I. Objectives

1. Investigate the similarities between rotational and linear motion kinematics equations.
2. Demonstrate the relationship among force, lever arm, and torque.

II. Introduction

In this lab we'll determine the corresponding linear and rotational kinematics variables, calculate both linear and angular velocities, and determine how a lever arm affects the amount of force that needs to be applied to an object.

III. Calculations

In order to calculate angular displacement, velocity, and acceleration, we can utilize kinematics equations analogous to those we use for linear displacement, velocity and acceleration:

Table 1 Kinematics Equations for Rotational and Linear Motion

Parameter	Rotational motion, constant α	Parameter	Linear motion, constant a
Angular displacement	$\theta = \frac{1}{2}(\omega_0 + \omega)t$	Linear displacement	$x = \frac{1}{2}(v_0 + v)t$
Angular displacement	$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$	Linear displacement	$x = x_0 + v_0 t + \frac{1}{2}at^2$
Angular velocity	$\omega = \omega_0 + \alpha t$	Linear velocity	$v = v_0 + at$
Angular velocity	$\omega^2 = \omega_0^2 + 2\alpha\theta$	Linear velocity	$v^2 = v_0^2 + 2ax$
Average angular velocity	$\overline{\omega} = \frac{\theta - \theta_0}{t - t_0}$	Average linear velocity	$\overline{v} = \frac{x - x_0}{t - t_0}$
Average angular acceleration	$\overline{\alpha} = \frac{\omega - \omega_0}{t - t_0}$	Average angular acceleration	$\overline{a} = \frac{v - v_o}{t - t_0}$

Part 1 Door

The equation for torque is:

$$\tau = F\ell$$

Part 2 Turntable

To convert from degrees to radians remember that 2π radians = 360^0 so to convert:

angle in radians = $\dfrac{\pi}{180^0}$ x angle in degrees

angle in degrees = $\dfrac{180^0}{\pi}$ x angle in radians

Table 2 Tangential and Centripetal Equations

Parameter	Equation
arc length	$s = r\theta$
tangential velocity	$v_T = r\omega$
tangential acceleration	$a_T = r\alpha$
centripetal acceleration	$a_c = \dfrac{v_T^2}{r} = \dfrac{(r\omega)^2}{r} = r\omega^2$
acceleration magnitude	$a = \sqrt{a_c^2 + a_T^2}$
acceleration vector	$\boldsymbol{a} = \boldsymbol{a_c} + \boldsymbol{a_T}$

Part 3 Bicycle Wheel

No calculations are necessary for this part of the lab.

IV. Equipment and Materials

Turntable, “sticky” dots, ruler, stop watch, bicycle wheel, rotating stool, calculator

V. Procedure

Part 1 Door

1. Unlatch the classroom door. Stand at right angles to its surface and push on the edge farthest from the hinge with just enough force to open it.

2. Again, unlatch the classroom door, and stand at right angles to its surface. This time apply just enough force, not to the edge of the door, but at a point halfway between the edge of the door and the hinge to open the door.

3. Repeat the process one more time, but apply the force a few centimeters from the door hinge. Be careful not to get your fingers caught in the hinge or door.

4. Record your observations about the amount of force required to open the door in each situation.

Part 2 Turntable

5. Place a sticky paper dot on the turntable approximately halfway between the center and the edge, and place another near the edge. If there are already sticky paper dots on the turntable, you may use those for your measurements.

6. Measure the distances from the center of the turntable to the center of each dot and record in Table 3, column B.

7. Calculate the total distance that each dot will travel during its 5 rotations and record in Table 3, column C. Remember 5 rotations is equivalent to 10π radians.

8. Rotate the turntable, time 5 rotations, and record the total time for all 5 rotations in Table 3, column D.

9. Complete Table 3.

10. Complete Table 4.

Part 3 Bicycle Wheel

11. Sit on the rotating stool holding the bicycle wheel by its handles. Ask your lab partner to spin the wheel.

12. Try tilting the wheel sideways, then stop the wheel from spinning and tilt the wheel again. Record your observations.

13. Try the same process, while spinning slowly on the stool. Record your observations.

VI. Data

Table 3 Turntable

A	B	C	D	E = C/D	F = E/B
Object	Distance *r* from center in m	Total linear distance in m	Total time in s	Linear speed *v* in m/s	Angular speed ω in rad/s
Dot #1					
Dot #2					

Table 4 Linear and Rotational Variables

A	B	C
Parameter	Linear motion variable	Rotational motion variable
displacement		
velocity		
acceleration		

VII. Discussion Questions

Part 1 Door

1. Did the force required to open the door depend on the distance from the hinge? How is this related to the concept of torque?

2. For which situation was the most force required? For which situation was the least force required? Why?

Part 2 Turntable

3. Explain why the linear velocities for the dots are different, but the angular velocities are the same. If the values you calculated in Table 3, column E are not approximately the same, you will need to redo your calculations.

Part 3 Bicycle Wheel

4. Describe the differences among the relative forces required to turn the bicycle wheel during the following situations:

   stool not rotating and wheel rotating clockwise or counterclockwise with its axis (handle) vertical:

   stool rotating clockwise and wheel rotating clockwise with its axis vertical:

   stool rotating clockwise and wheel rotating counterclockwise with its axis vertical:

   stool rotating clockwise and wheel rotating clockwise with its axis horizontal:

   stool rotating clockwise and wheel rotating counterclockwise with its axis horizontal: