PHYSICS 20 Lab 4: Projectile Motion 2 hours

INTRODUCTION:

Projectile motion is the motion of an object moving freely through two-dimensional space near the earth's surface. Projectile motion is characterized by the constant downward acceleration of the object due to gravity ($\vec{a}_y = 9.81\ m/s^2$, $downwards$) in the vertical direction; and a constant acceleration of zero ($\vec{a}_x = 0$) in the horizontal direction. The shape of the trajectory is a parabola, and thus this motion is also called parabolic motion.

OBJECTIVE:

- **To compare the experimental horizontal range with the calculated horizontal range for three different projectile motion set-ups.**

  % Error < 10 % for each setup

APPARATUS:

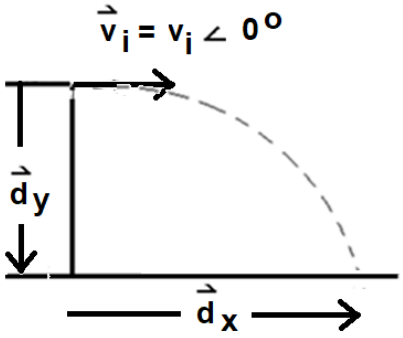
1	**Mini Launcher with plumb bob**
1	**Phone Jack Extender Cable**
2	**Photogate Head**
1	**Photogate Bracket**
1	**Large C Clamp**
1	**Metric Measuring Tape/Ruler**
1	**Pasco Smart timer with cables**
1	**Metric Ruler**
3	**11 x 17 sheets of paper**
1	**Carbon paper**

Theory:

If a projectile, near the earth's surface, starts with a known initial velocity ($\vec{v}_i = v_i \angle \theta$) from a known height ($h$) above a horizontal surface, the horizontal displacement or range (d_x) can be calculated using the kinematics equations learned in class. This lab will involve two different scenarios using three trials.

In the first scenario (Trial 1 only), the initial velocity is entirely horizontal, so the initial velocity can be stated using polar notation in the form: $\vec{v}_i = v_i \angle 0^o$.

Trial 1



Given the initial vertical velocity is zero, the magnitude of the range (d_x) can be calculated using the following equations:

(1) $\vec{v}_x = v_i \cdot cos0$

(2) $\vec{v}_{yi} = v_i \cdot sin0$

(3) $t = \sqrt{\frac{2 \cdot \vec{d}_y}{\vec{a}_y}}$

(4) $d_x = v_x \cdot t$

Example

1. If a pumpkin is launched with an initial velocity of 30.0 m/s horizontally from a height of 80.0 m above horizontal ground, determine the magnitude of the horizontal displacement or range of the pumpkin.

Given: $\vec{v}_i = 30.0\ m/s \angle 0^o$**;** $h = 80.0\ m$
Find: d_x
Let: Right = "+", Downwards = "-"

Horizontal

$\vec{v}_x = (30.0 m/s)cos0 = +30.0\ m/s$
$\vec{d}_x = ?\ m$
$t = ?\ s$

Vertical

$\vec{v}_{yi} = (30.0 m/s)sin0 = 0\ m/s$
$\vec{v}_{yf} = ?\ m/s$
$\vec{d}_y = -80.0\ m$
$\vec{a}_y = -9.81\ m/s^2$
$t = ?\ s$

$$\vec{d}_y = \vec{v}_{yi} \cdot t + \frac{1}{2} \cdot \vec{a}_y \cdot t^2 \text{ with } \vec{v}_{yi} = 0\ m/s \therefore\ \vec{d}_y = \frac{1}{2} \cdot \vec{a}_y \cdot t^2$$

$$t = \sqrt{\frac{2 \cdot \vec{d}_y}{\vec{a}_y}} = \sqrt{\frac{2(-80.0\ m)}{-9.81\ m/s^2}} = 4.039\ s$$

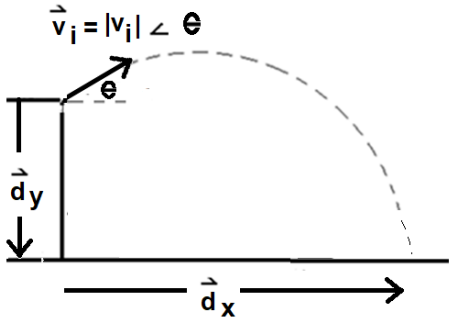
$t = 4.04\ s$ **(Time of flight to hit ground)**

$$d_x = v_x \cdot t = (30.0\ m/s)(4.039\ s) = +121.2\ m$$

$d_x = 121\ m$ **(Horizontal distance traveled or "range")**

In the second scenario (Trials 2 and 3), the angle of the initial velocity is greater than 0º but less than 90º, so the initial velocity can be stated using polar notation in the form: $\vec{v}_i = |v_i| \angle \theta$.

Trials 2 and 3



Given the initial vertical velocity is upwards and the final vertical velocity is downwards, the magnitude of the range (d_x) can be calculated using the following equations:

(1) $\vec{v}_x = v_i \cdot \cos\theta$

(2) $\vec{v}_{yi} = v_i \cdot \sin\theta$

(3) $\vec{v}_{yf} = -\sqrt{\vec{v}_{yi}^{\,2} + 2 \cdot \vec{a}_y \cdot \vec{d}_y}$

(4) $t = \frac{(\vec{v}_{yf} - \vec{v}_{yi})}{\vec{a}_y}$

(5) $d_x = v_x \cdot t$

Example

2. **If a cannonball is projected with an initial velocity of 56.0 m/s , 76° above the horizontal from a cliff that is 155 m above horizontal ground, determine the horizontal distance or range of the cannonball.**

Given: $\vec{v}_i = 56.0\ m/s \angle 76^o$**;** $h = 155\ m$
Find: d_x
Let: Right = "+", Downwards = "-"

Horizontal	**Vertical**
$\vec{v}_x = (56.0\ m/s)cos76 = +13.55\ m/s$	$\vec{v}_{yi} = (56.0\ m/s)sin76 = +54.34\ m/s$
$\vec{d}_x = ?\ m$	$\vec{v}_{yf} = ?\ m/s$
$t = ?\ s$	$\vec{d}_y = -155\ m$
	$\vec{a}_y = -9.81\ m/s^2$
	$t = ?\ s$

$$\vec{v}_{yi}{}^2 = \vec{v}_{yi}{}^2 + 2\vec{a}_y \cdot \vec{d}_y$$

$$\therefore \vec{v}_{yf} = -\sqrt{\vec{v}_{yi}{}^2 + 2\vec{a}_y\vec{d}_y}$$ (use "-" because final vertical velocity is downwards)

$$\therefore \vec{v}_{yf} = -\sqrt{(54.34\ m/s)^2 + 2(-9.81\ m/s^2)(-155\ m)} = -77.42\ m/s$$

$$t = \frac{(\vec{v}_{yf} - \vec{v}_{yi})}{\vec{a}_y}$$

$$\therefore t = \frac{[(-77.42\ m/s) - (+54.34\ m/s)]}{-9.81\ m/s^2} = 13.43\ s$$ **(Time of flight to hit ground)**

$$d_x = v_x \cdot t = (13.55\ m/s)(13.43\ s) = +182.0\ m$$

$$d_x = 182\ m$$ **(Horizontal distance traveled or "range")**

Similar to the examples above, in this lab, the main goal is to determine the experimental range for a given set-up (ie. known height and initial velocity) and compare it to the calculated range for the same set-up.

Given the equipment used in the lab, the height and angle can be measured directly, but the magnitude of the initial velocity (ie. initial speed) must be estimated using the time it takes the projectile to travel through photogates of a fixed distance when it is initially launched.

Given the definition of average speed is change in distance/change in time, the average speed of the projectile after it is initially launched, can be calculated using:

$$v_{avg} = \frac{\Delta d}{\Delta t} \text{ where } \Delta d = 0.100\ m \text{ and } \Delta t \text{ is measured}$$

If this average speed, calculated above, is used as an estimate of the initial speed ($|v_i|$), then the calculated range can be determined like in the Examples 1 and 2 above.

$$v_i = \frac{\Delta d}{\Delta t}$$

Example

3. If the projectile takes a time of $\Delta t = 0.0310\ s$ to travel through a distance of $\Delta d = 0.100\ m$, determine an estimate for the initial speed.

$$v_i = \frac{\Delta d}{\Delta t}$$

$$v_i = \frac{0.100\ m}{0.0310\ s} = 3.226\ m/s$$

$$v_i = 3.23\ m/s$$

Procedure:

Set up Apparatus

Safety
Wear Safety Goggles.
Do not place foreign objects into the Launcher.
Do not look into the Launcher.
Do not aim the Launcher at others.

I. **Note the circle on the side of the launcher that says "Launch Position of Ball." This indicates the position of the ball when it leaves the spring and becomes a free projectile. Measure the vertical drop or displacement in the y-direction from the bottom of the ball to the bench top. Record.**

II. **Set the Pasco Smart Timer as follows: Push 1 until Time is displayed. Using 2, scroll over and select 2 gates. Button 3 will be used to turn the timer on. Timer is ready to use when the * is displayed. Before each launch check the timer for the *.**

III. **Carefully adjust the launcher to fire horizontally. The protractor should read exactly zero degrees. You should try to set the angle within 0.5 degrees by making the string equidistant between the +1 and -1 degree hash marks on the protractor. You will not get good results if you are not careful when setting the angles.**

Trial 1: Projectile is launched with an initial velocity at 0°.

1. **Using the attached plumb bob, adjust the angle of the launcher to 0° so the initial velocity in the y-direction is zero.**
2. **Measure and record the height.**
3. **Load the spring in the launcher by compressing it to the one, two, or three click position using the wand. Place the ball in the launcher.**
4. **Check the Pasco Smart timer has the * displayed.**
5. **Pull the string and launch the projectile (ie. the yellow ball). Note where the ball lands and tape down an 11 x 17 sheet of paper.**
6. **Reload and set the timer. Launch.**
7. **Using the carbon paper, mark the spot the ball hits the counter on the piece of paper.**
8. **Record the time from the Pasco Smart Timer.**
9. **Repeat launch until you get a cluster of at least 3 marks on the 11 x 17 sheet of paper.**
10. **Measure and record these each horizontal distance. (use as experimental range)**

Trial 2: Projectile is launched with an initial velocity greater than 0°.

11. **Using the attached plumb bob, adjust the angle of the launcher to an angle of your choice between 5° and 85°.**
12. **Repeat Steps 2 to 10 as in Trial 1.**

Trial 3: Projectile is launched with an initial velocity greater than 0°.

13. **Using the attached plumb bob, adjust the angle of the launcher to an angle of your choice between 5° and 85°, so that it is different than in Trial 2.**
14. **Repeat Steps 2 to 10 as in Trial 1.**

Calculations Needed:

15. **Do and show all the calculations for all three trials and record these values in the final Results Table.**
16. **Given this a calculation lab only, no conclusion is needed.**
17. **Compile your completed lab to your instructor by the due date.**

Your completed lab should include:

The Initial Data Table

All Calculations (titles for each calculation do not need to be shown, but formulas and substitution with units should be included)

Final Results Table

Calculations:

Trial 1

(1) $\Delta t = \frac{(\Delta t_1 + \Delta t_2 + \Delta t_3)}{3}$

(2) $v_i = \frac{0.100\ m}{\Delta t}$

(3) $\vec{v}_x = v_i \cdot cos0$

(4) $\vec{v}_{yi} = v_i \cdot sin0$

(5) $t = \sqrt{\frac{2 \cdot \vec{d}_y}{\vec{a}_y}}$

(6) $d_{xcalc} = v_x \cdot t$ **(use as Calculated Range)**

(7) $d_{xexp} = \frac{(d_{x1} + d_{x2} + d_{x3})}{3}$ **(use as Experimental Range)**

(8) $\%\ error = \frac{|d_{xexp} - d_{xcalc}|}{d_{xcalc}} x100\ \%$

Trials 2 and 3

(1) $\Delta t = \frac{(\Delta t_1 + \Delta t_2 + \Delta t_3)}{3}$

(2) $v_i = \frac{0.100\ m}{\Delta t}$

(3) $\vec{v}_x = v_i \cdot cos\theta$

(4) $\vec{v}_{yi} = v_i \cdot sin\theta$

(5) $\vec{v}_{yf} = -\sqrt{\vec{v}_{yi}^{\,2} + 2 \cdot \vec{a}_y \cdot \vec{d}_y}$

(6) $t = \frac{(\vec{v}_{yf} - \vec{v}_{yi})}{\vec{a}_y}$

(7) $d_{xcalc} = v_x \cdot t$ **(use as Calculated Range)**

(8) $d_{xexp} = \frac{(d_{x1} + d_{x2} + d_{x3})}{3}$ **(use as Experimental Range)**

(9) $\%\ error = \frac{|d_{xexp} - d_{xcalc}|}{d_{xcalc}} x100\ \%$

Initial Data Tables

Note: For the online course, use the Data Set Number provided to you to complete the Initial Data Table and complete the lab.

Data Set Number = ____

Angle 1 ($\Theta = 0^o$)

Angle: $\Theta = 0^o$
Distance between photo-gates: Δd = _____
Height: h = _____

Run	Time between Gates - Δt (s)	Horizontal Displacement - $\vec{d}_x$ (m)
1		
2		
3		

Angle 2 ($\Theta \neq 0^o$)

Angle: Θ = ____
Distance between photo-gates: Δd = _____
Height: h = _____

Run	Time between Gates - Δt (s)	Horizontal Displacement - $\vec{d}_x$ (m)
1		
2		
3		

Angle 3 ($\Theta \neq 0^o$)

Angle: Θ = ____
Distance between photo-gates: Δd = _____
Height: h = _____

Run	Time between Gates - Δt (s)	Horizontal Displacement - $\vec{d}_x$ (m)
1		
2		
3		

Final Results Tables

Data Set Number = ____

Trial 1 (Θ = 0º)

Angle: Θ = 0º ____
Constant vertical acceleration: $\vec{a}_y$ = _____
Distance between photo-gates: Δd =_____; Average time between gates: Δt = _____
Initial velocity: $\vec{v}_i$= _____ (state using polar notation)
Constant velocity in horizontal direction: $\vec{v}_x$= _____
Initial velocity in vertical direction: $\vec{v}_{yi}$= _____
Time of flight: t = _____
Horizontal range: d_x = _____ (Calculated value)
Average horizontal range: d_x = _____ (Experimental value)
% error for d_x: % error = _____

Trial 2 (Θ ≠ 0º)

Angle: Θ = ____
Constant vertical acceleration: $\vec{a}_y$ = _____
Distance between photo-gates: Δd = _____; Average time between gates: Δt = _____
Initial velocity: $\vec{v}_i$= _____ (state using polar notation)
Constant velocity in horizontal direction: $\vec{v}_x$= _____
Initial velocity in vertical direction: $\vec{v}_{yi}$= _____
Final velocity in vertical direction: $\vec{v}_{yf}$= _____
Time of flight: t = _____
Horizontal range: d_x = _____ (Calculated value)
Average horizontal range: d_x = _____ (Experimental value)
% error for d_x: % error = _____

Trial 3 (Θ ≠ 0º)

Angle: Θ = ____
Constant vertical acceleration: $\vec{a}_y$ = _____
Distance between photo-gates: Δd = _____ ; Average time between gates: Δt = _____
Initial velocity: $\vec{v}_i$= _____ (state using polar notation)
Constant velocity in horizontal direction: $\vec{v}_x$= _____
Initial velocity in vertical direction: $\vec{v}_{yi}$= _____
Final velocity in vertical direction: $\vec{v}_{yf}$= _____
Time of flight: t = _____
Horizontal range: d_x = _____ (Calculated value)
Average horizontal range: d_x = _____ (Experimental value)
% error for d_x: % error = _____

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Lab 4 Data Sets

Data Set	1

Apparatus		
Trial	1	
Clicks	3	
Height	0.323	m

Time Between Gates		
Time 1	0.0143	s
Time 2	0.0162	s
Time 3	0.0141	s

Experimental Range		
dx1	1.45	m
dx2	1.99	m
dx3	1.88	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.411	m
Angle	62	deg

Time Between Gates		
Time 1	0.0307	s
Time 2	0.0300	s
Time 3	0.0307	s

Experimental Range		
dx1	0.98	m
dx2	1.02	m
dx3	1.14	m

Apparatus		
Trial	3	
Clicks	2	
Height	0.383	m
Angle	37	deg

Time Between Gates		
Time 1	0.0223	s
Time 2	0.0213	s
Time 3	0.0228	s

Experimental Range		
dx1	2.62	m
dx2	2.46	m
dx3	2.41	m

Data Set	2

Apparatus		
Trial	1	
Clicks	2	
Height	0.288	m

Time Between Gates		
Time 1	0.0221	s
Time 2	0.0216	s
Time 3	0.0216	s

Experimental Range		
dx1	1.02	m
dx2	1.25	m
dx3	1.23	m

Apparatus		
Trial	2	
Clicks	3	
Height	0.312	m
Angle	14	deg

Time Between Gates		
Time 1	0.0156	s
Time 2	0.0136	s
Time 3	0.0143	s

Experimental Range		
dx1	2.78	m
dx2	3.27	m
dx3	2.78	m

Apparatus		
Trial	3	
Clicks	1	
Height	0.367	m
Angle	52	deg

Time Between Gates		
Time 1	0.0298	s
Time 2	0.0304	s
Time 3	0.0299	s

Experimental Range		
dx1	1.47	m
dx2	1.28	m
dx3	1.13	m

Data Set	3

Apparatus		
Trial	1	
Clicks	3	
Height	0.306	m

Time Between Gates		
Time 1	0.0161	s
Time 2	0.0143	s
Time 3	0.0153	s

Experimental Range		
dx1	1.59	m
dx2	1.76	m
dx3	1.77	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.380	m
Angle	48	deg

Time Between Gates		
Time 1	0.0312	s
Time 2	0.0312	s
Time 3	0.0292	s

Experimental Range		
dx1	1.28	m
dx2	1.54	m
dx3	1.37	m

Apparatus		
Trial	3	
Clicks	2	
Height	0.322	m
Angle	9	deg

Time Between Gates		
Time 1	0.0217	s
Time 2	0.0233	s
Time 3	0.0219	s

Experimental Range		
dx1	1.62	m
dx2	1.54	m
dx3	1.43	m

Data Set	4

Apparatus		
Trial	1	
Clicks	3	
Height	0.289	m

Time Between Gates		
Time 1	0.0155	s
Time 2	0.0133	s
Time 3	0.0148	s

Experimental Range		
dx1	1.76	m
dx2	1.66	m
dx3	1.63	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.325	m
Angle	21	deg

Time Between Gates		
Time 1	0.0307	s
Time 2	0.0284	s
Time 3	0.0313	s

Experimental Range		
dx1	1.26	m
dx2	1.24	m
dx3	1.25	m

Apparatus		
Trial	3	
Clicks	2	
Height	0.382	m
Angle	68	deg

Time Between Gates		
Time 1	0.0226	s
Time 2	0.0223	s
Time 3	0.0227	s

Experimental Range		
dx1	1.54	m
dx2	1.36	m
dx3	1.58	m

Data Set	5

Apparatus		
Trial	1	
Clicks	3	
Height	0.308	m

Time Between Gates		
Time 1	0.0152	s
Time 2	0.0148	s
Time 3	0.0154	s

Experimental Range		
dx1	1.77	m
dx2	1.52	m
dx3	1.65	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.396	m
Angle	62	deg

Time Between Gates		
Time 1	0.0305	s
Time 2	0.0296	s
Time 3	0.0295	s

Experimental Range		
dx1	1.08	m
dx2	1.13	m
dx3	1.01	m

Apparatus		
Trial	3	
Clicks	2	
Height	0.349	m
Angle	24	deg

Time Between Gates		
Time 1	0.0219	s
Time 2	0.0227	s
Time 3	0.0229	s

Experimental Range		
dx1	2.01	m
dx2	1.75	m
dx3	2.07	m

Data Set	6

Apparatus		
Trial	1	
Clicks	3	
Height	0.288	m

Time Between Gates		
Time 1	0.0150	s
Time 2	0.0145	s
Time 3	0.0148	s

Experimental Range		
dx1	1.59	m
dx2	1.60	m
dx3	1.67	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.316	m
Angle	16	deg

Time Between Gates		
Time 1	0.0298	s
Time 2	0.0286	s
Time 3	0.0290	s

Experimental Range		
dx1	1.25	m
dx2	1.28	m
dx3	1.28	m

Apparatus		
Trial	3	
Clicks	2	
Height	0.363	m
Angle	49	deg

Time Between Gates		
Time 1	0.0216	s
Time 2	0.0218	s
Time 3	0.0213	s

Experimental Range		
dx1	2.37	m
dx2	2.49	m
dx3	2.24	m

Data Set	7

Apparatus		
Trial	1	
Clicks	3	
Height	0.275	m

Time Between Gates		
Time 1	0.0149	s
Time 2	0.0148	s
Time 3	0.0156	s

Experimental Range		
dx1	1.57	m
dx2	1.35	m
dx3	1.58	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.309	m
Angle	20	deg

Time Between Gates		
Time 1	0.0313	s
Time 2	0.0288	s
Time 3	0.0298	s

Experimental Range		
dx1	1.31	m
dx2	1.32	m
dx3	1.31	m

Apparatus		
Trial	3	
Clicks	2	
Height	0.360	m
Angle	58	deg

Time Between Gates		
Time 1	0.0222	s
Time 2	0.0230	s
Time 3	0.0224	s

Experimental Range		
dx1	1.89	m
dx2	2.19	m
dx3	2.00	m

Data Set	8

Apparatus		
Trial	1	
Clicks	3	
Height	0.283	m

Time Between Gates		
Time 1	0.0133	s
Time 2	0.0151	s
Time 3	0.0141	s

Experimental Range		
dx1	1.83	m
dx2	1.43	m
dx3	1.56	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.304	m
Angle	12	deg

Time Between Gates		
Time 1	0.0290	s
Time 2	0.0301	s
Time 3	0.0313	s

Experimental Range		
dx1	1.12	m
dx2	1.09	m
dx3	0.96	m

Apparatus		
Trial	3	
Clicks	2	
Height	0.355	m
Angle	46	deg

Time Between Gates		
Time 1	0.0225	s
Time 2	0.0225	s
Time 3	0.0220	s

Experimental Range		
dx1	2.34	m
dx2	2.34	m
dx3	2.01	m

Data Set	9

Apparatus		
Trial	1	
Clicks	2	
Height	0.319	m

Time Between Gates		
Time 1	0.0232	s
Time 2	0.0222	s
Time 3	0.0234	s

Experimental Range		
dx1	1.14	m
dx2	1.02	m
dx3	1.18	m

Apparatus		
Trial	2	
Clicks	3	
Height	0.412	m
Angle	69	deg

Time Between Gates		
Time 1	0.0147	s
Time 2	0.0145	s
Time 3	0.0142	s

Experimental Range		
dx1	3.17	m
dx2	3.40	m
dx3	3.77	m

Apparatus		
Trial	3	
Clicks	1	
Height	0.343	m
Angle	14	deg

Time Between Gates		
Time 1	0.0305	s
Time 2	0.0282	s
Time 3	0.0297	s

Experimental Range		
dx1	1.36	m
dx2	1.18	m
dx3	1.19	m

Data Set	10

Apparatus		
Trial	1	
Clicks	2	
Height	0.298	m

Time Between Gates		
Time 1	0.0234	s
Time 2	0.0220	s
Time 3	0.0234	s

Experimental Range		
dx1	1.07	m
dx2	1.13	m
dx3	1.09	m

Apparatus		
Trial	2	
Clicks	2	
Height	0.354	m
Angle	34	deg

Time Between Gates		
Time 1	0.0234	s
Time 2	0.0220	s
Time 3	0.0234	s

Experimental Range		
dx1	2.39	m
dx2	2.17	m
dx3	2.22	m

Apparatus		
Trial	3	
Clicks	3	
Height	0.390	m
Angle	67	deg

Time Between Gates		
Time 1	0.0154	s
Time 2	0.0155	s
Time 3	0.0151	s

Experimental Range		
dx1	3.23	m
dx2	3.55	m
dx3	3.54	m

Data Set	11

Apparatus		
Trial	1	
Clicks	3	
Height	0.347	m

Time Between Gates		
Time 1	0.0148	s
Time 2	0.0151	s
Time 3	0.0154	s

Experimental Range		
dx1	1.78	m
dx2	1.57	m
dx3	1.67	m

Apparatus		
Trial	2	
Clicks	2	
Height	0.389	m
Angle	25	deg

Time Between Gates		
Time 1	0.0229	s
Time 2	0.0217	s
Time 3	0.0230	s

Experimental Range		
dx1	2.16	m
dx2	2.22	m
dx3	2.06	m

Apparatus		
Trial	3	
Clicks	1	
Height	0.432	m
Angle	58	deg

Time Between Gates		
Time 1	0.0310	s
Time 2	0.0309	s
Time 3	0.0290	s

Experimental Range		
dx1	1.10	m
dx2	1.36	m
dx3	1.31	m

Data Set	12

Apparatus		
Trial	1	
Clicks	3	
Height	0.323	m

Time Between Gates		
Time 1	0.0144	s
Time 2	0.0147	s
Time 3	0.0164	s

Experimental Range		
dx1	1.73	m
dx2	1.75	m
dx3	1.65	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.401	m
Angle	51	deg

Time Between Gates		
Time 1	0.0306	s
Time 2	0.0314	s
Time 3	0.0305	s

Experimental Range		
dx1	1.25	m
dx2	1.37	m
dx3	1.26	m

Apparatus		
Trial	3	
Clicks	2	
Height	0.345	m
Angle	13	deg

Time Between Gates		
Time 1	0.0217	s
Time 2	0.0210	s
Time 3	0.0223	s

Experimental Range		
dx1	1.76	m
dx2	1.60	m
dx3	2.01	m

Data Set	13

Apparatus		
Trial	1	
Clicks	2	
Height	0.345	m

Time Between Gates		
Time 1	0.0213	s
Time 2	0.0215	s
Time 3	0.0207	s

Experimental Range		
dx1	1.11	m
dx2	1.24	m
dx3	1.28	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.418	m
Angle	47	deg

Time Between Gates		
Time 1	0.0312	s
Time 2	0.0301	s
Time 3	0.0315	s

Experimental Range		
dx1	1.37	m
dx2	1.38	m
dx3	1.29	m

Apparatus		
Trial	3	
Clicks	3	
Height	0.378	m
Angle	19	deg

Time Between Gates		
Time 1	0.0167	s
Time 2	0.0167	s
Time 3	0.0148	s

Experimental Range		
dx1	3.61	m
dx2	3.06	m
dx3	3.27	m

Data Set	14

Apparatus		
Trial	1	
Clicks	3	
Height	0.284	m

Time Between Gates		
Time 1	0.0145	s
Time 2	0.0151	s
Time 3	0.0156	s

Experimental Range		
dx1	1.50	m
dx2	1.72	m
dx3	1.54	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.323	m
Angle	23	deg

Time Between Gates		
Time 1	0.0299	s
Time 2	0.0294	s
Time 3	0.0300	s

Experimental Range		
dx1	1.19	m
dx2	1.43	m
dx3	1.12	m

Apparatus		
Trial	3	
Clicks	2	
Height	0.377	m
Angle	68	deg

Time Between Gates		
Time 1	0.0216	s
Time 2	0.0221	s
Time 3	0.0219	s

Experimental Range		
dx1	1.70	m
dx2	1.52	m
dx3	1.84	m

Data Set	15

Apparatus		
Trial	1	
Clicks	2	
Height	0.301	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.385	m
Angle	57	deg

Apparatus		
Trial	3	
Clicks	3	
Height	0.332	m
Angle	18	deg

Time Between Gates		
Time 1	0.0214	s
Time 2	0.0234	s
Time 3	0.0239	s

Time Between Gates		
Time 1	0.0285	s
Time 2	0.0308	s
Time 3	0.0298	s

Time Between Gates		
Time 1	0.0146	s
Time 2	0.0142	s
Time 3	0.0162	s

Experimental Range		
dx1	1.20	m
dx2	1.17	m
dx3	1.05	m

Experimental Range		
dx1	1.28	m
dx2	1.10	m
dx3	1.51	m

Experimental Range		
dx1	3.42	m
dx2	3.42	m
dx3	3.88	m

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Lab 4 Data Sets

Data Set 1

Apparatus		
Trial	1	
Clicks	3	
Height	0.323	m

Time Between Gates		
Time 1	0.0143	s
Time 2	0.0162	s
Time 3	0.0141	s

Experimental Range		
dx1	1.45	m
dx2	1.99	m
dx3	1.88	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.411	m
Angle	62	deg

Time Between Gates		
Time 1	0.0307	s
Time 2	0.0300	s
Time 3	0.0307	s

Experimental Range		
dx1	0.98	m
dx2	1.02	m
dx3	1.14	m

Apparatus		
Trial	3	
Clicks	2	
Height	0.383	m
Angle	37	deg

Time Between Gates		
Time 1	0.0223	s
Time 2	0.0213	s
Time 3	0.0228	s

Experimental Range		
dx1	2.62	m
dx2	2.46	m
dx3	2.41	m

Data Set 2

Apparatus		
Trial	1	
Clicks	2	
Height	0.288	m

Time Between Gates		
Time 1	0.0221	s
Time 2	0.0216	s
Time 3	0.0216	s

Experimental Range		
dx1	1.02	m
dx2	1.25	m
dx3	1.23	m

Apparatus		
Trial	2	
Clicks	3	
Height	0.312	m
Angle	14	deg

Time Between Gates		
Time 1	0.0156	s
Time 2	0.0136	s
Time 3	0.0143	s

Experimental Range		
dx1	2.78	m
dx2	3.27	m
dx3	2.78	m

Apparatus		
Trial	3	
Clicks	1	
Height	0.367	m
Angle	52	deg

Time Between Gates		
Time 1	0.0298	s
Time 2	0.0304	s
Time 3	0.0299	s

Experimental Range		
dx1	1.47	m
dx2	1.28	m
dx3	1.13	m

Data Set	3

Apparatus		
Trial	1	
Clicks	3	
Height	0.306	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.380	m
Angle	48	deg

Apparatus		
Trial	3	
Clicks	2	
Height	0.322	m
Angle	9	deg

Time Between Gates		
Time 1	0.0161	s
Time 2	0.0143	s
Time 3	0.0153	s

Time Between Gates		
Time 1	0.0312	s
Time 2	0.0312	s
Time 3	0.0292	s

Time Between Gates		
Time 1	0.0217	s
Time 2	0.0233	s
Time 3	0.0219	s

Experimental Range		
dx1	1.59	m
dx2	1.76	m
dx3	1.77	m

Experimental Range		
dx1	1.28	m
dx2	1.54	m
dx3	1.37	m

Experimental Range		
dx1	1.62	m
dx2	1.54	m
dx3	1.43	m

Data Set	4

Apparatus		
Trial	1	
Clicks	3	
Height	0.289	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.325	m
Angle	21	deg

Apparatus		
Trial	3	
Clicks	2	
Height	0.382	m
Angle	68	deg

Time Between Gates		
Time 1	0.0155	s
Time 2	0.0133	s
Time 3	0.0148	s

Time Between Gates		
Time 1	0.0307	s
Time 2	0.0284	s
Time 3	0.0313	s

Time Between Gates		
Time 1	0.0226	s
Time 2	0.0223	s
Time 3	0.0227	s

Experimental Range		
dx1	1.76	m
dx2	1.66	m
dx3	1.63	m

Experimental Range		
dx1	1.26	m
dx2	1.24	m
dx3	1.25	m

Experimental Range		
dx1	1.54	m
dx2	1.36	m
dx3	1.58	m

Data Set	5

Apparatus		
Trial	1	
Clicks	3	
Height	0.308	m

Time Between Gates		
Time 1	0.0152	s
Time 2	0.0148	s
Time 3	0.0154	s

Experimental Range		
dx1	1.77	m
dx2	1.52	m
dx3	1.65	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.396	m
Angle	62	deg

Time Between Gates		
Time 1	0.0305	s
Time 2	0.0296	s
Time 3	0.0295	s

Experimental Range		
dx1	1.08	m
dx2	1.13	m
dx3	1.01	m

Apparatus		
Trial	3	
Clicks	2	
Height	0.349	m
Angle	24	deg

Time Between Gates		
Time 1	0.0219	s
Time 2	0.0227	s
Time 3	0.0229	s

Experimental Range		
dx1	2.01	m
dx2	1.75	m
dx3	2.07	m

Data Set	6

Apparatus		
Trial	1	
Clicks	3	
Height	0.288	m

Time Between Gates		
Time 1	0.0150	s
Time 2	0.0145	s
Time 3	0.0148	s

Experimental Range		
dx1	1.59	m
dx2	1.60	m
dx3	1.67	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.316	m
Angle	16	deg

Time Between Gates		
Time 1	0.0298	s
Time 2	0.0286	s
Time 3	0.0290	s

Experimental Range		
dx1	1.25	m
dx2	1.28	m
dx3	1.28	m

Apparatus		
Trial	3	
Clicks	2	
Height	0.363	m
Angle	49	deg

Time Between Gates		
Time 1	0.0216	s
Time 2	0.0218	s
Time 3	0.0213	s

Experimental Range		
dx1	2.37	m
dx2	2.49	m
dx3	2.24	m

Data Set	7

Apparatus		
Trial	1	
Clicks	3	
Height	0.275	m

Time Between Gates		
Time 1	0.0149	s
Time 2	0.0148	s
Time 3	0.0156	s

Experimental Range		
dx1	1.57	m
dx2	1.35	m
dx3	1.58	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.309	m
Angle	20	deg

Time Between Gates		
Time 1	0.0313	s
Time 2	0.0288	s
Time 3	0.0298	s

Experimental Range		
dx1	1.31	m
dx2	1.32	m
dx3	1.31	m

Apparatus		
Trial	3	
Clicks	2	
Height	0.360	m
Angle	58	deg

Time Between Gates		
Time 1	0.0222	s
Time 2	0.0230	s
Time 3	0.0224	s

Experimental Range		
dx1	1.89	m
dx2	2.19	m
dx3	2.00	m

Data Set	8

Apparatus		
Trial	1	
Clicks	3	
Height	0.283	m

Time Between Gates		
Time 1	0.0133	s
Time 2	0.0151	s
Time 3	0.0141	s

Experimental Range		
dx1	1.83	m
dx2	1.43	m
dx3	1.56	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.304	m
Angle	12	deg

Time Between Gates		
Time 1	0.0290	s
Time 2	0.0301	s
Time 3	0.0313	s

Experimental Range		
dx1	1.12	m
dx2	1.09	m
dx3	0.96	m

Apparatus		
Trial	3	
Clicks	2	
Height	0.355	m
Angle	46	deg

Time Between Gates		
Time 1	0.0225	s
Time 2	0.0225	s
Time 3	0.0220	s

Experimental Range		
dx1	2.34	m
dx2	2.34	m
dx3	2.01	m

Data Set	9

Apparatus		
Trial	1	
Clicks	2	
Height	0.319	m

Time Between Gates		
Time 1	0.0232	s
Time 2	0.0222	s
Time 3	0.0234	s

Experimental Range		
dx1	1.14	m
dx2	1.02	m
dx3	1.18	m

Apparatus		
Trial	2	
Clicks	3	
Height	0.412	m
Angle	69	deg

Time Between Gates		
Time 1	0.0147	s
Time 2	0.0145	s
Time 3	0.0142	s

Experimental Range		
dx1	3.17	m
dx2	3.40	m
dx3	3.77	m

Apparatus		
Trial	3	
Clicks	1	
Height	0.343	m
Angle	14	deg

Time Between Gates		
Time 1	0.0305	s
Time 2	0.0282	s
Time 3	0.0297	s

Experimental Range		
dx1	1.36	m
dx2	1.18	m
dx3	1.19	m

Data Set	10

Apparatus		
Trial	1	
Clicks	2	
Height	0.298	m

Time Between Gates		
Time 1	0.0234	s
Time 2	0.0220	s
Time 3	0.0234	s

Experimental Range		
dx1	1.07	m
dx2	1.13	m
dx3	1.09	m

Apparatus		
Trial	2	
Clicks	2	
Height	0.354	m
Angle	34	deg

Time Between Gates		
Time 1	0.0234	s
Time 2	0.0220	s
Time 3	0.0234	s

Experimental Range		
dx1	2.39	m
dx2	2.17	m
dx3	2.22	m

Apparatus		
Trial	3	
Clicks	3	
Height	0.390	m
Angle	67	deg

Time Between Gates		
Time 1	0.0154	s
Time 2	0.0155	s
Time 3	0.0151	s

Experimental Range		
dx1	3.23	m
dx2	3.55	m
dx3	3.54	m

Data Set	11

Apparatus		
Trial	1	
Clicks	3	
Height	0.347	m

Time Between Gates		
Time 1	0.0148	s
Time 2	0.0151	s
Time 3	0.0154	s

Experimental Range		
dx1	1.78	m
dx2	1.57	m
dx3	1.67	m

Apparatus		
Trial	2	
Clicks	2	
Height	0.389	m
Angle	25	deg

Time Between Gates		
Time 1	0.0229	s
Time 2	0.0217	s
Time 3	0.0230	s

Experimental Range		
dx1	2.16	m
dx2	2.22	m
dx3	2.06	m

Apparatus		
Trial	3	
Clicks	1	
Height	0.432	m
Angle	58	deg

Time Between Gates		
Time 1	0.0310	s
Time 2	0.0309	s
Time 3	0.0290	s

Experimental Range		
dx1	1.10	m
dx2	1.36	m
dx3	1.31	m

Data Set	12

Apparatus		
Trial	1	
Clicks	3	
Height	0.323	m

Time Between Gates		
Time 1	0.0144	s
Time 2	0.0147	s
Time 3	0.0164	s

Experimental Range		
dx1	1.73	m
dx2	1.75	m
dx3	1.65	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.401	m
Angle	51	deg

Time Between Gates		
Time 1	0.0306	s
Time 2	0.0314	s
Time 3	0.0305	s

Experimental Range		
dx1	1.25	m
dx2	1.37	m
dx3	1.26	m

Apparatus		
Trial	3	
Clicks	2	
Height	0.345	m
Angle	13	deg

Time Between Gates		
Time 1	0.0217	s
Time 2	0.0210	s
Time 3	0.0223	s

Experimental Range		
dx1	1.76	m
dx2	1.60	m
dx3	2.01	m

Data Set	13

Apparatus		
Trial	1	
Clicks	2	
Height	0.345	m

Time Between Gates		
Time 1	0.0213	s
Time 2	0.0215	s
Time 3	0.0207	s

Experimental Range		
dx1	1.11	m
dx2	1.24	m
dx3	1.28	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.418	m
Angle	47	deg

Time Between Gates		
Time 1	0.0312	s
Time 2	0.0301	s
Time 3	0.0315	s

Experimental Range		
dx1	1.37	m
dx2	1.38	m
dx3	1.29	m

Apparatus		
Trial	3	
Clicks	3	
Height	0.378	m
Angle	19	deg

Time Between Gates		
Time 1	0.0167	s
Time 2	0.0167	s
Time 3	0.0148	s

Experimental Range		
dx1	3.61	m
dx2	3.06	m
dx3	3.27	m

Data Set	14

Apparatus		
Trial	1	
Clicks	3	
Height	0.284	m

Time Between Gates		
Time 1	0.0145	s
Time 2	0.0151	s
Time 3	0.0156	s

Experimental Range		
dx1	1.50	m
dx2	1.72	m
dx3	1.54	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.323	m
Angle	23	deg

Time Between Gates		
Time 1	0.0299	s
Time 2	0.0294	s
Time 3	0.0300	s

Experimental Range		
dx1	1.19	m
dx2	1.43	m
dx3	1.12	m

Apparatus		
Trial	3	
Clicks	2	
Height	0.377	m
Angle	68	deg

Time Between Gates		
Time 1	0.0216	s
Time 2	0.0221	s
Time 3	0.0219	s

Experimental Range		
dx1	1.70	m
dx2	1.52	m
dx3	1.84	m

Data Set	15

Apparatus		
Trial	1	
Clicks	2	
Height	0.301	m

Time Between Gates		
Time 1	0.0214	s
Time 2	0.0234	s
Time 3	0.0239	s

Experimental Range		
dx1	1.20	m
dx2	1.17	m
dx3	1.05	m

Apparatus		
Trial	2	
Clicks	1	
Height	0.385	m
Angle	57	deg

Time Between Gates		
Time 1	0.0285	s
Time 2	0.0308	s
Time 3	0.0298	s

Experimental Range		
dx1	1.28	m
dx2	1.10	m
dx3	1.51	m

Apparatus		
Trial	3	
Clicks	3	
Height	0.332	m
Angle	18	deg

Time Between Gates		
Time 1	0.0146	s
Time 2	0.0142	s
Time 3	0.0162	s

Experimental Range		
dx1	3.42	m
dx2	3.42	m
dx3	3.88	m