TA name ___________________________ Name _________________________

Lab section __________________________ UW Student ID # _________________________

Date ______________________________ Lab Partner(s) _________________________

TA Initials (on completion)_____________ _________________________

EXPERIMENT 7: ANGULAR KINEMATICS AND TORQUE (V_3)

121 Textbook Reference: ***Knight*****,** Chapter 13.1-3, 6.

SYNOPSIS

In this lab you will be introduced to two topics important for describing and quantifying rotational motion: A) rotational kinematics and B) Torque. In this Lab, part B, only static equilibrium situations will be considered. In Lab 8 you will repeat and use some of these concepts to study the dynamics of rotation about a fixed axis and measure moment of inertia, much like earlier in the study of mechanics you learned first about translational kinematics (Labs 1 and 2) followed by force, mass and translational dynamics (Labs 3 and 4).

A. ANGULAR KINEMATICS

When describing the rotation of a rigid body (not a point particle), it is particularly useful to utilize coordinates other than the rectangular (*x,y,z*) set we are used to. The simple cases of rotational motion you will see in these labs involve rotations either about an axis fixed in space (position and direction), or about an axis that if translating, like for an object rolling down an inclined plane, keeps its orientation fixed. Further simplifications occur when rotating objects are symmetric about the axis of rotation, in which case the axis of rotation goes through the Center of Mass of the object. For these simple cases, we will use (R,θ) coordinates as defined in the Fig. 1 below.

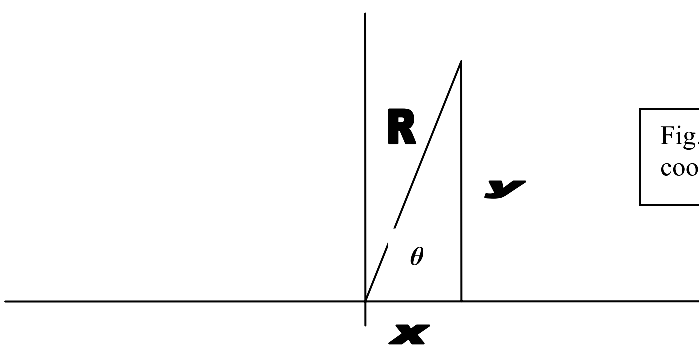


Fig. 1. The relationship between x,y rectangular coordinates and R, θ cyllindrical coordinates.

The relationship between the two sets of coordinates is given by:

$$x = R\cos\theta$$

$$y = R\sin\theta$$

For a three dimensional object rotating about a fixed axis, every small portion of its mass (Δm) rotates by the same angle as a function of time, no matter how close or far from the axis of rotation Δm happens to be. Every element of mass also has the same angular velocity, $\omega = \frac{\partial \theta}{\partial t}$, and the same angular acceleration, $\alpha = \frac{\partial \omega}{\partial t}$.

The TA will help the class make two stroboscopic movies of a rotating bicycle wheel, one while the wheel rotates freely and one when a weight hangs from the ream. A place on the ream of the wheel will have a piece of tape (black or gray marker) so it is easy to track that spot on the video. You will need a half-meter stick to be in the picture, without anybody standing in front of it, and close to the wheel. The base supporting the wheel is a good spot for it. TA will demonstrate the use of the camcorder and, when the class has acquired a good set of data, the data file will be saved on a server. For the first video, spin the wheel fast enough to have it turn one or more turns in about one second and video record its motion using ***VideoPoint*** software, as in Lab 2. Select the portion of the video for analysis (about ¾ of a full circle, or so). Save the video in the lab server with a name easy to identify. For the second video, use a string wrapped around the rim to hang a weight (about 250 grams). Hold the wheel and weight stationary. Start the video recording, release the wheel and weight, and stop the filming. Select the portion of the video you want to save (perhaps half to ¾ of a turn). Make another file in the server. You will download the resulting image files, using the ***VideoPoint*** software to make a table of data, make graphs, and analyze the motion of the taped "dot".

1. Motion with constant angular velocity.

We first explore motion with constant angular velocity (approximately equal angular displacements occur during equal time intervals).

1.1-Procedure

Open the program entitled "VideoPoint 2.5" in the 117/121Z folder.

You should download to your computer the file you just made for uniform circular motion following steps 1 to 3 below.

VideoPoint 2.5 Software Directions

1. If the lab software is not already running, double-click on **"VideoPoint 2.5"** on the Windows™ desktop. Even if it is running, you may wish to restart the software to be sure no settings have been altered.
2. After the **"About Video Point"** screen appears, click to close it.
3. Click on **"Open Movie".** Double click on the directory with your Lab 7 file**.** In the file selection list, double click on the appropriate data file.
4. Check that the number of objects to be tracked is 1, then click OK
5. **Maximize** the screen.
6. Click on the **"ruler"** icon (6^{th} from the top) on the left tool bar**.** On the **Scale Movie** screen that appears, you should see **1.00 m** , **<Origin 1>** and **Fixed** selected. CHANGE the 1.00m to 0.50 m. Click **Continue**.
7. Click the target cursor <u>carefully</u> on both ends of the meter stick in the video.

8. Use the cursor to click on the tape spot in every frame, clicking until motion ends. The image may blur if the velocity of the ball increases, or you may have too many points in the second video. Click on a consistent part of the image.
9. Transform origin: Click on Pointer Arrow (second on left margin). Drag origin to desired origin, which in this case is the center of the bicycle wheel. This step renormalizes all your readings to x,y and R,θ axis at center of wheel
10. Click on the **"data table"** (7th from the top) on the left tool bar and make prints of the data table for you and partner(s), for record keeping.

This concludes the data taking required for the uniform circular motion portion. Do the video with the falling weight later, after you analyze the first video. When you get there, choose **open** from the file menu and then repeat the procedure through 10.

1.2- Click on the **"plot"** icon (8th from the top) on the left toolbar**.** Select x-coordinate vs time, and y-coordinate vs. t. Print a copy for each partner. If things have gone well, your x *vs.* t and y *vs.* t graphs should have a familiar sinusoidal shape. Measure the radius of the bicycle wheel and write it down.

R = __________ ±________ m

Does the measured radius agree with your printout at maximum or minimum x or y excursion? If this does not seem right, check with TA!

1.3- Make graphs of v_x *vs.* t and v_y *vs.* t. Print copies for each partner. These graphs now may have (likely) some scatter, but they should have a familiar look, corresponding to the respective x *vs.* t and y *vs.* t graphs. Draw a smooth line through the velocity points in each of the graphs, averaging *by eye* as you go along, guided by the x and y plots. Write a sentence below explaining what you did. Does the phase of each one of the velocity graphs agree with the phase in the respective position vs time graphs?

1.4- In each of the velocity graphs, draw qualitative lines showing what the x and y components of the acceleration, a_x and a_y, should look like. Be careful with their phase relationship to the velocities. You should have now a complete set of what approximately uniform circular motion (no angular acceleration) looks like when described in rectangular x,y coordinates. If you want to check that your acceleration graphs are right, plot a graph of a_x *vs.* t and a_y *vs.* t, print a copy for each partner, check with your qualitative trace, and add it to your stack.

1.5- Use the ***VideoPoint*** software to generate a graph of angle θ *vs* t. Note that angular measurements are in radians, not degrees. Make a copy of this graph for each partner.

1.6- Write a paragraph describing the graph you just copied. Comment on the following statement: *if I had chosen a point half way between the rim and the axis of rotation the graph on Section 1.5 will look exactly the same* (True or false, and explain why!)

1.7- Calculate the angular velocity of the wheel using two methods: a) Using a ruler, draw your best line fit to your graph of θ *vs.* t and find the slope of that line, and b) Use ***VideoPoint*** to generate a graph of angular velocity versus time. Do the two methods agree? Comment on agreement, or lack of agreement. Should the two methods give the same answer? How about uncertainties? Is one method much better than the other one?

ω (ruler) = ________±_____ s^{-1} ω (graph) = __________±_______ s^{-1}

1.8- Angular and tangential velocities for particles in circular motion are related by

$$v_T = R\omega$$

In your graph of x (or y) position vs. t find the time at which x (or y) is maximum. Use your value of v_y (or v_x) at that same time and your value of R from Section 1.2 above to calculate ω at that same time.

ω =____________±________ s^{-1} (calculated from x-y measurement)

Does this value agree with the one you determined in Section 1.7? Comment briefly.

2. Motion with constant angular acceleration

2.1- Download the video with the motion of the wheel when a weight was hanging, and repeat the steps needed to make a table of data of position of the tape on the rim vs. time. Remember to set both the scale with the meter stick and the origin of rectangular coordinates. We will not go through all the analysis with linear coordinates. Produce graphs of angular displacement vs. time, angular velocity vs. time, and angular acceleration vs. time using the ***VideoPoint*** software. Make a copy of all graphs for each partner.

2.2- On the θ *vs.* t graph, use tangents to calculate the angular velocity, ω at two times, one near the start of your recording of the motion, one near the end of the recorded motion.

ω_1 =________________ s^{-1}

ω_2 =________________ s^{-1}

Place these points in your *ω vs. t* graph. Do they seem to fit in the right place? If they don't, check with TA!
2.3- A straight line drawn between ω_1 and ω_2 should look like the "average fit" of your *ω vs. t* graph (one can use F (Fit) in upper right corner of graphs to fit a straight line through data).

2.3- The slope of this line should be the constant angular acceleration. Do the calculation and place your calculated value in the angular acceleration vs. time graph. If not right, check with TA!!!

You have now a set of measurements of angular displacement, angular velocity, and angular acceleration for constant angular acceleration that hopefully helps you visualize the relationship between linear and angular positions, velocities, and accelerations. The uniform accelerated circular motion could have been analyzed further to calculate centripetal and tangential accelerations and how they relate to the angular quantities.

B. TORQUE AND EQUILIBRIUM

In most instances not all the forces acting on an object of mass *m* are known and/or are applied directly to the center of mass of the object. Often forces are applied at different locations of a rigid body and they are not aligned in any particular way. When this occurs, rotational motion may occur. The concept of **TORQUE** (***τ***), force (***F***) applied at a certain distance (***R***) from a pivot point with the vectors ***R*** and ***F*** making an angle *θ* between them allows us to formally understand and find the equations of motion of rigid bodies. Written in the vector form:

$$\tau = R \times F$$

The magnitude of ***τ*** is given by $\tau = R\,F\,\sin\theta$, see Fig. 2 below.

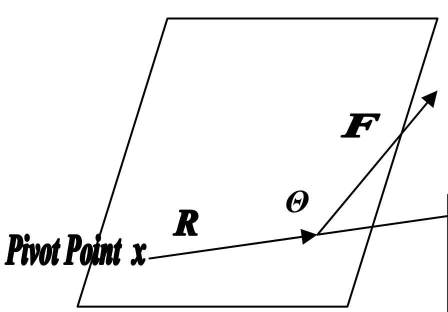


Figure 2. The vectors **R** and **F** and the angle θ defining torque for a two-dimensional object (a parallelogram). For the directions of **R** and **F** shown, the rotation produced by **F** about the Pivot Point will be counterclockwise, which means POSITIVE. Rotations clockwise, real or imagined, are negative.

3. Equilibrium situations

When forces are applied to a rigid body and the object does not translate or rotate, then the object is in equilibrium. In this case it must be true that the sum of all the forces as if acting on the center of mass of the object are zero (no net force), and the sum of all the torques applied to the object about a single pivot point are also zero.

3.1- Pick up a wooden one meter stick. Measure its mass

m =___________________ kg

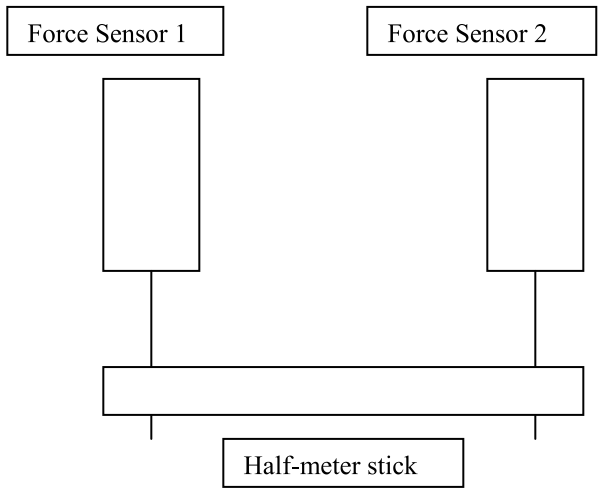
Lean the stick against the wall and start moving the base of the stick against the floor away from the wall until the meter stick slides off to the ground.

In the left of the space below, make a drawing of the equilibrium situation at just about the point of starting the slide. Measure the angle of maximum tilt using the protractor. In your drawing, draw arrows indicating all the forces acting on the meter stick while still in equilibrium, including friction and normal forces. You will be able to neglect friction against the wall, although it exists but the maximum force possible is small (think about why!). Write the equations for equilibrium [sum of all forces (x- and y- directions, two equations)] is zero, and sum of all torques (positive and negative, one equation) is zero, total three equations. For this last one, choose a pivot point (usually one end of the meter stick). Check with your TA at this point that you have the right drawing and the right equations!!!

3.2- Solve the equations to find the value of the coefficient of static friction between the meter stick and the floor. You <u>may</u> need to use measurements of the mass of the stick, the length of the stick, the location of its center of mass, and the angle at which the stick slides.

3.3- For the final experiment we will use the force sensors you have used in previous experiments (to measure tension, or force in a collision). This time we will use them as "scales" to measure force in an equilibrium situation. We will not use uncertainty calculations here, although you should keep in mind what they are.

Use the set up with the vertical posts at the end of the tables with the short half-meter stick. Carefully remove the stick from the loops and find its mass using the scales at the back of the room.



M =__________________

In your computer, turn on Data Studio and Open Activity. Go to Lab 7, Rotary Motion, then click on Lab 7b. A screen will appear with digital scales in Newtons. This is all that we will use the computer and force sensors for.

3.3- Push the zero button on the side of the force sensors. Carefully hang the half ruler from the loops hanging from the force sensors, or make new loops if they are not there so the half ruler hangs essentially horizontal with its flat side parallel to the table.

Write down at what meter markings the loops are attached.

X_{left}______________________ m $\qquad$ x_{right}________________________ m

Measure the force in each transducer by clicking on START. When done, click STOP

F_A = _______________________ N $\qquad$ F_B = _______________________ N

3.2- Calculate the weight of the half ruler from your mass measurement above, and compare to the weight as measured by the transducers.

Weight from mass = ____________ N *Weight from A and B* = ___________ N

Are they the same?

3.3- Place 200 gram mass on the half ruler and move it from left to write four or five times to span the entire half ruler. At each position record the ruler reading, and the forces F_A and F_B on each sensor. Write your results below

x_1_____________ F_{A1}_________________ F_{B1} _____________

x_1_____________ F_{A1}_________________ F_{B1} _____________

x_1_____________ F_{A1}_________________ F_{B1} _____________

x_1_____________ F_{A1}_________________ F_{B1} _____________

3.4- The force sensors actually measure the tension up from the strings on the half ruler (even if the sign is negative because it is pulling on the hooks). In sketch of setup above, draw vectors indicating all the forces acting on the ruler when loaded. Verify that the sum of all the forces on the ruler is zero and that the sum of all the torques on the ruler is also zero since the system is in static equilibrium. Choose a “pivot point” to do the calculation of torques (left end of ruler, for example, 0 meter mark, or right end of ruler, or center of ruler, or…). Indicate the pivot point in your drawing. Do the calculations using the data in the table above and the weight of the ruler as done in Section 3.2 above. Do your results give approximately what you expected?

This is all! Could you write comments here or on back of this page as to what works and what doesn’t work in this experiment? This is the first time it is being tried, so we appreciate comments that certainly will improve it for the next time. If you had to rate this experiment compared to other ones you have done this quarter, would you say that in a scale of 1 (worst than most) to 5 (better than most), with 3 about the same as most this experiment deserves a……… Thank you very much!