Torque and Rotation

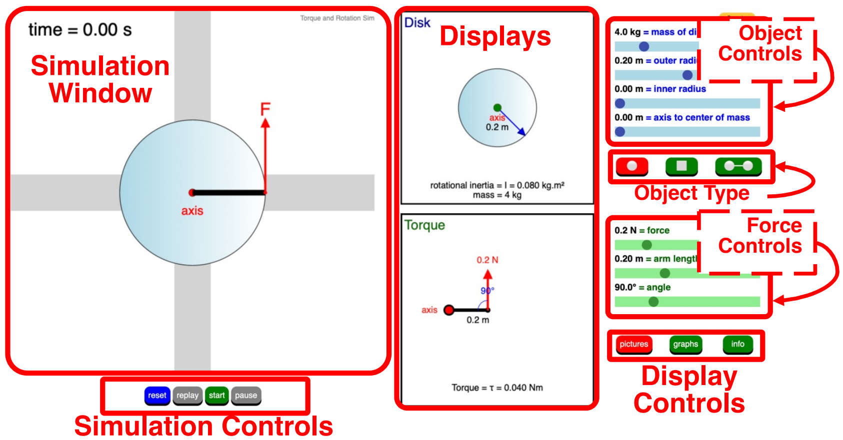
Purpose: To identify the variables that affect the angular acceleration of an object.

Getting Ready: Navigate to the **Torque and Rotation Simulation** found in the **Physics Interactives** section at **The Physics Classroom**.

https://www.physicsclassroom.com/Physics-Interactives/Balance-and-Rotation/Torque-and-Rotation

Navigation:
www.physicsclassroom.com => Physics Interactives => Balance and Rotation => Torque and Rotation

Getting Acquainted/Play: This interactive consists of a simulation window on the left side of the screen, some **Simulation Controls** below it, a collection of **Display and Output Parameters** in the middle of the screen, and several **Slider Controls** for the **Input Parameters** on the right side of the screen. The **Input Parameters** control properties of the object (object type, mass, and dimensions) and properties of the force (magnitude, direction, and location where it is applied). The **Display** options include Pictures, Graphs, and Info. **Output Parameters** include rotational inertia, torque, and a collection of rotational quantities pertaining to kinematics, momentum, and kinetic energy.



Spend some time experimenting with the sliders and controls; this includes the simulation controls, the display controls, and the sliders for the input parameters. Be sure to understand the distinction between **Replay** (returns the simulation to the initial state without changing the input parameter values) and **Reset** (returns the simulation to the initial state and changes the input parameters to the original default values). Familiarize yourself with the three display options. Experiment with the three object types – disk, rectangle, and barbell. Once you have acquired some familiarity with the interface, tap on the **Reset** button, select the **Pictures** display, and select the **Disk** object type. Begin Part 1 below.

Part 1: What Does Torque Do?

1. Set the **Force** sliders so that there is a torque displayed in the **Torque Display** panel. This may require changing the force **angle** and the **arm length**. Press **Start** and observe the simulation. Is the disk changing its angular velocity? ___________ Does the disk have an angular acceleration? ______________ Tap the **Graph** or **Info** display if uncertain. Write a simple sentence explaining the effect that torque has on the disk's motion.

Part 2: What Affects Torque? What Affects Angular Acceleration?

Torque causes an object to change its angular velocity. That is, torque causes an angular acceleration. Now we will investigate the variables that do and don't affect the torque value.

2. Tap the **Reset** button to restore all default values. Use a range of different force values to investigate the possible effect of force upon **torque** (τ) and **angular acceleration** (α). Use the **Graphs** display to acquire angular acceleration (α) values. Control other variables, changing only the value of the force. Also do some doubling and tripling of the force. Record your results in the table at the right.

Trial	Force (N)	τ (N•m)	α (rad/s^2)
1			
2			
3			
4			

3. How does **force** affect the **torque**? How does a doubling or a tripling of the force affect the torque? Make a claim and support it with evidence and reasoning.

4. How does **force** affect **angular acceleration**? How does a doubling or a tripling of the force affect angular acceleration? Make a claim and support it with evidence and reasoning.

5. Now let's investigate the effect of the direction of the force upon torque. Tap the **Reset** button to restore all default values. The default value for angle is 90°. This **angle** is the angle between the line along which the force acts and a second line drawn from the axis of rotation to the point on the object where the force is applied. For a disk, a line draw from the axis to the point of application of the force is in a *radial direction*. And so, for an **angle** of 90°, the force is applied tangent to the disk or perpendicular to the radial line. Drag the angle slider and observe torque values displayed in the **Torque Display** panel.

   a. What angle results in the greatest torque? __________

   b. Is/are there any angle(s) that would result in no torque? _________ If so, what are they?

   c. How does the torque for an angle of 60° (30° short of ⊥) compare to an angle of 120° (30° past ⊥)? ______________________

6. Repeat the same student (described in question #5) for a **Square** object type. What did your find out about the angle of greatest torque, the angle of no torque, and the 60°-120° comparison?

7. Repeat the same student (described in question #5) for a Barbell object type. What did your find out about the angle of greatest torque, the angle of no torque, and the 60°-120° comparison?

8. Tap the **Reset** button to restore all default values. The last force property that can be changed is the location where the force is applied. In the simulation, this is depicted as the distance from the axis of rotation to the point on the object where the force acts. (NOTE: A *massless, rigid torque arm* extends radially from the object's center beyond the disk's edge. And so, a force acting at a location beyond the object's edge can still cause a torque on the object due to its action upon the torque arm. Yes; weird.) This distance is called the **arm length** (not to be confused with the *moment arm*).

   Use a range of **arm length** (**d**) values to investigate the effect of **d** on **torque** (τ). Control other variables, changing only the arm length. Also do some doubling and tripling of the arm length. Record your results in the table at the right.

Trial	d (m)	τ (N•m)
1		
2		
3		
4		

9. How does **arm length** affect the **torque**? How does a doubling or a tripling of the arm length affect the torque? Make a claim and support it with evidence and reasoning.

10. Tap the **Reset** button to restore all default values. Make modifications of object properties – mass, outer radius, inner radius, distance from the rotation axis to the center of mass (COM). Do object properties affect the torque? ____________

Part 3: Rotational Inertia

Rotational inertia refers to the tendency of an object to resist changes in its rotational state. Now we will investigate variables that do/do not affect the rotational inertia.

11. Tap the **Reset** button to restore all default values. Use a range of **mass** (**m**) values to investigate the effect of **m** on the **rotational inertia** (**I**) of a solid disk. Control other variables, changing only the mass. Also do some doubling and tripling of the mass. Record your results in the table at the right.

Trial	m (kg)	I (kg·m²)
1		
2		
3		
4		

12. How does **mass** affect the **rotational inertia**? How does a doubling or a tripling of the mass affect the I value? Make a claim and support it with evidence and reasoning.

13. Reset the mass to 4.0 kg. Use a range of **outer radius** (**R_{outer}**) values to investigate the effect of **R_{outer}** on the **rotational inertia** (**I**) of a solid disk. Control other variables, changing only the **R_{outer}** value. Also do some doubling and tripling of the **R_{outer}**. Record your results in the table at the right.

Trial	R_{outer} (m)	I (kg·m²)
1		
2		
3		
4		

14. How does **R_{outer}** affect the **rotational inertia**? How does a doubling or a tripling of the outer radius affect the I value? Make a claim and support it with evidence and reasoning.

15. Reset the outer radius to 0.20 m. Modify the distance from the axis of rotation to the center of mass of the solid disk. How does an increase in this distance affect the rotational inertia?

16. Tap the **Reset** button to restore all default values. Modify the inner radius of the disk so that it becomes a **Disk with Hole**. Note that the mass is not changing; only the location of the mass is being changed. As the inner radius is increased, the mass begins to concentrate further and further from the COM. What affect does this have upon the rotational inertia?

17. Tap on the **Rectangle** object type. Adjust the dimensions so that the rectangle is 10 times wider than its height (e.g., 0.20 m x 0.02 m). Record the **rotational inertia** (**I**). Then without changing the height, gradually change the width and record the **I** value.

Trial	Width (m)	Height (m)	I (kg•m^2)
1	0.20	0.02	
2		0.02	
3		0.02	
4		0.02	

18. Suppose we refer to this shape as a **solid rod**. How does increasing the length (width) of the rod affect its rotational inertia? Can you identify a quantitative pattern in how doubling or a tripling the length affects the I value?

19. Modify the distance from the axis of rotation to the center of mass of the solid rod. How does an increase in this distance affect the rotational inertia?

20. Tap the **Reset** button to restore all default values. Select the **Barbell** object type. Modify the **mass** (**m**) of the spheres to determine the effect of **m** on the **rotational inertia** (**I**) of a barbell. Do some doubling and tripling of the mass. Record your results in the table at the right. How does the sphere's **mass** affect the **rotational inertia**? How does a doubling or a tripling of the mass affect the I value? Make a claim and support it with evidence and reasoning.

Trial	m (kg)	I (kg•m^2)
1		
2		
3		
4		

21. Reset the mass of sphere to 4.0 kg. Modify the **separation distance** (**d**) between the spheres to determine the effect of **d** on the **rotational inertia** (**I**) of a barbell. Do some doubling and tripling of the separation distance. Record your results in the table at the right. How does the **d** value affect the **rotational inertia**? How does a doubling or a tripling of the separation distance affect the I value? Make a claim and support it with evidence and reasoning.

Trial	d (kg)	I (kg•m²)
1		
2		
3		
4		

Part 4: Angular Acceleration, Torque, and Rotational Inertia

22. Conduct a controlled study in which you investigate the quantitative effect of **rotational inertia** (**I**) upon the **angular acceleration** (α). Be sure to double, triple, and quadruple the **I** value. Describe your method below. Record your data in the table.

Trial	I (kg•m²)	α (rad/s²)
1		
2		
3		
4		

23. Describe the mathematical relationship between **I** and α. Support your answer with references to your data. Finally, write a proportionality statement ($\alpha \propto$ **...**) that matches your data.

24. Repeat the above process to conduct a controlled study in which you investigate the quantitative effect of **torque** (τ) upon the **angular acceleration** (α). Be sure to double, triple, and quadruple the τ value. Describe your method below. Record your data in the table.

Trial	τ (N•m)	α (rad/s^2)
1		
2		
3		
4		

25. Describe the mathematical relationship between τ and α. Support your answer with references to your data. Finally, write a proportionality statement ($\alpha \propto$ **...**) that matches your data.

26. Use the results of your Part 4 studies to propose an equation that relates the three variables – α, τ, and **I**.