Data Handling and Interpretation
The Bouncing Ball

Key Terms: Mean, standard deviation, histogram, random error, systematic error, blunder.

Objective: Σ, δ, σ*#!; *what exactly is all of this mess and what does it mean?* This reaction is typical of many students upon receiving their first real dose of experimental statistics. This exercise is to help you become better acquainted and more comfortable with the methods of data analysis used by scientists. We will explore a rudimentary graphing technique, do some simple "number crunching" with data that you will collect, and gain some experience with the statistical methods discussed in the previous section of this manual. As you proceed with this exercise you should see how mean, standard deviation, number of trials and confidence, and graphical analysis all play a part in determining how scientists evaluate the outcome of an experiment.

This exercise consists of two parts: In the first part you will conduct an experiment then collect and analyze the data. In the second part you will use your experimentally gathered data to determine the acceleration due to gravity close to the earth's surface.

Procedure: In this exercise you will examine an extremely simple system: a bouncing ball. You will drop the ball from a predetermined height (h_0) and measure the time interval between the first and second bounces (Δt_1). Figure 1 shows the notation convention that we will use for this procedure.

Experimental: It will be left up to you to devise a scheme to drop a golf ball 100 times from a set height of at least 1.5 meters (any convenient height above 1.5 meters will do). Notice that this height, h_0, is measured from the *bottom* of the golf ball. Since this distance is set, you need to record it only once. You will measure the time interval, using a digital stopwatch, between the 1st and 2nd bounce for each trial. As you will see, 100 trials should be enough to insure a high degree of confidence in your experimental findings.

Some coordination is necessary to carry out this experiment and you may encounter an occasional mishap. Suppose that you elect to drop the ball for the first 50 trials while your lab partner operates the digital stopwatch. Your lab partner might start the stopwatch too early or too late a few times during the course of 50 drops of the ball. Feel free to reject such data as experimental *blunders* and start the measurement over. Be aware, however, that you should obtain slightly different numbers even for measurements

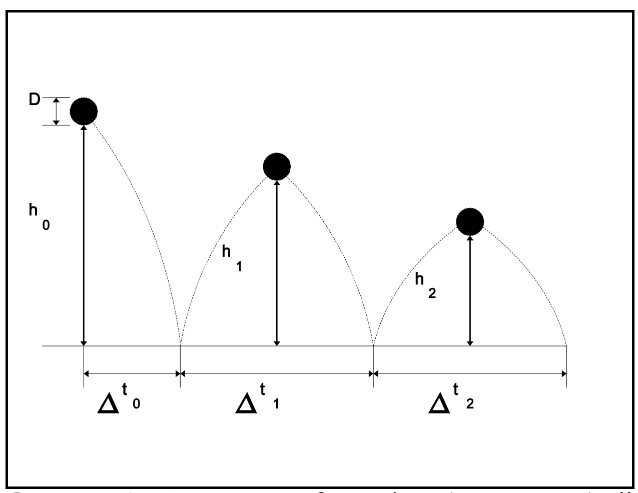

Figure 1. Notation for the bouncing ball experiment.

that have been made correctly as a result of *random error*.

After 50 trials you will probably want to change places with your lab partner to avoid any *systematic error*.

Bounce Times

1	______	26	______	51	______	76	______
2	______	27	______	52	______	77	______
3	______	28	______	53	______	78	______
4	______	29	______	54	______	79	______
5	______	30	______	55	______	80	______
6	______	31	______	56	______	81	______
7	______	32	______	57	______	82	______
8	______	33	______	58	______	83	______
9	______	34	______	59	______	84	______
10	______	35	______	60	______	85	______
11	______	36	______	61	______	86	______
12	______	37	______	62	______	87	______
13	______	38	______	63	______	88	______
14	______	39	______	64	______	89	______
15	______	40	______	65	______	90	______
16	______	41	______	66	______	91	______
17	______	42	______	67	______	92	______
18	______	43	______	68	______	93	______
19	______	44	______	69	______	94	______
20	______	45	______	70	______	95	______
21	______	46	______	71	______	96	______
22	______	47	______	72	______	97	______
23	______	48	______	73	______	98	______
24	______	49	______	74	______	99	______
25	______	50	______	75	______	100	______

Data Analysis: Make a histogram of your data. A histogram is a type of graph that shows the number of occurrences of a range of data vs. the value of that range of data. You are probably acquainted with a familiar histogram used to post grades, i.e., the number of students scoring between 61-70, 71-80, 81-90, 91-100, etc. on an exam vs. the score ranges 61-70, etc. In this experiment, the x-axis (abscissa) will be time values (or ranges of time values) and the y-axis (ordinate) will be the number of times that time value, or a number on that range of time values, was recorded. Plot the time values along the length of the page and fill in a block on the corresponding column for each occurrence of that time value. An example of a histogram is shown in Figure 2. When your histogram is complete you should be able to trace a bell-shaped curve which approximately conforms to the shape of the bars on the graph. The shape of this curve is a characteristic of processes involving random error.

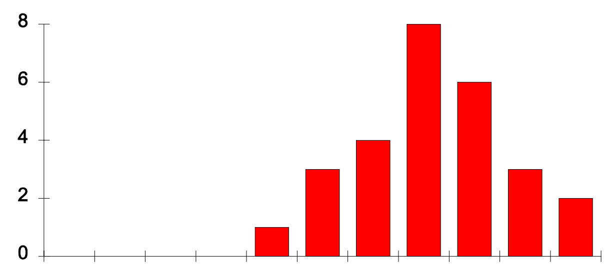

Figure 2. A histogram

Calculate the mean and standard deviation of the first 5 data points recorded, the first 10 data points, the first 50 and finally all 100 points. The mean is simply the average of all your data and the standard deviation is a measure of the spread of your data points. What do you notice about the mean and the standard deviation that you obtain compared to your histogram? Just above the histogram draw a horizontal line centered on the mean with a length of twice the standard deviation. This error bar graphically represents the mean plus or minus the standard deviation ($\mu \pm \sigma$). You will note that about 68% of the filled blocks fall within the range of $\mu \pm \sigma$ (count them!). For a normal random error curve such as this 68% of the data fall within $\pm \sigma$, 95% within $\pm 2\sigma$, and 99.7% within $\pm 3\sigma$.

Histogram

First five
data points

μ ____________

σ ____________

First ten
data points

μ ____________

σ ____________

First fifty
data points

μ ____________

σ ____________

All one
hundred
data points

μ ____________

σ ____________

Determination of *g* - the acceleration due to gravity

Newton's laws (and some mathematics) yield the following relationship for distance in terms of time and initial velocity for a freely falling body:

$$h - h_0 = v_{0t} + \frac{1}{2}gt^2 \qquad \textbf{1}$$

For an object in free fall starting from rest (v_o=0) at height h_0 = 0, this relationship may be written:

$$h = \frac{1}{2}gt^2 \qquad \textbf{2}$$

where g = 9.80m/s^2 close to the earth's surface, assuming that retarding forces (such as air friction) are not present. *Is this a good assumption for all objects?*

Consider the bouncing ball data. The time from the initial release to the ball hitting the floor the first time is given by:

$$\Delta t_0 = \sqrt{\frac{2h_0}{g}} \qquad \textbf{3}$$

Similarly, for the time between a bounce, *i,* and the next bounce, *i + 1*, the time interval is twice as long as it would be if the body were dropped a distance h_i:

$$\Delta t_i = 2\left(\sqrt{\frac{2h_i}{g}}\right) \qquad \textbf{4}$$

For the time interval between the first and second bounce, i = 1 and we can solve for g to obtain:

$$g = \frac{8h_i}{(\Delta t_i)^2} \qquad \textbf{5}$$

In the first part of this experiment you obtained a fairly good value of Δt_1. You now need to obtain a value for h_1. This is not a particularly easy measurement to obtain. You are free to choose any method that works. Once you have obtained a value for g, compute a % error. Use 9.80m/s^2 for the accepted value of g.

Questions for Thought

1. What does the graphing of experimental data reveal? What is the difference between a histogram and a line graph?

2. What do the mean and standard deviation of a set of measurements represent?