Laboratory 4: Projectile Motion – Prelab

1 Projectile launched horizontally

Various projectiles are launched horizontally off a table above a horizontal floor.

a) Determine the time taken to fall and the horizontal distance from the edge of the table to where the ball lands if the table surface is 1.20 m above the floor and the launch speed is 1.50 m/s.

b) Determine the time taken to fall and the horizontal distance from the edge of the table to where the ball lands if the table surface is 1.20 m above the floor and the launch speed is 2.25 m/s.

c) Determine a general formula for the time taken to reach the floor if the height of the table is h. Does this depend on the launch speed?

Laboratory 4: Projectile Motion – Experiment

A projectile is an object close to the Earth's surface which moves solely under the influence of the Earth's gravitational force. Newtonian physics predicts the exact trajectory of a projectile given knowledge of its initial state of motion. The aims of this laboratory are to verify these predictions and to familiarize you with the use of the equations of motion for projectile motion.

1 Projectile motion with horizontal launch

Classical physics predicts that any projectile moves with constant acceleration with horizontal component $a_x = 0\,\mathrm{m/s^2}$ and vertical component $a_y = -g = -9.8\,\mathrm{m/s^2}$. This can be used to relate the location and velocity of the object at a later moment to those at an earlier moment. Let

$$\boxed{\begin{aligned} x_0 &= \text{horizontal position coordinate at the earlier moment,} \\ y_0 &= \text{vertical position coordinate at the earlier moment,} \\ v_{0x} &= \text{horizontal component of velocity at the earlier moment and} \\ v_{0y} &= \text{vertical component of velocity at the earlier moment.} \end{aligned}}$$

Similarly

$$\boxed{\begin{aligned} t &= \text{time at later moment,} \\ x &= \text{horizontal position coordinate at the later moment,} \\ y &= \text{vertical position coordinate at the later moment,} \\ v_x &= \text{horizontal component of velocity at the later moment and} \\ v_y &= \text{vertical component of velocity at the later moment.} \end{aligned}}$$

Then the kinematic equations give

$$v_x = v_{0x} + a_x t \tag{1}$$

$$x = x_0 + v_{0x} t + \frac{1}{2} a_x t^2 \tag{2}$$

$$v_x^2 = v_{0x}^2 + 2a_x(x - x_0). \tag{3}$$

Similar equations apply for the vertical components. Simply replace x with y.

In this experiment you will launch a ball horizontally, from a known height and with a speed which can be measured. After launch the ball undergoes projectile motion eventually hitting the floor; you will be able to measure how far it travels horizontally. Separately you will develop a formula which predicts how far the ball travels horizontally before hitting the floor. You will then check whether the prediction agrees with the measurement.

The formula that you will develop will contain the following two variables

$$\boxed{\begin{aligned} h &= \text{height through which the ball falls and} \\ v_{\text{launch}} &= \text{the } \textit{speed} \text{ with which the ball is launched} \end{aligned}}$$

plus other constants. In this analysis the "earlier" instant will be the moment of launch and the "later" instant will be the moment just before the ball hits the ground.

a) Sketch the velocity vector, $\vec{\mathbf{v}}_0$, at the moment of launch and use this to determine general expressions, that are *true for any height and launch speed*, for its horizontal and vertical components. The only entities that are allowed appear in the expressions are v_{launch}, h, g and numbers

$$v_{0x} =$$
$$v_{0y} =$$

The correct formulas might be very simple and might not include all of the variables listed above.

b) By considering both vertical and horizontal aspects of the motion, determine a formula for the horizontal distance traveled by the ball from the point of launch to the point where it hits the floor. The formula can only contain h, g, v_{launch} and constants. Verify your formula with the instructor.

2 Experiment

The ball can be rolled along a groove in the track and launched so that it strikes a piece of paper taped to the floor. A piece of carbon paper placed above this will make a mark at the point where the ball strikes the floor.

a) Tape a piece of paper to the floor in the approximate location where the ball will land. Place a loose sheet of carbon paper over this.

b) Level the track and align the launch point with the table edge.

c) Measure and record the vertical height through which the ball falls.

The speed of the ball prior to launch can be determined by first measuring how long it takes to pass between two points, that are a known distance apart, on the track. The timing will be done by two photogates.

d) Start CapStone and connect the two photogates separately using the Photogate option in the Hardware Setup tab. Follow the instructions of page 6 to configure these to read the time between photogates.

e) Place a Digits window in the main display. Click Select Measurement and choose Time Between Gates (Ch 1& Ch2) .

f) Describe *how* you would use the time between the photogates to determine the speed of the ball as it reaches the launch point.

g) Roll the ball along the track and measure the time between the photogates. Use this to determine the speed with which the ball leaves the track. Use the formula you developed earlier to calculate the distance through which the ball will travel from the moment of launch off the track until it hits the floor and denote your result x_{calc}. Measure the horizontal distance through which the ball traveled from the moment of launch until it struck the floor and denote this x_{meas}.

h) Determine the percentage difference between x_{meas} and x_{calc} via

$$\text{Percentage difference} = \frac{|x_{\text{meas}} - x_{\text{calc}}|}{x_{\text{calc}}} \times 100\%$$

This gives a rough method for comparing theory to experiment. A good result would be anything less than 5%.

i) Repeat the procedure of parts (g) and (h) at least two more times.

3 Conclusion

a) Do the equations of motion predict the horizontal distance covered correctly?

b) What are possible sources of error in this experiment? Note that friction between the ball and track here is irrelevant.

c) What is your main conclusion from this experiment?

4 Exercises

a) One possible source of error is an inaccuracy in measuring x_{meas}. Using a meter stick it is reasonable to assume that your measurement may be as much as 5 mm too small or too large. This will give a range of values for x_{meas}. Choose one run of your experiment and list the range of possible values for x_{meas}. Does x_{calc} lie within this range? Can the percentage error for this run be explained by such measurement discrepancies in x_{meas}?

b) Suppose that the track was tilted slightly upwards at the launch end and that this had a negligible affect on the horizontal component of the initial velocity. However, it provides an non-zero positive vertical component of initial velocity. As a result, will x_{calc} (as calculated assuming a perfect horizontal launch) be too large or too small? Explain your answer.

Setting up photogates as timers

To configure the photogates to measure the time between the gates, click Timer Setup in the Tools palette and do as follows:

(1) Select Pre-configured and click next.

(2) Check both photogates and click next.

(3) Select Two Photogates (Single Flag) and click next.

(4) Check the Time Between Gates box and click next.

(5) Use the default parameters and click next.

(6) Provide a name and and click next.

(7) Click finish.