Falling Bodies (last edited)

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Purpose

To investigate the motion of a body under constant acceleration, specifically the motion of a mass falling freely to Earth. To verify the parabolic time dependence of the distance fallen and the linear time dependence of the velocity.

Background

We use a digital free fall apparatus to measure times that a mass falls a given distance. This apparatus consists of a launcher with a screw release, a large ball bearing, a touch sensitive landing pad, and a millisecond-resolution digital timer operated through the Science Workshop interface (Fig. 1).

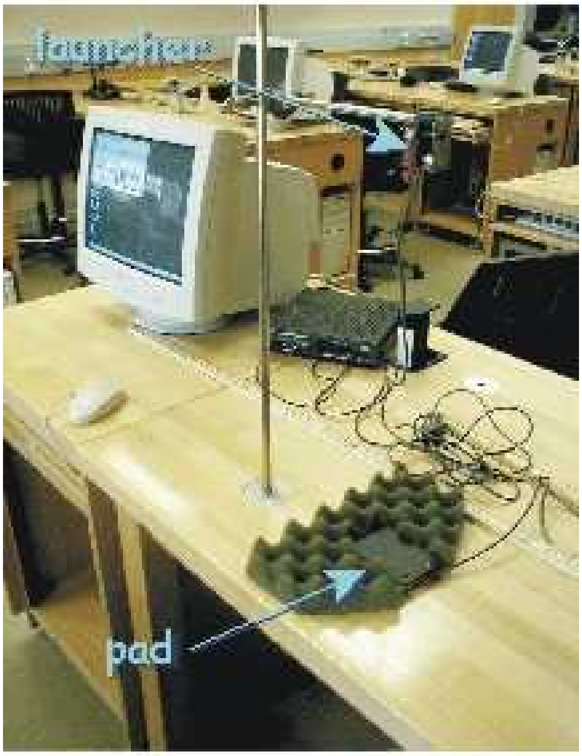

Figure 1 Digital free fall apparatus.

The experiment consists of measuring the distance from the ball in the launcher to the landing pad, then timing the ball dropping this distance. As noted in the Measurement and Uncertainty experiment, there will be some randomness associated with measurement of the time. The experimental fall time varies because of non-uniformity of both the release method and the initial ball position. Thus we need to determine $u\{t\}$ statistically.

This data gives you the distance x vs. time t curve. For a constant acceleration a, zero initial position and zero initial velocity, one of the equations of motion is

$x = \frac{1}{2} a t^2$.(1)

From basic algebra (Arghhh!) we know that this is a quadratic equation and that when we plot it, we get a parabola.

There are two different ways to express the average velocity of the ball after dropping a certain distance:

- One way is to take the average of the initial velocity (Which is zero.) and the final velocity (Call it v. Without friction, this is also the instantaneous velocity of any object that has fallen this distance from rest.): $v_{av}=(0+v)/2=v/2$.
- The other way is to divide the distance traveled by the time it took: $v_{av}=x/t$.

Equating the two, we get that

$v = 2x/t$.(2)

A second equation of motion of an object under a constant acceleration a is

$v = v_0 + at$.(3)

So if we calculate the velocity from Eq. 2 and plot it against the corresponding time, we should get a straight line with a slope equal to the acceleration of gravity g, and a zero y-intercept (the ball is falling from rest).

A note to clarify matters:

We have two different expressions for the velocity. Eq. 2, derived independently of the equations of motion under a constant acceleration, is used to calculate the *experimental* value of v. Eq. 3 (as well as Eq. 1) comes from the theoretical mathematical model of what we're trying to prove. In the Analysis you have to calculate the velocity. How? You have to use Eq. 2. If you use Eq. 3, you are using the equation to prove the equation; that is, you don't prove anything. This is something you have to watch out for in these labs. Be aware of the context of any equation given in the Background.

Procedure

You need the following equipment:

- meter stick and 2-meter stick
- launcher with set screw release
- ball bearing
- landing pad
- Science Workshop interface
- computer

1. Set up the following two tables on your data sheet:

for x=	
u{x}(cm)=	
Trial #	t(s)

and

$x_{suggested}$(cm)	x_{actual} (cm)	t (s)

2. Click on **Start> Science Workshop Experiments> First Quarter> Falling Bodies** to start the DataStudio program.
3. Set the ball in the release mechanism.
   a. Push in the pin at the top so that the ball is nestled in the hole of the flexible metal strip, between the brass contact and the strip. (See Fig. 2.)

Figure 2 Putting the ball in the launcher.

   b. Lightly tighten the thumb screw to lock the ball in place. Make sure the landing pad is directly beneath the ball.

4. Set the initial distance that the ball falls to between 5 and 10 cm, measuring from the landing pad to the bottom of the ball with a meter stick as in Fig. 3.
   a. Record the actual distance in cm.
   b. Record your estimate of the uncertainty of the measurement, u{x}. How dependent is your measurement on the viewing angle? When or where exactly does the ball bearing cause the circuit to be completed and the timing to stop?

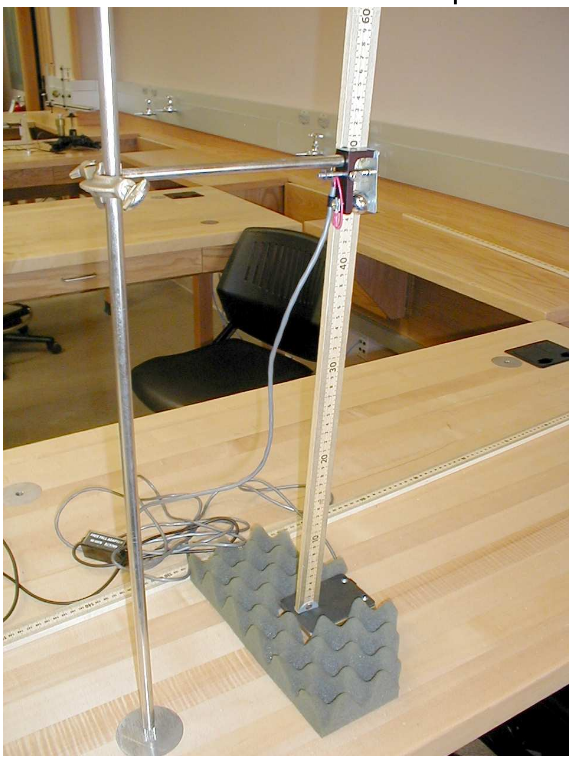

Figure 3 Measuring the ball drop distance.

5. Click on the **Start** icon at the top of the DataStudio window.
6. Untwist the thumb screw to release the ball.
7. Record the **Time of Fall**.
   a. If the ball did not land on the pad, disregard this time (a single line through the number) and retake the data.
   b. *Do not click on the* **STOP** *icon*.
   c. Reseat the ball.
8. Repeat Steps 6 and 7 until you have ten valid times.

- The timer automatically resets when you have the ball locked then untwist the set screw.
- There should not be a spread of more than 0.010 s.

One of the many things to learn from the Measurement and Uncertainty experiment is that the standard deviation of any ten measurements of a single quantity measured in the same way is the uncertainty in any single measurement. We assume that this error in the time *measurement* is independent of the time *interval*, meaning that it will be the uncertainty in the times measured at all distances. So your time uncertainty u{t} for this experiment *for each timing* is the standard deviation of these ten times. You still estimate an uncertainty of the time to record on your data sheet, but do not put any calculations on the data sheet. In the Error Analysis of your report, you state the calculated standard deviation as the actual time uncertainty.

9. Make single time measurements for each of the suggested distances in the following table. They do not have to be exact. As long as you're within a few millimeters, you're OK.
   a. For the last distance, make it as large as you can– put the landing pad on the floor and position the launcher as high as it will go and so that the ball will drop over the edge of the lab bench. Use the two-meter stick to measure the distance.
   b. After the measurements you should have at least 30 times; 10 times for the first distance and single times for the 20 subsequent distances.

x (cm)	x (cm)	x (cm)	x (cm)
21.6	33.1	47.1	63.5
23.7	35.7	50.2	67.1
25.9	38.4	53.4	70.8
28.2	41.2	56.6	74.5
30.6	44.1	60	(to the floor)

10. Click on the timer **Stop** button and exit DataStudio. Do not save the activity.

Analysis

1. There is no template for this experiment. Starting from the **Generic Lab Spreadsheet**, copy in your first distance, the uncertainty u{x}, and the ten times in appropriately labeled cells. Remember to label the cells appropriately and to shade all data cells.
2. Use the **AVERAGE** function of Excel to calculate t_{av} for this distance.

3. Use the **STDEV** function to calculate $u\{t\}$.
4. Type these headings into your spreadsheet:

t (s)	x (cm)	v (m/s)	u{v} (m/s)

5. Fill in the first two columns with your distance and time data. The first time should be t_{av} and the first distance the initial distance where you took the ten times.
6. Calculate the instantaneous velocity v in *meters* per second from Eq. 2 in the third column.
7. In the fourth column, calculate the uncertainty $u\{v\}$ in the velocity:

$$u\{v\} = v\sqrt{\left(\frac{u\{x\}}{x}\right)^2 + \left(\frac{u\{t\}}{t}\right)^2} \quad . \tag{4}$$

8. Plot x vs. t. The distance x is along the y-axis and t is along the x-axis.
   a. Add a **Trendline...** Make it a polynomial of second order instead of linear. (Remember, it's supposed to be a parabola.) From the **Options** tab,
   b. **Display the equation** on the chart. The x^2 coefficient should be close to $\frac{1}{2}g$, $490\ cm/s^2$.
   c. **Forecast backward** 0.2 units.
   d. Do the points fit the parabola? Does the bottom of the parabola cup coincide with the origin?
   e. Include x- and y- error bars.
9. Plot v vs. t.
   a. Highlight the t-values. While holding down the **Ctrl** key, highlight the corresponding v-values. Click on **Chart Wizard** and continue the process as usual.
   b. Include a linear trendline with the equation displayed and the line extrapolated back 0.2 units.
   c. Include x- and y-error bars. $u\{t\}$ is the same for all values of t, so this is a **Fixed value**. You have calculated a different $u\{v\}$ for each v, so you have to enter all of these as **Custom**, both **+** and **-**, as in the Data Graphics and Analysis experiment.
   d. Do a least squares fit with errors of this data (i.e., use **LINEST** to get the slope, y-intercept and errors in the slope and the y-intercept).

e. Compare the slope with the accepted value of 9.80 m/s^2 and the y-intercept with the expected value.

Questions

1. In Step 4 of the Procedure, why don't we measure the distance to the center of the steel ball instead of to the bottom?
2. Is the diver below correct in his calculation? How fast in miles per hour he would be going when he hits the water (if he ever jumps)? Show your work.

There are times when being a whiz at physics can be a definite drawback.

Is this guy really a whiz?