ACCELERATION

Here is how some questions in typical first year physics textbooks begin. "Alice is standing on a table whose surface is 1.00 metre above the floor." Although you may be wondering why Alice is standing on a table, a more important issue for us is whether the table's surface is really 0.99, 1.00, or 1.01 metres above the floor. This experiment will help you better understand how to quantify measurements. It examines a topic in mechanics that is relevant to what you will learn in your lectures. You will take one small step to appreciating more complex problems such as putting a communications satellite in orbit around the Earth.

References

Your course textbook, web based Error Analysis Assignment, sections of the Laboratory Manual (Commonly Used Instruments, Data Fitting Techniques)

Equipment

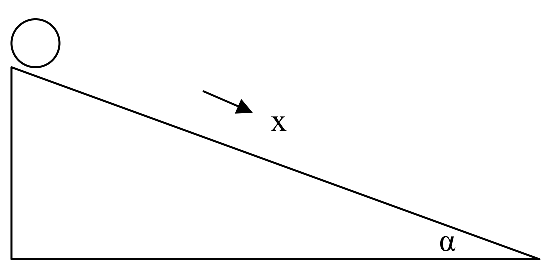
Metal balls, metal track, support stand, stopwatch, caliper, ruler, tape measure, photogate

Please treat the equipment with care! Please do not mark or bend the metal tracks.

Procedure

The main goal of this experiment is to determine how the position of a metal ball rolling down an inclined track depends on time.

1. Place the small metal ball at some location on the metal track and allow it to roll starting at time t=0. The ball's initial position and velocity are **x**=0 and **v**=0. The angle α that the metal track makes relative to the table's surface should be small. Is the ball accelerating according to your visual observations? How do you know? Devise a method for measuring the time t required for the ball to reach the approximate position x=10 cm along the surface of the track. Block the end of the track so that the ball does not roll along the table. Your method should minimize the error in t as much as possible. Each member of your subgroup should perform the time measurement three times. Collect your results in a table, such as the one shown below.



Measurement of time t for ball to reach approximate position x=10 cm. Date:

Reading	t (s)	$t-\bar{t}$ (s)	$(t-\bar{t})^2$ (s^2)	Experimenter's Initials
1				
…				
15				
Sums				
$\bar{t}$ (s)				
σ (s)				
σ_m (s)				

The average $\bar{t}$ is the sum of the individual values of t divided by the number of measurements n. The standard deviation σ is the square root of the sum of the values of $(t-\bar{t})^2$ divided by n-1. The standard error $\sigma_m=\sigma/\sqrt{n}$ is the error of the average value $\bar{t}$.

Do the calculations and discuss the errors involved in these measurements. The stopwatch you are using is digital. What is the reading error for a given time measurement? What is the random error associated with statistical variations in the measurement process? Are there any systematic errors? What should you quote for the final value of t and its error?

2. Using the method you developed above, measure the time required for the small ball to roll to approximate positions x=10, 20, 30, 40, and 50 cm. What should you estimate for the error in t? Collect your results in a table and make a hand drawn graph of x versus t. How does x vary with t?

3. Use the lab computer to fit a polynomial to your x versus t data. Refer to the Data Fitting Techniques section of the Laboratory Manual. Is it possible to select variables that yield a graph which is best fit by a straight line? To what physical quantities do the coefficients of the polynomial you have chosen correspond?

The quantity chi-squared χ^2 measures how closely the fitted curve matches the data. The value is weighted with one over the values of the errors in the data points. If the errors are large, the chi-squared is small. If the errors are small, the chi-squared is large. The *degrees of freedom* of a fit is the number of data points minus the number of parameters to which you are fitting. The ideal value of χ^2 is roughly equal to the number of degrees of freedom. If χ^2 is not on the order of the number of degrees of freedom, consider the following.

a. The model you are using is not appropriate. For example, if air resistance is significant and you are fitting position versus time to only a second-order polynomial then the fit does not include the effects of air resistance. This would make the chi-squared too high. In this case you could try adding a third-order term to the polynomial.

b. You have been too optimistic in assigning errors to your data.
c. You have been too pessimistic in assigning errors to your data.

Another tool for evaluating a fit involves the residuals of the fit. These are the values of the difference between the fitted and the actual data points. For a good fit, the residuals should be randomly distributed around zero. If the model you are using is not appropriate for the data, the residuals will often show systematic deviations from zero.

4. The photogate is a great measuring device. There is a beam of light that passes from one arm of the photogate to the other. When you place the device in GATE mode, it begins timing if the beam is interrupted by an object entering the gate and stops timing when the object exits the gate. Try moving your hand through the gate. Observe the time that is registered when your hand travels slowly compared to quickly through the gate. The RESET button clears the time display. The accuracy of the gate is specified by the manufacturer as $\pm$(1% of reading + 1 digit).

Use the photogate to measure the passage time τ for the small ball at approximate positions x=10, 20, 30, 40, and 50 cm. Can you relate τ to a physical quantity that describes the ball's motion? Can you make a graph of x versus some variable that is best fit by a straight line? To what physical quantities do the coefficients of the linear relation correspond?

5. Will the relation between x and t be different for the large metal ball compared to the small ball? First make a prediction in your Lab Notebook and explain your reasoning. Now perform some measurements to determine how the larger ball behaves.

Preparatory Question

An object slides down a frictionless ramp inclined at an angle α to the horizontal. How does the object's position x along the surface of the ramp vary with time t? Assume the object starts at initial position x_0 and with speed v_{x0} at time t=0.

General Advice

- Bring your Laboratory Manual, pens, pencils, ruler, calculator, and guide sheet to every lab session.
- Complete records must be kept in your Lab Notebook. Do not bring to or use scraps of paper in the laboratory.
- For your safety, do not consume food or drink in the laboratory.
- Graphing and error analysis are important topics in experimental physics, biology, chemistry, and so on. Although it will not be graded, you should do the Error Analysis Assignment prior to your first lab session. There are error analysis formulae on the inside cover of your Lab Notebook.
- You should clean up your lab space beginning at ten minutes before the end of your lab session. You should speak with you lab demonstrator beginning at five minutes before the end of your lab session.
- Do not plagiarize. Do not copy someone else's work in your Lab Notebook.