College Physics 201
Circular Motion

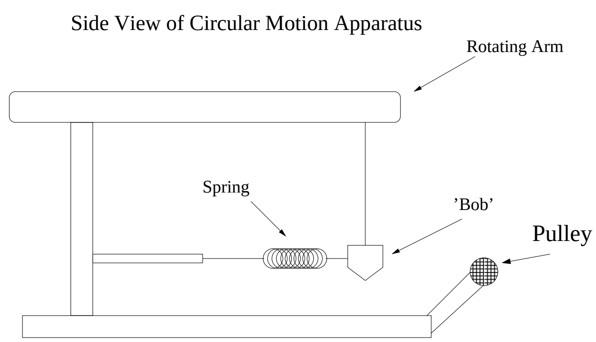
Materials: *Circular motion apparatus, stopwatches, laptop computers, short rulers, heavy mass sets with 50-g hangers*

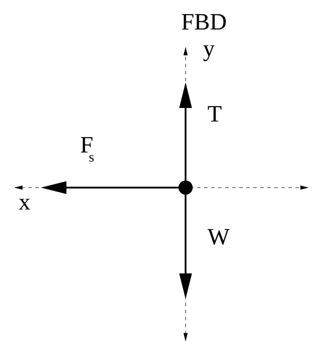
1 Purpose

The purpose behind this lab is for the student experimenters to investigate the centripetal motion and the force which keeps an object in circular motion. Students will continue to refine their analysis skills.

2 Introduction

The uniform circular motion of an object can be studied using the following apparatus.





From the FBD for this system, we see that the circular motion of the 'Bob' is caused by the force supplied by the spring, F_s. This force is constant throughout the experiment. The net force in the x-direction is thus the spring force. This then is equal to the centripetal force so we can represent this as

$$F_s = m\frac{v^2}{R}. \tag{1}$$

With this apparatus, the experimenter measures the rotational period of the pendulum 'Bob' as a function of total 'Bob' mass, m, so it is necessary to replace the v with an equivalence in terms of T. Replacing the v with

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

and solving for T yields

$$T = \left(\frac{4\pi^2 R}{F_s}\right)^{1/2} m^{1/2}. \tag{3}$$

We can now measure the dependence of the the rotational period on the mass of 'Bob'. Note here that the theory in Eq. 3 predicts the relationship to be a power law form so for complete analysis you will have to perform a logarithmic analysis.

3 Procedure

Follow all the instructions of your lab instructor. They will point out important aspects of the apparatus. Make sure you tighten down all set screws and attachments after making changes.

3.1 Rotational Period Measurements

1. Carefully detach the pendulum 'Bob' and measure it's mass. Reattach it to the apparatus **WITHOUT** attaching the spring.
2. Measure the radius of rotation for the pendulum 'Bob' when it is in its fully vertical position. (Note: Do not rotate the system!)
3. Reattach the spring to the pendulum 'Bob'.
4. Rotate the system until the 'Bob' is perfectly vertical while being rotated. This requires a bit of practice.
5. Once you are comfortable, measure the period of rotation for **10** complete rotations of the 'Bob' and record the **period** in a table of the 'Bob's' total mass versus rotation period. NOTE: Think about what the period is and its relationship to the time you measured. They are not equal!
6. Repeat the measurement two more times and average the results. This will help to minimize stopwatch starting and stopping uncertainties.
7. Add 40-grams to the 'Bob' and repeat steps 4 through 5. Do this for 100-g, 140-g, 200-g, 240-g, and 300-g added to the 'Bob'. The last couple of mass additions will require additional "modifications".

3.2 Spring Force Measurement

Measure the amount of force in the spring when the 'Bob' is vertical by attaching a string to the opposite side of the 'Bob' and suspending mass over the small pulley on the apparatus.

1. Attach a string to the 'Bob' so it can be strung over the small pulley.
2. Place a 50-g hanger on the end of the string and add mass until the 'Bob' is vertical while not rotating.
3. Record the amount of mass suspended on the end of the string. This is the mass necessary to 'balance' the spring force. Thus, we know have a direct measurement of the spring force since for this system in equilibrium since $T = mg$.

4 Analysis

1. Generate a table that has the following columns: total mass of pendulum 'Bob' (including added mass), each period measurement, average of all three measurements, square root of bob's mass, natural log of the period, and natural log of the total mass of the pendulum 'Bob'. Are you in SI units?
2. Generate a plot of *Natural log of period vs. natural log of total 'Bob' mass* and fit the result with a straight line.
3. Generate a plot of *Period vs. square root of total 'Bob' mass* and fit the result with a straight line.

5 Questions

As usual answer the following question clearly and concisely.

1. Discuss the physical significance of the slope of the first graph you generated (*Natural log of period vs. natural log of total 'Bob' mass*). This will require the manipulation of Eq. 3 with logarithm rules into this form:

$$Ln[T] = \frac{1}{2}Ln[m] + Ln\left[\left(\frac{4\pi^2 R}{F_s}\right)^{1/2}\right]. \tag{4}$$

   For full credit you need to show the derivation.

2. Using a percent difference comparison, comment on how well the theory and experiment match for the first graph.

$$\%diff = \frac{|measured - theory|}{theory} \times 100 \tag{5}$$

3. Using the y-intercept from the theory equation you just derived (Eq. 4) and the numerical y-intercept you got from the best fit to the first plot, calculate the net force supplied by the spring to the rotating system. You will of course need to use your measured value for R.

4. Compare the net force you just calculated in question 3 with the force found from the section 3.2 direct measurement. Use the % difference comparison equation (Eq. 5). Here you will use the value from Question 3 as the "measured" value and the value found in Section 3.2 as the "theory" value.

5. Using the slope from the second graph and Eq. 3, determine the spring force exerted on the pendulum 'Bob' while it was swinging around. This will require you to compare Eq. 3 to the linear fit from EXCEL.

6. How does this value of F_s compare to the value you determined in Section 3.2? Use the % difference comparison equation (Eq. 5). Here you will use the value from Question 5 as the "measured" value and the value found in Section 3.2 as the "theory" value.

6 References

- OpenStax *Physics*, Chapters 5 and 6
- *Physics*, 8^{th} edition by Cutnell and Johnson, Chapter 5