Aidan O'Keeffe
alo779
PHY f105M: Lab for PHY 317K
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Lab 0: Measuring Distance and Time

Part 1: Geometry and Precision Measurement

Objective

The goal of Part 1 is to determine if a marble is a sphere.

Hypothesis

Table 1: Quick Check for Part 1

Large Marble Diameter Measurement (cm)	3.3 +/- 0.2	3.4 +/- 0.2	3.4 +/- 0.2

The diameter measurements in Table 1 were taken for the large marble using a tape measure. The diameters were aligned with three orthogonal axes. Note that the systematic error is much larger than the least count of the tape measure. The reason for this is that it was very difficult to use the tape measure to measure the diameters of the marble, which made getting a precise measurement difficult.

Based on the data in table 1, our hypothesis was that that the marbles were spherical.

Materials

The materials required for this experiment were: one small white marble, one small black marble, one large marble, one caliper, and one Expo marker.

Methods

Using the caliper, we measured six diameters of each marble. First, we measured an arbitrary diameter. Then, we rotated the marble so that this diameter was orthogonal to the table, and we took the measurements of five diameters spaced equally around the equator of the marble, where the equator is defined in terms of the poles being aligned with the first diameter. An expo marker was used to keep track of which diameters had already been measured.

Note that we used calipers instead of the screw gauge micrometer because the later tool was too small to take measurements on the large marble.

There were not any extra variables that needed to be kept constant.

Data and Observations

Table 2: Marble Diameters

Trial	Large Marble Measurement (mm)	White Marble Measurement (mm)	Black Marble Measurement (mm)
1	34.0 +/- 0.5	16.0 +/- 0.5	15.5 +/- 0.5
2	35.0 +/- 0.5	15.5 +/- 0.5	15.5 +/- 0.5
3	35.0 +/- 0.5	16.0 +/- 0.5	15.0 +/- 0.5
4	34.0 +/- 0.5	15.5 +/- 0.5	15.5 +/- 0.5
5	35.0 +/- 0.5	16.0 +/- 0.5	15.5 +/- 0.5
6	35.0 +/- 0.5	16.0 +/- 0.5	15.5 +/- 0.5

The lengths of the diameters measured for each marble. Note that for the large marble, some of the diameters are not equal to the others within the error, whereas for the white and black marbles, they are.

Analysis

To examine the variation of the marble diameters, we used the standard deviation of the mean diameter. We used a TI-84 to calculate the value for the large marble, but for reference, the standard deviation of the mean $\delta\bar{x}$ is given by

$$\delta\bar{x} = \frac{\sigma_x}{\sqrt{N}},$$

where N is the number of measurements,

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

$$\bar{x} = \frac{\sum_{i=1}^{N} x_i}{N},$$

and x_i is the i-th data point. As for the white marble and the black marble, it was unnecessary to calculate the actual value. This is because the standard deviation of a data set is at most the range of the data set. The range of diameter measurements for the white marble and the black marble was 0.5 mm, the same as the systematic error, meaning that the random error was no larger than the systematic error. This guarantees that we made our error as small as necessary.

Table 3: Estimates of Standard Deviations of the Mean of Marble Diameters

Marble	Standard Deviation of the Mean Diameter
Large Marble	0.2 mm
White Marble	< 0.5 mm
Black Marble	< 0.5 mm

Conclusion and Discussion

Based on the data in Table 2, this experiment demonstrated that the large marble was not spherical, and it failed to show within the precision of 0.5 mm that the black marble was not spherical or that the white marble was not spherical. This means that our hypothesis was incorrect for the large marble, and it has yet to be proven incorrect for the other two marbles.

There are a number of improvements that can be made to this experiment. The first would be to acquire a larger screw guage micrometer, as this would allow for more precise measurements. Another would be to take diameter measurements for orientations judiciously chosen so that we get uniform coverage of the diameters, as opposed the the fairly non-uniform coverage given by our choice of diameters. Yet another would be to calculate the approximate curvature along a collection of geodesics. The reason for this has to do with the counterexample provided in the module; even if all of the diameters were found to be equal, the object could still fail to be spherical. This additional test would detect such counterexamples as that.

Despite our finding, it is not wrong to claim that these marbles are spherical. We have to consider the marbles' intended use. They are usually not meant for precision purposes, rather, they are for children to play with or for artwork. Visually, the marbles do appear as spherical, so within the scope of their intended purpose, they are spherical. Therefore, the manufacturer should not be sued.

Part 2: Rolling Time and Statistical Uncertainty

Objective

The goal of this experiment was to determine if the color or identity of a marble influenced its rolling time, the time it took to roll down a ramp.

Hypothesis

Table 4: Quick Check for Part 2

Marble	Rolling Time
White Marble	2.05 +/- 0.01 s
Black Marble	2.07 +/- 0.01 s

The rolling times in Table 4 are not equal within the error; therefore, our hypothesis is that the rolling time depends on color and identity.

Materials

The following materials were used: one white marble, one black marble, one large marble, one digital stopwatch accurate to 0.01s, one ramp, one book, and one Expo marker.

Methods

First, the ramp was set to approximately 5.40 degrees. This was determined by measuring the length of the legs of the right triangle of which the ramp was the hypoteneuse, and then using trigonometry. The book was placed at the bottom of the ramp to keep the marble from rolling off the table.

Two people were involved, one to release the ball, the releaser, and one to manage the stopwatch, the timer. For each trial, the releaser placed the marble at the top of the ramp and held it in place with the Expo marker. The marker was used because we found that it resulted in a more consistent initial velocity than if the marble was released using one's fingers. The releaser would release the marble at the time of their choosing, and the timer would start the stopwatch as soon as they realized the marble was released. The timer would stop the stopwatch when they heard the sound of the marble strike the book. The elapsed time was recorded. This process was carried out several times for each marble.

We attempted to keep the initial position of the marble fixed to the top of the ramp, and we attempted to keep the initial velocity fixed to 0.

Data and Observations

Table 4: Marble Rolling Times

Trial	Large Marble Measurement (s)	White Marble Measurement (s)	Black Marble Measurement (s)
1	1.94 +/- 0.01	2.09 +/- 0.01	2.09 +/- 0.01
2	1.99 +/- 0.01	2.05 +/- 0.01	2.06 +/- 0.01
3	1.99 +/- 0.01	2.07 +/- 0.01	2.12 +/- 0.01
4	2.09 +/- 0.01	2.15 +/- 0.01	2.09 +/- 0.01
5	2.04 +/- 0.01	2.08 +/- 0.01	1.99 +/- 0.01
6	1.90 +/- 0.01	2.15 +/- 0.01	2.06 +/- 0.01
7	1.98 +/- 0.01	1.99 +/- 0.01	2.13 +/- 0.01

8	2.08 +/- 0.01	2.11 +/- 0.01	2.06 +/- 0.01
9	2.06 +/- 0.01	2.01 +/- 0.01	2.13 +/- 0.01
10	2.06 +/- 0.01	2.19 +/- 0.01	2.08 +/- 0.01
11	2.00 +/- 0.01	2.07 +/- 0.01	2.02 +/- 0.01
12	2.01 +/- 0.01	2.08 +/- 0.01	2.03 +/- 0.01
13	2.01 +/- 0.01	2.13 +/- 0.01	N/A
14	1.93 +/- 0.01	2.22 +/- 0.01	N/A
15	2.06 +/- 0.01	2.08 +/- 0.01	N/A
16	2.01 +/- 0.01	2.04 +/- 0.01	N/A
17	2.04 +/- 0.01	2.10 +/- 0.01	N/A
18	2.08 +/- 0.01	2.13 +/- 0.01	N/A
19	2.08 +/- 0.01	2.15 +/- 0.01	N/A
20	2.01 +/- 0.01	2.04 +/- 0.01	N/A
21	2.04 +/- 0.01	N/A	N/A
22	2.08 +/- 0.01	N/A	N/A
23	2.04 +/- 0.01	N/A	N/A
24	2.01 +/- 0.01	N/A	N/A
25	2.06 +/- 0.01	N/A	N/A
26	2.06 +/- 0.01	N/A	N/A
27	2.04 +/- 0.01	N/A	N/A
28	2.01 +/- 0.01	N/A	N/A
29	2.06 +/- 0.01	N/A	N/A
30	2.01 +/- 0.01	N/A	N/A

Note that the reason we have missing data is that, after the first trial, the lab instructor told us that we could stop conducting trials for a given marble as soon as the standard deviation of the mean rolling time was smaller than the systematic error.

Analysis

Table 4: Number of Trials, Mean Rolling Time, and Standard Deviation of Mean Rolling Time

Marble	Number of Trials	Mean Rolling Time (s)	Standard Deviation of Mean Rolling Time (s)
Large Marble	30	2.03	0.01
White Marble	20	2.09	0.01
Black Marble	12	2.07	0.01

The data in Table 3 was used to populate Table 4. The formulas included in Part 1 for the mean and standard deviation of the mean were used, with a calculator carrying out the computations. It should be noted that the unrounded values of the standard deviation of the mean rolling time were all greater than 0.01, but less than 0.015, so that within the measurement precision, the random error was no larger than the systematic error.

Unlike in Part 1, where we were doing an equality test, in this part, it made sense to take the mean of the rolling times. A spherical object has infinitely many diameters, all of which are necessarily equal for it to be a sphere, but a marble should only have one rolling time, around which the experimental data should cluster.

Conclusion and Discussion

Based on Table 4, we determined that all the spheres had different rolling times within the error. However, we cannot conclude that the color and identity of the marbles are the cause of this. This is because, instead of color or marble identity, it is more likely that the rolling times were altered by random influences, including but not limited to: random fluctuations in the initial velocity, random fluctuations in the initial position, the reaction time of the person using the stopwatch, and the surface of the ramp not being uniformly smooth.

While we are considering improvements to the experiment, we have to concede that there was a methodological error in this experiment that weakened the result: we only used one marble of each color. This means that if the identity of the marble was changed, the color of the marble was changed as well, the consequence being that, even though differences in the rolling times were found, we cannot distinguish if they were due to color or identity.

Given the above, we must conclude that this experiment was inconclusive with respect to our hypothesis.

That being acknowledged, there are many modifications that could be made to improve this experiment. First, we should use two marbles of each color, that way identity could be changed while keeping color constant. The rest of the modifications have to do with reducing the random error. We could use a rail made of stainless steel instead of wood, as stainless steel offers a more uniform surface. We could also put a mark on the initial position of the marble to keep it

more consisten between trials. Perhaps most influential of all would be to use photogates to measure the rolling time, that way the data is not perturbed by a person's reaction time.