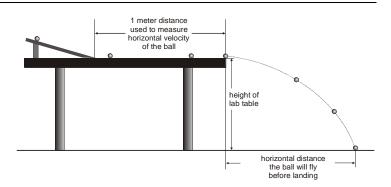The objective of this lab is to use the physics of projectile motion to predict the distance a horizontally launched projectile will travel before hitting the ground. We'll roll a steel ball down a ramp on a lab table and measure its velocity across the table. We'll assume that the ball will not slow down much as it makes its way across the table top, and use this velocity as the horizontal launch velocity. Using this velocity and the height of the lab table above the floor, we'll use the physics of projectile motion we've been learning to predict how far away from the table edge the ball will hit the ground.

When we make our prediction, we will specify the horizontal distance the ball will fly as a range of distances, based on the uncertainty of the measurements we use to calculate our prediction. We'll see whether our prediction is correct within the range of uncertainty we specify.

Procedure Part 1: Measure the time for the ball to roll across the table

1. Record which ramp you are using here:_____

2. Position the ramp so that the end of the ramp is about 1 meter from the edge of the table. Carefully measure the distance from the end of the ramp to the table edge. Estimate the uncertainty of your measurement and record it here:

    x_{table}=_____ ±_____m

3. Now measure the time it takes for the ball to travel the distance from the bottom of the ramp to the edge of the lab table.
    a. Make a mark on the ramp so you release the ball from the same spot each time
    b. Roll the ball down the ramp and across the table top, but catch it before it hits the ground.

    Do not let the ball hit the floor!

    c. Use the stopwatch to measure the time it takes for the ball to roll from the **bottom of the ramp to the edge of the table**
    d. Repeat this at least 10 times and record the results in the table at right.

Procedure Part 2: Calculate the horizontal velocity of the ball across the table

1. Use $v_{horizontal} = \dfrac{x_{table}}{average\ time}$ to find the horizontal speed of the ball:

    $v_{horizontal}$=_____m/s

2. Next we'll find the uncertainty of this velocity. Since we used ***division*** to calculate velocity, we have to ***add the relative uncertainties*** of the distance and time to find the relative uncertainty of the velocity.

    a. Complete the table at right. Find the average time and average deviation, which we will use as an estimate of the uncertainty.

trial	time	deviation
avg		**±**

b. Calculate the relative uncertainty of the time. Use the average time as **t** and the average deviation as **Δt**

$$\text{relative uncertainty} = \frac{\text{absolute uncertainty}}{\text{measured value}} \times 100 = \frac{\Delta t}{t} \times 100$$

Time for ball to roll across lab table: _____ s ± _____%

c. Using your estimate of the uncertainty of the measurement of the horizontal distance from the bottom of the ramp to the edge of the lab table, calculate the relative uncertainty of the distance measurement:

d. Horizontal distance ball rolls across table: $x_{horizontal}$= _____m ±_____%

e. Calculate the relative uncertainty of the velocity by adding the relative uncertainties of the distance and time measurements.

Velocity of ball across table top: $v_{horizontal}$= _____m/s ± _____%

Procedure Part 2: Calculate the time for the ball to drop to the floor

1. Measure the distance from the tabletop to the floor, and estimate the uncertainty, and record it here: y=_____ ±_____m
Calculate the relative uncertainty of y since we'll need it for the next step:

y=_____ m ±_____%

2. Next, we'll find the time, *t,* for the ball to fall from the tabletop to the floor. Use the equation $\Delta y = v_i \Delta t + \frac{at^2}{2}$. Take v_i to be zero and

a to be 9.81 ±0.02 m/s². You must first solve this equation for *t*.

t.=_____s

Next, we want to find the relative uncertainty of *t*. When we calculated Δt, we used the equation $\Delta t = \sqrt{\frac{2\Delta y}{a}}$. Using the rules for

uncertainty propagation, we add the relative uncertainties of y and acceleration, since we are dividing. Finally, since we are taking the square root (raising to the ½ power) we multiply the sum of these relative uncertainties by ½. This gives the relative uncertainty of the time. Show your work for your calculations.

t=_____ s ±_____%

Procedure Part 3: Calculate the distance the ball will fly

1. Using $x_{floor} = v_{horizontal}t$ calculate the horizontal distance across the floor the ball will fly before landing. *Use $v_{horizontal}$ from part 1and t from part 2,*

    x_{floor}=_____m

2. Since we used multiplication to find this distance, we'll add the relative uncertainties of the horizontal velocity and time to find the relative uncertainty of the horizontal distance.

    x_{floor}=_____m±_____%

3. Use the relative uncertainty to calculate the **absolute** uncertainty of the horizontal distance the ball will fly before hitting the floor.

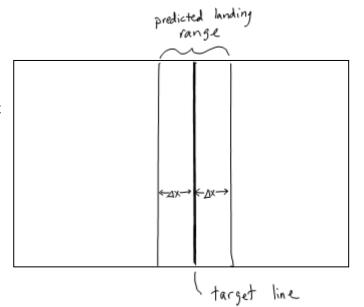 $$relative\ uncertainty = \frac{\Delta x}{x} \times 100$$

    Predicted horizontal distance the ball will fly across floor: Δx_{floor} (predicted) = _____m ±____m

Procedure Part 4: Test your prediction

1. Construct a target by making three lines on a piece of paper separated by the absolute uncertainty of your distance measurement.

2. Locate your target on the lab floor by measuring the distance from the edge of the table to the spot on the floor where you predict the ball will land. Place the piece of paper with the target line on the floor at that location.

3. Place a piece of carbon paper over the target paper. Roll the ball off the ramp to see if it lands in between the lines you've drawn on your paper.

4. Measure the distance to the landing spot. Include an estimate of uncertainty:

    x_{floor} (actual) = _____m

5. Calculate the difference between your predicted distance and the actual distance.

6. Calculate the percent difference between your prediction and the actual distance.

predicted landing range

target line

Lab Questions

1. People who have not studied physics sometime question whether the horizontal and vertical motion of a projectile really are independent. Does this lab give you evidence to support this concept? Support your answer.

2. Imagine that we increased the height of the ramp to 20 cm, making the ramp a much steeper slope.
   a. How would this affect the horizontal velocity of the ball off the end of the table?

   b. How would it affect the drop time of the ball?

   c. How would it affect the distance the ball flies?

3. Imagine that we increased the height of the table from the floor:
   a. How would this affect the horizontal velocity of the ball off the end of the table?

   b. How would it affect the drop time of the ball?

   c. How would it affect the distance the ball flies?

4. What if you used a ball with twice as much mass, but similar size:
   a. How would this affect the horizontal velocity of the ball off the end of the table?

   b. How would it affect the drop time of the ball?

   c. How would it affect the distance the ball flies?

5. Could you use the distance a horizontally launched projectile flies to find the initial velocity of the projectile? Describe how.

6. How do you thing the results would change if you used a ping-pong ball instead of a steel ball?

7. Why didn't we consult the manufacturer's specifications to find the uncertainty of the stopwatch and include this in our uncertainty?

8. Which uncertainty contributed the greatest relative uncertainty to the final answer?

9. Identify at least three plausible sources of systematic error that could be affecting our results.

10. One possible source of systematic error is that we assume the ball does not slow down as it rolls across the table. If the ball does slow down, how could we modify this experiment so we still predict the distance accurately?