

Make ten or more trials, and find the average value of the distance d , the distance the ball travels before hitting the ground.

average

d value [m] = _____

What is the uncertainty in a single measurement of d ?

uncertainty in

d [m] = _____

Standard Deviation, σ

Another tool for reporting the error of a measurement is to use the *standard deviation*. This is a better tool than simply reporting the uncertainty of a measurement using the methods we have so far. The mathematical definition of the standard deviation of the individual measurements:

x_1, x_2, x_3, \dots , is

$$\sigma_x = \sqrt{\frac{1}{N} \sum (x_i - \bar{x})^2}$$

x_i is the value for a particular measurement, and \bar{x} would be the average of all N measurements, i.e. the mean. Essentially, it compares each measurement to the average of the measurements. A small σ_x implies that the measurement is closer to the mean value.

An example experiment where we can use this might be finding little g , as you did a few weeks ago. Let's say you did 5 experiments that measured the acceleration due to gravity. Your results are:

Exp #	Value
1	9.9
2	9.6
3	9.5
4	9.7
5	9.8

You could then calculate the mean ($\bar{g} = 9.7$) and then do the summation shown in the equation above. That gets tedious, so we generally use a calculator function to do this. For example, go to WolframAlpha (<https://www.wolframalpha.com/>) and enter the following code:

StandardDeviation[{9.9, 9.6, 9.5, 9.7, 9.8}]

Or, another way would be enter these values into an excel spreadsheet then use the STDEVA() function to find the standard deviation of the cells where your data is. Here is an example file. (<http://physicslabs.ccnysites.cuny.edu/docs/standard-deviation-example.xlsx>) Both methods should give you a standard deviation of $\sigma_g = 0.1581$.

The final step is to then find the standard deviation of the mean $\sigma_{\bar{x}}$, or the *standard error*. This is defined as:

$$\sigma_{\bar{x}} = \frac{\sigma_x}{\sqrt{N}}$$

where N is the number of measurements. This is the value you will report when sharing the results of the experiment. For example, with the 5 measurements taken above for g , we will have a $\sigma_{\bar{g}} = \frac{0.1581}{\sqrt{5}} = 0.071$ You can then use this value to report the results of your experiment:

$$g = 9.7 \pm 0.071 \text{ m/s}^2$$

9.7 m/s² is the mean value, and 0.071 is the standard error. A useful feature of the standard deviation method is that as you make more measurements, you can decrease the standard error, (provided there are no systematic errors, such as a mis-calibrated scale).

Now, redo your uncertainty in the measurement of d using the standard error of the mean method. You'll probably want to set up an excel file to do this. Enter your results the box below:

mean of

d [m] = _____

$\sigma_{\bar{d}}$ [m] = _____

From these data, calculate the time of flight, and the velocity of the center of the sphere as it leaves the track.

velocity [m/s] = _____

Use the error propagation techniques (<http://physicslabs.ccnysites.cuny.edu/errors.php#propagation>) to obtain the uncertainty in velocity using the standard deviation from the d measurement:

uncertainty in v [m/s] = _____

Report Question 1

Now we have two ways to calculate the uncertainty of an experimental measurement. The first simply looks at the average of the uncertainties over a repeated measurements, as you did in the first lab. The new method uses the standard deviation. How do multiple measurements of d change the uncertainty? Compare the uncertainties in the velocity of the ball using these two different methods.

Collide 'em

Determine the mass of the steel sphere. Also record the mass of the wooden block, which is inscribed on the block. Mount the slider guide and slider in the box. Suspend the block at the appropriate level such that the faces of the block are parallel to the corresponding faces of the box. The block should hang freely, with a gap of about 1/8 inch between it and the track. The block must be perfectly still while awaiting the arrival of the sphere.

Measure the distance h .

h [m] = _____

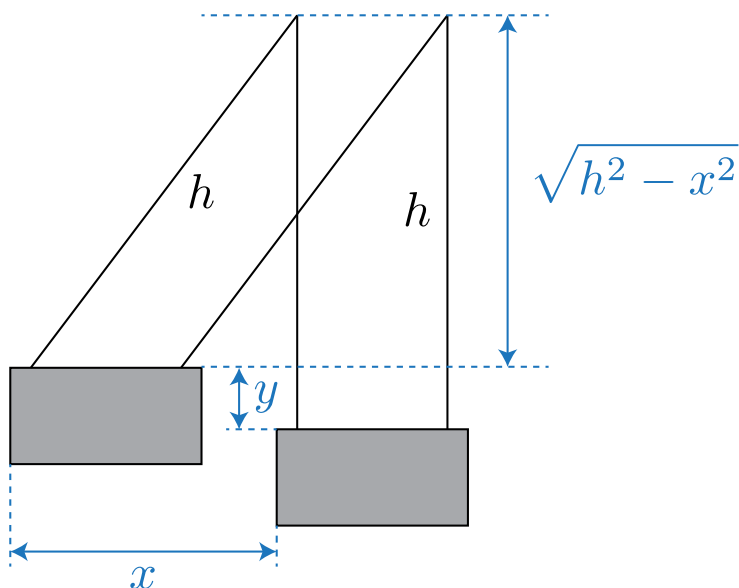
What is your uncertainty in the measurement of h ?

uncertainty in

h [m] = _____

Notice that when the block swings, the suspension prevents rotation. The horizontal distance x , through which the block swings after impact must be measured (see below), and the vertical distance y is calculated from:

$$y = h - \sqrt{h^2 - x^2}$$



Using the conservation of energy, we can use this change in height to figure out the velocity of the block/mass system, v_{b+m} , immediately after the collision.

$$v_{b+m} = \sqrt{2gy} \quad (1)$$

To determine x , first position the slider so that it is barely touching the stationary block, and record this distance setting as read from the slider guide. Next, perform a few trial runs until you succeed in positioning the slider such that for ten successive impacts the block at the end of its swing sometimes just barely flicks the slider, and at other times just barely fails to reach it. Note the position of the slider and calculate x .

Calculate the linear momentum of the system before impact (mv_b) and after impact ($(m + M)v_{b+m}$), and compute the relative difference (in %).

Report Question 2

Within the limits of your experimental accuracy, is momentum conserved during the collision?

More Report Questions

3. Derive equation (1), starting from general physics principles.
4. From your results, compute the fractional loss of kinetic energy of translation during impact. Disregard rotational energy of the sphere.
5. Derive an expression for the fractional loss of kinetic energy of translation in terms only of m and M , and compare with the value calculated in the preceding question. Consider the collision as a totally inelastic one.