M24b: Torque Vectors

Introduction:

Torque is the application of a force on a body in such a way as to produce rotation of the body about some point. This means that a torque requires two pieces of information to adequately describe it, the magnitude and the direction of rotation. Torque is a vector defined by the cross product of the radius vector crossed into the force vector. This represents a three dimensional picture because the torque will always be perpendicular to both the radius and the force. The Torque Vector Apparatus makes it possible to investigate this three dimensional aspect of torques. Multiple torques will be applied to the apparatus and then a condition of equilibrium will be reached. The individual torques can be obtained by applying the definition of torque to the apparatus and making the appropriate measurements. The condition of equilibrium can be investigated by utilizing Newton's first law.

To conduct the experiment multiple torques are applied to the pivot ball by hanging masses from the balancing arms. Once the torques are applied the squeeze bulb is pumped to activate the air bearing. The pivot ball will rotate until it reaches a state of equilibrium. At this position each torque can be obtained. The direction of the torque can be read directly off of the degree scale on the base of the apparatus. The magnitude of the torque can be obtained by measuring the mass suspended from the balancing arm, calculating its gravitational force and then multiplying this by its measured effective lever arm. After all torques have been calculated a torque vector diagram can be constructed and the equilibrium condition checked.

Apparatus:

- Pivot ball with 6 rods for balancing arms
- Cm scale effective lever arm ruler
- Degree scale for direction
- Squeeze bulb for air bearing
- Mass Kit

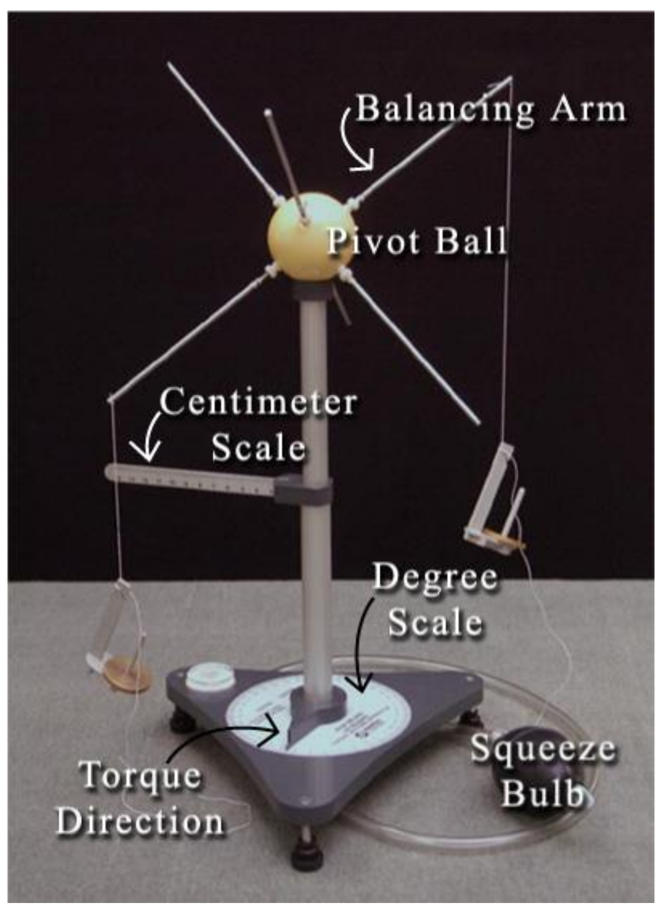


Figure 1

Discussion:

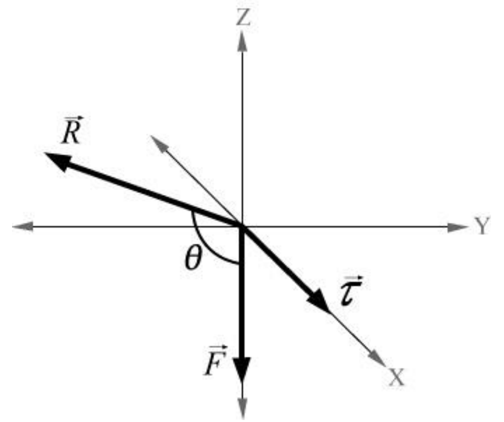
Mathematically torque is defined by the vector equation:

$\vec{\tau} \equiv \vec{R} \times \vec{F}$

$\vec{\tau}$ = the torque vector

$\vec{R}$ = the radius vector
(the distance from the axis
of rotations to the point where
the force is applied)

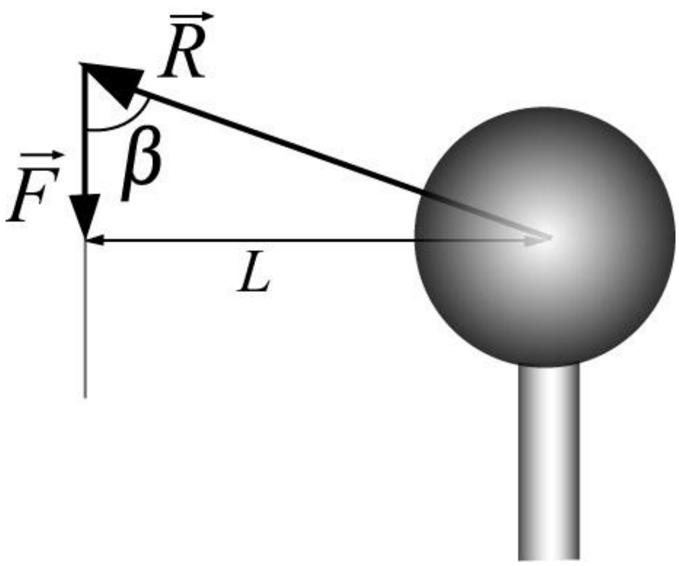
$\vec{F}$ = the applied force vector



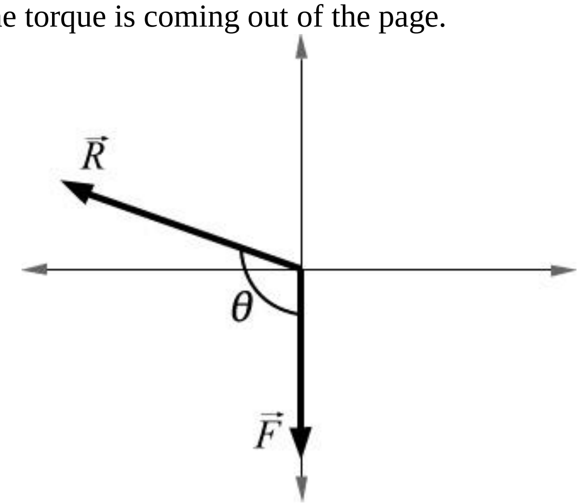
Next apply the definition of a cross product to this equation:

$$|\vec{\tau}| = |\vec{R}||\vec{F}|\sin\theta$$

This provides the magnitude of the torque. The direction of the torque is found by applying the right hand rule for vector cross products.



Consider the picture to the left taken from the apparatus. Since both the radius and the force are in the plane of the page, it means the direction of the torque is coming out of the page.

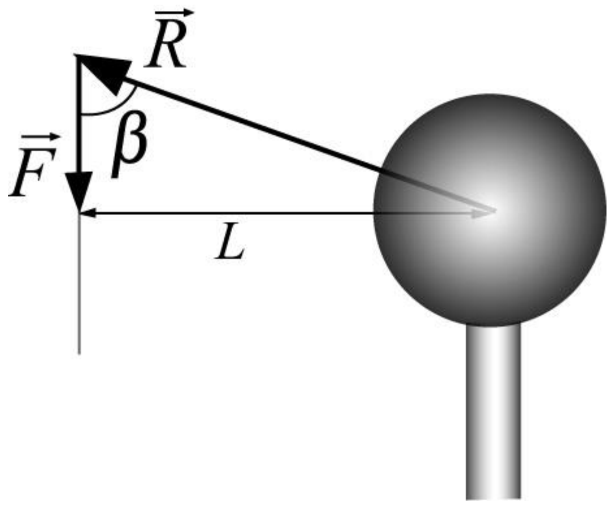


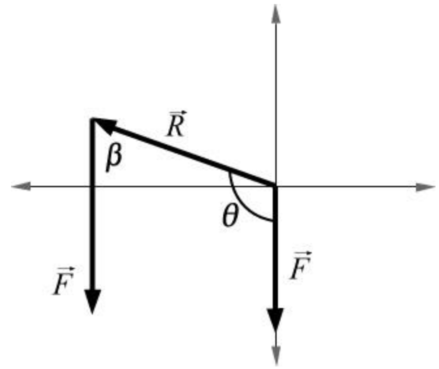
When looking at the two diagrams one may question which angle is the appropriate angle to use when finding the torque; theta or beta?

The definition of a vector cross product has the force vector and the radius vector beginning at the origin of the coordinate system.

Upon inspection it is found that the two angles theta and beta are related such that:

$$\sin\beta = \sin\theta$$





The apparatus does not allow the direct measurement of either angle beta or theta. But the effective lever arm can be measured.

L=the effective lever arm

Notice: $L = |\vec{R}|\sin\beta$

Now this can be utilized in the torque equation to give a simple expression for calculating the experimental torque:

$$|\vec{\tau}| = L|\vec{F}|$$

Newton's first law provides the necessary conditions for equilibrium of a body:

The sum of all forces applied on a body must equal zero.

The sum of all torques applied on a body must equal zero.

This apparatus allows the investigation of this second condition that the torques must equal zero.

Procedures:

1. Level the apparatus by adjusting the three screw-post legs as needed while observing the bubble level until the air bubble is centered in the circle. If there are any issues or questions, please see a lab instructor before proceeding.
2. Utilize five of the rods attached to the ball that are acting as balance arms. Do not remove any of the rods. All strings with mass hangers and masses must be attached to the pivot ball with it removed from the air shaft and setting on the table. Masses will be connected to the balance arms using the attached strings. Note: Attach the hangers to the strings in such a way that permits the string length to be easily adjusted. This may become necessary when measuring the effective lever arm.
3. Observe the following conditions when selecting the masses: The total mass added to each of the five rods must be different in magnitude; The mass added to any single rod must not exceed 50 grams; The total of all mass added to the device must not exceed 200 grams.
4. Place the selected masses on a hanger and measure their combined mass for each arm as precisely as possible. Then attach them to one of the arms. Do this with each mass & hanger combination.
5. Now very carefully pick up the pivot ball and place it onto the top of the air shaft.
6. Pump the squeeze bulb several times allowing the pivot ball to rotate. When the pivot ball quits rotating (except for small, seemingly random slight variations), even though the squeeze pump is still being pumped, then it has reached its state of equilibrium.
7. Check to be certain that none of the arms attached to the ball are in contact with the air shaft. If any of them are touching then adjust your mass selection until you find a combination that is in equilibrium and not touching.
8. Measure the direction of the torque and the effective lever arm for each of the five rods.
9. The centimeter scale measuring arm must be fully extended when measuring the effective lever arm but can be pivoted upward if necessary to more easily measure the torque direction. While making the measurements it is important to be very careful to not move the pivot ball on the apparatus. If it moves during any of the measurements then it voids all of the measurements collected up to that point. So if it moves then pump the bulb again to reach a new state of equilibrium and begin the measurements again.

Analyses:

1. Once all measurements are collected, calculate all forces and torques.
2. Since the torques are vectors calculate the components of each torque. Note there are no torque components along the z-axis, only along the x-axis and y-axis.
3. Calculate the sum of the (+ x-axis) torque components. Separately calculate the sum of the (– x-axis) torque components. Calculate the percent difference between these two values.
4. Calculate the sum of the (+ y-axis) torque components. Separately calculate the sum of the (– y-axis) torque components. Calculate the percent difference between these two values.
5. Construct a torque vector diagram using the head to tail method and verify the equilibrium condition.

Experiment M24b: Torque Vectors

Student Name____

*Lab Partner Name*____

*Lab Partner Name*____

Physics Course____

Physics Professor______________________________________

Experiment Start Date__________________________________

Lab Assistant Name	*Date*	*Time In*	*Time Out*

Experiment Stamped Completed

Data Sheets: M24b: Torque Vectors

NAME: ______________________________ DATE: __________________

	Rod 1	Rod 2	Rod 3	Rod 4	Rod 5
Mass					
Lever Arm					
Angle					
Force					
Torque					
Torque X-direction component					
Torque Y-direction component					