Experiment 3: Circular Motion and Centripetal Force

I. Purpose

Circular motion is one of basic motions in the world. For example,

For example, spin of electron in the atom and interaction between planets…etc.

In this chapter, we would find out the relation of centripetal force with mass, radius, and rotation velocity by studying the circular motion in constant velocity.

II. Theory[1]

A particle is in **uniform circular motion** if it travels around a circle or a circular arc at constant (uniform) speed. Although the speed does not vary, the particle is accelerating because the velocity changes in direction. The acceleration is always directed radially inward. The acceleration accelerated with uniform circular motion is called a **centripetal acceleration**. The magnitude of this acceleration **a** is

$$\vec{a} = \frac{v^2}{r}$$

From Newton's second low, a force must cause this acceleration. Moreover, the force must also be directed toward the center of circle. Thus, it is a **centripetal force**, where the adjective indicates the direction. We can write the magnitude F of a centripetal force (or a net centripetal force) as

$$\text{F} = \frac{mv^2}{r} = mr\omega^2 \qquad (1)$$

The linear velocity $v = \omega r$，if the point moves in uniform circular motion, the period T of the motion for the point and the body is

$$\text{T} = \frac{2\pi r}{v} = \frac{2\pi}{\omega} \qquad (2)$$

From eq.(1) & eq.(2)

$$\text{F} = \frac{4\pi^2 mr}{T^2} \qquad (3)$$

The exp.is verified the relationship between (a)rotating mass, (b) centripetal force, (c) Radius of rotation during uniform circular motion.

III. Apparatus

As shown in Figure 1

1.	"A" base	1set
2.	rotating platform	1 set
3.	center post	1 set
4.	side post	1 set
5.	mass (100g*1+50g*2)	1 set
6.	clamp-on pulley	1 set
7.	thread	several
8.	weight (10g/個)	1 set
9.	12V-DC motor	1 set
10.	Photogate	1 set
11.	Arduino box	1 set
12.	square mass(300g)	1 set
13.	level	1 set
14.	DC power supply	1 set

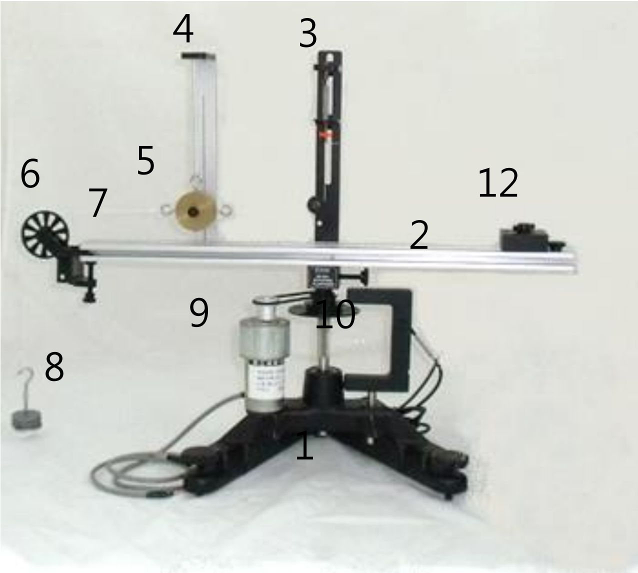


Figure 1 Centripetal Force

IV. Experimental Setup

Before Exp:

(1) Arduino (open-source electronics platform) **Software download:**

Arduino Introduction: https://www.arduino.cc/

(2) 2. CoolTerm: http://freeware.the-meiers.org

Used Coolterm to get database and load out to EXCEL for graphing.

A. Assembling the Rotating Platform :

Some experiments require the apparatus to be extremely level. If the track is not level, the uneven performance will affect the results.

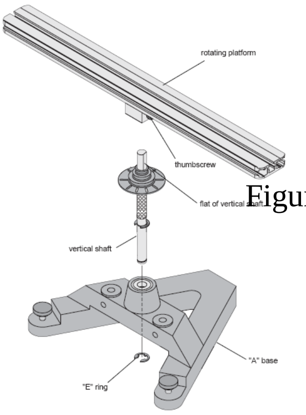


Figure 2-1

1. As shown in figure 2-1. Purposely make the apparatus unbalanced by attaching the 300 g square mass onto either end of the aluminum track. Tighten the screw so the mass will not slide.
2. As shown in figure 2-2. 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.
3. Rotate the track 90 degrees so it is parallel to one side of the "A"base and adjust the other leveling screw until the track will stay in this position.
4. The track is now level and it should remain at rest regardless of its orientation.

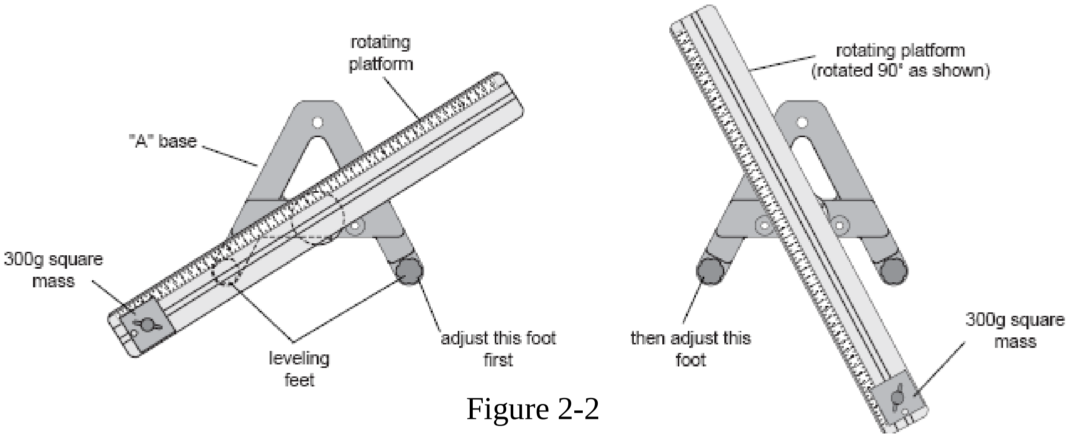


Figure 2-2

B. Mount Photogate

1. It can be used to mount a photogate head to the “A” base in the correct position to use the 10 holes in the pulley on the rotating shaft to measure angular speed.
2. Loosen the thumb screw on the base to allow the black rod to rotate. Orient the rod and photogate head so the infrared beam passes through the holes in the pulley. If the photogate head is powered by a computer, you can tell when the photogate is blocked by watching the LED indicator on the end of the photogate. The photogate head should not be rubbing against the pulley. When the head is in the correct position, tighten the bottom screw to fix the rod in place.

C. Mount Motor

Set Motor on the other hole of “A” base.

D. Measure Motor characteristic curve：(if teacher asked)

Connect only motor and power supply. Set voltage 1~6V to the motor, record the relationship of voltage and rotating speed. Note: make sure the output voltage set zero before turn on the power supply.(If the motor turning too fast at high voltage may throughout the equipment to hurt others.

E. Centripetal Accessory

1. ◦As shown in figure 3. Mount the center post in the T-slot on the side of the track that has the rule. Align the line on the center post with the zero mark on the rule and tighten the thumb screw to secure it in place. Then mount the side post on the same side of the track.

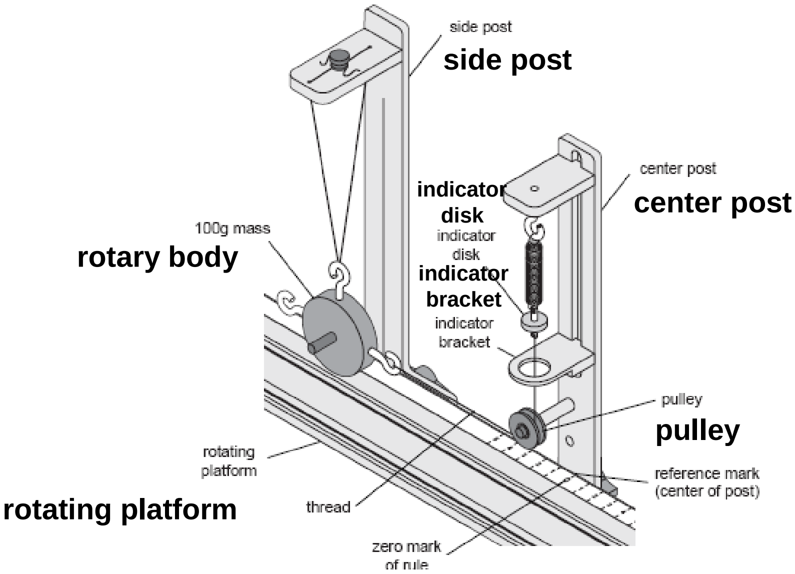


Figure 3 Circular motion and Centripetal Force Setup

2. Hang the rotary body from the string on the side post and adjust the height of the object so the string coming from the center post will be level.

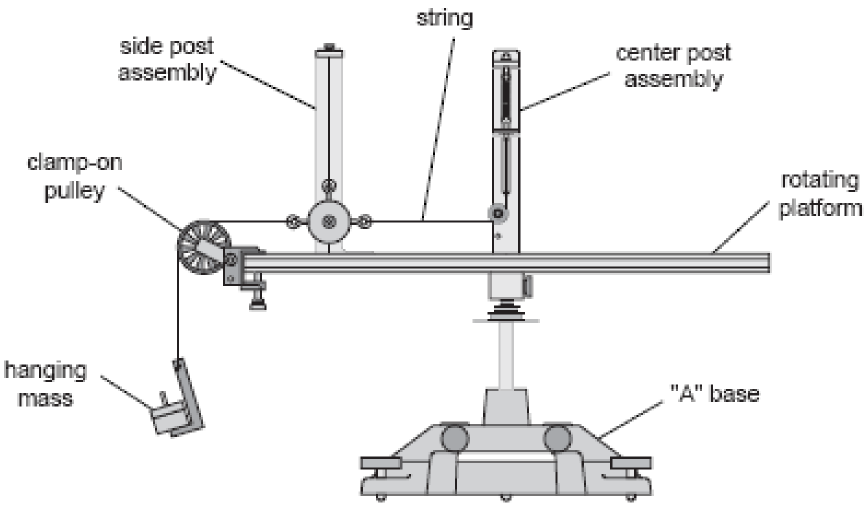


Figure 4

F. Use electronic scale to measure rotary body and the mass of weights and hook.

Remarks

(1) Change square mass position if the data oscillating.

(2) Don't add big Voltage(power) suddenly, the piece on the platform may be throw out and to be dangerous.

V. Produce

A. Vary Radius（Fix centripetal face and the mass of rotary body）

1. The centripetal force and the mass of the rotary body will be held constant for this part of the experiment.
2. Measure the mass of weight and record its mass in Table 3.1. Hang the rotary body from the side post and connect the string from the spring to the object. The string must pass under the pulley on the center post. As shown in figure 4.
3. Record the mass of weight in Table 3.1. (Centripetal Face will be constant.)

4. Select a radius by aligning the line on the side post with any desired position on the measuring tape. While pressing down on the side post to assure that it is vertical, tighten the thumb screw on the side post to secure its position. Record this radius in Table 3.1.
5. The rotary bady on the side bracket must hang vertically.
6. Align the indicator bracket on the center post with the orange indicator.
7. Remove the mass that is hanging over the pulley and remove the pulley.
8. Rotate the apparatus, increasing the speed until the orange indicator is centered in the indicator bracket on the center post. This indicates that the string supporting the rotary body is once again vertical and thus the rotary body is at the desired radius.
9. Maintaining this speed. Record the period in Table 3.1.
10. Move the side post to a new radius and repeat the procedure. Do this for a total of five radius.

Table 3.1 Varying the Radius

The mass of rotary body M =

Mass hanging over the pulley m =

Slope of the graph =

Radius of rotary body r	Period T	T^2

Data Analysis

1. The weight of the mass hanging over the pulley is equal to the centripetal force applied by the spring. Calculate this force by multiplying the mass hung over the pulley by "g" and record this force at the top of Table 3.2.
2. Calculate the square of the period for each trial and record this in Table 3.1.
3. Plot the radius versus the square of the period. This will give a straight line since:

$$r = \left(\frac{F}{4\pi^2 M} \right) T^2$$ M is the mass of rotary body

4. Draw the best-fit line through the data points and measure the slope of the line. Record the slope in Table 3.1.
5. Calculate the centripetal force from the slope and record in Table 3.2.
6. Calculate the percent difference between the two values found for the centripetal force and record in Table 3.2.

Table 3.2 Varying Radius

Centripetal Force = mg	
Centripetal Force From Slope	
% Percent Difference	

B. Vary Centripetal Force（Fix radius and the mass of rotary body）

The radius and the mass of the rotary body will be held constant for this part of the experiment.

1. ◦Measure the rotary body and record its mass in Table 3.3. Experimental setup as shown in

Figure 4.

2. Record the mass of weight in Table 3.3.
3. Select a radius by aligning the line on the side post with any desired position on the measuring tape. While pressing down on the side post to assure that it is vertical, tighten the thumb screw on the side post to secure its position. Record this radius in Table 3.3.
4. Align the indicator bracket on the center post with the orange indicator.
5. Remove the mass that is hanging over the pulley and remove the pulley.
6. Rotate the apparatus, increasing the speed until the orange indicator is centered in the indicator bracket on the center post. This indicates that the string supporting the rotary body is once again vertical and thus the rotary body is at the desired radius.
7. Maintaining this speed. Record the period in Table 3.3.
8. To vary the centripetal force, clamp the pulley to the track again and hang a different mass over the pulley. Keep the radius constant and repeat the procedure from Step #4-7. Do this for a total of five different centripetal forces.

Table 3.3 Varying the Centripetal Force

The mass of rotary body M =

The radius of rotary body r =

Slope from graph =

Mass over pullet m	Centripetal Force = mg	Period T	$1/T^2$

Data Analysis

1. The weight of the mass hanging over the pulley is equal to the centripetal force applied by the spring. Calculate this force for each trial by multiplying the mass hung over the pulley by "g" and record the results in Table 3.3.
2. 。Calculate the inverse of the square of the period for each trial and record this in Table 3.3.
3. Plot the centripetal force versus the inverse square of the period. This will give a straight line since.
4. Draw the best-fit line through the data points and measure the slope of the line. Record the slope in Table 3.3.
5. By $F_c = \left(\frac{4\pi^2 Mr}{T^2}\right)$ equation. Calculate the mass of the object from the slope and record in Table 3.4.
6. Calculate the percent difference between the two values found for the mass of the object and record in Table 3.4.

Table 3.4 Varying the Centripetal Force

Mass of Rotary Body (from scale)	
Mass of Rotary Body (from slope)	

% Percent Difference	

C. Vary the mass of rotary body（Fix radius and centripetal force）

1. The radius and the centripetal force will be held constant for this part of the experiment.
2. Measure the rotary body and record its mass in Table 3.5. Experimental setup as shown in Figure 4.
3. Record the mass of weight in Table 3.5.
4. Select a radius by aligning the line on the side post with any desired position on the measuring tape. While pressing down on the side post to assure that it is vertical, tighten the thumb screw on the side post to secure its position. Record this radius in Table 3.3.
5. Align the indicator bracket on the center post with the orange indicator.
6. Remove the mass that is hanging over the pulley and remove the pulley.
7. Rotate the apparatus, increasing the speed until the orange indicator is centered in the indicator bracket on the center post. This indicates that the string supporting the rotary body is once again vertical and thus the rotary body is at the desired radius.
8. Maintaining this speed. Record the period in Table 3.5.
9. Vary the mass of the rotary body by removing the side masses. Keep the radius constant and repeat the procedure from Step #4-7. Record the mass and period in Table 3.5.

Table 3.5 Varying the Mass of the Rotary Body

Mass hanging over the pulley m =

Centripetal Force = mg =

The radius of rotary body r =

The mass of rotary body M	Period T	Centripetal Force F_c	% Percent Difference

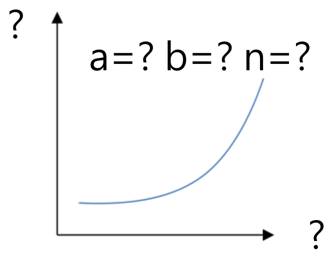
Data Analysis

1. The weight of the mass hanging over the pulley is equal to the centripetal force applied by the spring. Calculate this force by multiplying the mass hung over the pulley by "g" and record the result at the top of Table 3.5.
2. Calculate the centripetal force for each trial using: $F_c = \frac{4\pi^2 Mr}{T^2}$. Record this in Table 3.5.
3. Calculate the percent difference between the calculated centripetal force for each trial and mg. Record in Table 3.5.

VI. Questions and Dissuasion

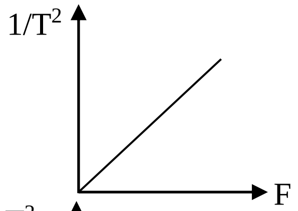
1. What factors may cause the errors in this experiment?
2. Period of rotating motion will increase or decrease when the radius increase
3. How to change central force to increase the period of motion when radius and mass are fixed?
4. Central force will increase or decrease if the mass increase?

5. If the relationship of central force F and period T is $F=aT^n+b$，n,a and b are constant. Which graph can analysis and get the value of n,a and b.

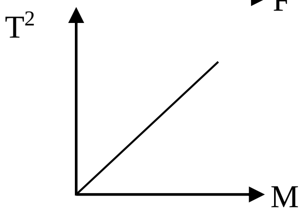


6. Drawing the graph by your exp. data.

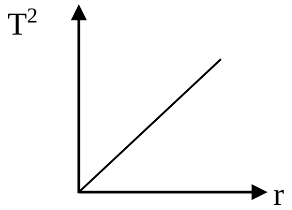
(1) $1/T^2$ vs. rotating force (F)



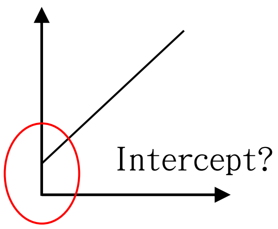
(2) T^2 vs. rotating Mass (M)



(3) T^2 vs. rotating radius (r)



By theory, three diagram should be linear relationship. Use linear regression to analysis it. What does the result means? How does intercept come from?



Reference:

(1)Principles of Physics, Wiley, Tenth Edition, P.67, P.116, P232