Motion in Two Dimensions: Centripetal Acceleration

Name:

Group Members:

Date:

TA's Name:

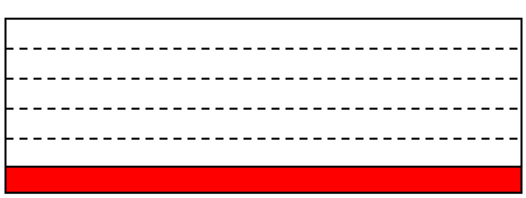
Apparatus: Rotating platform, long string, liquid accelerometer, meter stick, masking tape, stopwatch

Objectives:
1) To learn and physically identify the direction of acceleration in uniform circular motion.
2) To show that centripetal acceleration is proportional to the square of angular speed.

Part1: Liquid accelerometer and Centripetal Acceleration

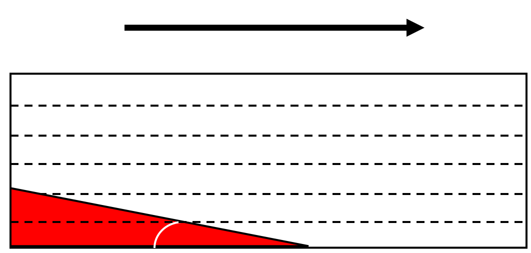
A liquid accelerometer is a rectangular hollow device made out of clear plastic partially filled with colored water. If the accelerometer is at rest or moving at constant speed in a straight line then the water level is horizontal as shown in the figure to the left. If the accelerometer is attached to an object which is moving with acceleration to the right, the water level makes a slope angle with the horizontal as shown in the figure to the right. The magnitude of the acceleration of the object can be measure as a function of the angle θ and it is given by g tanθ, where g is the acceleration due to gravity and θ is the slope angle as shown in the figure to the right. According to the equation the slope angle increases with increasing acceleration. Thus larger angle would indicate larger acceleration. Note the direction of orientation of water level with respect to the direction of acceleration.

No acceleration



Accelerometer at rest
or moving with constant velocity

Direction of the acceleration

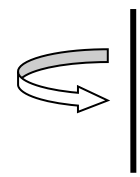


Accelerating to the right
Note the angle θ to the horizontal
$a = g \tan\theta$

As you have read and seen already, an object moving on a curved path is undergoing acceleration since its velocity is changing. Velocity is a vector and changes in its magnitude (the object's speed) or direction result in acceleration. In this experiment we will investigate the idea that an object in uniform circular motion has an acceleration toward the center of the circle called centripetal acceleration and given by $a_c = v^2/r$, where v is the velocity of the object and r is the radius of the circular path. We can also express centripetal acceleration in terms of the angular velocity, ω, in rad/s. Since $v = r\,\omega$, we can rewrite the equation for centripetal acceleration as $a_c = r\,\omega^2$.

Part 2: Using the liquid accelerometer to determine acceleration

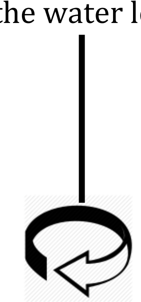
A. Now you need to use above information to physically identify the direction of acceleration of uniform circular motion. To see how, hold the accelerometer vertical with water level horizontal keeping the plane of the accelerometer along the radius of rotation (your TA will demonstrate this). Now do a 360° counterclockwise turn and ask a group member to see what happens to the water level. Sketch the orientation of the water level below.



Angular speed = 0 Non zero angular speed Axis of rotation

What is the direction of the acceleration? ____________________________

B. Now try this again for a 360° clockwise turn. Sketch the orientation of the water level below.



Angular speed = 0 Non zero angular speed Axis of rotation

What is the direction of the acceleration? ____________________________

C. How does the direction of the acceleration compare between the counterclockwise and clockwise rotations?

Part 3: Using the liquid accelerometer on the rotating platform to determine acceleration

Make sure that you have watched the TA's demonstration and understand the operation of the rotating platform before using it.

Fix the accelerometer to the rotating platform. Make sure that the water level is horizontal before you start by using the two adjusting screws on the feet. Make the platform rotate at approximately constant speed by steadily pulling the wrapped string underneath the rotating platform. Always take care not to entangle the string under the rotating pulley. Pull the string in a steady motion to make the apparatus rotate at a slow angular speed.

D. For a slow speed, sketch the water column you observe.

E. For a moderate speed, sketch the water column you observe.

F. For a faster speed, sketch the water column you observe.

G. What do you conclude about the angle of the water column as the angular speed is increased?

H. What do you conclude about the acceleration as the angular speed is increased?

Part 4: Measuring Acceleration vs. Angular Speed

Now we are almost ready make some measurements and test the hypothesis that $a_c = r\,\omega^2$.

First, answer the following questions about the procedure needed to test your hypothesis.

I. From what you learned in class or the textbook, how is the angular speed, ω, related to period, T?

J. How then do you propose to measure the angular speed of the platform?

K. How will you keep a given speed approximately constant while taking a reading? Explain.

L. How can we measure the acceleration using the liquid accelerometer?

M. To test the hypothesis, we need to pick one distance from the center of rotation to use. The accelerometer has squares and number written on it that we will use. We will choose the vertical line marked "10" that is close to the far end of the accelerometer as our location for measurements. Measure the distance from the center of rotation to the line marked "10" close to the far end of the accelerometer. Include units.

r = ________________________

N. Take a short piece of masking tape and place it on the glass in the region between 8 and 12 at the far end of the accelerometer. We want to place it so that it makes an angle θ where $\tan\theta = 1/4$. Remember that the tangent will be the rise over the run, so we can do this using the squares if we place the tape so that it has a rise of one square for a run of 4 squares. Place it near the bottom of the glass. Now rotate the platform while pulling the string steadily so that the slope angle of the water line is parallel with the angle marked. When that angle is achieved, keep the speed steady and take data for calculating angular speed.

Record your measured data and show how you calculate angular speed, ω, from your data.

O. Follow the same procedure for the following angles.

$\tan\theta = 1/2$ $\qquad$ $\tan\theta = 3/4$ $\qquad$ $\tan\theta = 1$

Enter your data for all four angles into an Excel file. Your table in Excel should have your raw data (those quantities you actually measured, e.g what the stopwatch read) and also the quantities you calculated from the raw data. Make a plot of centripetal acceleration versus angular speed squared. Describe the shape of your plotted data.

Does the plot of centripetal acceleration versus angular speed squared have the shape you expected? If not, why not? Do you need to take some data again?

P. Based on our hypothesis, what should the slope of the graph of centripetal acceleration versus angular speed squared be equal to?

Q. Determine the slope of your graph using Excel. What is the slope and does it match what you expect?

R. Does your graph support the hypothesis? Explain why or why not.

S. Probably you observed a curved water surface during your experiment. Explain it using what you know about how the centripetal acceleration varies with radius.

Make sure you copy your table and graph from the Excel file into a Word document with your names, print it out and attach it to this report.