Lab 3

Centripetal Force

A. Purpose

To study the effects of varying the centripetal force on an object rotating in a uniform circular motion, and to determine the unknown mass.

B. Introduction

A centripetal force is a force making a body follow a curved path with the direction always orthogonal to the motion of the body and towards the fixed point of the instantaneous center of curvature of the path. Newton described it as "a force by which the body is drawn or impelled, or in any way tend, towards a point as to a center." In Newtonian mechanics, gravity provides the centripetal force resulting in astronomical orbits.

When an object of mass m, attached to a string of length r, is rotated in a horizontal circle, the centripetal force on the mass is given by

$$F = \frac{mv^2}{r} = mr\omega^2 \tag{1}$$

where v is the tangential velocity and ω is the angular speed $(v = r\omega)$. To measure the velocity, the time for one rotation (the period, T) is measured. Then

$$v = \frac{2\pi r}{T} \tag{2}$$

and the centripetal force is given by

$$F = \frac{4\pi^2 mr}{T^2} \tag{3}$$

This experiment studies the effect of centripetal force, trying to determine the unknown mass.

C. Apparatus and software

1. Software to use:
    (1) Driver for Arduino Uno
        Mac: http://www.wch.cn/download/CH341SER_MAC_ZIP.html
        Windows: http://www.wch.cn/download/CH341SER_EXE.html
    (2) CoolTerm: http://freeware.the-meiers.org
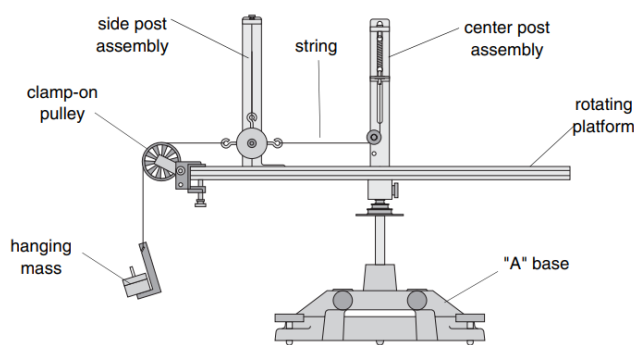
2.   Experimental setup

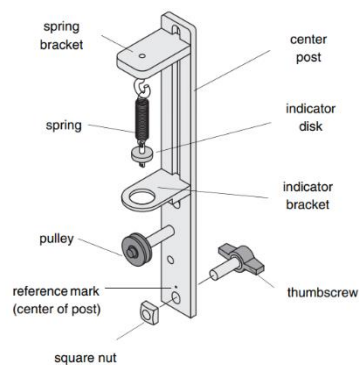Fig. 1. Schematic of Centripetal Force Apparatus

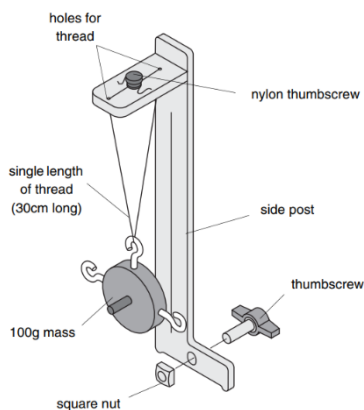Fig. 2. Center Post Assembly
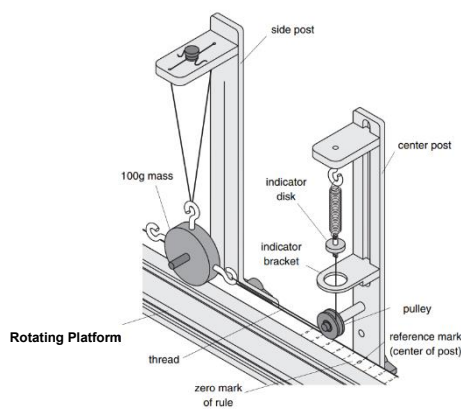

Fig. 3. Side Post Assembly

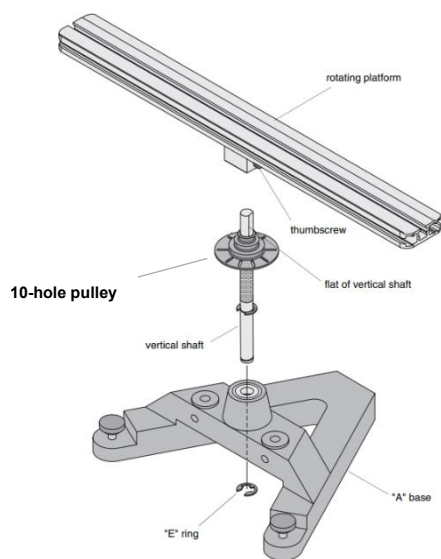Fig. 4. Threading the Centripetal Force Accessory

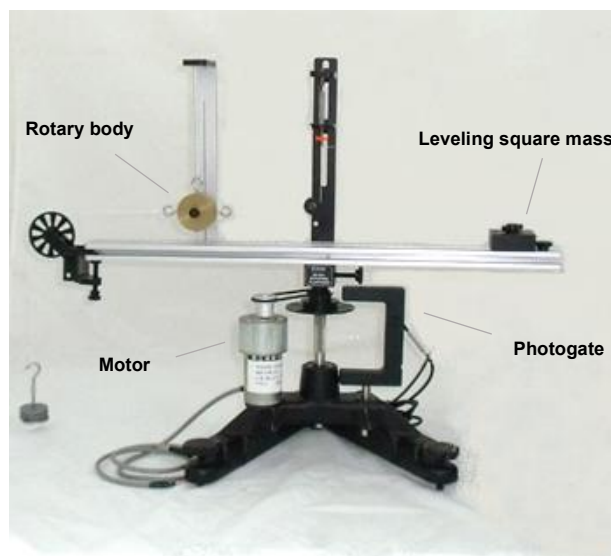Fig. 5. Attaching the Vertical Shaft to the Base
and Rotating Platform Assembly

Fig. 6. Centripetal Force Apparatus

D. Procedures

1. Pre-lab assignments (hand in before the lab)
   (1) Download the software needed for this experiment in advance
   (2) Make a flowchart of this experiment and answer the questions
      (i) Consider the experiment setup illustrated in Fig. 1~ Fig. 5,
         (a) Explain the function of the indicator disk in the Center Post
         (b) Explain the function of the hanging mass
         (c) Explain the function of the 10-hole pulley and what we use it to obtain
      (ii) To study the relationship between centripetal force F and rotating period T, one obtains the experimental data by changing the hanging mass as shown in the Table with the mass of rotary body $M = 107.92$ g placed at $r = 0.14$ m.

m (g)	T (s)
39.67	1.139
59.47	0.989
78.90	0.880
98.11	0.789
118.00	0.699

   (a) Find the relationship between F and T by dimensional analysis.
   (b) Draw a graph of F versus T using the data.
   (c) Suppose $F = aT^n$. Find their relationship by fitting data. Note that it's incorrect to simply use the quadratic fit, since you do not know whether n is an integer or not.
   (d) Compare the result between (a) and (c). Discuss the systematic effect that may result in the difference.

2. In-lab activities
   (1) Set up the equipment, as shown in Fig. 1.
      (i) Level the Base
         (a) Make the apparatus unbalanced by attaching the 300 g square mass onto either end of the track and tighten the screw so that the mass won't slide. Note that if the hooked mass is hanging from the Side Post in the centripetal force accessory, place the square mass on the same side.
         (b) Adjust the leveling screw on one of the legs of the base until the end of the track with the square mass is aligned over the leveling screw on the other leg of the base. See Fig. 7.
         (c) Rotate the track 90 degrees so it is parallel to one side of the "A" and adjust the other leveling screw until the track stays in this position.
         (d) The track is now level, and it should remain at rest in any orientation. **(Why?)**
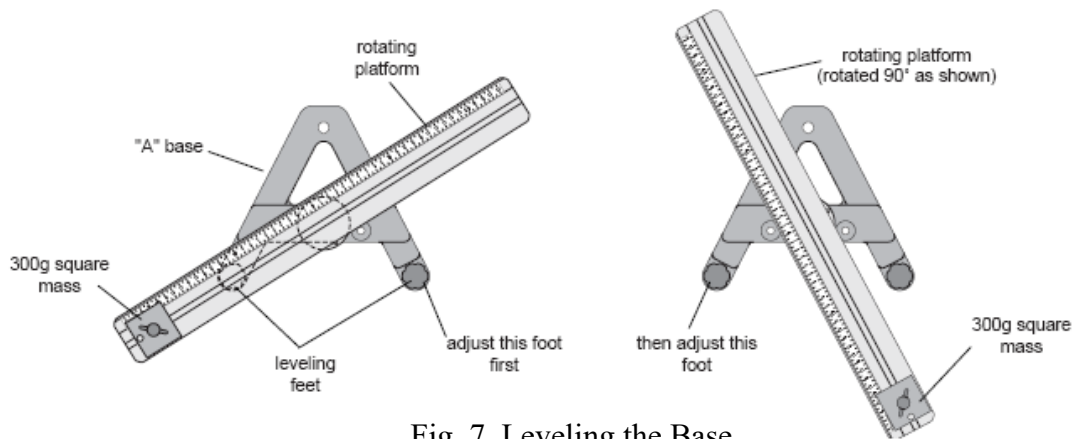
Fig. 7. Leveling the Base

(ii) Mount the Photogate Head

(a) Slide the non-threaded end of the photogate mount rod into a hole in the A-base and clamp it in place with the thumbscrew.

(b) Adjust the Photogate Head so that its infrared beam can be interrupted by the 10-hole pulley on the vertical shaft as the shaft turns.

(c) Connect the cable to the Photogate Head and Arduino Case, and when the Photogate Head is powered, you can tell when the photogate is blocked by watching the LED indicator on the photogate.

(iii) Mount the motor

Set the motor on the other hole of the "A" base.

(iv) Assemble the Center Post (See Fig. 2)

(a) Attach one end of the spring to the spring bracket and connect the indicator disk to the other end of the spring. Insert the spring bracket into the slot on the Center Post and tighten the thumbscrew.

(b) Tie one end of a string (about 30 cm long) to the bottom of the indicator disk and tie a loop in the other end of the string

(c) Insert the indicator bracket into the slot on the Center Post, placing it below the spring bracket. Tighten the thumbscrew.

(d) Attach the pulley in the higher of the two holes on the center bracket. Insert the thumbscrew at the bottom of the Center Post and attach the square nut.

(v) Assemble the Side Post (See Fig. 3)

(a) Insert the thumbscrew at the bottom of the Side Post. Attach the square nut.

(b) Tie a string (about 30 cm long) around the screw head on the top of the Side Post. Then thread the other end of the string down through one of the holes in the top of the Side Post and then back up through the other hole. ***Note: Do not pull the string taut.**

(c) Loosen the screw on the top of the Side Post and wrap the loose end of the string around the threads of the screw and tighten the screw.

(vi) Thread the Centripetal Force Accessory (See Fig. 4)

    (a) Mount the Center Post in the T-slot on the side of the track that has the rule.

    (b) Align the line on the Center Post with the zero mark on the rule and tighten the thumbscrew to secure it in place.

    (c) Mount the Side Post on the same side of the track.

    (d) Hang the 100 g rotary body from the string on the Side Post and adjust the height of the mass to make the string coming from the Center Post level.

(vii) To use Arduino to measure the period T of revolution

    (a) The Arduino records the time when the light passes through the 10-hole pulley as shown in Fig. 8. For the first set (#1), t_1 and t_2 are the fiirst and second time that the light passes through the pulley, and t_2 becomes the starting time for the second set (#2).

    (b) The period of revolution can be calculated by $10 \cdot (t_2 - t_1)$ for each set, from which we can state the period of revolution in the standard form with the best estimate and the uncertainty by considering several sets of rotation.
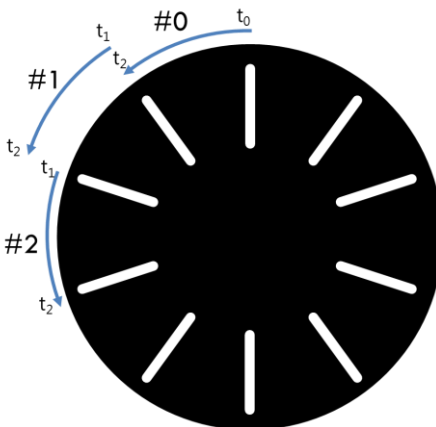

Fig. 8. Schematic of the time record in Arduino

(viii) Determine the radius of rotation R and the centripetal force F

    (a) Attach the clamp-on pulley to the end of the track nearer to the rotary body. Attach a string to it and hang a known mass over the clamp-on pulley.

    (b) Select a radius R by aligning the line on the Side Post with the chosen position on the measuring tape.

    (c) Vertically adjust the spring bracket on the Center Post until the string from which the rotary body hangs on the Side Post is aligned with the vertical line on the Side Post.

    (d) Align the indicator bracket on the Center Post with the orange indicator

    (e) Remove the hanging mass and the clamp-on pulley

    (f) Turn on the motor to rotate the apparatus and slowly increase the speed (by increasing the voltage provided by power supply) until the orange indicator is centered in the indicator bracket on the Center Post, which indicates the

string supporting the rotary body is once again vertical and the centripetal

force F now is the same value of the weight of the hanging mass **(Why?)**

(2) Find the relation between the centripetal force F and the period T

First think what quantities are fixed so as to design an experiment to obtain the data you need. Verify the relation by plotting a graph of the responding variable versus the manipulated variable in each part. Draw a best-fit line for the data and compare the slope of the line with its theoretical value.

***Note: At least 5 different data points are needed for a graph.

(3) Determine the value of an unknown mass

Design an experiment by the apparatus to measure the unknown mass. At least 5 independent measurements are required, and the propagation of uncertainty is needed to state the result in a standard form. After you obtain the result, compare it with the result measured by the electronic balance.

3. Post-lab report

(1) Recopy and organize your data from the in-lab tables in a neat and more readable form.

(2) Analyze the data you obtained in the lab and answer the given questions.

E. Questions

1. In this experiment, the period T seems to always be the responding variable during the measurement. Is it possible for us to design an experiment in which the period T becomes the manipulated variable during the measurement with the same apparatus? Explain.

2. Long-term exposure to the free-fall condition of an orbiting space station has serious negative health consequences for astronauts. One idea that would help is to build a space station in the shape of a wheel and rotate it. The space station could be spun fast enough so that the centripetal acceleration was the same as the free-fall acceleration on Earth. Assume the space station will not be rotated faster than five times per minute so the astronauts don't get sick. What radius would it need to have so that the centripetal acceleration is 9.81 m/s^2 ? Why do you think a space station like this has not been built yet? Show all of your work and use the correct units.

F. References

Angular Velocity and Centripetal Acceleration, PASCO.

Instruction Manual and Experiment Guide for the PASCO scientific Model ME-8950A.

Globus, Al, and Theodore Hall. "Space settlement population rotation tolerance." NSS Space Settlement Journal 2 (2017): 1-25.