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Anything included in this report in RED (with the exception of the equations which are in black) was added by me (Bill) and represents the data obtained when the experiment was run. *Use your own data you collected and perform the calculations for your own data!*

Title: Projectile Motion

Name

Objective

The purpose of this experiment was to study and analyze the dynamics of 2 dimensional projectile motion. This was accomplished by providing a ball with a horizontal velocity and measuring the trajectory range and time of flight, and then comparing the values obtained experimentally with theoretical calculation via the kinematic equations.

Data and Calculations

Part B: Time for some physics!

- Remember to locate the origin as described earlier.

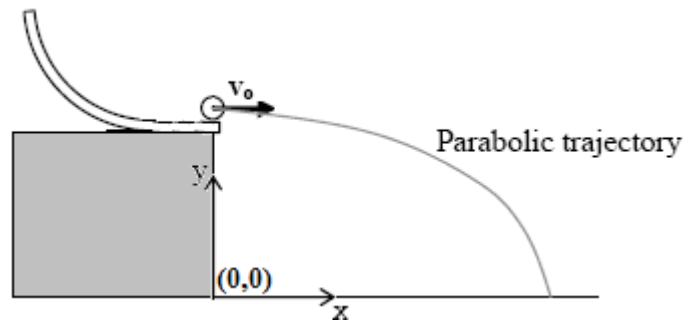


Figure 1: Experimental setup showing initial velocity, parabolic trajectory traveled by the ball, and established coordinate system

Starting Position #1

$$y_0 = \underline{1.05} \text{ m}$$

Trial	Time between photogates (sec) [calculated]	Time of Flight (sec) [calculated]	Range (m) [measured]
1	0.032266 s	0.462795 s	0.430 m
2	0.032395 s	0.46148 s	0.425 m
3	0.03239 s	0.4644 s	0.428 m
4	0.032684 s	0.465091 s	0.425 m
5	0.0327 s	0.461456 s	0.424 m
Average [calculated]	0.032486 s	0.4630444 s	0.4264 m

Starting Position #2 (select a new starting position on the ramp)

Trial	Time between photogates (sec) [calculated]	Time of Flight (sec) [calculated]	Range (m) [measured]
1 (6)	0.035664 s	0.464396 s	0.390 m
2 (7)	0.034984 s	0.464132 s	0.397 m
3 (8)	0.0352 s	0.462102 s	0.395 m
4 (9)	0.035219 s	0.466198 s	0.395 m
5 (10)	0.035394 s	0.465903 s	0.393 m
Average [calculated]	0.0352922 s	0.4645462 s	0.394 m

Note that the time between photogates and the time of flight were calculated for each trial. The data obtained via the experiment is contained in Appendix A at the end of the report for verification.

- Use the previous data to calculate the following information.

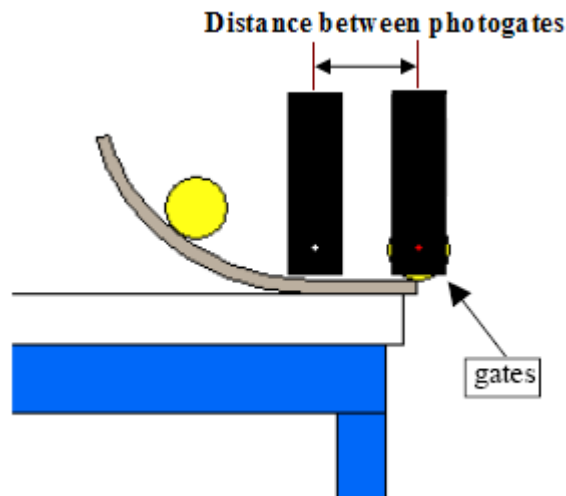


Figure 2: Side view of experimental setup showing the measured distance between photogates

	Starting Position #1	Starting Position #2
Distance between photogates (m) [measured]	0.03 m	0.03 m
Average Time between photogates (s) [from above]	0.032486 s	0.0352922 s
Average initial velocity (v_0) [calculated]	0.923475 m/s	0.850046 m/s

Show an example of your work for each type of calculation.

- To calculate the time between photogates for each trial:

Trial 1

Time [sec]	Gate State 1	Gate State 2
0.6013188	1	
0.6170848	0	
0.6335844	1	
0.6496024	0	
1.1123976		1
1.1322204		0

Use the difference of the values of time where Gate State 1 = 1's:

$$t = 0.6335844\text{ s} - 0.6013188\text{ s}$$

$$t = 0.032266\text{ s}$$

- We used the following method to calculate the time of flight for each trial:

Use the difference of the values of time where Gate State 2 = 1 and Gate State 1 = last 0:

$$T = 1.1123976\text{ s} - 0.6496024\text{ s}$$

$$T = 0.4627952\text{ s}$$

- We used the following method to calculate the average time between photogates (t):

$$\langle t \rangle = \frac{1}{n} \sum_{i=1}^n t_i$$

(where n is the total number of values obtained experimentally)

$$\langle t \rangle = \frac{1}{5} \sum_{i=1}^5 t_i = \frac{1}{5} (0.032266\text{ s} + 0.032395\text{ s} + 0.03239\text{ s} + 0.032684\text{ s} + 0.0327\text{ s})$$

$$\langle t \rangle = 0.032486\text{ s}$$

- We used the following method to calculate the average time of flight (T):

$$\langle T \rangle = \frac{1}{n} \sum_{i=1}^n T_i$$

$$\langle T \rangle = \frac{1}{5} \sum_{i=1}^5 T_i = \frac{1}{5} (0.462795\text{ s} + 0.46148\text{ s} + 0.4644\text{ s} + 0.465091\text{ s} + 0.461456\text{ s})$$

$$\langle T \rangle = 0.4630444\text{ s}$$

- We used the following method to calculate the average range (R):

$$\langle R \rangle = \frac{1}{n} \sum_{i=1}^n R_i$$

$$\langle R \rangle = \frac{1}{5} \sum_{i=1}^5 R_i = \frac{1}{5} (0.430\text{ m} + 0.425\text{ m} + 0.428\text{ m} + 0.425\text{ m} + 0.424\text{ m})$$

$$\langle R \rangle = 0.42624\text{ m}$$

- We used the following method to calculate the average initial velocity:

$$\langle v_o \rangle = \frac{d}{\langle t \rangle} = \frac{0.03m}{0.032486s}$$

$$\boxed{\langle v_o \rangle = 0.923475 \frac{m}{s}}$$

- Use your results from the Prelab questions to calculate the predicted range (R) and time of flight (T) using the initial velocity and the initial position data. For both starting positions.

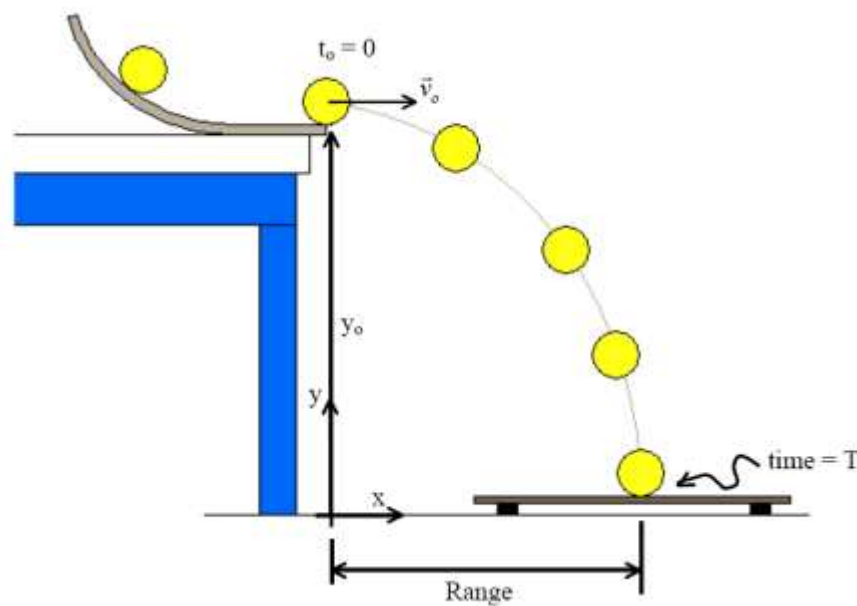


Figure 3: Experimental setup showing measured values of initial height, range and time of flight

Notice that the location of the coordinate system is on the table surface. By placing our coordinate system at the location show above, we can get the following initial conditions:

$$x_o = 0 \text{ m}$$

$$v_{o,x} = \text{<based on starting position>}$$

$$a_x = 0 \text{ m/s}^2$$

$$y_o = 1.05 \text{ m}$$

$$v_{o,y} = 0 \text{ m/s}$$

$$a_y = -g = -9.81 \text{ m/s}^2$$

From the pre-lab questions, using the kinematic equations, we found the following equations for the range and time of flight as functions of the initial height, initial velocity (speed), and acceleration due to gravity.

$$R = \sqrt{\frac{2y_o v_o^2}{g}} = v_o \sqrt{\frac{2y_o}{g}} \qquad T = \sqrt{\frac{2y_o}{g}}$$

Starting Position #1:

$$R_1 = v_{o,1} \sqrt{\frac{2y_o}{g}}$$

$$R_1 = \left(0.923475 \frac{m}{s} \right) \sqrt{\frac{2(1.03m)}{\left(9.81 \frac{m}{s^2} \right)}}$$

$$\boxed{R_1 = 0.42318m}$$

$$T_1 = \sqrt{\frac{2y_o}{g}}$$

$$T_1 = \sqrt{\frac{2(1.03m)}{\left(9.81 \frac{m}{s^2} \right)}}$$

$$\boxed{T_1 = 0.45825s}$$

Starting Position #2:

$$R_2 = v_{o,2} \sqrt{\frac{2y_o}{g}}$$

$$R_2 = \left(0.850046 \frac{m}{s} \right) \sqrt{\frac{2(1.03m)}{\left(9.81 \frac{m}{s^2} \right)}}$$

$$\boxed{R_2 = 0.38953m}$$

$$T_2 = \sqrt{\frac{2y_o}{g}}$$

$$T_2 = \sqrt{\frac{2(1.03m)}{\left(9.81 \frac{m}{s^2} \right)}}$$

$$\boxed{T_2 = 0.45825s}$$

- Create a table displaying your predicted and the experimentally measured values for the Range and Time of flight for each starting position.

Starting Position	R_{calc} (m)	T_{calc} (sec)	R_{exp} (m)	T_{exp} (sec)
#1	0.42318 m	0.45825 s	0.4264 m	0.4630444 s
#2	0.38953 m	0.45825 s	0.3940 m	0.4645462 s

- Perform a percent difference calculation between the predicted and measured quantities.

Starting Position	%diff R	%diff T
#1	0.761 %	1.046 %
#2	1.046 %	1.374 %

$$\% \text{ difference} = \left| \frac{X_{\text{Calculated}} - X_{\text{Measured}}}{X_{\text{Calculated}}} \right| \times 100\%$$

Starting Position #1:

$$\% \text{ difference } R = \left| \frac{R_{\text{Calculated}} - R_{\text{Measured}}}{R_{\text{Calculated}}} \right| \times 100\% = \left| \frac{(0.42318 \text{ m}) - (0.4264 \text{ m})}{(0.42318 \text{ m})} \right| \times 100\%$$

$$\% \text{ difference } R_1 = 0.761 \%$$

$$\% \text{ difference } T = \left| \frac{T_{\text{Calculated}} - T_{\text{Measured}}}{T_{\text{Calculated}}} \right| \times 100\% = \left| \frac{(0.45825 \text{ s}) - (0.4630444 \text{ s})}{(0.45825 \text{ s})} \right| \times 100\%$$

$$\% \text{ difference } T_1 = 1.046\%$$

Starting Position #2:

$$\% \text{ difference } R = \left| \frac{R_{\text{Calculated}} - R_{\text{Measured}}}{R_{\text{Calculated}}} \right| \times 100\% = \left| \frac{(0.38953 \text{ m}) - (0.3940 \text{ m})}{(0.38953 \text{ m})} \right| \times 100\%$$

$$\% \text{ difference } R_2 = 1.046\%$$

$$\% \text{ difference } T = \left| \frac{T_{\text{Calculated}} - T_{\text{Measured}}}{T_{\text{Calculated}}} \right| \times 100\% = \left| \frac{(0.45825 \text{ s}) - (0.4645462 \text{ s})}{(0.45825 \text{ s})} \right| \times 100\%$$

$$\% \text{ difference } T_2 = 1.374\%$$

Results and Questions

- What are the ball's x and y average initial velocities?

Starting Position #1:

$$v_{o,x} = 0.923475 \text{ m/s}$$

$$v_{o,y} = 0 \text{ m/s}$$

Starting Position #2:

$$v_{o,x} = v_o$$

$$v_{o,y} = 0 \text{ m/s}$$

- What are the ball's x and y initial positions (at the moment the ball left the ramp)?

Starting Position #1:

$$x_o = 0 \text{ m}$$

$$y_o = 1.05 \text{ m}$$

Starting Position #2:

$$x_o = 0 \text{ m}$$

$$y_o = 1.05 \text{ m}$$

- What are the ball's x and y accelerations?

Starting Position #1:

$$a_x = 0 \text{ m/s}^2$$

$$a_y = -g = -9.81 \text{ m/s}^2$$

Starting Position #2:

$$a_x = 0 \text{ m/s}^2$$

$$a_y = -9.81 \text{ m/s}^2$$

- Fill in the blanks of the general equations with the coefficients you found for each starting position.

Starting Position #1

x		y	
x vs. t		y vs. t	
$x = (0 \text{ m}) + (0.922475 \text{ m/s}) t + (0 \text{ m/s}^2) t^2$		$y = (1.05 \text{ m}) + (0 \text{ m/s}) t + (-4.905 \text{ m/s}^2) t^2$	
v_x vs. t		v_y vs. t	
$v_x = (0.922475 \text{ m/s}) + (0 \text{ m/s}^2) t$		$v_y = (0 \text{ m/s}) + (-9.81 \text{ m/s}^2) t$	
a_x vs. t		a_y vs. t	

$$a_x = (0 \text{ m/s}^2)$$

$$a_y = (-9.81 \text{ m/s}^2)$$

Starting Position #2

x	y
x vs. t	y vs. t
$x = (0 \text{ m}) + (0.850046 \text{ m/s}) t + (0 \text{ m/s}^2) t^2$	$y = (1.05 \text{ m}) + (0 \text{ m/s}) t + (-4.905 \text{ m/s}^2) t^2$
$v_x \text{ vs. } t$	$v_y \text{ vs. } t$
$v_x = (0.850046 \text{ m/s}) + (0 \text{ m/s}^2) t$	$v_y = (0 \text{ m/s}) + (-9.81 \text{ m/s}^2) t$
$a_x \text{ vs. } t$	$a_y \text{ vs. } t$
$a_x = (0 \text{ m/s}^2)$	$a_y = (-9.81 \text{ m/s}^2)$

- What would the ball's position (x and y) and velocity (x and y) be at a time of 6 seconds. *That is if the floor did not get in the way!*

We can simply plug the value of time = 6s into the equations of motion we found above tusing the initial conditions to determine the answer to this question:

Starting Position #1:

$$x = \left(0.922475 \frac{m}{s} \right) t$$

$$x_{t=6s} = \left(0.922475 \frac{m}{s} \right) (6s) = 5.53485 \text{ m}$$

$$\boxed{x_{t=6s} = 5.53485 \text{ m}}$$

$$y = (1.05 \text{ m}) + \left(-4.905 \frac{m}{s^2} \right) t^2$$

$$y_{t=6s} = 1.05 \text{ m} + \left(-4.905 \frac{m}{s^2} \right) (6s)^2 = -175.53 \text{ m}$$

$$\boxed{y_{t=6s} = -175.53 \text{ m}}$$

(Notice that the position is negative since it's below the established origin)

$$v_x = \left(0.922475 \frac{m}{s} \right)$$

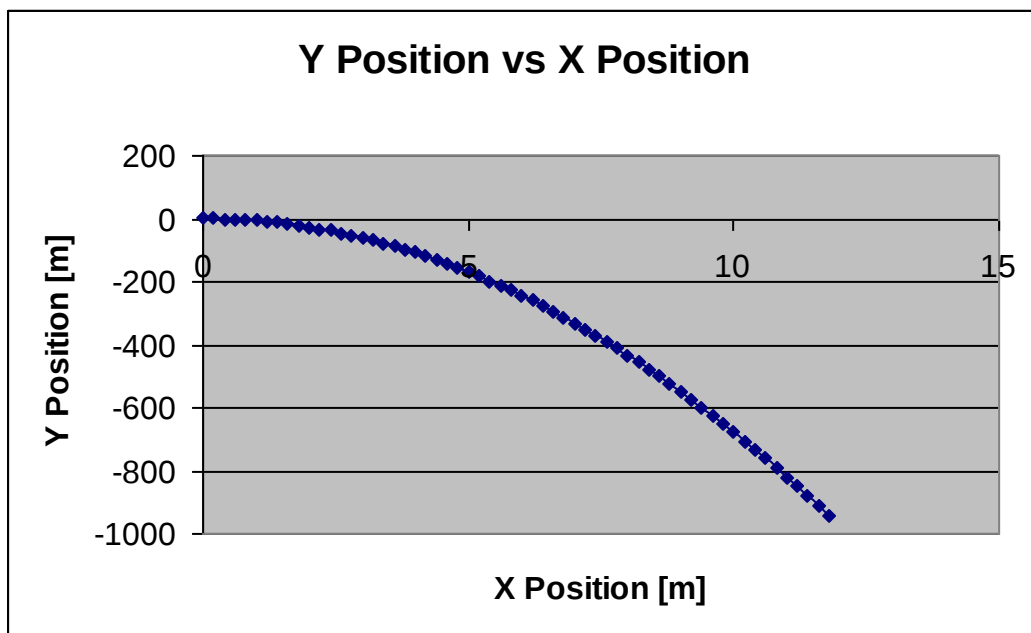
$$v_{x,t=6s} = 0.922475 \frac{m}{s}$$

$$v_y = \left(-9.81 \frac{m}{s^2} \right) t$$

$$v_{y,t=6s} = \left(-9.81 \frac{m}{s^2} \right) (6s) = -58.86 \frac{m}{s}$$

$$v_{y,t=6s} = -58.86 \frac{m}{s}$$

(Notice that the velocity is negative since it's pointing down [in the $-y$ -hat position])



Starting Position #2:

$$x = \left(0.850046 \frac{m}{s} \right) t$$

$$x_{t=6s} = \left(0.850046 \frac{m}{s} \right) (6s) = 5.1003 \text{ m}$$

$$x_{t=6s} = 5.1003 \text{ m}$$

$$y = (1.05 \text{ m}) + \left(4.905 \frac{m}{s^2} \right) t^2$$

$$y_{t=6s} = 1.05 \text{ m} + \left(-4.905 \frac{m}{s^2} \right) (6s)^2 = -175.53 \text{ m}$$

$$y_{t=6s} = -175.53 \text{ m}$$

$$v_x = \left(0.850046 \frac{\text{m}}{\text{s}} \right)$$

$$v_{x,t=6s} = 0.850046 \frac{\text{m}}{\text{s}}$$

$$v_y = \left(-9.81 \frac{\text{m}}{\text{s}^2} \right) t$$

$$v_{y,t=6s} = \left(-9.81 \frac{\text{m}}{\text{s}^2} \right) (6\text{s}) = -58.86 \frac{\text{m}}{\text{s}}$$

$$v_{y,t=6s} = -58.86 \frac{\text{m}}{\text{s}}$$

- How was the range affected by the change in starting position? Explain.

The starting position changed the initial velocity in the x-direction. We saw that when we started the ball higher up the ramp (trials 1-5), it had a higher initial velocity then when we started it lower on the ramp (trials 6-10).

We found the range equation to be given by:

$$R = \sqrt{\frac{2y_o v_o^2}{g}} = v_o \sqrt{\frac{2y_o}{g}} = \frac{v_o}{g} \sqrt{2gy_o}$$

Using purely inductive logic, since the range is directly proportional to the initial velocity, we can deduce that a larger initial velocity will produce a longer range. This was supported using the data collected via the experiment. We saw that the higher position had a longer measured range then the lower position.

- How was the time of flight affected by the change in starting position? Explain.

We found the time of flight to be given by:

$$T = \sqrt{\frac{2y_o}{g}} = \frac{1}{g} \sqrt{2gy_o}$$

Using purely inductive logic, since the acceleration due to gravity is constant and the initial height is constant, this value should always be constant. Although there were some very minor differences to the measured value of the time of flight, this was supported using the data collected via the experiment. We saw that the time of flight was relatively

constant over all measurements. The error of time is in the hundredths of seconds (which can most likely be attributed to the tool itself used for data collection).

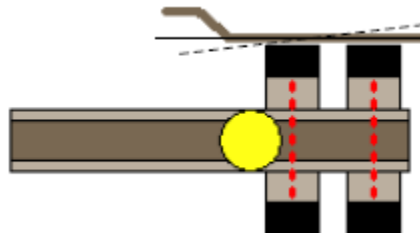
Conclusion

- This closing paragraph is where it is appropriate to conclude and express your opinions about the results of the experiment and all its parts. Only the final result(s) needs to be restated. This part is up to you this time; see the “Write up Guidelines” link on the web page for further help.

You are intelligent scientists. Follow the guidelines provided and write an appropriate results and conclusions section based on your results and deductive reasoning. See if you can think of possible causes of error.

**** NOTE:** There are several components of error which could significantly modify the results of this experiment. Some of these are listed below:

- Actual vs Assumed acceleration due to gravity (Altitude, Earth’s Oblateness, see prelabs 2 and 3 for examples) [9.76 m/s^2 vs. 9.81 m/s^2]
- Parallax
- Angle of the ramp (causing ballistic motion with non-zero velocity in the y-direction)
- Technique
- Drag and air resistance
- Snagging and catching
- Calibration
- Sensor limitation parameters
- Computer processor speed and reading registration
- Sensor Alignment (see lab procedures and the figure below – also recall the discussion of tilt covered in class a few weeks ago)



- Other

A few of the potential errors listed above may be applicable to YOUR experiment.

Appendix A: Data Obtained via Logger Pro from Experiment

Starting Position #1:

Trial 1	Time [sec]	Gate State 1	Gate State 2
	0.6013188	1	
	0.6170848	0	
	0.6335844	1	
	0.6496024	0	
	1.1123976		1
	1.1322204		0

Trial 2	Time [sec]	Gate State 1	Gate State 2
	0.8370896	1	
	0.8528244	0	
	0.8694848	1	
	0.8856148	0	
	1.3470944		1
	1.3668848		0
	1.3691844		1
	1.3891108		0

Trial 3	Time [sec]	Gate State 1	Gate State 2
	0.1268064	1	
	0.142584	0	
	0.1591968	1	
	0.1753848	0	
	0.6397844		1
	0.659594		0

Trial 4	Time [sec]	Gate State 1	Gate State 2
	2.4386008	1	
	2.4545852	0	
	2.4712848	1	
	2.4874932	0	
	2.9525844		1
	2.9723888		0
	2.974884		1
	2.9947844		0
	3.0015844		1
	3.0215048		0

Trial 5	Time [sec]	Gate State 1	Gate State 2
	0.3215852	1	
	0.3374848	0	
	0.3542852	1	
	0.3706156	0	
	0.832072		1
	0.8518984		0

Starting Position #2:

Trial 6

Time [sec]	Gate State 1	Gate State 2
0.2135196	1	
0.2307856	0	
0.2491836	1	
0.2668896	0	
0.7312856		1
0.7511252		0
0.7878852		1
0.8077856		0

Trial 7

Time [sec]	Gate State 1	Gate State 2
0.1675008	1	
0.1844844	0	
0.2024844	1	
0.2199844	0	
0.684116		1
0.7039848		0
0.7065852		1
0.7265048		0

Trial 8

Time [sec]	Gate State 1	Gate State 2
0.5061844	1	
0.5232852	0	
0.5413848	1	
0.559012	0	
1.021114		1
1.0409844		0
1.0436088		1
1.0635844		0

Trial 9

Time [sec]	Gate State 1	Gate State 2
0.3491852	1	
0.366214	0	
0.384404	1	
0.4020868	0	
0.8682844		1
0.8881112		0
0.9501844		1
0.97003		0

Trial 10

Time [sec]	Gate State 1	Gate State 2
1.3458924	1	
1.3630924	0	
1.3812864	1	
1.398986	0	
1.8648888		1
1.884784		0
1.8873836		1
1.9072856		0