M24a: 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 balancing arms
- Cm scale effective lever arm ruler
- Degree scale
- Squeeze bulb
- Set of assorted masses
- 4 mass hangers

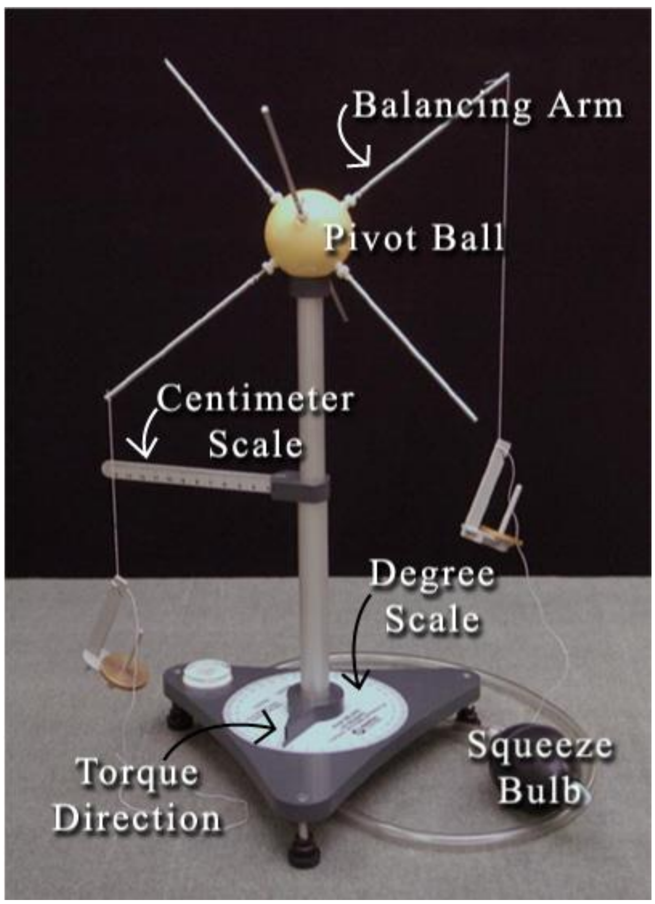


Figure 1

Discussion:

Mathematically torque is defined by the vector equation:

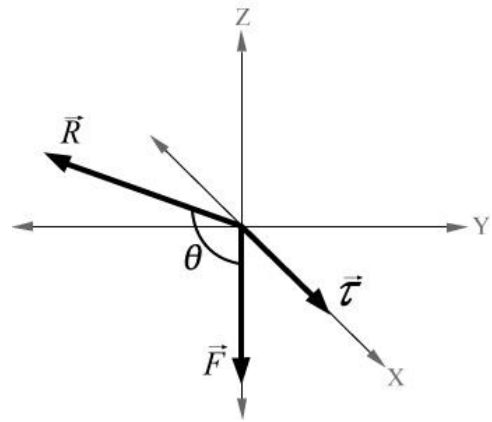
$\vec{\tau} \equiv \vec{R} \times \vec{F}$

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

$\vec{R}$ = the radius vector

(the distance from the axis of rotations to the point where the force is applied)

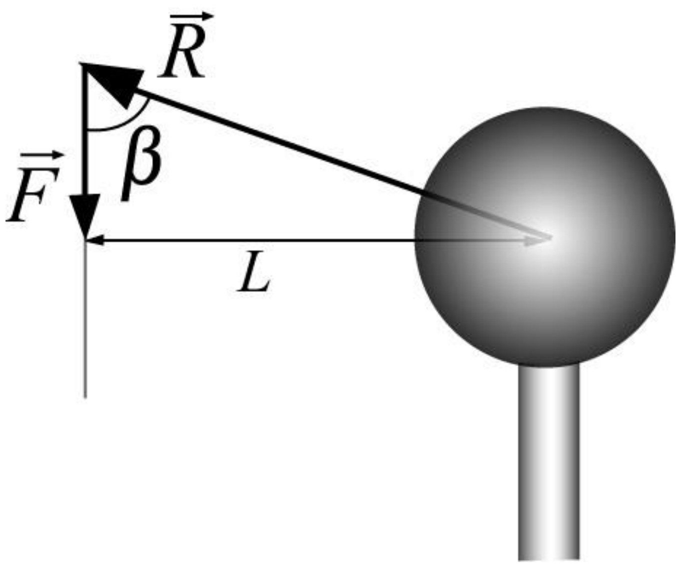
$\vec{F}$ = the applied force vector



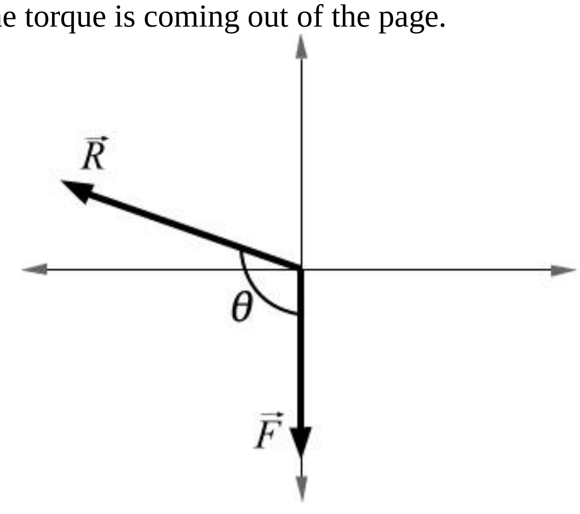
Next apply the definition of a cross product to this equation:

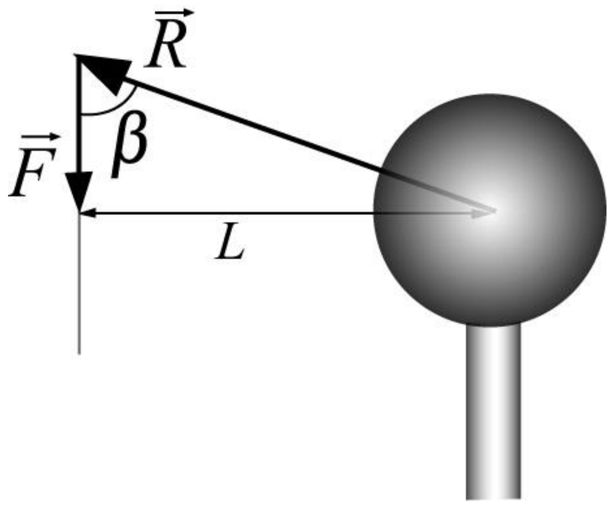
$$\left|\vec{\tau}\right| = \left|\vec{R}\right|\left|\vec{F}\right| \sin\theta$$

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.



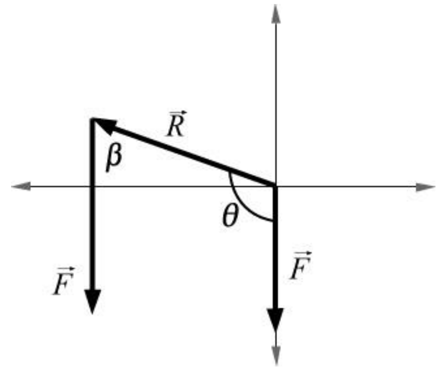


When looking at the two diagrams one may question which angle is the appropriate angle to use when finding the torque; theta or beta?

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. Confirm that the assorted masses kit with the torque vector apparatus has sufficient masses and hangers for the two trials: one 50 gram, five 20 gram, two 10 gram, two 5 gram and four light mass hangers.
2. 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.

Trial One:

3. The first trial will utilize three of the balance arms. All strings with mass hangers and slotted masses must be attached to the pivot ball with it removed from the air shaft and setting on the table. Masses will be attached to balance arms labeled (A, B, & C).
4. Note: Attach the strings to the balance arms in such a way that permits the length to be easily adjusted. This may become necessary when measuring the effective lever arm.
5. Place 10 grams on a hanger, measure their combined mass and attached them to arm A.
6. Next place 15 grams on a hanger, measure their mass and attached them to arm B.
7. Finally place 20 grams on a hanger, measure their mass and attached them to arm C.
8. Now very carefully pick up the pivot ball and place it onto the top of the air shaft.
9. 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.
10. Measure the direction of the torque.
11. Measure the effective lever arm.
12. 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.
13. Once all measurements are collected, calculate all torques, construct a torque vector diagram and verify the equilibrium condition.

Trial Two:

14. Follow the same procedures as the first trial. Attach mass hangers to balance arms (A, B, D, & E). Place 40 grams on the hanger attached to arm A, 45 grams to arm B, 35 grams to arm D and 50 grams to arm E. Carefully place the pivot ball on the air shaft. Pump the squeeze bulb until a state of equilibrium is reached. Make all necessary measurements. Calculate all torques, construct a torque vector diagram and verify the equilibrium condition.

Experiment M24a: 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: M24a: Torque Vectors

NAME: ______________________________ DATE: __________________

TRIAL ONE

Arm "A"			Mass:__________		
Force	**Lever Arm**	**TORQUE Magnitude**	**TORQUE Direction**	**TORQUE X Component**	**TORQUE Y Component**

Arm "B"			Mass:__________		
Force	**Lever Arm**	**TORQUE Magnitude**	**TORQUE Direction**	**TORQUE X Component**	**TORQUE Y Component**

Arm "C"			Mass:__________		
Force	**Lever Arm**	**TORQUE Magnitude**	**TORQUE Direction**	**TORQUE X Component**	**TORQUE Y Component**

Sum of Positive X Components	Sum of Negative X Components	% Difference

Sum of Positive Y Components	Sum of Negative Y Components	% Difference

Data Sheets: M24a: Torque Vectors

NAME: ______________________________ DATE: __________________

TRIAL TWO

Arm "A"				**Mass:___________**	
Force	**Lever Arm**	**TORQUE Magnitude**	**TORQUE Direction**	**TORQUE X Component**	**TORQUE Y Component**

Arm "B"				**Mass:___________**	
Force	**Lever Arm**	**TORQUE Magnitude**	**TORQUE Direction**	**TORQUE X Component**	**TORQUE Y Component**

Arm "D"				**Mass:___________**	
Force	**Lever Arm**	**TORQUE Magnitude**	**TORQUE Direction**	**TORQUE X Component**	**TORQUE Y Component**

Arm "E"				**Mass:___________**	
Force	**Lever Arm**	**TORQUE Magnitude**	**TORQUE Direction**	**TORQUE X Component**	**TORQUE Y Component**

Sum of Positive X Components	**Sum of Negative X Components**	**% Difference**

Sum of Positive Y Components	**Sum of Negative Y Components**	**% Difference**