Conservation of Energy with a Peg and Pendulum

Materials: *Peg and pendulum setup (Figure 1); two photogates with compatible interface and software; meterstick; triple beam balance; and Vernier caliper.*

1 Purpose

The purpose of this experiment is to use the principle of energy conservation and Newton's laws to determine several parameters for a pendulum as it swings down and wraps around a peg. Comparison between the measured and predicted parameters will be made.

2 Introduction

The lab apparatus is shown in Figure 1. This lab will use concepts of conservation of mechanical energy and circular motion to predict the minimum height from which you can release the bob and have it pass around the smaller loop without any slack when at the top. You will then test your prediction by experiment.

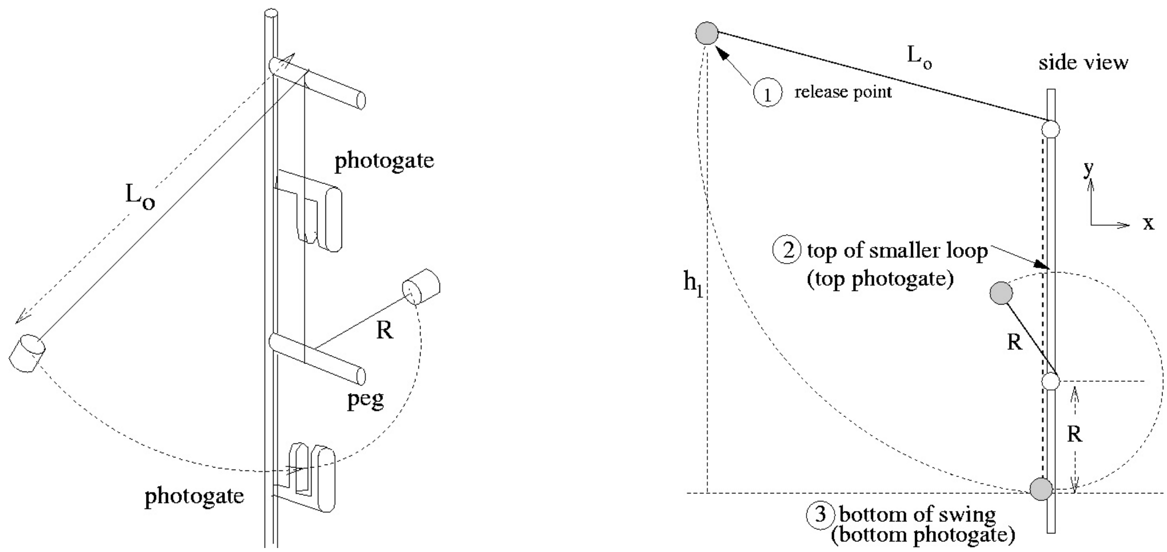

Figure 1: Basic configuration and parameters for peg and pendulum experimental setup.

3 Procedure

3.1 Basic Parameters

These parameters are necessary for the theoretical calculations; see Figure 1 for clarification.
Carefully measure and record:

1. The length of the string L_o (from bar where it is tied to the center of the bob)
2. The radius of the smaller circle R (from the peg to the center of the bob).
3. The diameter D (not length) of the bob (cylindrical rod attached to end of string)
4. The Mass M of the bob (cylindrical rod attached to end of string)

3.2 Predictions

These steps guide you through predicting h_1, v_2 and v_3 (experimentally determined in *Section 3.3*). Note: You may perform the experiment, as described in *Section 3.3*, prior to working through these theoretical predictions.

1. Draw a free body diagram for the bob as it goes through the top of the smaller loop (point 2).

2. For the bob at point 2, derive a general expression for tension on the string ($F_{T,2}$) in terms of the mass of the bob (M), speed (v_2), radius of the smaller loop (R), length of string (L_o) and gravitational acceleration (g). The final expression may not necessarily have all these symbols. *Show all of your work.*

3. Using the expression from the last part, derive a symbolic expression for the speed v_2 in the special case where the string is exactly 'slack' as the bob passes through the top of the smaller loop (i.e.: $F_{T,2} \to 0$). Once you have the symbolic expression, substitute the numbers from your setup and put a box around your final v_2. *Show all of your work.*

4. Derive an expression for the height h_1 (from the bottom of the swing) the bob should be released, from rest, so that it the tension in the string is exactly zero (exactly 'slack') as the bob passes through the top of the smaller loop. Once you have the symbolic expression, substitute the numbers from your setup and put a box around your final result h_1. *Show all of your work.*

5. Derive an expression for the speed v_3 of the bob at the bottom photogate if the bob is released from the height h_1 determined above. *Show all of your work.*

3.3 Experimental Data Collection

These steps guide you through experimentally determining h_1, v_2 and v_3 (predicted in *Section 3.2*).

1. Open the PASCO Capstone software, connect to the interface and configure the software so that each photogate measures the time their beam is blocked. (A file may have been prepared ahead of time by your instructor. If available, download and open the file. Then verify the interface is configured to measure the time the pendulum (bob) spends within the each gate.

2. Start with the bob at rest and determine the minimum height h_1 to release the bob so that it has just enough energy to go around the lower peg without any slack in the string as the bob passes through the top of the smaller loop (position 2 in Figure 1). Remember, this is an *experiment* – hone in on h_1 by trial until you and your partner agree on the best h_1 for this condition.
[Suggestion: Start with an h_1 that is intentionally too low and systematically increase h_1 by $\sim$2 cm until you find a position that is close to meeting the desired condition. Then make smaller changes to h_1, as needed.]

3. Once you have decided on an appropriate starting height, release the bob from that position (h_1) then measure and record the time it takes for the bob to pass through each photogate. Repeat these measurements for a total of, at least, five (5) times per photogate. Average the results to yield a single time for each photogate.

4 Analysis

For full credit, your complete analysis for this lab must include (labeled and in this order):

1. *A diagram of the setup.* On this diagram, indicate where the relevant parameters are measured and record the values for each (e.g.: h_1; Length of string L_o; Radius of small loop R; bob diameter D; bob mass M). This may be hand drawn. The right frame of Figure 1 is a good guide.

2. Concise, clear and organized work completing the steps in *Section 3.2* to determine theoretical expressions and values for each parameter. Written comments within the work can be helpful to guide a reader through your thought process. Numeric 'answers' are useless without the supporting work and explanation.

3. A summary table of your measured times; see for example Table 1.

Table 1: Time through bottom (t_{bot}) and top (t_{top}) photogates

	t_{bot} [s]	t_{top} [s]
Trial 1		
Trial 2		
⋮		
t_{avg}		

4. One calculation for the experimental velocity through the bottom gate: v_{bot} =[Diameter]/$t_{avg,bot}$

5. One calculation for the experimental velocity through the top gate: v_{bot} =[Diameter]/$t_{avg,top}$

6. One percent error calculation for a parameter: $\%Err = \frac{exp-pred}{pred} \times 100\%$

7. A summary table of experimental, predicted and comparison data, see for example Table 2.

Table 2: Summary of experimental, predicted and comparison data

	Experimental	Prediction	% Error
h_1 [m]			
v_{bot} [m/s]			
v_{top} [m/s]			

Be sure to follow any other specific instructions your instructor may provide for submitted work.

5 Questions

There are no questions prescribed by this handout.

References

- Penn State Behrend Energy Conservation handout... Thanks!
- OpenStax, *Physics*, Chapters 6 and 7
- *Physics*, 8^{th} Edition by Cutnell and Johnson, Chapters 5 & 6