

4. UNIFORM CIRCULAR MOTION

Read Appendix G before coming to the laboratory

OVERVIEW:

This week you will use a balanced circular motion apparatus to explore the relationship between an applied force and the centripetal acceleration. An object moving along a circular path is constantly accelerating. This acceleration requires a net external force. The computer will aid your measurement of the period of rotation from which you will be able to determine the acceleration. You will directly measure the force by examining the stretching of a spring under tension from hanging weights.

LEARNING OBJECTIVES:

- Test Newton's 2nd Law for circular motion
- Relate the period of rotation to the tangential velocity and centripetal acceleration
- Relate the centripetal acceleration to the applied force
- Use error estimates to ascertain whether your result agrees with expectations or not

PROCEDURE:

The apparatus is sketched in Fig. 4.1. A mass hangs from a cross-arm, which you can rotate by hand. The radially inward force F_S is provided by a spring, whose force you measure by hanging a weight from it. (The hanging weight is shown lightly shaded.) The radius r is measured directly, and the period of rotation T is determined with a photogate timer. Review Appendix G to set-up the photogate properly for use in timing rotational periods in this laboratory exercise.

The Setup: First, measure the rotating mass m with a scale. Then, hang the mass from the crossbar and position the apparatus so that weights hanging from the pulley will clear the table edge. Set the index rod for the largest r the apparatus will allow, and adjust the cross-arm so that m hangs directly over the index rod when the spring is disconnected. The string supporting the mass m should also be vertical. (This setup should have been completed by your lab instructor before you arrived, but verify that the apparatus is properly aligned.)

Next you should adjust the leveling screws until the spindle does not tend to rotate when released. You should verify the level by releasing m at several positions around the circle. If it doesn't tend to move from any point around the circle, you've done it! **Think about why you need to level the apparatus!**

When you have completed this step, check to see that the counterweight roughly balances the cross-arm, and that m is still centered over the index rod. *Once you've aligned the index rod and the hanging mass, do not move the index rod for the remainder of the laboratory exercise.*

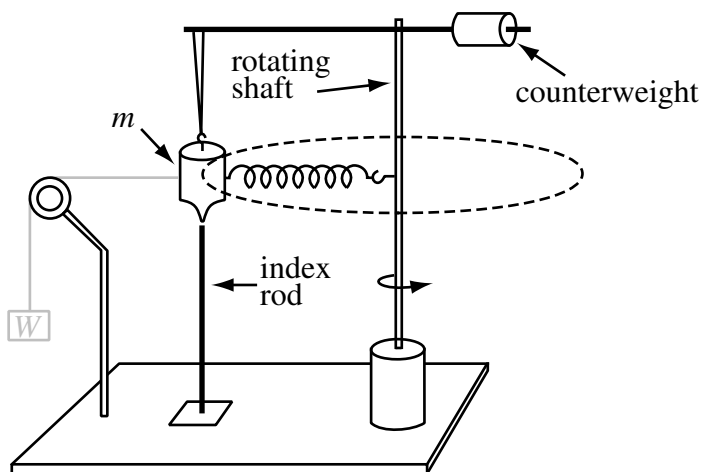


Figure 4.1. Circular motion apparatus. When the rotating shaft is turned the mass m follows the dashed circle. The weight W and string, shown in gray, are used to measure the spring force when the apparatus is not rotating.

The photogate should be placed so that the flag attached to the counterweight will interrupt the beam once in each full turn of the spindle.

Measure the force F_S the spring provides: You will attach one end of a string to the mass m and the other end to a known weight W hanging over the pulley to stretch the spring. (This step is shown as the lightly shaded hanging mass in Fig. 4.1) Make sure that the string between m and the pulley is level. **Think about why this is very important!** First, hang a 1000g mass on the end of the string running over the pulley. Adjust the screw at the spindle end of the spring until the mass m hangs directly above the index rod. In this configuration, the spring force is equal to the hanging weight. (If you cannot get the mass to hang directly above the index rod, reduce the hanging mass slightly, but use as large of a mass as is possible.) After you've completed the adjustments, you should remove the hanging weight and disconnect the string attaching the weight W to mass m . Once the apparatus is properly set up, you can use the photogate timer to measure the period T for a known force F_S while rotating the mass m about a circle of known radius r .

Measure and record r , the distance between the center of the spindle and the center of the index rod. Use calipers to measure the diameter of the spindle so that you can get a more precise estimate of the distance between the center of mass m and the axis of rotation (i.e., the center of the spindle). This distance is the radius r of the circle around which the mass m moves.

Rotate the spindle: Use your fingers to smoothly rotate the spindle until the mass m is moving in a constant-diameter circle that passes directly over the index rod. At this point, you know the force F_S that the spring is exerting (you just measured it above). In practice, you may find it best to spin up the rotation so that the mass m initially passes outside of the index rod. The rotation will slow due to air resistance and friction in the spindle bearings if you don't keep using your fingers to try to keep the rotation rate constant. **Keep your hands and head out of the path of the moving weights!**

When the mass m hangs directly above the index rod, the spring is now supplying the force F_S responsible for the circular motion of the mass m . You will want to refer to the free-body-diagram for the mass m from the pre-lab.

Start **LoggerPro** from the file **Circle.cmbl**, and click **Collect** to start measurement. The software will measure the period T for each rotation of the spindle. Continue the rotation until you have several consistent values of T , then click on **Stop** and halt the rotation. Copy and paste the data into Excel. Use Excel's AVERAGE and STDEV functions to determine the mean and standard deviation for the periods measured by the computer.

Now repeat the procedure, reducing the hanging weight W and changing the length of the spring by adjusting the screw, so the mass m hangs directly over the index rod. The goal is to have data from *at least six runs* with six different values of the spring force F_S (corresponding to six different hanging weights W). We would like your six hanging masses to cover the range from roughly 500-1000g.

Graphical Analysis: How is the centripetal acceleration a_c related to the measured period T ? You'll need to derive a mathematical relationship. Show this derivation and result on the report form along with the data indicated. Now calculate the centripetal acceleration and the force exerted by the spring for each of your six runs. Make a plot of the calculated a_c versus F_S using your data. If it appears linear, perform a linear regression on the acceleration versus force data and calculate a line of best fit, adding it to the graph. Complete your analysis to find an experimental value for the hanging mass m and its error, and answer the questions on the report form.

TURN IT IN:

1. Your report form with the **Data Table** and the analysis completed. You may "build" and fill out this **Data Table** in Excel and simply print it (see # 3 below).
2. The acceleration vs. force graph, with proper title, labels, caption, and fit line.
3. The part of your spreadsheet with the **Data Table** and the linear regression results. **Note: Do not print your full spreadsheet.**