

251: Projectile Pendulum [v.05]

Name: _____

Section: _____

Group Name: _____

Background / Introduction

1. A small weight at the end of a string of length, L , forming a simple pendulum.
2. A horizontal rod is located a distance, d , directly beneath the pivot point.
3. The mass is held so that the string is taut and horizontal and then let fall.
4. What is the minimum distance, d , such that the mass will cause the string to loop over the pin at least once? In theory, we assume the bob is a point mass and the horizontal rod which is a distance d from the fulcrum is infinitesimally thin. However, experimentally, we are looking for the minimum value of d such that the mass hits the lower rod and falls on the other side of it.

Some Physics principles to keep in mind:

- Since the only considered forces acting on the mass are tension and weight, and since the tension does no work on the mass (the tension is perpendicular to the displacement), energy of the mass is conserved.
- Once the string goes slack, the tension disappears and the only force acting on the bob is the force of gravity. Thus, the mass is in projectile motion.
- At the point of the string going slack, the tension drops to zero, but at that moment there is still a centripetal force.

A final analysis note: It is acceptable to ask the instructor for general advise on set-up or if the approach is sound. Do not ask the instructor if the answers are correct or what the approach should be.

Apparatus

- 2 Stands and Vertical Rods (at least one should be tall)
- 2 horizontal rods (at least one should be skinny)
- 3 right angle connectors
- Vernier Caliper
- At least 1-m of String
- 100g hooked mass
- Lab Quest 2,
- 2 photogates

Note: Steps marked with the following do not have to be done in the lab:

- (T) indicates a step in the procedure which requires deriving a theoretical value.
- (R) indicates a step in which results will be calculated.

Position	Meaning
A	Starting position. String is horizontal from the upper rod to the mass.
B	At bottom of arc. String is vertical from the upper rod to the mass.
C	String is horizontal from the lower rod to the mass
D	String starts having slack
E	Mass just barely makes it over the lower rod.

Procedure 0: Set up

1. Set up a stand with vertical rod. Add the two right angle connectors to the rod and suspend a rod horizontally from each of the right angle connectors. The rod attached to the lower connector should be skinny. The lower rod should be directly below the upper rod.
2. Attach a string to the upper horizontal rod and securely attach to the string a 100 g mass to act as a bob for the pendulum.
3. Let L = the length of the string from the center of the pivot point to the center of the 100 g mass
4. Let d = the distance from the center of the upper rod to the center of the lower rod. ($d < L$)
5. Pick five values of L and four values d for each L to use throughout the lab.
6. Secure the connections so the rods don't move when the pendulum is swung.

Procedure A: Speeds at the Bottom of the Swing (Position B)

7. (T) Based on conservation of energy, for five different lengths of the pendulum, determine the theoretical speed of the bob at the bottom of the arc. Record in Table 1.
8. Measure the thickness of the bob using the vernier caliper. This is the distance the bob will travel while blocking the photogate eye.
9. Set up a photogate at the bottom of the swing so that the bob's full thickness will block the beam at position B.
10. At each of the five previously chosen values of L , thrice measure the time (to the precision of the LabQuest2) for the bob to pass by the photogate eye at position B. Record in Table 1.
11. (R) Determine the experimental speed of the bob. Record in Table 1.
12. (R) Plot Theoretical Speed vs... and Experimental Speed vs Square Root of L on the same graph.

Procedure B: Speed Going Up When String is Horizontal (Position C) and Angle at which the String Goes Slack (Position D).

13. (T) Based on conservation of energy and the values of L and d , determine the theoretical speed of the bob at the at position C and the theoretical angle at position D. Record in Table 2.
14. Set up a photogate to record the time of passing for the bob at position C.
15. For each combination of L and d , take two measurements:
 - a) the time, t , for the bob to pass by position C, and
 - b) the reference angle, θ , at position D. Record in Table 2. (If string does not slacken or does not reach position C, pick a new d)
16. (R) Calculate the experimental speed at position C. Record in Table 2.
17. (R) Plot Theoretical Speed vs... and Experimental Speed vs Square Root of d on the same graph.

Procedure C: Speed at Position D to reach Position E.

18. (T) If r = the distance from the mass to the lower rod, v = the speed when the string goes slack, and θ = the angle the string makes with the horizontal when it goes slack if it reaches point E, then
 - a) Using the principles of projectile motion, find t as a function of r , v , and θ .
 - b) Using the principles of projectile motion, find v^2 as a function of r and θ .
 - c) Using the principles of centripetal motion, find v^2 as a function of r and θ .
 - d) Using the principles of conservation of energy, find v^2 as a function of r and θ .
 - e) Find θ
 - f) Find the theoretical value for d as a function of L
 - g) Keep in mind that given the bob moving in the $+\hat{i}$, $+\hat{j}$ direction and given its going from D to E,
 $\Delta \vec{s} = -r\cos\theta \hat{i} + r\sin\theta \hat{j}$, $\vec{a} = 0\hat{i} - g\hat{j}$,
19. For each value of L , experimentally determine the **minimum** value of d such that the bob will hit the bar and fall onto the other side.
20. (R) Determine the value of n so that a plot of d^n vs L trend line should produce a 1st order polynomial. Plot d^n vs. L .

Data and Results

Thickness of the Bob (m): _____

Trial	L (m)	Time 1 (s)	Time 2 (s)	Time 3 (s)	\bar{t} (s)	$v_{experimental}$ (m/s)	$v_{theoretical}$ (m/s)
1							
2							
3							
4							
5							

Table 1: Data/Results for Speed of Bob at Bottom of Arc

Trial	L (m)	d (m)	Time (s)	$\theta_{experimental}$ (°)	$v_{experimental}$ (m/s)	$v_{theoretical}$ (m/s)	$\theta_{Theoretical}$ (°)
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							

Table 2: Data/Results for Bob Swing at C and D

Analysis A

1. Derive the formula for the speed of the object as a function of L .
2. What is the % error in the slopes of the two trend lines?

Analysis B

3. Derive the formula for the speed of the object as a function of d .
4. What is the % error in the slopes of the two trend lines?

Analysis B

5. Show work for deriving step 18a-f.
6. Interpret the meaning of the equation of the trend line. (Discuss the meaning of the value n in the procedure as well as the physical meaning of the slope and vertical intercept.)