SP211 Lab 4
Uniform Circular Motion

Equipment

You will need the following equipment to complete this lab. Quantities needed are listed inside of the parentheses.

Pointer (1)
Bob (1)
Heavy Harmonic Spring (1)
Crossbar (1)
Counterweight (1)
Pulley Attached to Centripetal Force Apparatus (1)
String (1 roll per room)
Masking Tape (1 roll per room)
Hook (1)
Slotted Mass Set (1)
Meter Stick (1)
Ruler (1)

You will also need Google Gemini to complete this lab.

Experiment 1: Centripetal Force on the Bob

1) Remove the bob from the equipment (see Figure 1). Measure its mass and record it in Table 1 on the attached worksheet. Estimate an uncertainty on the mass (Δm_{Bob}) and record it as well.

2) Set the pointer about midway in its track and measure the distance from the pointer to the *center* of the shaft. Record this radius (r_{PS}) and an estimate of its uncertainty (Δr_{PS}) in Table 1.

3) Hang the bob from the spring. Using the thumbscrew at the top of the shaft, adjust the position of the crossbar until the bob hangs directly over the pointer. Adjust the counterweight so that the crossbar is balanced. Make sure everything is tightened back up when you are done.

4) Attach the spring to the bob and the shaft. Adjust the height of the bob so that when the bob is hanging over the pointer, the spring is level horizontally. The apparatus should look like Figure 1 when the bob is directly over the pointer.

5) Prepare a timer (e.g. you can use your phone if you'd like). Spin the pendulum so that the bob is directly over the pointer and time how long it takes for the bob to do 15

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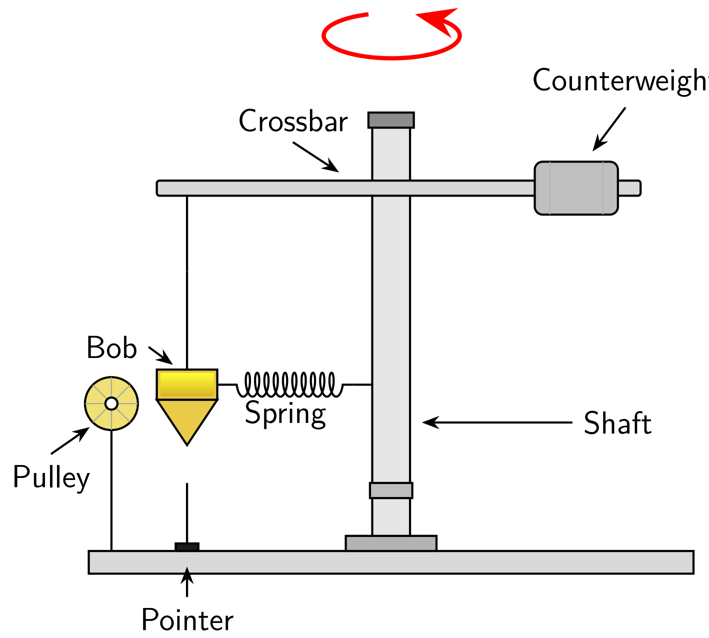

Figure 1: Sketch of our equipment setup for Experiment 1.

turns. *Don't put your head near the apparatus!* The bob must stay overtop of the pointer the entire time. Record this time in Table 2 on the attached worksheet. Repeat this procedure 4 more times so that we can estimate the uncertainty in your timing measurement.

6) Using the times you just measured, calculate the period ($T_{1\ turn}$) for one revolution of the bob for each trial. Record this in Table 2.

7) Using Google Gemini and the period you just calculated for each trial, determine the overall average period (T_{avg}) and the standard deviation of your period data. We will use the standard deviation as the uncertainty in your average period (ΔT_{avg}). Record these in Table 3 on the attached worksheet.

8) Now using Newton's Second Law that *includes centripetal acceleration* and the equation that relates period to velocity, derive the equation for the centripetal force on the bob as a function of period. Show your work for this in Question 1 on the attached worksheet.

9) Next we will derive the equation that will calculate the uncertainty on the centripetal force on the bob. The basic error propagation formula is

$$\Delta f = \sqrt{(\frac{\partial f}{\partial x}\Delta x)^2 + (\frac{\partial f}{\partial y}\Delta y)^2 + ...}$$

where Δx, Δy, etc. are the uncertainties on the x and y measurements, and the $\frac{\partial f}{\partial x}$, $\frac{\partial f}{\partial y}$, etc. are the derivatives of the equation that calculates f with respect to the quantities that have uncertainty measurements.

In our case, we have three uncertainties (on the period, radius, and mass). So our equation to calculate the uncertainty on the centripetal force has three terms:

$$\Delta F_C = \sqrt{(\frac{\partial F_C}{\partial T_{avg}}\Delta T_{avg})^2 + (\frac{\partial F_C}{\partial m_{Bob}}\Delta m_{Bob})^2 + (\frac{\partial F_C}{\partial r_{PS}}\Delta r_{PS})^2} \tag{1}$$

Find the partial derivatives of the equation you just derived in Step 8 (Question 1) with respect to period ($\frac{\partial F_C}{\partial T_{avg}}$), mass ($\frac{\partial F_C}{\partial m_{Bob}}$), and radius ($\frac{\partial F_C}{\partial r_{PS}}$). Record these in Question 2 on the attached worksheet and plug them into Equation 1.

10) Now that you have an equation for the centripetal force and the uncertainty on the centripetal force, calculate both quantities. Record your answers in Table 4 on the attached worksheet.

11) Answer Question 3 on the attached worksheet.

CHECK POINT: ☐

5-day section breakpoint ______________________

Experiment 2: Determining the Force of the Spring on the Bob

1) In Question 4 on the attached worksheet, draw free body diagrams for the hanging mass and the bob shown in Figure 2. Use your free body diagrams to determine the force of the spring on the bob (Question 5 on the attached worksheet).

2) Attach a mass hanger to a string, pass the string over a pulley, and attach the string to the bob as shown in Figure 2. Hang masses on the hanger until the bob is directly over top of the pointer. Then remove all of the masses, including the hanger, and measure their combined mass (m_{HM}) using an electronic scale. Record the mass you measured and an estimate of its uncertainty in Table 5 on the attached worksheet.

3) Using the equation you developed in Question 5 on the attached worksheet and the mass measurement you just took, calculate the force of the spring on the bob. Record it in Table 5.

4) Apply the general formula for uncertainty to the equation you developed in Question 5 to calculate the uncertainty in the force of the spring on the bob. Record it in Table 5 as well.

5) Answer Questions 6 and 7 on the attached worksheet.

CHECK POINT: ☐

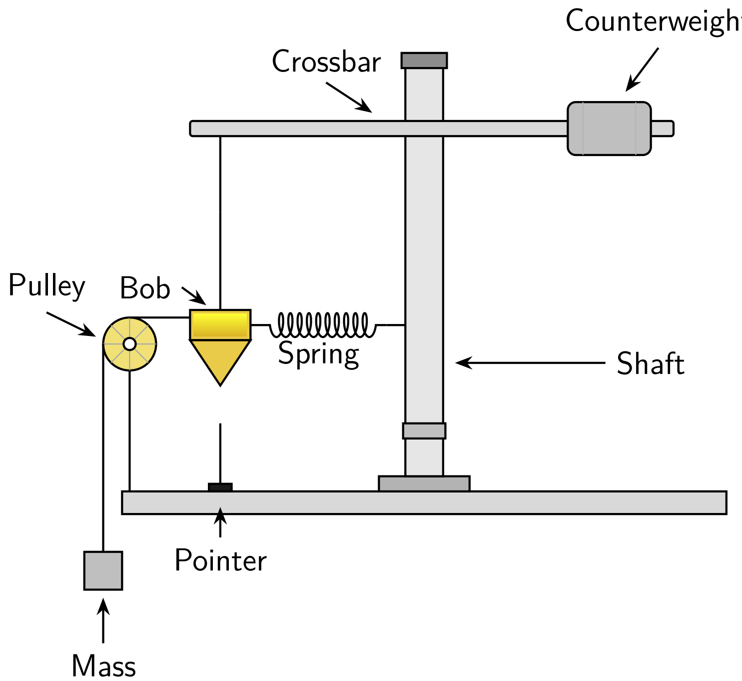

Figure 2: Sketch of our equipment setup for Experiment 2.

Clean Up

Please return your lab station and the drawer of equipment to a clean and organized form. Follow any directions your instructor gives you about where to return equipment to when you are finished with the lab.

LAB 4 Worksheet

Name(s) and Alpha(s) Date

Experiment 1: Centripetal Force on the Bob

Table 1: Record your mass and radius measurements here.

m_{Bob}:		Δm_{Bob}:	
r_{PS}:		Δr_{PS}:	

Table 2: Record your timing measurements here.

Trial #:	$t_{15\ turns}$:	$T_{1\ turn}$
1		
2		
3		
4		
5		

Table 3: Record average period and its uncertainty here.

T_{avg}		ΔT_{avg}	

Question 1: Using Newton's Second Law that *includes centripetal acceleration* and the equation that relates period to velocity, derive the equation for the centripetal force on the bob as a function of period. Show your work!

Question 2: Find the partial derivatives of the equation you just derivative in Step 9 (Question 1) with respect to period ($\frac{\partial F_C}{\partial T_{avg}}$), mass ($\frac{\partial F_C}{\partial m_{Bob}}$), and radius ($\frac{\partial F_C}{\partial r_{PC}}$). Show your work! Substitute them into the uncertainty equation.

Table 4: Record the centripetal force on the bob and its uncertainty here.

F_C		ΔF_C	

Question 3: Draw a free body diagram for the bob assuming it is moving in a circle, like it just was in Experiment 1. Based on your free body diagram, what force is the centripetal force on the bob?

Experiment 2: Determining the Force of the Spring on the Bob

Question 4: Draw a free body diagram for the hanging mass and the bob shown in Figure 2.

Question 5: Based on your free body diagram (Question 4) and Newton's Second Law, what is the magnitude of the force of the spring on the bob?

Table 5: Record your mass measurements here. Calculate the force of the spring on the bob and its uncertainty. Show your work!

m_{HM}:		Δm_{HM}:	
F_{spring}:		ΔF_{spring}:	

Question 6: Do the centripetal force and the force of the spring on the bob agree with each other within uncertainties? If not, what may be a reason why? What are some sources of error that may have gone into your measurements that weren't accurately taken care of in our analysis?