the prediction.

2. Using three weights to balance the beam

- 2.1) Connect a 50 kg weight to the first hole on the right. Place a 50 kg weight on the third hole to the right.
- 2.2) Determine where to place a 100 kg weight on the left side in order to balance the torques.
- 2.3) Determine where to place a 50 kg weight on the left side in order to balance the torques.

3. Using multiple weights to balance the beam

- 3.1) Connect a 100 kg weight to the fourth hole on the right side.
- 3.2) Using any combination of 50 kg and 100 kg weights find all the ways in which the torque from the right side can be balanced on the left side.

Representative Results:

Part 1.2: Connect a 50 kg weight to the second hole on the left.

Part 2.2: Connect the 100 kg weight to the second hole on the left.

Part 2.3: Connect the 50 kg weight to the fourth hole on the left.

Part 3.2: Six ways.

- 1) 100 kg - 4th hole
- 2) 100 kg - 1st hole, 100 kg - 3rd hole
- 3) 50 kg - 2nd hole, 100 kg - 3rd hole
- 4) 50 kg - 1st hole, 100 kg 2nd hole, 50 kg 3rd hole
- 5) 100 kg - 2nd hole, 50 kg - 4th hole
- 6) 50 kg - 1st hole, 50 kg 3rd hole, 50 kg 4th hole

These results confirm the predictions made by Equation 1. Each weight connected to the beam provides a torque on the system. While weights on one side cause a torque in one direction, weights on the other side cause a torque in the opposite direction.- When the ~~sumsome~~ of the torques on the beam is equal to zero the beam will not rotate if released from rest according to Equation 2. In each part of the experiment when the beam is in equilibrium the torques must be adding up to zero.;

Summary: In this experiment the two main components of torque were examined. Torque is the product of a force and the distance between the force and an axis of rotation. By placing different weights at different positions on a rotating beam, various quantities of torque were created. - The heavier weight corresponded to a larger force and therefore a larger torque. Placing weights further from the axis of rotation created a larger lever arm which resulted in a larger torque than if the same weight had been placed closer to the axis of rotation. When the total torque on the beam was equal to zero the system was in equilibrium.

Applications:

As mentioned in the principles section, a simple application of torque is that of a wrench tightening a bolt. The important thing to remember is that torque has two components. If it is difficult to tighten a bolt with the wrench in hand, a worker has two options. Either apply more force or just get a longer wrench. Usually the latter is the easier choice.

When a car commercial quotes some value of torque it would be a good idea to pay attention. As can be seen by the equation $\vec{\tau} = \vec{r} * I$ torque is what makes the wheels on a car accelerate. The more torque the more acceleration.

A seesaw on the playground is a perfect application of torque. The ~~beam wants to rotate~~ rotates about the fulcrum and the people sitting on either end provide the torque. ~~is provided by the people sitting on either ends.~~ If one person has more mass then the torque they provide will be larger and the person on the other side will be lifted up. To get them down the person on the ground provides a torque by pushing up with their legs to counter the force of their weight and they in turn are lifted up.

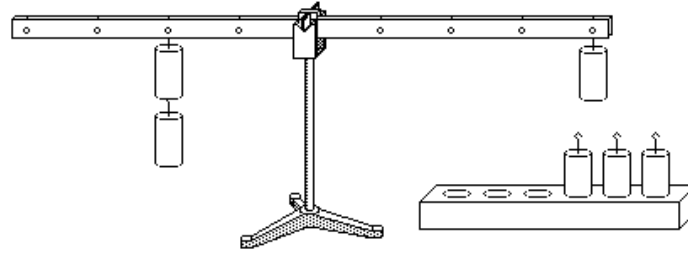


Figure 1