**Lab PM - Projectile motion**

**Online version**

**Equipment**

* Projectile trajectory (posted on Canvas next to this notebook), printed on standard letter size paper
* Ruler
* Protractor

**Background**

A projectile is launched with initial speed *v*0 and angle *θ* with the horizontal direction. Let us use the most common choice of coordinate axes for this situation: *x* along the horizontal direction, *y* in the vertical direction. In the general case, at *t* = 0 the projectile is not at the origin but at (*x*0, *y*0).



If the projectile is not very light for its size and shape, and does not move very fast, neglecting air resistance is an excellent approximation. Then, the acceleration of the ball is:



where *g* is the magnitude of the acceleration of gravity. The position (*x*,*y*) of the ball at any given time *t* is given by:



Sketch *x* and *y* as a function of time if are all positive.



**Experiment**

A good camera that can capture enough frames per seconds is an excellent way to study motion.

[This video](https://youtu.be/qLWtT0gmSlw) shows the parabolic motion of a ball tossed in the air.

In the first part, we just see the ball in slow motion. In the second part, a diamond marks the position of the ball at intervals of 1/24 s.

We took a snapshot of that second part of the video, turned it into a line drawing, and printed it on graphing paper.

**Data collection**

Your lab kit contains a copy of the trajectory snapshots on graphing paper. We will use it to analyze the motion. The data collection should be first recorded directly on your copy. We strongly recommend using a pencil, so you can erase mistakes and keep things clean and organized.

* Number the diamonds, starting with 1 for the earliest event.
* We will use the coordinate axes described above: *x* along the horizontal direction, *y* in the vertical direction. Choose an origin for the coordinate system and indicate it with an O on your paper.
* Add labels every 5 cm in both directions.
* Determine the coordinates of the center of each diamond, in cm, and write it next to the diamond using the notation (*x*, *y*).

Insert a picture of your copy of the trajectory snapshots showing all your measurements.

Use a ruler to measure the apparent size of the ball on your paper and record it below.

Create a table on Logger Pro with the following columns:

* Diamond number
* *x* (cm on the paper)
* *y* (cm on the paper)

and enter the data you collected. In any experiment, you should always record the raw data, and keep any subsequent calculation as a separate step, as we will do next.

**Data analysis**

The video provides a reference length: the diameter of the ball is 3¾ inches. Find the distance in the real world that 1.0 “cm on the paper” corresponds to, in meters. Show your calculation.

We are also given the time interval between each recorded event: 1/24 s. If the first diamond corresponds to *t* = 0, to what time does the 4th diamond correspond?

We can now create 3 new Calculated Columns in the table. The mathematical expression for each column is like the calculations above, involving a raw column and a conversion factor.

* Time (s)
* Real *x* (m)
* Real *y* (m)

Once the columns have been added, insert a snapshot of your table below.

We will produce two plots: Real *x vs.* Time and Real *y vs.* Time.

**Real *x vs.* Time**

This graph should look like a straight line (if it does not, go back and check your measurements!). Perform a linear fit (see Logger Pro Help document if needed for help). Then, insert your graph below.

What physical quantities do the slope and intersection with the Real *x* axis correspond to? Write the quantities and their values below.

What is the acceleration in the *x* direction? Justify your answer based on your graph.

**Real *y vs.* Time**

This graph should be a parabola. In this case, it is not possible to obtain a linear graph with some simple manipulation of the data, so we will use a Curve Fit for a quadratic polynomial.

Insert your graph below.

What physical quantities do the three parameters of the fit correspond to? Write the values below.

Use the results from both fits to obtain experimental estimates for:

* The acceleration of gravity, *g*
* The initial speed of the ball, *v*0
* The angle between the initial velocity and the horizontal, *θ*

Show your work below.

**Uncertainty**

If your measurements were careful enough, your graphs should present a straight line and a parabola that are close to perfect. That is why the value of R2 is extremely close to 1 in both cases. This also means that the statistical error of the fit parameters is very small, so we will not bother with them.

A picture containing graphical user interface

Description automatically generatedThe largest source of uncertainty is the measurement of the apparent size of the ball on the paper. We measured this distance with a ruler, where the precision is limited to around 0.5 mm. On top of that, in the copy you worked with, the ball is a circle with sharp edges. However, the real image of the moving that was used to produce that line drawing ball, shown to the right, has blurred edges.

We can estimate that the overall effect is that we might be getting the apparent diameter wrong by up to 1 mm.

Since this measurement provides the distance scale, its uncertainty is propagated through all the calculations. In other words, this produces an uncertainty in the conversion factor between distances on the paper and real distances.

Determine what the conversion factor would be if the apparent diameter of the ball was 1 mm smaller (which we can call the “minimum apparent diameter”), enter that value on your table, and use the new fit parameters to determine again *g*, *v*0and *θ.* Record the results in the first three columns of the table below.

Repeat the same process for the maximum apparent diameter (you measurement plus 1 mm).

Then, calculate the last column, which provides an estimation of the experimental uncertainty for each of the physical quantities.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Quantity | Using measured apparent diameter | Using minimum apparent diameter | Using maximum apparent diameter | Uncertainty  (max-min)/2 |
| *g* |  |  |  |  |
| *v*0 |  |  |  |  |
| *θ* |  |  |  |  |

**Conclusion**

Does your experimental determination of *g* match the accepted value of 9.8 m/s2? Explain. Your reasoning must include the uncertainty.

Estimate the value of *θ* directly on the print using a protractor. You will notice that it is not easy to guess the direction of the initial velocity (*i.e*., the tangent to the trajectory at *t* = 0). Therefore, the uncertainty for this measurement can be up to 5°.

How does this last measurement compare to the value of *θ* we determined from all the position data? Your reasoning must include the uncertainty of both measurements.