Projectile Motion

The purpose of this lab is to study projectile motion of an object,t which is launched horizontally and drops a certain height before it hits the ground.

Equipment

1 ramp shaped like a "ski jump" with a horizontal positioning screw
1 clip positioned on down ramp for placing the steel ball reproducingly at same position
1 steel ball
1 photo gate
1 interface box (photo gate – computer)
1 computer
1 ruler
1 sheet of carbon paper
1 sheet of white paper
1 poor man's "plumb bob" (string with paper clip)

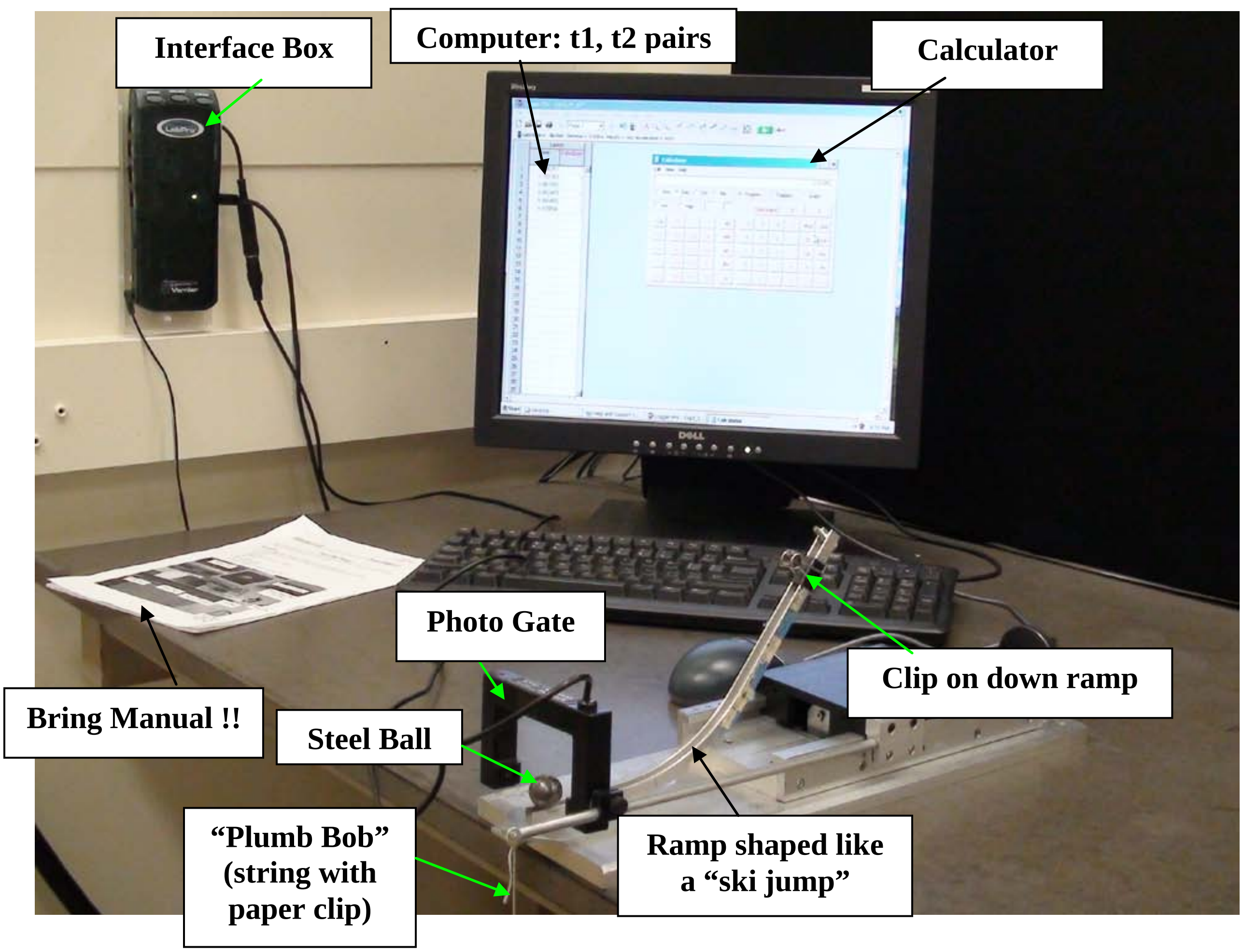


Fig. 1

Introduction

This experiment presents an opportunity to study motion in two dimensions. We study projectile motion, which can be described as **accelerated** motion in the **vertical** direction and motion at **uniform velocity** in the **horizontal** direction. An object launched horizontally with a velocity v_x and dropping a height h, has the following relation between its horizontal distance traveled and v_x :

$$x = v_x \sqrt{\frac{2h}{g}} \qquad (1)$$

Q1. Derive equation (1). Write down the equation of motion in 1 dimension, which describes the distance traveled. Write the equation twice, once for motion with uniform velocity in the x-direction, and once for accelerated motion in the y-direction. Then substitute for the time t.

Determine experimentally the relationship between horizontal distance,x, and velocity, v_x:

You will establish the proportionality constant between the horizontal distance, x, and the horizontal velocity, v_x, by studying the motion of a steel ball launched from a ramp.

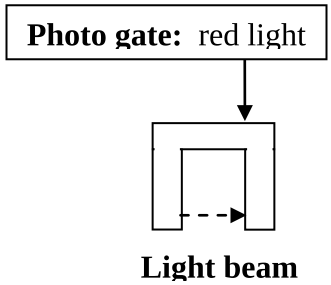
Procedure

Measure the height, h, the vertical distance from the end of the ramp down to the floor and record it in your **REPORT SHEET**. Use the "poor man's plumb bob" (string with paper clip attached) to define the point vertically downward from the point where the string touches the pulley tangentially. Assume that h has an absolute error of 2 mm.

Measure the "effective diameter" d_{eff} of the steel ball, that is the diameter "seen" by the photo gate. This may be accomplished by moving the photo gate from the front to the back of the steel ball on the launching ramp. The front and back are indicated by where the photo gate is blocked or unblocked as seen by the LED (light emitting diode) on top of the photo gate. The LED is on when the gate is blocked. You read the displacement on the scale attached to the platform. Record your measurement in your **REPORT SHEET** and assume the absolute error for the diameter to be 1 mm. Note once you have measured your d_{eff}, DO NOT change the position of the photo gate because shifting the photo gate will change d_{eff}.

Drop the steel ball from the lowest mark on the ramp and note where it lands on the floor, then repeat for the highest mark on the ramp. Make sure your platform with the ramp is solidly clamped to the lab bench when you turn the wheel displacing the photogate. Tape the carbon paper with a piece of white paper underneath it to the floor, so that the ball will hit the paper when it's launched from the ramp.

Now, connect the photo gate output to the interface box by plugging its cable into the **top** socket (labeled "DIG/SONIC 1") of the black interface box ("LabPro"). Test the photo gate: block the photogate beam with your finger and see the red light on the cross bar of the photogate turn on:



Turn on the computer and check the system by following these instructions: Double click the icon "**Exp3_t1_t2**". A window with a spreadsheet on the left (having a "Time, column) comes up. On top is a window "**Sensor Confirmation**". It should show:

Sensor Specified In File:	**Sensor To Set Up:**	**Where:**	**Use:**
✔ Photogate	Photogate	DIG1 on LabPro	✔

Click OK.

[If you don't see the above do:
Click Experiment->Set Up Sensors->Show All Interfaces->DIG/SONIC1: you can check the photogate by blocking it and seeing "Unblocked' go to "Blocked".
Click "Close"]

Click Experiment->Start Collection.

Drop the ball from the lowest mark on the ramp, and the computer will record the time t_1 when the ball enters the light beam and t_2 when the ball leaves the light beam. The difference $\Delta t = t_2 - t_1$ is the time the effective diameter d_{eff} traverses the beam of the photogate. You measure the horizontal distance *x* in the following way: you hang the plumb bob from the end of the ramp and measure the distance between the point where the plumb bob touches the floor, and the mark the steel ball makes on the white paper. (Note **do not shift the position of the paper** at all until you are finished with all measurements.) Each time the ball passes through the photo gate, the time pair t_1, t_2 appears on the screen and you record the difference $(t_2 - t_1)$ in Table 1 in your **REPORT SHEET**. For each mark on the ramp, you drop the steel ball 3 times and record the difference $(t_2 - t_1)$ and the distance measurement. For each mark **make sure** you position the steel ball **reproducibly at the same location** on the ramp. (Since there are 5 marks on the ramp, you should have a total of 15 time measurements and 15 distance measurements).

Once Table 1 has been completed, for each mark on the ramp find the average of the values of *t* and *x* according expression (5) in **"Error and Uncertainty" ("EU")** and enter them into Table 2. You would have to calculate the error of the average t and x using expression (5'') in "EU". But here we will simply estimate the errors from

(Maximum value – minimum value)/2 (for *t* and *x*)

and enter them into Table 2.

For each mark, calculate the horizontal velocity v_x using the following formula:

$$v_x = d_{eff}/t_{avg} \qquad (2)$$

Then enter each value into Table 2. For each value of v_x, calculate its error by applying expression (7) in "EU".

Analysis:

After you have completed Table 2, plot your five pairs of values (v_x, x_{avg}) including the error bars on both axes (NOTE you may neglect error bars which are smaller than your plotted points). Fit your best straight line and draw the lines with maximum and minimum slope. Get the slope k of your best-fit line according to expression (10) in "EU" and its error according to expression (11) in "EU".

Q2: What is the relation between your measured slope k and the gravitational acceleration g from equation (1)? Write this relation in the form g = ….

Q3: In Q2 you get an equation of the form g = N/D, where N stands for "numerator" which has the form constant*variable, and D stands for "denominator", which has the form $(\mathrm{variable})^2$. Thus, once the relative errors of N and D are known, the relative error of g is obtained by applying equation (7) of "EU". In problem 4 of the "Error quiz" you learned, that, when you neglected in the propagation of two errors (applying formula (6) for absolute errors) one error completely, you only made an error of a few % in your error calculation, although the neglected error was a few 10's of % of the other error. This effect is due to the quadratic addition of the two errors, in this lab, relative errors. Show, that in this lab the (relative error of the numerator N)^2 is negligible relative to the (relative error of the denominator D)^2.

Q4: Find the experimental value of the gravitational constant, g_{exp}, from your slope. Calculate the error for g_{exp} and compare it to the expected value of 9.81 m/s^2 (Hint for the error calculation: in Q3 you showed, that in this lab the error of the numerator N in the relation g = N/D can be neglected. That means, for the error calculation of g_{exp} you can write g_{exp} = const * 1/D, where D = $(\mathrm{variable})^2$. Use expression (8) in "EU" to get the error of D and expression (3) in "EU" to get the error of g_{exp}.

REPORT SHEET (to be signed by instructor)

EXPERIMENT 3 Projectile Motion

Name:_____________________________________

SB#:___________________Date:________________

Lab Section:_____________ Lab Instructor:______________________________

Q1: Show your derivation explicitly ____

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<u>Part I Determine the relationship between horizontal distance,*x*, and velocity, v_x:</u>

Height h: ______________________________[ ] Δh: _________________________[ ]

Effective Diameter d_{eff}: ____________________[ ] Δd_{eff}:_________________________[ ]

<u>Table 1:</u>

	Time (t) [ ]	Horizontal distance (x_i) [ ]
From Lowest Point on Ramp		
2nd		
3rd		

4th		
From Highest Point on Ramp		

Table 2:

	x_{avg} [ ]	Δx_{avg} [ ]	t_{avg} [ ]	Δt_{avg} [ ]	v_x [ ]	Δv_x[ ]
Lowest						
2nd						
3rd						
4th						
Highest						

Calculate the average of x, its error and units here (show your calculation explicitly for the lowest mark):

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____[ ]

Calculate the average of t, its error and units here (show your calculation explicitly for the lowest mark):

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____[ ]

Calculate the horizontal velocity v_x , its error and units here (show your calculation explicitly for the lowest mark):

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[ ]

Horizontal distance vs. Horizontal velocity graph using data from Table 2 (with both axes labeled, error bars, units and ranges of x_{avg} and v_x used for the calculation of your slope):

Show explicitly the calculation of slope k and its error and units

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____[ ]

Q2: ____

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Q3: ____

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Q4. $g_{exp} \pm \Delta\, g_{exp}$ (show calculation explicitly for both gexp and its errors and units):__________________________

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____[ ]